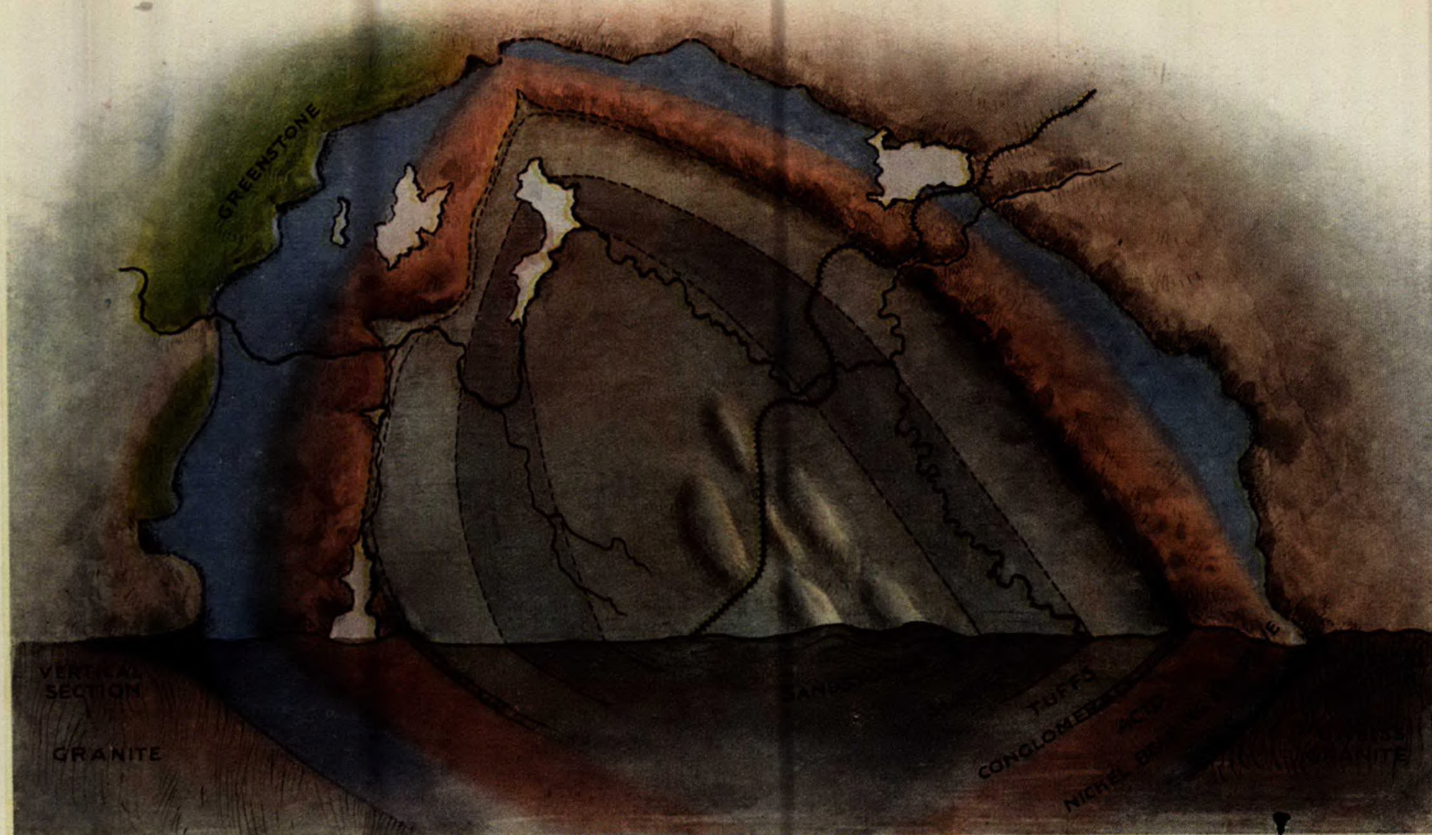

Birdseye view and ideal section through Sudbury Nickel Region ; looking southwest.

CANADA
DEPARTMENT OF MINES
MINES BRANCH
Hon. Robert Rogers, Minister; A. P. Low, LL.D., Deputy Minister;
Eugene Haanel, Director.

THE NICKEL INDUSTRY:

WITH SPECIAL REFERENCE TO THE SUDBURY REGION, ONTARIO

BY

A. P. Coleman, Ph.D.

OTTAWA
GOVERNMENT PRINTING BUREAU
1913

No. 170

LETTER OF TRANSMITTAL.

To Dr. EUGENE HAANEL,
Director of Mines Branch,
Department of Mines, Ottawa.

SIR:—I have the honour to transmit to you a Monograph on the Nickel Industry, with special reference to the Sudbury region, with a general geological map, and special maps of the more important mines, the whole representing the advances made in our knowledge of the region due to three summers' work in the field.

In addition to descriptions of all the known nickel ore deposits in Ontario, there are accounts of methods of mining and smelting the ores, and of the chief nickel regions of other countries.

The work has been greatly aided by the hearty assistance afforded by all engaged in mining and smelting nickel ores in the Sudbury region.

I have the honour to be, sir,
Your obedient servant,

(Signed) **A. P. Coleman.**

Geological Department,
University of Toronto,
Toronto, Ontario.
March 28, 1912.

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THE NICKEL INDUSTRY: WITH SPECIAL REFERENCE TO THE SUDBURY REGION, ONTARIO

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A. P. Coleman, Ph. D.

INTRODUCTION

In accordance with the instructions of Dr. Eugene Haanel, Director of Mines, the work of revising the map of the Sudbury Nickel Region, and of obtaining materials for the preparation of a monograph on the subject of nickel, was undertaken in the summer of 1911. During the two previous summers the writer had studied and mapped the geology of several important working mines for the Canadian Copper Company; and, owing to the generosity of that company, the materials thus obtained were made available for the purposes of the present monograph. Every mine which has been worked along the nickel ranges was visited and examined, as far as possible, and most of the prospects where ore or gossan occur were also visited during a succession of journeys covering the greater part of the boundary of the norite with which all the ore deposits are connected. In this work the map of the region prepared by the present writer for the Bureau of Mines of Ontario in 1904, and various maps made at about the same time by Dr. Barlow, served as a foundation, to be modified or added to.

It gives me great pleasure to acknowledge the cheerful assistance rendered by every one interested in nickel mining, to whom application was made, without which the monograph would be much less complete. All the companies working in the district aided in this respect: the largest of them—the Canadian Copper Company—being naturally of the greatest importance; and I wish to thank the President and officers of the Company for the assistance given, particularly Mr. David H. Browne, who is not only a skilful and experienced metallurgist, but a man of science interested in all the problems of the region, and well acquainted with its history. With the permission of Mr. A. P. Turner, President of the Company, Mr. Browne, Superintendent John Lawson, and others of the staff have supplied me with much useful information.

In connexion with the Mond Company, Mr. C. V. Corliss, Manager, and Mr. O. Hall, Mines Superintendent, rendered valuable aid, as far as the policy of their company permitted. Mr. J. A. Holmes, General Manager of the Dominion Nickel Copper Company, assisted personally in the field work, and in various other ways: especially in regard to the Eastern and Northern Ranges; and Mr. Kirby Thomas—then in the employ of the Nickel Alloys Co., of New York—assisted greatly in the examination of the Trillabelle locations at the southwest end of the ranges.

To all these gentlemen, and many others, thanks are due.

In addition, acknowledgment should be made of the skilful services of the late Mr. M. T. Culbert, and of Dr. E. S. Moore, who were my chief field assistants during the earlier work, and aided in the preparation of the first detailed geological map of the nickel region, which served as a basis for the map accompanying the present monograph. Great assistance was also rendered by the Ontario Bureau of Mines, in the way of necessary information furnished directly, or obtained indirectly from their reports.

The compiling of the accompanying maps and plans has been the work of Mr. R. R. Rose, who has had much experience in field work and mapping in the Sudbury district.

Position and Means of Communication.

Sudbury—from which the mining region takes its name—is in Lat. 46° 30′, W. Long. 81°, and lies about 35 miles north of Georgian bay, the northeastern part of Lake Huron. It may be reached from Montreal by a journey of 439 miles westward on the main line of the Canadian Pacific railway, or from Toronto by a journey of 260 miles north on a branch of the Canadian Pacific railway, or the Canadian Northern railway. Sudbury itself—the largest town in the region—is a little southeast of the most important nickel range, the nearest mines being two miles to the north and three miles to the west.

The nickel region has sharply defined boundaries of a geological nature; since all the ore deposits are connected with a single great sheet of eruptive rock, roughly boat-shaped, with a blunt bow to the southwest and a square stern to the northeast, conforming to the general strike of the Archaean rocks of the district. Only the upturned edges of the sheet are exposed, since it is basin-shaped and has its interior filled with sedimentary rocks. The basin is 36 miles long, from southwest to northeast, and 16 miles wide, and the known ore deposits are all either along the edge of the sheet or less than four miles away from it on projections or "offsets."

The nickel region is served by six lines of railway. The main line of the Canadian Pacific railway crosses the basin diagonally from southeast to northwest, and the "Soo" branch runs southwest from Sudbury, parallel to its southern edge and touching the Worthington mine on one of the offsets. The Algoma Central runs west from Sudbury to Victoria Mines touching a number of important mines, and the Canadian Northern crosses the basin from north to south toward the east end, sending a branch to Garson mine and connecting with the Nickel Range railway, which runs to the Whistle mine at the northeast corner of the basin. In addition the Canadian Copper Company has private lines to some of its mines and is now building a line four miles long to connect Copper Cliff with the Frood or No. 3 mine to the northeast. Every mine which has produced more than a few thousand tons of ore has had railway connexions, though a few of these branch lines have been removed on the shutting down of the mines which they served.

In early days the nickel deposits were grouped in two ranges, a main or southern range and a northern range, but, since it was proved that the ores are all connected with the edges of a single sheet of eruptive rock, one might think of them all as belonging to a single oval range. It is found, however, that the important deposits are not distributed uniformly round the basin but that there are rich portions separated by barren portions. It is probable that in the future a third or eastern range will be recognized, and possibly a fourth or western range, though thus far the ore deposits at that end are not known to be of much importance.

At present the main nickel range may be defined as running from the Sultana mine six miles southeast to Victoria mine, then turning northeast for 23 miles to the Sheppard mine, and finally east for four miles to the Garson mine. There is, however, a gap of about five miles toward the southeast between the Crean Hill and Gertrude mines where no ore has been found. Along this somewhat irregular line of 33 miles on the southern margin of the nickel-bearing eruptive seventeen mines have produced ore, and within two or three miles to the south of it ten other mines have been worked.

Practically all the ore hitherto mined and smelted in the region must be credited to the main or southern range. The northern range is not so continuous as the southern but is generally reckoned as extending from certain deposits in Levack township to the Whistle mine at the northeast corner of the basin, a distance of 25 miles. There are, however, two gaps of six miles each within this extent, one between Levack and the southwest corner of Bowell township, and the other extending from the middle of Wisner township to the Whistle mine in Norman township; so that on the northern range there are only 13 miles of the margin of the nickel eruptive which are ore bearing. In addition, however, some ore has been found for six miles west along an offset beginning about the middle of Bowell township and ending at about the middle of Foy.

In reality it would conform better to the known arrangement of the ore deposits to detach the Whistle mine from the northern range, which would then extend for only about 18 miles, and make it the north end of an eastern range extending for 13½ miles south to the Falconbridge properties.

The three ranges are at very unequal stages of development, the southern range being followed for almost its whole length by railways to transport its ores, while only one other mine, the Whistle at the north end of the eastern range, has rail connexions.

The outlying properties of the southern range can almost all be reached by roads, some well built and used by automobiles, others rough lumber roads with bridges and corduroy falling into decay. Much of the northern range is best reached on foot or by water, and the eastern range is almost as inaccessible. The small western range can be visited by a lumber road on the south, but the northern outcrops are best approached by canoe.

The central valley of the nickel basin consists largely of agricultural land, now divided into farms and well settled. It is crossed by the main line of the Canadian Pacific railway, and the northern branch as well as the main line of the Canadian Northern railway, so that it is well provided with means of communication. On the other hand it is cut off by rugged ranges of hills from the nickel mines to the north and south, the natural markets for its produce.

The whole nickel basin includes an area of 550 square miles, divided among twenty-four townships of the regular size and shape. Mining has taken place in eight of these townships, while important ore deposits are known to exist in several others.

Omitting the villages connected with the farming region of the interior basin, the nickel mining industry supports two towns, Sudbury and Copper Cliff, and four villages, all told with a population of perhaps 10,000 people.

Physiography of the Nickel Region.

The physiography of the region is very closely bound up with the geology of the nickel-bearing eruptive and often serves as a guide to the position of ore deposits. The lower Huronian and Laurentian rocks enclosing the basin present the usual irregular Archaean surface, with hard granites or gabbros or quartzites standing up as rugged hills or short ridges without any definite order except for a general strike of the structures in a direction of N. 60° or 70° E. The nickel eruptive sheet, on the other hand, expresses itself with surprising uniformity. Its outer (and lower) edge consists of the easily weathered rock norite, often more vulnerable because charged with sulphides, while its inner (and upper) portion is formed of micropegmatite, a strong, resistant rock, which commonly stands up as high hills. Just within this belt of granite hills come conglomerate and tuff, the lowest members of the series of sediments occupying the basin; and these rocks have been metamorphosed and thus greatly strengthened by the action of the eruptive rock beneath, thus forming a band of even more rugged hills than the micropegmatite. The interior of the basin is floored with soft sediments, tuff and slate, with some low anticlinal hills of arkose or sandstone toward the centre.

The resulting land forms are characteristic. All round the outside of the basin rise the tumultuous hills of older Archaean rock, followed by a valley representing the basic, easily decomposed, edge of the nickel eruptive, wide on the southern side where the norite is wide; but relatively narrow on the northern and eastern sides. Frequently the basic margin has been eaten into hollows, now filled with drift or muskegs or small lakes, hiding the actual edge of the norite and making the exploration for ore deposits more difficult. Patches of ore are commonly found on the slopes of harder rocks surrounding this belt of low ground.

Besides the narrow lakes of the basic margin there are many larger bodies of water entangled among the hills of the granitic or acid edge of the eruptive. A glance at the map shows how frequently lakes have this position, often furnishing the only convenient gateways between the flat interior of the basin and the narrow valley of the basic edge. Parts of the northern nickel range are best reached, after leaving the end of the wagon roads of the interior basin, by boats on a lake or by winter roads on the ice.

Many of the lakes along the basic edge of the nickel eruptive on the northern range are so small that they have not received names. Thirteen of them have been noted on the map but many ponds are almost too small to appear on the scale employed. On the eastern range these marginal lakes are larger and include from north to south Lake Selwyn, Lake Waddell, Ella lake, Clear lake, Blue lake and Pyrrhotite lake, beside several small unnamed ponds.

The southern nickel range with its wider band of norite has comparatively few lakes; but in all there cannot be less than 30 small bodies of water along the basic edge of the norite, often with ore bodies dipping under them from the slope of country rock behind. Occasionally these lakes have been taken up as nickel locations.

The lakes belonging to the acid portion of the nickel eruptive are generally larger than those of the basic edge, and include Cameron, Fairbank, Whitewater, Whitson, and Garson lakes on the south side; and Joes lake, Trout lake and Moose lake on the north range; while Windy lake extends almost across the nickel eruptive. These lakes are of consequence to the nickel miners, partly as indicating points where ore has been deeply attacked, and partly as a water supply for mining camps or smelters.

The nickel basin is drained almost entirely by Vermilion river and its tributaries; Rapid river, Nelson river, Sand Cherry creek and Onaping river coming in from the north and west; Cameron creek from the southwest; Levy river and Whitson creek from the east. The whole system of lakes and rivers is controlled by the basin shape of the nickel eruptive and the relative hardness or softness of the sediments deposited within it. Vermilion river enters the basin by a low pass near the northeast corner and leaves it by a still lower pass near the southwest end. On entering the interior of the basin it expands to Onwatin lake at the east end, and just before passing out it widens to Vermilion lake at the west end. The rest of the interior basin is almost free from lakes, making a strong contrast with the nickel-bearing eruptive which encloses it.

Outline of the General Geology of the Sudbury Region.

The Sudbury region includes rocks belonging probably to all the subdivisions of the Pre-Cambrian as recognized in America, but the nearest fossiliferous sedimentary rocks are nearly 40 miles away on Manitoulin island in Lake Huron, and no direct relationship can be followed up in the intervening rocks. While the solid formations of the region end probably with the Pre-Cambrian, much of the surface is covered with glacial and old lake deposits of the Pleistocene.

The ore deposits are often very closely bound up with the structures of the older rocks, which have greatly affected their size, shape and position.

The accepted classification of the Pre-Cambrian of the Upper Lakes region is as follows:—

Keweenawan.
Upper Huronian or Animikie.
Middle Huronian.
Lower Huronian.
Keewatin.
Laurentian.

In this system the Laurentian is looked upon as entirely eruptive, always later in age than the Keewatin, and sometimes later than lower Huronian.

There are rocks belonging to all of the sub-divisions given above in the region mapped, except the middle Huronian, and also probably rocks representing the Grenville series of southeastern Ontario. The latter are distinctly older than the Laurentian, but whether they are the equivalents of the Keewatin is not quite certain.

The rocks underlying the sheet of nickel eruptive may be divided broadly into a crystalline group mainly eruptive, including the Keewatin, Grenville series, and Laurentian, and a mainly sedimentary group consisting of the lower Huronian, and a newly defined Sudbury series, now tilted at high angles and penetrated by various eruptives. The rocks above the nickel eruptive sheet make a third group, almost wholly sedimentary, though partly pyroclastic, and bent into a syncline, but not steeply inclined. The norite-micropegmatite sheet is later than any of them, and probably of Keweenawan age, while certain dykes which cut all the other rocks are perhaps Palaeozoic in age.

In this brief account of the geology the different formations will be described as nearly as may be in the order of their age.

THE KEEWATIN.

In this district the Keewatin includes greenstones and green schists and in its upper part small amounts of the iron formation. The greenstone was probably once gabbro, but it and the green schists are now largely changed to hornblende. Many bands and irregular areas of greenstone are included in the part mapped as Laurentian, since on the scale of the map it would be impossible to separate them in detail. Frequently they form the foot-wall of ore bodies and a breccia of their fragments is often cemented with norite and ore.

The iron formation included in the region mapped consists of small outcrops of quartzitic silica interbanded with magnetite near Clear lake in Wisner township and a pond to the south. It is enclosed in Laurentian gneiss and has no practical value, though the Hutton township deposits of a similar kind a few miles north are of considerable importance.

GRENVILLE SERIES

Hitherto the Grenville series has not been recognized in the Sudbury region; but certain rocks in the township of Dill associated with a quartz mine worked there by the Canadian Copper Company have all the characteristics of that series, as found 60 miles to the southeast in the township of Mills and extending south for more than 40 miles to Parry Sound. The rocks in Dill township, which it is proposed to call Grenville, include the coarse white quartzite which is mined, and also fine grained grey gneiss and schist having in part a distinct granular structure in thin sections. Less than two miles to the north there is a small band of crystalline limestone containing rounded grains of green serpentine, exactly like the crystalline limestones of Parry Sound.

The grey gneiss is not unlike the Couchiching of Western Ontario, but the limestones of the Huronian in that region are entirely unlike the Dill outcrop and are far more modern in appearance.

SUDBURY SERIES.

Later in age than the Grenville and Keewatin, but earlier than the Laurentian, is a great series of sediments, chiefly quartzite, but including also arkose, greywacke, slate, and some thin sheets of conglomerate. These are steeply tilted and sometimes folded, and have been penetrated and partly metamorphosed by acid and basic eruptives. They have hitherto been called lower Huronian, but they differ so much in attitude and relationship from the typical lower Huronian not far to the west that they probably belong to an earlier period, equivalent perhaps to the Timiskaming series, described by Dr. Miller and other geologists in the Cobalt region as lower than the Huronian. It is proposed to call them the Sudbury series.

The Timiskaming series and the rocks here referred to are not to be looked upon as a "Lowest Huronian," beneath the usually recognized bottom of that series, but as a new division of the Archaean equal in rank to the Huronian and Keewatin.

If these rocks are put in the position suggested it will imply also that the conglomerate near Ramsay lake, hitherto called middle Huronian, must be lowered one stage and be named lower Huronian. The Ramsay Lake conglomerate is more like the Cobalt and Echo Lake conglomerates of the lower Huronian regions hitherto carefully studied than are the sedimentary rocks underlying, giving support to the suggested change.

These rocks form a band 10 or 12 miles wide, extending all across the district, just to the southeast of the main nickel range; generally separated from the norite, however, by a very irregular belt of basic and acid eruptive rocks of various kinds somewhat later in age, but, for the present, included with them. The southeastern side of the band of sediments consists mainly of quartzite, more or less metamorphosed, but still retaining a very distinct bedding and often cross bedding, and having in the

PLATE I.

Clear lake, edge of Nickel basin—Eastern range.

PLATE II.

Grenville crystalline limestone, one mile north of Wanup.

main a tilt of 45° degrees to the southeast, with many local variations, including one indistinct anticline on Ramsay lake. The beds of quartzite are often parted by thin sheets of slate or greywacke; and several bosses or bands of greenstone penetrate them and interfere with the regularity of their structure.

These quartzites have a width of from 3½ to 6 miles, and if they have not been reduplicated by faulting, of which there is no evidence, have a maximum thickness of 15,000 or 20,000 feet, making them one of the greatest well defined sedimentary formations in Ontario.

Apparently beneath the quartzites there is a thinner, but still important band of greywacke and slate, also well stratified and showing its original structures when not too much affected by adjoining eruptives. It has a width of two miles or more and a thickness of several thousand feet, and, in various places it comes in contact with offset ore deposits but scarcely touches the main nickel range.

A third, and probably lower division of the sediments is more enigmatic, since it has undergone much greater changes, largely obliterating its original structure. This consists of quartzite or arkose, pink in colour and greatly recrystallized, running northeast and southwest as a band of hills not more than half a mile wide from near Frood mine to a point southeast of Creighton. This rock touches Copper Cliff mine and was described earlier as felsite.

The three sedimentary formations may have a total thickness of 30,000 feet. In places they are of economic importance as supplying quartz for the smelters and building stone used in Sudbury and at other points.

BASIC ERUPTIVES OF THE SUDBURY SERIES.

In many places greenstones and coarse hornblende porphyrites of indeterminate origin rise through the sedimentary rocks mentioned above; and there are also two belts of better defined basic eruptives of considerable continuity, one the Sudbury laccolithic belt, beginning at a group of hills east of the town and stretching southwest for nine miles to the lower end of Kelley lake, and the other following with interruptions the basic edge of the southern nickel range from its east end to Little Stobie mine. This is separated at intervals from the norite by a band of granites as far as a point a mile east of Crean Hill mine, after which if follows the basic edge of the norite to its end near Sultana mine.

These basic eruptives are of great variety. The Sudbury chain of laccolithic hills consists of gabbro which pushed up the greywacke on each side, and which contains along its irregular summit ridge a number of quartz deposits, segregations or inclusions of quartzite, one of which has been mined for flux. A little nickeliferous pyrrhotite has been found at two or three points in these hills, and the gabbro is probably an earlier segregation from the nickel bearing magma than the great norite sheet.

The long irregular band of greenstones following the southern nickel range consists of rocks of extraordinary variety, the least modified being lava streams showing pillow and amygdaloidal structures. They are often formed of perfectly fresh norite, much more basic than the nickeliferous rock, seamed with ribs of green hornblende, and passing into porphyrites of several kinds that are sometimes very like those found in the quartzites to the south. All of these rocks have carried off masses of greywacke or quartzite, which are commonly more or less transformed into gneiss or schist, while the adjoining greywacke has developed immense numbers of staurolite crystals as a result of contact metamorphism.

The "older norite" lava streams seem to have supplied a plane of weakness followed later by the nickel-bearing eruptive, and it is frequently the foot-wall for ore bodies on the southern range.

ACID ERUPTIVES OF THE SUDBURY SERIES.

Later than the "older norite" lava streams came eruptions of deep seated acid rocks, coarse granite, syenite, and granitoid gneiss, generally flesh coloured, and frequently carrying off fragments of the greenstones just mentioned and also of greywacke, and sending dykes into these rocks. The most important area of granite runs from Copper Cliff southwest to near Crean Hill, as a band from one to two and a half miles wide, forming the country rock of the nickel range for more than half of this distance, which includes the famous Creighton mine. These rocks are of various textures and ages; some being undoubtedly older than the nickel eruptive and others younger, since the ore sometimes cooled against them as a foot-wall and was sometimes cut by dykes of the later granite, which is usually finer grained than the earlier eruptions.

THE LAURENTIAN.

The southeastern edge of the lower Huronian is bounded by granitoid gneiss and hornblende schist, etc., later in age, but generally called Laurentian; and the whole western, northwestern, and northern parts of the region are occupied by similar rocks, usually coarse granitoid gneisses streaked with dark green stripes and lenses, no doubt rolled out greenstones of Keewatin age. The schistose structure of these rocks commonly has the usual strike of the region, 60° to 80° east of north, and a vertical or steeply inclined dip. They are monotonous and of no great practical importance except as the country rock supplying the foot-wall for many of the ore deposits of the northern range. The norite and ore often seem plastered up against the slopes of these Laurentian hills, remnants left when the greater part of the deposit has been eroded and removed.

Except along the brecciated edges of the ore deposits at the basic edge of the norite, the Laurentian has been little studied; but its gneisses and granites appear to be younger than the Timiskaming or lower Huronian sediments, though perhaps of about the same age as the bulk of the lower Huronian eruptives, from which they are nearly always separated in the field.

They are, however, far older than the nickel eruptive and the sediments that overlie it; for the Laurentian gneisses and hornblende schists, as well as all the other rocks thus far described, had been consolidated, thrust into mountain folds, and eroded to a peneplain before the upper Huronian sediments were laid down. The gap in time must have been enormous.

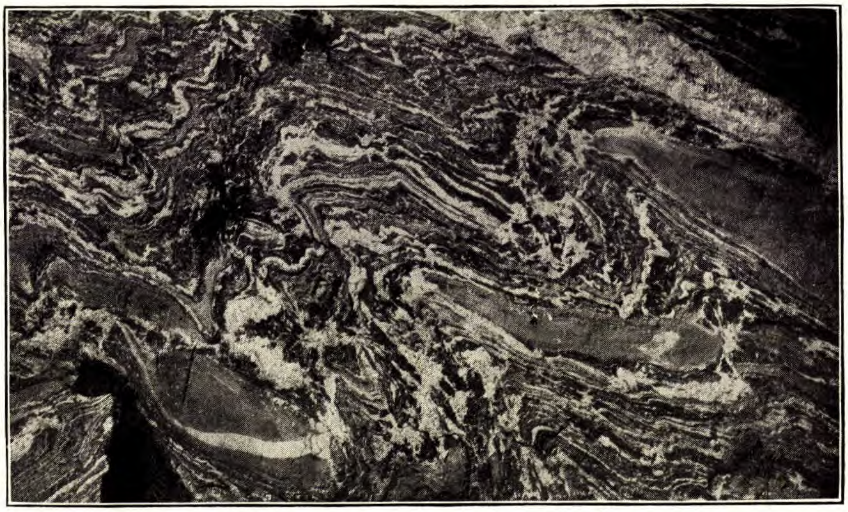
THE LOWER HURONIAN.

What was described as the middle Huronian in previous reports, now considered lower Huronian, is developed in only one small part of the immediate Sudbury region, just north of Ramsay lake, where a peculiar boulder conglomerate extends for about two miles and a half, with a greatest

PLATE III.

Lower Huronian quartzite, Wanapitei.

PLATE IV.



Laurentian gneiss—north of Quartz.

width of about half a mile. This rock has a dark grey ground mass of greywacke with no visible stratification, in which are imbedded pebbles and boulders of the older rocks, especially granite and quartzite. The boulders are angular or subangular or well rounded, and of all sizes up to tons in weight; and the whole appearance suggests an ancient tillite or boulder clay, though no striated stones have been found. Rocks of the same kind but covering a much larger area are found in the Wanapitei region to the east.

As the boulders of quartzite are like the quartzite of the Timiskaming or lower Huronian to the southeast it is inferred that these rocks are of later age. Since there is scarcely a suggestion of stratification to be found, their attitude with reference to the lower rocks is not always very certain, though at one point on the north shore of Ramsay lake a basal conglomerate may be seen resting uncomformably upon the quartzite here referred to as older.

If this conglomerate is transferred to the lower Huronian, the middle Huronian seems to drop out altogether, since the next series of rocks has in general the characters of the upper Huronian or Animikie.

THE UPPER HURONIAN OR ANIMIKIE.

Much later than the Timiskaming or lower Huronian and the Laurentian there was deposited on their planed down surface a second great series of sediments, whose exact age is not certain, owing to the absence of fossiliferous rocks, though they resemble in many respects the western Animikie, now referred to the upper Huronian, and may, at least provisionally, be placed in that position.

In the Sudbury region these rocks occupy a basin in the nickel eruptive, and have been found nowhere else; they are therefore not at present in côntact with the lower Huronian and Laurentian, since the nickel eruptive came in as a later sheet, separating the younger from the older rocks.

These rocks form a well defined series beginning with a basal conglomerate and passing on to tuff, slate and sandstone, and they have been given separate formational names taken from characteristic localities, as follows:—

Chelmsford sandstone	800—1,500 feet
Onwatin slate	3,700
Onaping tuff	3,800
Trout Lake conglomerate	450
	8,750—9,450

The Trout Lake conglomerate makes a continuous band round the basin immediately overlying the acid side of the nickel eruptive, but it varies greatly in width, in one case being a mile across, in most others a few hundred feet, and in a few instances sinking to less than 100 feet. The rock is found in its least changed form, as a boulder conglomerate with a matrix of dark green, fine grained rock, north of Sultana mine, where the micropegmatite is at its narrowest, and the thin edge of the eruptive had comparatively little power of metamorphism. Along other parts of the acid edge the conglomerate is greatly changed and in some places has been squeezed or sheared into schist conglomerate.

The Onaping tuff is mainly formed of tiny glass fragments rained down as volcanic ash, but includes a good deal of ordinary sediment also, such as granite and quartzite pebbles. It also forms a continuous band, in most places rising as steep hills, round the interior basin. The Onwatin slate is a mud rock charged with carbon enough to give it a dark colour, and as it is the softest rock of the series it is generally buried under drift deposits taken up as farms, though it occasionally forms low hills. In it the curious veins of anthraxolite occur.

Finally, the Chelmsford sandstone runs as a disjointed range of low hills down the centre of the basin. Though it was originally named sandstone it might almost be called arkose or even greywacke, since the quartz grains are mixed with a good deal of other matter. The whole series of sediments is now bent into a synclinal basin with an average dip inwards of about 30°; while the Chelmsford sandstone in the middle has been forced into small dome-shaped anticlines in the process.

As shown in a table on an earlier page the upper Huronian sediments are of considerable thickness, and their general relationships, such as dip, and width, are more completely known than those of the older formations and justify a more exact statement. Their great thickness of nearly 10,000 feet probably had an important bearing on the segregation of the ore bodies, since that process must have demanded a lengthened period of fluidity of the nickel bearing magma; and this huge blanket of sediments must have greatly retarded the rate of cooling.

THE NORITE-MICROPEGMATITE SHEET.

After the succession of sediments just mentioned had been deposited the vast mass of molten rock of the nickel eruptive ascended, mostly from beneath an area near the middle of the southern range, as will be shown later. As the molten magma welled up from below, the crystalline rocks forming the roof of the great crucible gradually collapsed as a block 12 or 15 miles long and several miles broad, giving rise to extensive faulting and fissuring.

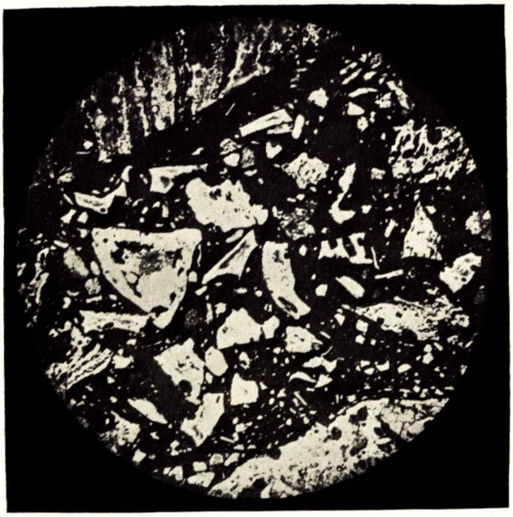
The flood of molten material found an opportunity to spread out between the ancient surface of the older rocks and the basal conglomerate of the sediments, producing a laccolithic sheet having an area of over 500 square miles. Since thousands of feet of rock have been eroded from the region in later times, the original area of the sheet must have been much greater than that. An extension of one mile in all directions would add about 100 square miles to the area and probably more than a mile has been removed from the rim since Cambrian times. The eruptive sheet cooled extremely slowly, partly because of the great bulk of molten material and partly because of the thick mantle of sedimentary rocks above; and during the cooling much of the ore sank to the bottom, though its upper part remained mixed with norite, which finally blended into micropegmatite or granite on top, the three materials arranging themselves according to their specific gravities.

The collapse of the foundations of older rock caused the cooling sheet of magma to settle into a basin shape, and the once nearly flat sediments above it took the same form, cradled in the plastic micropegmatite, which ate into and greatly metamorphosed the Trout Lake conglomerate just above.

The norite-micropegmatite sheet is one of the largest laccolithic sheets known, containing not less than 600 cubic miles at the present time, and probably having had a much greater bulk in the beginning.

Just when this tremendous mass of molten material reached its present position is uncertain, though the event probably took place during Keeweenawan times.

PLATE V.



Thin section of volcanic glass (vitrophyre tuff), Onaping.

LATER DYKES.

After the norite and ore had completely cooled, the region was cut by long fissures, and dykes of diabase penetrated impartially all the rocks mentioned above. Dozens of these dykes are known, especially in and near the large ore bodies where the geology has been most carefully worked out; and some of them are 100 or more yards in width and as much as seven miles in length, so that the total amount of diabase is by no means insignificant. This last eruption probably took place somewhere in Palaeozoic times; and except for cutting across the ore and so causing more or less trouble to the miner, the dykes have had no appreciable effect on the mines. Some little dykes of granite cut the diabase itself and so are the latest rock in the region.

The history just outlined is one of the most complex on record, including almost all the Pre-Cambrian formations and a long succession of eruptive rocks of the most varied kinds and of all ages up to the Palaeozoic. From that time till the Pleistocene destructive forces were active, removing thousands of cubic miles of the solid rock. During the Pleistocene important beds of morainic material, boulder clay, and lake deposits were laid down, covering considerable areas of the surface.

Historical Sketch of the Development of the Sudbury Nickel Region.

A large literature has sprung up in regard to the Sudbury nickel mines and their associations, but the earlier history of the region may be found summed up in two reports, that of Dr. Barlow on the "Nickel and Copper Deposits of the Sudbury Mining District,"[1] and the final report on "The Sudbury Nickel Field" by the present writer.[2]

Dr. Barlow's report gives in much detail the various stages in the development up to 1903, describing unsuccessful as well as successful ventures in mining and smelting the ores; and many of the less important features referred to may be omitted from the present monograph. Since 1905 perhaps the most important contribution to the subject has been an account of "The Nickel-Copper Industry of Ontario", by Alex. Gray,[3] which however is confined to the development of the Canadian Copper Company's mines and smelters, much the most important of the region, but not the only ones. Even more important from the practical side than the written reports on the region have been the successive geological maps prepared by the Survey at Ottawa and the Bureau of Mines of Ontario, embodying the advances in our knowledge of the field relations of the ore bodies. In connexion with the Geological Survey Report of 1890, four years after real mining had begun, a map prepared by Dr. Bell with the assistance of Dr. Barlow and others showed the geological relations of parts of the southern and northern nickel ranges, indicating belts of diorite which accompanied the ore deposits. This map, though on the small scale of four miles to an inch, proved very useful; and was republished by the Bureau of Mines in 1902 with few changes, but on the scale of two miles to the inch.

[1]Geol. Sur. Can. Part H, Vol. XIV, 1904.
[2]Bureau of Mines, Ont., Vol. XIV, Part III, 1905.
[3]Mining World, Vol. XXXII, Nos. 20, 21 and 22, 1910.

In 1904 the Bureau of Mines published on the same scale a map prepared by the present writer showing the northern Nickel Range and indicating the continuous character of the nickel eruptive, now known to be norite, its outcrop extending as an ellipse round the area of sedimentary rocks placed between the two nickel ranges on Dr. Bell's map. The nickel-bearing sheet of eruptive rock had been proved to form a synclinal basin. The map showed also the inner or acid edge of the differentiated eruptive, and brought out the important facts that ore deposits were connected chiefly with bay-like projections or narrow offsets from the basic edge of the eruptive and were most frequent and important where the width of the outcrop of norite and micropegmatite was greatest.

In the same year Dr. Barlow published two map sheets on the scale of one mile to an inch covering the Copper Cliff and Victoria Mines areas; and two other maps, of Copper Cliff and Murray mine, on the scale of 400 feet to the inch. The Victoria Mines sheet was defective in not separating the nickel-bearing norite from the adjoining greenstones, but the other maps are excellent.

In 1905 the first fairly complete map of the geology of the region was published by the Bureau of Mines on a scale of one and a half miles to the inch. This map has been of great service, but requires numerous small corrections and is now almost out of print,

Nickel was first reported from the Sudbury region by Murray in 1856.[1] The well known land surveyor, Salter, had found a disturbance of the compass on a meridian line north of Whitefish lake, and suggested that Murray should examine the place. He found "an immense mass of magnetic trap," specimens of which were sent to Sterry Hunt for analysis. Magnetic pyrites was found disseminated through the rock and the analysis showed the presence of some nickel and copper. Salter's line is now the boundary between Creighton and Snider townships and the rock with pyrrhotite was obtained a little west of the famous Creighton mine, the greatest nickel mine in the world. However, the discovery attracted little attention, since at that time the metal nickel was a rarity of little practical importance and the region was a wilderness without roads, where canoes were the only practicable means of travel.

In 1883 the Canadian Pacific railway reached the Sudbury region, and the stretch of flat plain in the interior of the nickel basin attracted the railway engineers, who brought the line by a steep grade up from Sudbury to what later became the Murray mine, from which the railway descends to Azilda between hills belonging to the acid edge of the eruptive. It is said that at this time Dr. Howie discovered on the summit of the pass a low hill of pyrrhotite with some chalcopyrite.[2] Specimens shown to Dr. Selwyn, then Director of the Geological Survey, were pronounced valueless, since pyrrhotite from Canadian localities had not hitherto been found to contain more than a fraction of a per cent of nickel.

Early in 1884 the railway reached this deposit and a cutting disclosed copper pyrites at what was afterwards known as the Murray mine. Other discoveries soon followed at what became the Lady Macdonald, Evans, Copper Cliff, Stobie, and Blezard mines; all taken up for copper, the presence of nickel being at first overlooked. The Creighton mine was rediscovered not long after by another land surveyor, John McAree, who surveyed an adjoining township, though the mine was not opened up till several years later owing to its difficulty of access.

[1] G.S.C., 1853-6, pp. 180-181.
[2] Dr. Barlow, G.S.C., Vol. XIV, Part H, pp. 23-24.

PLATE VI.

Interior basin from inner edge of Nickel eruptive, Azilda.

Prospectors swarmed over the region searching everywhere for the gossan which showed the presence of ore, and men like Thomas Frood, Henry Ranger, William McVittie, A. McCharles, and others quickly learned that gossan and ore accompanied only one kind of rock, then called diorite, but now known to be norite. In a short time almost all the main deposits had been located, and two ranges, a southern or main range, and a northern, began to be distinguished.

The first important mining was done in 1886 at the Copper Cliff, where an open cut was made against the side of a steep gossan covered hill, the work being carried on by the newly formed Canadian Copper Company, which soon opened up also the Stobie and Evans mines. The first ore mined was supposed to be simply copper ore, as the name of the mine and company suggest; and until 3000 tons were shipped to Constable Hook for treatment, the presence of nickel was not suspected. There, however, difficulties were met in smelting the ore, and assays showed that nickel was the disturbing element. The first ore mined is reported to have been unusually high in copper, running from 15 to 20 per cent, probably because enriched above water level. Later the tenor of the ore was lower, but it still averaged higher in copper than in nickel. This has been true also of another mine, the Crean Hill.

The history of mining and smelting in the Sudbury region is so closely bound up with the Canadian Copper Company that its progress may be followed first, and other, later formed companies may be taken up afterwards.

THE CANADIAN COPPER COMPANY.

In 1888 Dr. Peters was put in charge of smelting operations at Copper Cliff, roast beds were got under way, and near the end of the year a Herreshoff water jacket furnace was blown in to produce copper-nickel matte, so as to reduce freight expenses.

For ten years the same three mines produced most of the ore that was smelted at Copper Cliff; but in 1899 the Evans closed down and in 1901 the Stobie ceased working, after producing more than 400,000 tons of ore, low in grade but high in sulphides and supplying a useful fluxing mixture with the rocky ore from Copper Cliff mine.

New mines were being developed in the mean time, No. 1, southwest of Copper Cliff mine and No. 2 north of it, beginning in 1898; the former proving to be a small but rich deposit, while the latter is large, though of average grade. In addition No. 4 and No. 5 mines, northwest of No. 2, yielded some ore in 1899; and in 1900 the Frood mine, since called No. 3, a mile southwest of the Stobie, began operations, and the ore from the two was shipped by rail to Copper Cliff where it was mixed with ore from other mines on the roast beds.

The great Creighton mine, six miles west of Copper Cliff, was one of the last to be opened up, for lack of railway connexions; but in 1900 stripping was commenced upon it, and in the following year it began to ship ore by the Algoma Central railway to Copper Cliff. As the deposit is immense and the ore of higher grade than that of most other large mines, and mixed with little rock, the Creighton mine for some years supplied most of the ore smelted by the Canadian Copper Company, and their other mines were closed down one after another in consequence, the Copper Cliff after reaching the 14th level at a depth of 1052 feet.

Since its opening the Creighton mine with its great supplies of rich sulphides has dominated the situation, but it was found advisible to have a supply of rockier ore with a larger percentage of copper to mix with it for fluxing purposes and to give a convenient proportion for the separation of the metals, nickel and copper. On this account Crean Hill mine, eight or nine miles southwest of Creighton, and about 14 miles from Copper Cliff, was opened up in 1905, and in 1906 began to ship ore to Copper Cliff over the "Soo" branch of the Canadian Pacific railway. For some years these two mines supplied the whole of the ore for the company; but the demand for nickel was increasing, and in 1910 No. 2 mine, which had been closed since 1902, once more began operations. At this time the rich little Vermilion mine, a mile southwest of Crean Hill, also supplied 1200 tons of ore almost as high in nickel and copper as some grades of matte.

To provide for a future increase in the output of nickel No. 3 mine, sometimes called the Frood, was carefully explored with the diamond drill, showing reserves of ore estimated by Mr. Alex. Gray at 30,000,000 or 35,000,000 of tons,[1] and in 1911 work was begun in sinking a shaft to tap this great body of ore, and a railway four miles long was commenced to connect it directly with Copper Cliff.

As Creighton mine has been proved by drilling to contain 5,000,000 tons of ore, it will be seen that it and No. 3, without reference to several other deposits which are by no means exhausted, contain a supply of ore sufficient for many years to come even if the rate of production is considerably increased.

The first smelting works at Copper Cliff was erected in 1888 under the direction of Dr. Peters, well known as a metallurgist of copper, Mr. James McArthur and Mr. J. D. Evans being his assistants. This was the East smelter which began to ship matte the following year. The plant was added to in a rather haphazard way as years went on and the need for accommodation increased, and in 1891 and 1892 a bessemer plant was provided. In 1890 Dr. Peters severed his connexion with the company and Mr. Woodbury became manager for three months, when he was succeeded by Mr. Evans, who occupied the position till 1893. Mr. McArthur then took charge of the works and remained manager till 1902. During his regime a new West smelter was put up in 1899, near No. 2 mine, and three years later the East smelter suspended operations, and some time after was burned.

In 1900 a new method of producing high grade matte from standard matte was introduced by the Orford Copper Company, which put up the Ontario Smelting Works a half mile southwest of Copper Cliff mine. Here the standard or furnace matte was roasted in Brown calciners, and then smelted a second time in a water jacket furnace, thus changing matte containing about 30 per cent of nickel and copper into matte averaging 75 per cent of the two metals, corresponding nearly to the former bessemer matte.

In April 1902 the whole organization of the Company was changed and the Canadian Copper Company became subsidiary to the International Nickel Company, which had been formed to combine a number of companies interested in the mining, smelting and refining of nickel and copper. In connexion with this change Mr. A. P. Turner was made president of the Canadian Copper Company, and Mr. John Lawson general superintendent.

In its second Annual Report the International Nickel Compa[illegible]s described as a consolidation of mines and smelters in the United States, Canada, Great Britain, and New Caledonia, including the Canadian Copper

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[1]The Mining World, Vol. XXXII, 1910, p. 1025.

Copper Cliff mine.

Company, Orford Copper Company, Anglo-American Iron Company, Vermilion Mining Company, American Nickel Works, Nickel Corporation, Limited, and the Sociètè 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 following 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."[1]

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. An account of the new smelter is given in the section on smelting so that no description of it is required here.

Since 1904 the most important advances have been the introduction of a few large basic converters instead of numerous small quartz lined acid converters, and the erection of a reverberatory plant to treat fines and flue dust.

The cost of fuel for power purposes is very high in the Sudbury region and the Canadian Copper Company acquired rights for the development of power at High Falls on Spanish river, 23 miles west of Copper Cliff, in 1904; and since then from a head of 85 feet electric power has been generated not only for the needs of the smelter but also for the mines of the company. This effects a most important saving in expense.

In its early years the Canadian Copper Company had an uphill struggle with the difficulties that always beset a new and complicated enterprise until the best methods of treatment have been devised. Fortunately the company owned some extremely large and valuable mines, so that the problem of an ore supply has not greatly troubled them. With a reserve of ore sufficient for 60 years and a smelting plant probably second to none in America for completeness and efficiency the prospects of the company are bright.

In 1909, according to Mr. Gray's account of the company, the ore mined averaged $5 or $6 per ton in value of nickel and copper, allowing on a conservative (if unauthorized) estimate a profit of $1.50 to $2.00

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

per ton mined, which "would mean a yearly profit of $522,900 or $697,200." "The 13,000,000 lbs. of nickel disposed of in 1909, it is claimed, brought a profit of 7½ cents per pound spread over mining, smelting and refining charges," which implies a "total profit of $1,027,000."[1]

On the same basis for 1910, Mr. Gibson in the Bureau of Mines Report estimates the profit on the ore smelted at from $726,253 or $968,338, and on the nickel marketed of $2,377,100.[2]

In its 6th Annual Report the company states that a dividend of 6 per cent was paid on its preferred stock and 7 on its common stock, after an extra dividend of 25 per cent on the common stock. The value of its investments and plant is put at $27,262,138, and the statement is made that the demand for the Company's products is the greatest in its history, largely because of the development of the motor vehicle industry.[3]

It is evident that this pioneer company, after a number of years of little or no returns for the capital invested, has in recent years been very prosperous; and since for a long time it was the mainstay of mining in the Province of Ontario under depressing conditions, its present good fortune seems well deserved.

H. H. VIVIAN AND COMPANY.

The next company to operate a mine and smelter in the Sudbury region was that of the Vivians from Swansea, Wales, celebrated for their great metallurgical plant. They acquired the Murray mine, the first discovered in the district, and began to develop it in 1889, continuing operations with one or two short interruptions 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 bessemerising this to a high grade matte. The Manhés 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. This 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.

In 1912 it was purchased by the Dominion Nickel Copper Co., and it is said that at least 4,000,000 tons of ore have been disclosed by their diamond drilling operations.

Though the Murray mine was not one of the richest, it is probable that competent local management would have given better results than were attained by direction from England. The failure of this venture made by so famous a company for some years exerted a depressing effect on the development of the nickel industry.[4]

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[1]Mining World, Vol. XXXII, 1910, pp. 1022–3. Should this not be $975,000?
[2]Bureau of Mines, Vol. XX, Part I, 1911, p. 28.
[3]E.M.J., Vol. 92, July- Dc., 1911, p. 458.
[4]Bur. Mines, Vol. XIV, ePart III, pp.141–2.

DOMINION MINING COMPANY.

The Blezard mine, a mile north of Stobie, in lot 4, con. II of the township of the same name, and the Worthington mine 25 miles west of Sudbury on the "Soo" line, were worked for some time by the Dominion Mining Company, who opened the former mine in 1889 and the latter in 1890. A smelter constructed at Blezard mine served to treat the ore from both the mines, producing in Herreshoff furnaces a matte averaging 27 per cent of nickel and 12½ per cent of copper, which was marketed without bessemerising. Some of the Worthington ore is said to have been rich enough for shipment without smelting. The Blezard mine was shut down in 1893, and the Worthington in the year following. Mr. Robert McBride, who was in charge of the Blezard mine in 1892, states that about 100,000 tons of ore came from it in all, averaging from 5 to 7 per cent of nickel and copper, the nickel being more than double the copper in amount; so that the ore resembled that from Creighton in value, and much surpassed that of Murray mine.

The ore from Worthington is reported at only about 25,000 tons, but it was the richest mined in the region, with the exception of that from the still smaller Vermilion mine, and is said to have carried from 8 per cent upwards of nickel and copper.

Except for some diamond drilling and the unwatering of the mines for examination little has been done on these properties since the closing down of the smelter; though a few carloads of ore were obtained from the Worthington in 1908 and sent to the Victoria Mines smelter three miles to the east.

THE MOND NICKEL COMPANY.

The carbon monoxide process of refining nickel, by which a volatile compound of nickel could be produced and afterwards decomposed, thus depositing the metal, was discovered by Dr. Carl Langer while working on other problems in the laboratory of Dr. Mond. Having found a method of refining the metal Dr. Mond naturally looked for a deposit of nickel ore and in 1899 bought what was then called the McConnell mine, on the north half of lot 8, con. IV, of Denison township, about 3 miles northeast of Worthington.

Smelting works were established beside the "Soo" branch of the Canadian Pacific railway two miles south of the Victoria mine, as the deposit was named, and a cable tramway was constructed to transport the ore 11,000 feet from the mine to the smelter. In 1900 the Mond Nickel Company was formed with a capital of £600,000, to take over the mine and smelter, and in the following year bessemer matte was being produced under the management of Mr. Hiram W. Hixon, who had obtained experience as a copper smelter in the Western States.

The roast yards were at first near the smelter and village but after a fire at the landing station of the ore, necessitating more or less reconstruction, the roast beds were removed to a flat half way between the mine and the smelter.[1]

Trouble with the refining works at Clydach, near Swansea, Wales, caused delays on this side of the water also, but ultimately the Mond process was brought into good working order, and the company began to look for new sources of ore, since Victoria mine is not a very large deposit.

[1]G.S.C., Vol. XIV, Part H. pp. 40-43.

After testing some small deposits, such as the North Star and the Little Stobie, in 1907 a larger one was purchased toward the east end of the main nickel range and named the Garson mine, from the township in which it occurs, on lot 5, con. III. Mr. C. V. Corliss, who had been mine superintendent, became manager on the resignation of Mr. Hixon in 1908, and Mr. O. B. Hall was made mine superintendent. During this year the Garson mine began shipping ore to Victoria Mines, by the Canadian Northern railway to Sudbury, and then by the "Soo" branch of the Canadian Pacific to the smelter. By this time Victoria mine and smelter were equipped with electric power, from Wabageshik falls on Vermilion river nine miles to the southwest; and Garson mine was operated with current from Wanapitei river.

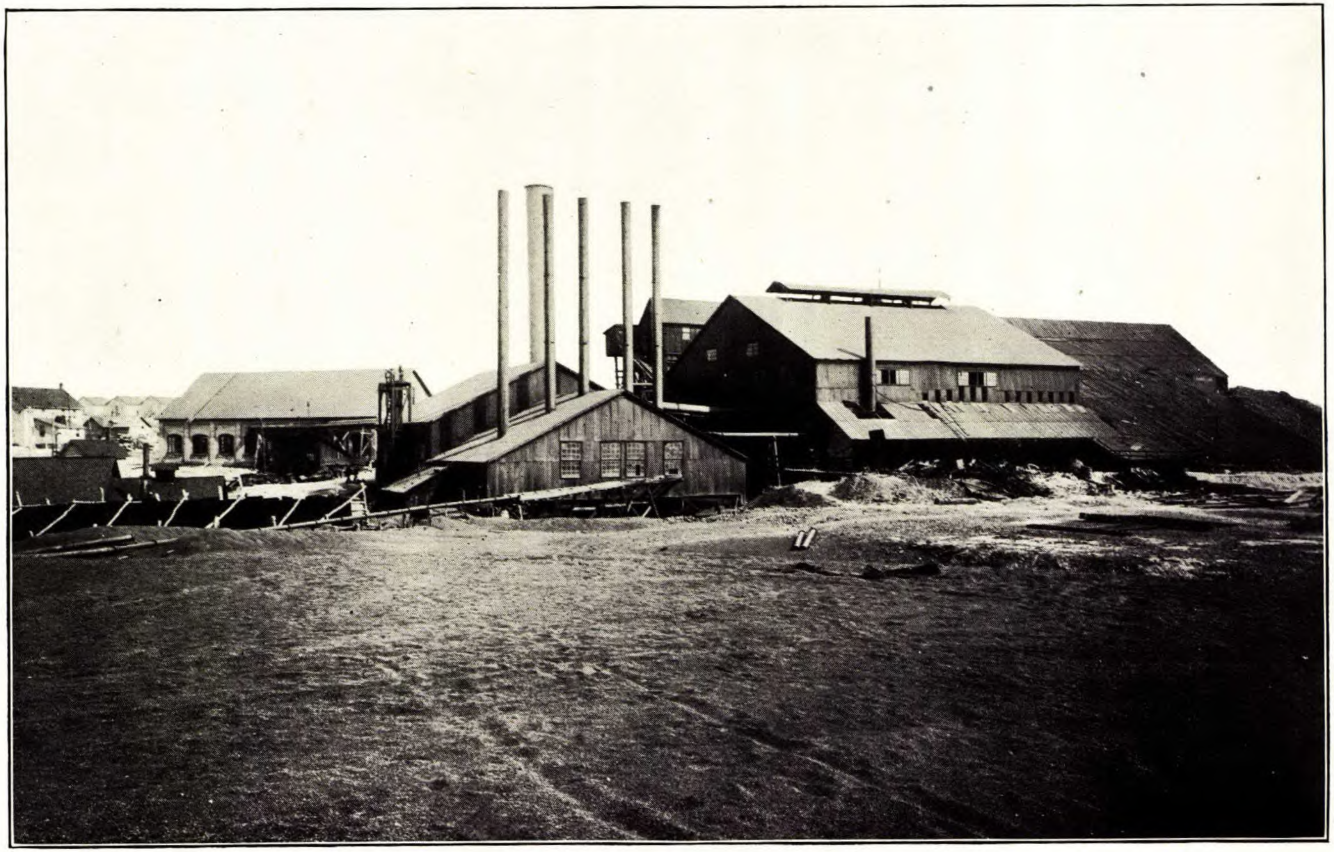
In 1910 diamond drilling was done to test the Cochrane and McVittie property, which covers a corner of the great Frood deposit, and this was purchased to furnish an additional supply of ore. Also plans were made to build a new smelter at Coniston, where 3,700 acres were secured as a site at a point much nearer to their chief mines, the Garson and Frood extension.

The Mond Company has the distinction of working the deepest mine in Ontario, and in spite of rather small ore deposits the Company is prospering, so that it is planning not alone to build much larger smelting works in Canada but to double its refinery in Clydach.

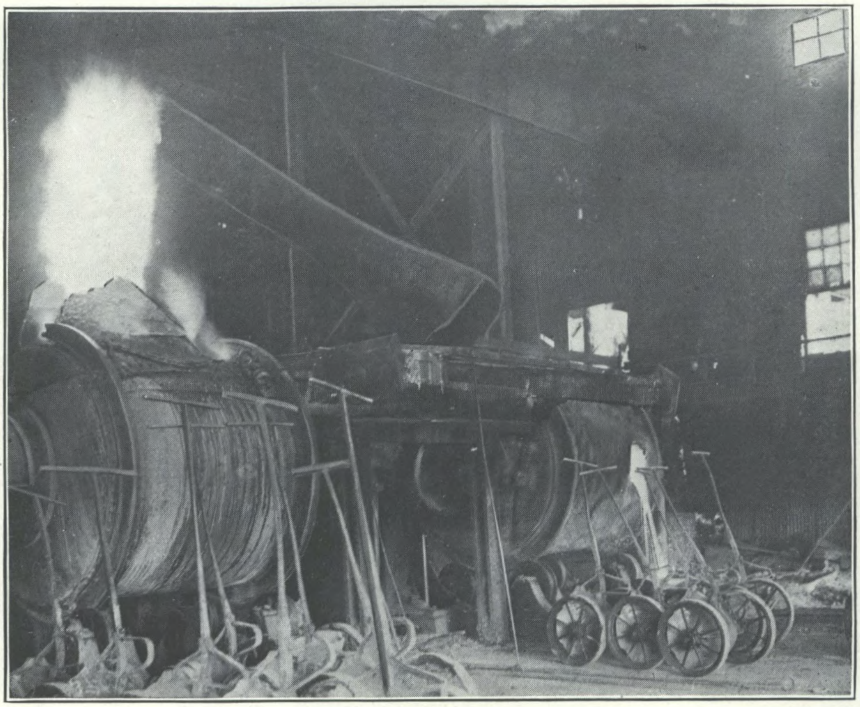
The following statement has recently been made as to the financial conditions of the company:—

The original capital of the company was £600,000, divided into £250,000 7 per cent cumulative preference £5 shares, £300,000 ordinary, and £50,000 deferred shares of £1 each, without debentures or other prior charges. The ordinary shares carried a preferential dividend of 7 per cent, thereafter sharing with the deferred shares in surplus earnings. In 1908 the capital was increased to £850,000 by the creation of 50,000 cumulative preference shares, of which 30,000 were issued, raising the preference share capital to £400,000. It was not until 1905 that the profits of the company provided any return to the ordinary shareholders, since when they have gone up by constant increases, and the returns for the past three years have been:—

	Year to April 30.		
	1909.	1910.	1911.
	£	£	£
Net profit	111,320	114,107	140,803
Pref. div. 7 p.c.	22,716	26,367	26,367
Ord. dividend	42,751	42,375	45,906
Ord. rate p.c.	15	15	16¼
Deferred div.	22,800	22,600	26,131
Def. rate p.c.	48	48	55½
Balance of year	23,053	22,765	42,399
Brought in	29,923	32,976	20,741
For reserve, etc.	52,976	55,741	63,140
To reserve	20,000	35,000	35,000
Carried forward	32,976	20,741	28,140

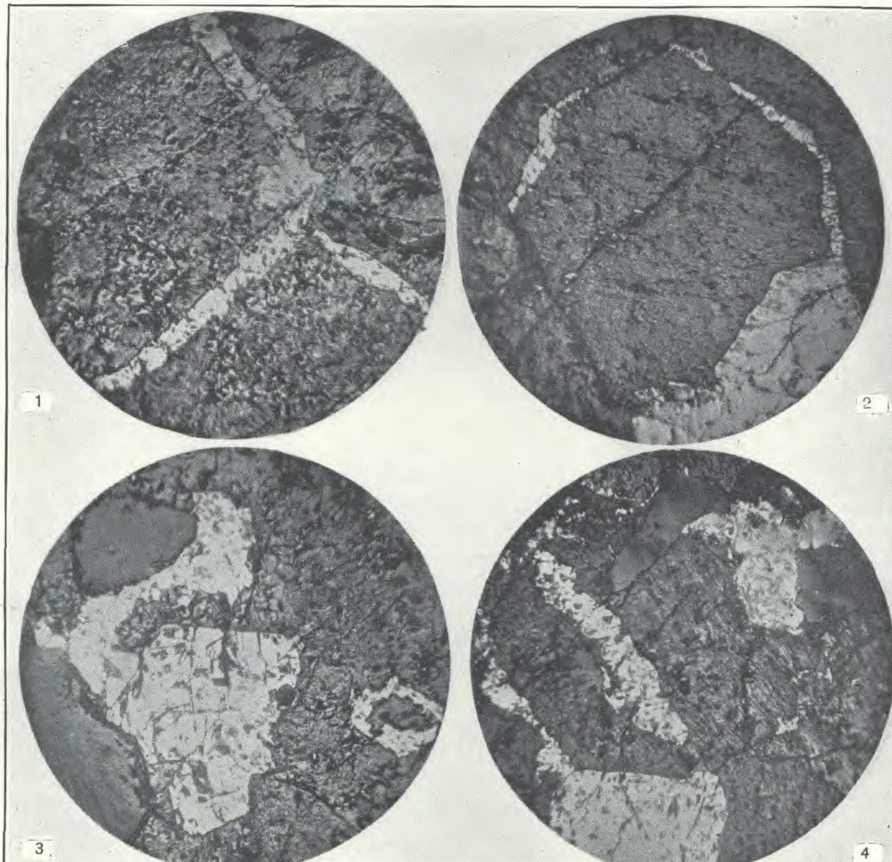


Mond smelter, Victoria Mines.



Converters: Mond smelter, Victoria Mines.

PLATE X.



Polished Sections of pyrrhotite with pentlandite and chalcopyrite: Copper Cliff ore.
After Messrs. Campbell and Knight. X 50 under microscope.

Pyrrhotite dark and rough surface.
Pentlandite light in Nos. 1 and 2.
Chalcopyrite, also light, at top of No. 4.

analysis of a very small fragment from the crystal gave 2·3 per cent of nickel". This unique specimen is in the mineralogical collection of the University of Toronto.

While crystals are always lacking, one finds at a number of localities distinct platy cleavage, probably basal, as in Levack township, and at the Crean Hill mine, examples from Levack showing cleavage surfaces two inches wide. Some good authorities believe that the coarse textured platy ore is richer than the finer grained varieties, but it is doubtful if this rule holds everywhere in the region, since at most of the mines, even when the ore is rich, this basal cleavage can hardly be noticed. On fresh surfaces the ore is bright steel grey with a touch of bronze, but it quickly weathers to a distinct bronze colour.

The Sudbury pyrrhotite seems to vary greatly in magnetism, some examples being feebly magnetic, scarcely affecting a compass needle, while certain specimens from near Blue lake on the eastern range show distinct polarity and attract iron filings. Generally small pieces of the pyrrhotite affect a compass needle only at very short distances. The cause of this variation has not been determined, but it is possible that finely disseminated magnetite plays a part in the most strongly magnetic varieties. Occasionally considerable quantities of magnetite are found mixed with the pyrrhotite, and the difference in the strength of the magnetism of the two minerals makes it possible to separate them magnetically by careful adjustment.

As pure pyrrhotite contains 60 per cent of iron, it surpasses in percentage many workable ores of that metal and might naturally be looked on as a possible source of iron as well as nickel. The only attempt thus far made to use it so proved a failure, however. Ore from the Gertrude mine in its earlier days was unusually free from copper pyrites, and was smelted on a small scale for ferro-nickel by the Lake Superior Power Co., after it had been roasted sweet and the SO_2 used in the plant for sulphite pulp. However, it was found that copper pyrites increased so much in amount as the mine was developed that the process was given up. A small amount of copper is no longer looked upon as specially injurious in steel, and it may be that deposits will yet be found low enough in copper to be used in this way. The ore from one of the northern range properties is thought to be suitable for such uses. It certainly seems unfortunate that a metal destined to be combined with iron should first have all the iron with which it naturally occurs carefully slagged off from it by expensive processes.

If the chalcopyrite found with pyrrhotite were not so intimately mixed as it is in most cases, the two minerals might be separated magnetically.

As the Sudbury pyrrhotite always contains small amounts of rock or of rock-forming minerals, even when carefully selected, probably 40 or 45 per cent of iron is all that could be hoped for from any of the mines worked on a large scale; but this is equal to many iron ores which are now mined and smelted in other parts of the world.

PYRITE.

Iron pyrites, $Fe S_2$, is found at many of the mines, its hardness, resistance to weathering and pale brassy yellow colour making it readily distinguishable from pyrrhotite. It may be more widely spread than is supposed, disseminated through the pyrrhotite. At Blue lake and some other localities well formed octahedra of pyrite are found embedded in the pyrrhotite; but in most cases it occurs in separate masses, often as part of the filling of veins crossing the ore deposits and therefore later in age. In the latter case it appears to carry no nickel, as was shown, for example, by an assay of cubical pyrite found with quartz and calcite at Elsie mine; but the pyrite associated with pyrrhotite and of the same age appears to be nickeliferous. Prof. T. L. Walker found 4·34 per cent of nickel, 39·70 of iron, and 49·31 per cent of sulphur, with 5·76 per cent of insoluble matter in pyrite from Murray mine; and expresses the opinion that the nickel replaces part of the iron in the pyrite, since the amount of sulphur present is too great for any other compound of nickel than $Ni\ S_2$.[1] Dana also states that nickel and cobalt sometimes replace part of the iron in pyrite or else occur as mixtures.

Pyrite is rather common in rusty Huronian greywacke and schist to the south of the nickel eruptive, but is not known to contain nickel, though some of these fahlbands have been taken up as locations, with the idea that they were connected with offsets from the range.

Pyrite from later veins crossing nickel ore bodies is frequently well crystallized and often shows faces of the cube and pentagonal dodecahedron; but pyrite originally forming part of the nickel ore seems, as a rule, to be octahedral, or else, like the pyrrhotite, to show no crystal forms.

MARCASITE.

The rhombic species, marcasite, occurs at a number of the mines, sometimes largely replacing pyrrhotite, as along parts of the Worthington offset to the northeast of Worthington mine. Though no crystals have been found here, the whitish colour and general appearance of the mineral show that it is not ordinary pyrite. An assay made by Prof. T. L. Walker showed it to contain 4·5 per cent of nickel; and a more complete analysis by Dr. Hildebrand of the U. S. Geological Survey gave:

Iron	38·36
Nickel	4·57
Sulphur	45·11

The rest of the contents of the ore were mainly insoluble except for two per cent of calcite. The suggestion is made that a little polydymite is mixed with the marcasite to account for the nickel, though there is no proof of this.[2]

While crystals are not found near Worthington, Prof. Walker reports good crystals of marcasite from a narrow vein crossing ore at Murray mine. This contained no nickel, however, and was no doubt of later origin than the nickel ore proper, having a relation similar to that of the crystals of pyrite mentioned above.

One would hardly expect to find pentlandite or polydymite, with their low proportions of sulphur, intimately mixed with an iron compound containing two atoms of sulphur to one of iron; so that probably the nickel found in pyrite and marcasite really replaces iron in these minerals in the form of $Ni\ S_2$, as suggested by Prof. Walker.

PENTLANDITE.

By all means the most important mineral in the Sudbury deposits is pentlandite (Fe Ni) S, since in the great majority of cases this is considered to be the real nickel-bearing mineral; nevertheless it is rather rarely seen in the ores and has not been found in quite a number of mines.

[1]Am. Jour. Sc., 3rd Series, Vol. XLVII, pp. 312-14.
[2]G.S.C., 1890-91, p. 116 SS.

If carefully looked over, the Crean Hill and Creighton ores often show it, and the old Evans and Worthington mines furnished it also. The pentlandite of the Sudbury region is without crystal forms but has a characteristic octahedral cleavage which distinguishes it from the enclosing pyrrhotite, which generally has no definite cleavage planes. On fresh surfaces the two minerals are almost the same in colour, and the pentlandite is hard to recognize unless ones eye is well trained; but it soon weathers to a brassy yellow easily picked out from the bronzy background of pyrrhotite. Cleavage surfaces are sometimes an inch or more in diameter though this is by no means common.

The proportions of iron to nickel in pentlandite are quite variable, the mineral as first described by Scheerer having only 18·35 per cent of nickel, while some Sudbury examples contain nearly 40 per cent of the metal, as may be seen from the following analyses:

—	I.	II.	III.	IV.	V.	VI.	VII.
Ni	18·35	21·07	34·23	34·82	33·70	34·98	39·85
Co	....	....	0·85	0·84	0·78	0·85	traces
Fe	42·70	40·21	30·25	30·00	29·17	30·04	25·81
S	36·45	36·64	33·42	32·90	32·30	33·30	34·35
Cu	1·16	1·78	....	....	....	....	....
Gangue	....	....	0·67	....	....	....	....
	98·66	99·70	99·42	98·56	95·95	99·17	100·15

The first two are from Lillehammer, analysed by Scheerer; III is from Sudbury, analysed by J. K. Mackenzie (Dana, 6th Ed., p. 65); IV by Prof. Penfield; V, VI, and VII by Dr. Dickson.[1]

Pentlandite was first recognized in Sudbury ores in 1891, by Prof. Walker, then chemist at Murray mine, who named a specimen sent to him from Worthington by Dr. Barlow *Eisen nickel kies*, the German term for the mineral.[2]

As pentlandite is practically non-magnetic and pyrrhotite is usually decidedly attracted by the magnet it was natural to think that the two minerals could be separated magnetically, and elaborate attempts at such a separation were made by Browne, Barlow, Dickson and others; but it has been found that the minerals are too intimately mixed to permit of a complete separation except by methods too costly to be of practical value. Reference will be made later to work of this kind.

Some of the analyses show that ·78 to ·85 per cent of cobalt occurs in the pentlandite, accounting probably for the cobalt contents of the standard matte of the region. The three closely related metals, iron, nickel, and cobalt, replace one another more or less in their compounds.

POLYDYMITE.

Polydymite, $Ni_4 S_5$, according to Dana, as described from Grünau, Westphalia, is a sulphide of nickel with a small amount of iron and a very small amount of cobalt replacing part of the nickel.[3] The examples ana-

[1]Trans. Am. Inst. Min. Eng., 1903.
[2]G.S.C., Vol. XIV, Part H, p. 13.
[3]Dana, 6th Ed., p. 75.

lysed from the Sudbury region contain from 15 to 18 per cent of iron, but as they agree in other respects with the properties of the original mineral, they may be included also under the name. The proportions of nickel and iron to sulphur approach those found for iron and sulphur in pyrrhotite, but while pyrrhotite crystallizes in hexagonal forms, polydymite, like pentlandite, is isometric. No crystals have been reported, but there is a well marked cubic cleavage making the system of crystallization certain.

Polydymite from our region is dark iron grey in colour with good metallic lustre on fresh surfaces, but it very quickly tarnishes and soon falls to powder in the weather.

The only place where it has been found with certainty is at the Vermilion mine, where it is associated with copper pyrites, often intimately intergrown, though large masses may sometimes be found nearly free from it. The following analyses show its composition:

——	I.	II.	III.	IV.
Ni	53·51	53·13	41·96	36·85
Fe	3·84	4·12	15·57	18·17
Co	0·61	....	....	....
S	40·27	39·20	40·80	38·43
Sb	0·57	1·15	....	....
As	1·04	2·30	....	....
Cu	....	....	0·62	4·47
SiO_2	....	....	1·02	....
	99·78	99·90	99·97	98·45

Nos. I and II are from Grünau, by Laspeyres, as quoted by Dana, No. III from Clark and Catlett,[1] and No. IV from David Browne[2].

It is possible that polydymite instead of pentlandite supplies the nickel in some of the mines where the latter mineral has not been found. From its relations of metal to sulphur it would more naturally accompany pyrrhotite than pentlandite would; and if finely disseminated it would easily escape notice in pyrrhotite.

It would be surprising if this mineral should occur to the amount of hundreds of tons at one mine and not at all in any of the other ore deposits of the region.

MILLERITE.

Millerite, Ni S, is the richest in nickel of all the ores, containing when pure 64·6 per cent. It was thought, in the earlier development of the region, to be disseminated through the pyrrhotite and so to form the real nickel carrier; but the discovery of pentlandite in several of the mines makes this quite improbable. Millerite has been reported from the Copper

[1]Am. Jour. Sc. Vol. XXXVII, 1889, pp. 372-4.
[2]Engineering and Mining Journal, Vol. LVI, p. 566.

Cliff mine by Dr. Peters and Dr. Dickson, the latter considering it secondary after pentlandite. It has been reported also from the Sheppard mine, lot, 1, con. 3, of Blezard township, and Prof. Walker and the writer found a few small blade-like crystals of it on the dump of Vermilion mine some years ago; but it is evidently quite unimportant as a source of nickel.

GERSDORFFITE.

All the minerals referred to thus far are compounds of the same elements, nickel, cobalt, and iron with sulphur, but in varying proportions and with very different physical characters. In many other regions where sulphides are prominent there are found also some arsenic minerals; but so far as known these are almost entirely absent in the Sudbury district, except at a few unimportant outcrops along the Worthington offset southwest of Victoria mines. One of these minerals, gersdorffite, Ni S As, contains both sulphur and arsenic. It is a white or steel grey, highly metallic looking mineral, containing when pure 35·4 per cent of nickel, and occurs especially northeast of Worthington where it is more or less mixed with nickelite. A prospect has been named the Gersdorffite mine from its presence.

NICKELITE OR NICCOLITE.

Nickelite, the German *Kupfer nickel,* Ni As, contains 43·9 per cent of the metal, and was the earliest source of nickel. Its pale copper colour and high metallic lustre make it a very handsome mineral. It is found in the Sudbury region only on the Worthington offset, mainly associated with gersdorffite, but has no practical importance as a source of the metal.

CHALCOPYRITE.

In addition to the sulphides containing nickel and iron there is one very important ore of copper almost invariably present, chalcopyrite or copper pyrites, Cu Fe S_2. Unlike most of the nickel minerals mentioned above chalcopyrite is practically constant in composition, containing when pure 34·5 per cent of copper, 30·5 per cent of iron, and 35 per cent of sulphur. Chalcopyrite comes next in amount to pyrrhotite and pentlandite and is always a more conspicuous component of the ore than the latter mineral because of its striking greenish brassy hue and its liability to tarnish with irridescent colours. Good crystals of the minerals appear to be lacking. Copper pyrites may either be intimately mixed with the pyrrhotite or form considerable masses by itself. It appears to be more easily dissolved and redeposited than pyrrhotite and so is more frequently found in fissures in the country rock; and it is especially common near the walls of ore bodies or associated with masses of rock enclosed in the sulphides, so that as a rule rocky ore contains a higher percentage of copper than ore rich in sulphides. In two important mines, the Copper Cliff and the Crean Hill, copper is present in larger amounts than nickel, and at Garson and Victoria mines it about equals the nickel; but all the other mines contain more nickel than copper. As the percentage of copper in chalcopyrite is about equal to the percentage of nickel in pentlandite, we may assume according to the usual theory, that pentlandite occurs in larger quantities than copper pyrites in most ores, though it is so rarely seen.

OTHER COPPER MINERALS.

Bornite and chalcocite were reported from the Vermilion mine in earlier days, but neither was to be seen when the mine was freshly opened up on a large scale in 1910; so that probably they were secondary minerals formed by surface waters and did not reach very deep. Malachite too occurs as green stains at many of the mines, but is, of course, entirely superficial and due to the weathering of copper pyrites.

Native copper has been found rather frequently at the Vermilion mine, and has been obtained at depths of probably fifteen feet; but it is mostly in thin films too fragile to preserve. It has no doubt been precipitated from the sulphate solution by some reducing agent, probably organic matter carried by descending waters. The same may be true also of the native copper reported from Copper Cliff mine; though this was found a thousand feet below the surface, which makes its origin doubtful. All these copper minerals are of secondary origin, derived from the primary copper pyrites.

MAGNETITE.

Though the sulphides greatly preponderate among the Sudbury minerals, oxides occur also, particularly magnetite, Fe_3O_4; which is sometimes seen as scattered crystals in the pyrrhotite, and occasionally forms masses of ore even tons in weight, as at Clarabelle mine north of Copper Cliff. It is highly magnetic and not the titaniferous variety. The crystals, where distinguishable in the pyrrhotite, have octahedral and other forms, polished and a little rounded, as if the sharp edges had been somewhat dissolved away. In ore from one outcrop in Levack township the magnetic crystals make up about ten per cent of the whole; and diamond drill cores from parts of the Northern range show enough magnetite to have importance as an iron ore if the deposits are of large enough dimensions.

TITANIFEROUS MAGNETITE.

The titaniferous variety of magnetite is almost always found in basic igneous rocks and is of frequent occurrence in the nickel-bearing norite, as shown by a whitish rim of leucoxene round the crystals in thin sections. Prof. Walker has found titaniferous iron ore in small quantities in the pyrrhotite from Murray mine, but it seems much less common in the ore than the more magnetic variety mentioned above.

CASSITERITE.

Cassiterite, the oxide of tin, is the only other oxide of interest in the nickel ores, but occurs in quite insignificant amounts, and has been reported only from Vermilion mine, where Messrs. Penfield and Wells found it along with sperrylite.

LATER METALLIC MINERALS.

With the exception of millerite and copper ores other than chalcopyrite, all the minerals mentioned above seem to be original parts of the deposits in which they are found. The more important of them, pyrrhotite, pyrite, marcasite, pentlandite, and chalcopyrite, appear to have been regular constituents of the norite-micropegmatite magma which slowly settled to the bottom of the molten mass, somewhat as matte separates from slag in smelting furnaces. They are in a sense rock-forming minerals associated with the magnetite and silicates of the norite at its lower or basic edge, and reached their present position before the eruptive sheet finally cooled. There has been some rearrangement since, especially in offset deposits, but the materials dissolved, transported, and redeposited were obtained from the norite itself and were not shifted far from their source. They are not associated with water formed minerals such as quartz and calcite. There are, however, on the other hand, in most of the ore deposits later veins of characteristic aqueous formation, including quartz, carbonates, and a few metallic sulphides other than those described above.

Pyrite or marcasite, galena, zinc blende and molybdenite are found in such veins at several of the mines, especially on offsets. They are known from Creighton, Crean Hill, Copper Cliff and Garson mines, and would probably be found at others if looked for.

These veins, usually very narrow, cut right across both norite and ore and were evidently formed under totally different conditions from the typical minerals of the ore. Their source may have been the overlying or underlying rocks; since the same sulphides and gangue minerals have been found in the underlying Huronian slate and greywacke, and also in the sedimentary rocks of the basin above the acid phase of the nickel eruptive.

Zinc blende, brownish black in colour and coarse textured, is rather often found at Crean Hill, and is known at one or two other points. It is the only known compound of zinc.

Galena is somewhat more common and occurs in considerable amounts at Garson mine, a vein several inches wide cutting the ore body. Here it is very coarsely crystalline. It is found too at Copper Cliff and Creighton in very small quantities, always apparently of later deposit than the ore. It has been suggested that the galena present in some of the ores might account for the small quantity of silver always to be found in the matte, but galena is too infrequent and too irregularly distributed to be of importance in this respect, particularly since specimens assayed prove very low in silver,

Molybdenite has been reported only once, from the Worthington offset, which has a greater variety of minerals than any other part of the region.

NATURAL GAS.

In the Copper Cliff mine at the lower levels an odorless combustible gas was observed, but no careful examination seems to have been made of it. This suggests a reducing agent capable of producing the native copper found on the 12th level of the mine.

A little graphite has been picked up on the dump at the Lady Macdonald mine, north of Copper Cliff. The source of the carbon and hydrocarbons is unknown, unless it could have been derived in some way from the once bituminous slate overlying the nickel eruptive.

THE GOSSAN MINERALS.

Pyrrhotite is readily attacked by the processes of weathering, and chalcopyrite also soon tarnishes and yields to surface action; so that a number of iron, nickel and copper compounds are formed, mostly of a fugitive kind. Everyone familiar with the nickel region remembers the peculiar copperas smell of the nickel deposits, especially after damp weather.

The first stage in the process is the formation of hydrous sulphates of the three metals, which may often be seen as crusts or short icicle-like forms where there are projecting or overhanging masses of ore. The sulphates are bluish green when completely hydrated, but turn white by loss of moisture. These sulphates are quite evanescent compounds, scarcely deserving the name of minerals. They are very soluble and give their peculiar bluish green colour to the water of pools on the ore or filling the open pits of abandoned mines. The chief sulphate is, of course, that of iron, $FeSO_4 \, 7H_2O$, (melanterite or copperas); but that of copper, $CuSO_4 \, 5H_2O$ (chalcanthite), of nickel, $NiSO_4 \, 7H_2O$ (morenosite), and probably also of cobalt, $CoSO_4 \, 7H_2O$, (bieberite) must occur also.

The next stage is the formation of limonite, the hydrated sesqui-oxide of iron, which is the typical gossan product of the region. What becomes of the sulphates of nickel and copper is unknown, though occasionally a film of green malachite may be found where the ore is rich in copper. A permanent secondary compound of nickel has not been reported from the region.

The brownish red gossan is the most characteristic sign of nickel deposits on the ranges, and where the gossan is widespread and thick there is almost certainly ore of importance beneath it. The limonite is a very stable mineral and often stands up as mounds or hills, but a very few years are sufficient to transform pyrrhotite ore on the mine dumps into a crumbling mass of rusty fragments from which most of the copper and nickel has been leached away. It is therefore unwise to open up deposits on a large scale before the ore is required for smelting unless it can be stored under cover.

Probably millions of tons of nickel and copper have been dissolved and carried away by the drainage of the region since its first exposure to the weather in Palaeozoic times; and this age long wastage seems nowhere to have resulted in the concentration of the metals in workable secondary deposits. They have probably passed in solution to the sea and are lost to man forever.

MINERALS OF THE PRECIOUS METALS.

All of the Sudbury ores contain small amounts of the precious metals, but these are seldom found in recognizable minerals. Native gold was early found in the gossan of the Vermilion mine, which was first taken up as a gold mine; and soon after it was obtained from Victoria mine a mile or two west. A little was found also at Crean Hill when the mine was discovered. Of the other precious metals, silver, platinum, and palladium, the source of only one is known, the platinum.

SPERRYLITE.

Sperrylite, $PtAs_2$, the arsenide of platinum, was first obtained from the gossan of Vermilion mine, and later from the Victoria mine, then called the McConnell property. The name was given by the Messrs. Wells and Penfield in honour of Mr. F. L. Sperry, chemist of the Canadian Copper Co., who had sent it to them for examination. The mineral was found during the crushing and washing of the material for gold in a miniature stamp mill, where it collected with the gold on a blanket over which the pulp was passed. Its brilliant silvery colour and lustre naturally surprised the gold miners.

It crystallizes in tiny cubes and octahedra with a few other forms of the isometric system, and is very hard (from 6 to 7) and resists weathering perfectly. As its specific gravity is 10·6 it is concentrated along with the gold in the gossany debris above ore deposits. The mean of two analyses by Wells and Penfield give the following composition:

Arsenic	40·98
Antimony	0·50
Platinum	52·57
Rhodium	0·72
Palladium	trace.
Iron	0·07
Cassitérite (SnO_2)	4·62
Total	99·46

The sperrylite of the ores is mainly contained in copper pyrites, and may be obtained from it by dissolving the latter mineral with acid, as shown by Mr. Mickle and later by Dr. Dickson, but it occurs more sparingly in the other sulphides, such as polydymite. This mineral has not been found at the other mines, though the platinum obtained from matte made from their ores suggests that it is really present.

It is known that palladium occurs in the Sudbury ores in larger amounts than platinum; but no palladium compound has yet been discovered. The silver, also, is not accounted for unless contained in the copper pyrites.

The Source of the Ores.

From the foregoing description it is evident that in most of the Sudbury mines the ores are very few in number and very monotonous in character, pyrrhotite, pentlandite, and chalcopyrite making up most of them almost exclusively; and even these three minerals practically never show crystal forms. Further we know that they are invariably associated with a single rock, norite, which is almost as monotonous in its habit as the sulphides, and mixes with them in every gradation. The association is so impressive to the field geologist that he inevitably looks for a causal connexion between them; and it may be added that all geologists who have studied the relationships in the field are convinced that the causal connexion is magmatic segregation. The molten mass of eruptive rock was charged with the sulphides of iron, nickel and copper, which separated out before cooling was complete.

It is, however, interesting to find that certain metallurgists and others who have studied the ores chiefly in the laboratory or with the microscope hold a totally different view, believing that the ores have been brought in by water, replacing the rock-forming minerals.

The first to state this opinion in a decided way was Dr. C. W. Dickson,[1] who studied sections of rock and ore; but the work of Messrs. Wm. Campbell and C. W. Knight, illustrated by beautiful microphotographs of polished sections, is perhaps the more important[2]. They have

[1] Trans. Am. Inst. Min. Eng., 1904, p. 36.
[2] Econ. Geol., Vol. II, No. 4, 1907, p. 350-366.

shown conclusively from the study of specimens of ore from several of the Sudbury mines, as well as from Norway and other regions, that a definite order of succession can be recognized among the sulphides, pyrrhotite being oldest, pentlandite next, and chalcopyrite last. Where rock forming minerals are present also, the order is, magnetite, silicates, pyrrhotite, pentlandite, and chalcopyrite.

These results may be accepted without opposition by those who hold the magmatic theory, since the study of polished sections shows simply the final disposition of the minerals. It can throw no light on the origin of these minerals beyond affirming that a certain amount of fracturing of pyrrhotite allowed pentlandite or chalcopyrite to migrate into the fissures; but where the later minerals came from is still an unsolved problem. The magmatic segregation theory provides for all the ores as separating more or less completely from the molten rock, but does not deny that there may have been later rearrangements among them, so that the two theories are in reality complementary and harmonious.

The numerous lines of evidence in favor of the magmatic theory are well given by Dr. Barlow[1], who seems to have been the first to reach such a conclusion, though a number of others, including Von Foullon, Vogt, Adams, Browne, Walker, Kemp, and the present writer, have argued in its favour.

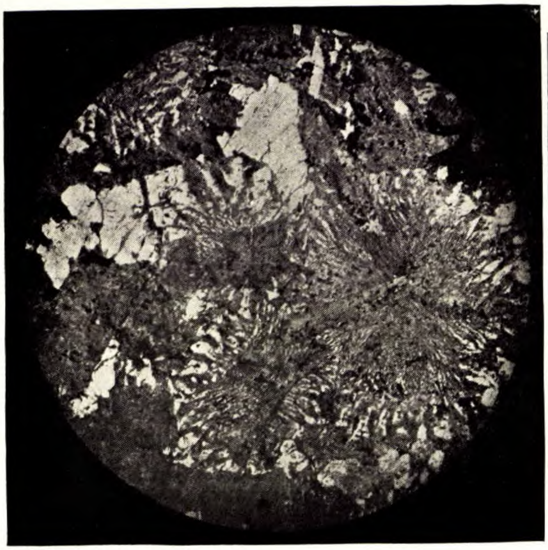
The evidence for the magmatic theory hardly needs to be repeated here, since most geologists and mining engineers interested in the Sudbury deposits are already satisfied of its correctness. In the course of the following account of the region the soundness of the theory will become clear without any formal summing up of the arguments.

Rocks Associated with the Ore.

The Sudbury pyrrhotites always contain small amounts of ordinary rock forming minerals, such as pyroxene and plagioclase feldspar, and these may increase until the silicates equal the sulphides in amount, when the mixture may be called pyrrhotite-norite. Such intermediate rocks are found at every ore deposit, so far as known, and form a transition towards ordinary norite. In fresh examples some blebs or specks of the sulphides, pyrrhotite, and in less amount chalcopyrite, are seen disseminated through the usual grey rock. When weathered the sulphides are dissolved or turned to iron oxide, and the brownish surface of the rock is spotted with limonite or has many rusty holes from which the sulphides have been removed. This 'pock marked' surface is characteristic of the norite near ore bodies. A few blebs of ore or tiny rusty cavities are often found in the rock hundreds of yards away, and occasionally even a mile or two from the basic edge of the norite. This often serves as a guide in field work, since no other rock in the region has the same peculiarity. For this and other reasons the pyrrhotite, almost always associated with some copper pyrites, may be looked on as itself a part of the succession of differentiation products of the great laccolithic sheet mentioned earlier.

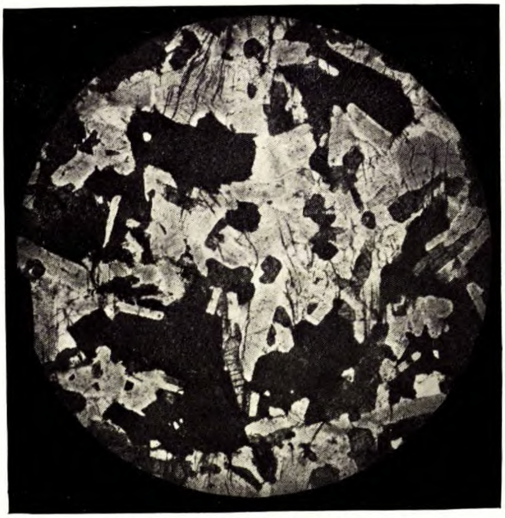
The norite of the basic edge accompanying the ore varies greatly in freshness and in appearance, so that the prospector or mining engineer requires to have a certain range of experience in order to recognize it in different localities. The typical norite of the southern range is a rather coarse, dark grey massive rock in which one can distinguish a little brown biotite and also bluish quartz in scattered blebs, though the bulk of the rock

[1]G.S.C., Vol. XIV., Part H, pp. 124, etc.



1.—Micropegmatite.
Polarized light X 10.
Quartz light, andesine pale grey, hornblende dark grey.

2.—Norite: Creighton mine.
Ordinary light X 10.
Labradorite pale grey, hypersthene darker grey.



3.—Pyrrhotite-norite X 10.
Labradorite pale grey, hypersthene dark grey, pyrrhotite black.

is clearly made up of grey feldspar and a darker grey or green mineral in smaller amounts. The darker mineral often has the character of hornblende, so that the name diorite was applied to the rock in the beginning, and most prospectors still use the term. Fresh examples however prove to contain two varieties of pyroxene, ordinary augite and hypersthene; the latter usually in large amounts; so that the hornblende is evidently of secondary origin. That the fresh rock is norite and not diorite or gabbro was proved first by Baron von Foullon[1] who visited Murray mine in 1891; and was confirmed by Dr. T. L. Walker two years later from the same mine and from Blezard mine[2]. This was of much interest as bringing the Sudbury deposits in line with those of Norway previously investigated by Prof. Vogt.

Through the work of Dr. Barlow and the present writer the presence of fresh norite has been shown at many other places, including the great Creighton mine, and the rock forming minerals are often found unchanged in contact with disseminated masses of the ore.

In thin sections of the pyrrhotite-norite the ore itself, when unaffected by later changes, is grouped with the more basic minerals as might be expected. It is often close beside magnetite, the two opaque minerals making a single mass, or it may enclose magnetite, or be enclosed by it. It is frequently found alongside of hypersthene or augite crystals and also beside or imbedded in mica. It may, however, lie between the dark coloured minerals and the feldspars.

Where the rock is least changed the outlines of the ore masses are as sharp and apparently undisturbed as those of the other minerals, and the inference is natural that the pyrrhotite assumed its position in the same way as the other rock forming minerals. All are strikingly fresh, even the hypersthenes, which are usually among the first of the silicates to be attacked and rearranged.

When hypersthene has begun to change into fibrous hornblende, however, the pyrrhotite and chalcopyrite usually show signs of disturbance, penetrating cracks in the adjoining partially decomposed minerals. To one unacquainted with the general geological associations this might be interpreted as replacement, though it is not really so, and implies only a rearrangement of materials already present in the rock, and not a transport of materials from a distance to take the place of ingredients which had been dissolved.

Even in the greatly weathered specimens of the rock where the pyroxenes are transformed to uralite the ore blebs are found completely enclosed, often far apart from one another, and the microscope shows no channels through which solutions might circulate from a distance. That there has been a certain amount of solution and redeposition in many of the ore deposits is admitted by all, but this was of the nature of a rearrangement of the minerals of the rock, and not due to the introduction of new materials. It is therefore quite consistent with the accepted theory of magmatic segregation.

Admitting this theory, and admitting also that gravity played a preponderating part in the separation of ore from rock, as it does of matte from slag in metallurgical practice, conclusions of great importance may be drawn. The chief ore bodies will be found where there are large depressions in the floor on which the molten norite rested, so as to concentrate the ore in one place instead of allowing it to spread out thinly on an even bottom. In addition, where the thickness of molten magma

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[1]Jahrbuch der K.K. Geol. Reichsanstalt, Vienna, 1892, pp. 223-310.
[2]Quar. Journ. Geol. Soc. Vol. LIII, pp. 40-46.

was greatest there will be the largest accumulation of ore, supposing that it was evenly dissolved in the original magma. Both points have been conclusively proved by the field work.

On the other hand no ore need be looked for on upward or inward bends of the floor, since the molten sulphides would settle down into the hollows on each side. This too is confirmed by the results of the field work. It is evident then that the careful working out of the boundary of the norite and of the thickness of different parts of the norite-micropegmatite sheet is of fundamental importance in determining the position and size of the accumulations of ore.

It has been proved that nickel ore is always accompanied by norite for the good reason that it formed a part of the common magma. Though there is no ore without norite, the reverse is not true, since there are wide stretches of norite with little or no ore, in accordance with the arrangement of the underlying country rock, as shown before.

The typical coarse grey norite with a little mica and blue quartz described above occurs along the most productive part of the main nickel range, from Victoria mine to Blezard mine; but along other parts of the basic edge the rock changes somewhat in appearance, being lighter in colour and showing less of the two accessory minerals. In some places, as near Garson mine, it has been sheared or squeezed into a rather pale grey schist which contains none of the original norite minerals and would never be recognized as belonging to that rock if the contact had not been followed up without a break from the typical region to the southwest. On the northern and eastern ranges the norite is about as coarse grained but paler in colour.

The basic edge of the norite and the marginal ore bodies everywhere dip inwards toward the central axis of the syncline and rest unconformably on the truncated edges of the older rocks, which may be of any description without affecting the ore deposits. On the northern range the country rock is chiefly greyish or pinkish granitoid gneiss with bands of green schist and dykes of pegmatite—the characteristic Laurentian gneiss of the Canadian Archaean. On the eastern range the underlying rock is chiefly green schist or greenstone with dykes of granite, probably of Keewatin age. The country rocks of the southern range present the greatest variety. Beginning at the southwest corner of the syncline there are greenstones and granites intermixed, perhaps Laurentian, or perhaps of later age. At the Chicago mine the greenstones are largely replaced by pale grey or white anorthosite, followed by greenstones at Victoria mine and Crean Hill. To the east of this a later granite makes the boundary for a mile or two, followed by greenstone penetrated by granite. At Gertrude mine a band of confused volcanic rocks, including an older norite, extends nearly to Creighton, where coarse granitoid gneiss lies beneath the norite and ore. Coarse and fine granitoid rocks extend from this to the Copper Cliff region; after which there are more volcanics, including the older norite and pillow lava. Then come two or three miles of a medium grained granite probably later than the norite, succeeded at Little Stobie by older norites and lava flows, which reach to the Blezard mine. After this the country rock is mainly greenstone with some greywacke or quartzite.

The norite and ore along different parts of the boundary rest upon at least a dozen types of rock as foot wall, mostly eruptives, but varying in composition from acid granite to a very basic norite or greenstone with not more than 50 per cent of silica. These rocks are partly coarse plutonics which cooled at great depths, and partly lava streams. At certain points the ore comes against sediments also. None of these rocks has the slightest effect on the norite or ore except as a solid foundation with an irregular surface on which both ore and rock might solidify. The magma of the nickel eruptive was the parent of the ore, and the country rock beyond and below was a purely accidental thing influencing the formation of the ore bodies only by its shape and other physical features, not by its composition or chemical properties.

In various places, as at Murray and Creighton mines, both ore and norite become finer grained against the country rock beneath, showing that it was then cold and chilled the molten materials where they came in contact with it.

TRANSITION FROM NORITE TO MICROPEGMATITE.

As mentioned before there is no break between the norite of the basic edge of the nickel-bearing eruptive and the micropegmatite of its acid edge. If one crosses it at one of the widest parts, for instance, near Murray mine or Creighton, one passes from ore to pyrrhotite-norite in one or two hundred feet, and within a few hundred yards reaches typical norite, the coarse grey rock with a few rusty spots where round blebs of ore have weathered out, which has been mentioned before. For one and a half or two miles there is little change in the appearance of the rock except that there are few, if any, blebs of ore in it, and for this distance it weathers somewhat rapidly in rounded masses enclosed in coarse sand and gravel resulting from its own decomposition. The microscope shows no great change in the rock up to this, except an increase in the quartz intergrown with the feldspars; but beyond this the eruptive becomes reddish on weathered surfaces and looks like a dark syenite, though the microscope shows mainly plagioclase as the feldspar, with a considerable amount of micropegmatite between the crystals. There is little orthoclase to be seen, though analyses prove that this phase of the rock contains almost as much potash as soda.

The coarse reddish variety seldom continues to the actual acid edge, where the rock usually becomes finer grained, grey or greenish in colour and often somewhat schistose, so that it has been mapped as gneiss or Huronian schist. The feldspar crystals are seen, under the microscope, to be andesine as well as orthoclase, generally having platy shapes suggesting the trachitic structure. The micropegmatite has increased in amount, and crystals of andesine are apt to be enclosed in a wide border of plumy intergrowths of quartz and feldspar which can hardly be resolved even with high powers of the microscope. Analyses show little change in the chemical composition except a slight increase of silica.

Types of Ore Deposits in the Sudbury Region.

When the Sudbury ores first attracted attention magmatic segregations were scarcely recognized as ore deposits and the terms used for the Sudbury ore bodies were naturally those applying to the better known deposits formed by circulating waters. They were spoken of as "veins" or "stockworks" or "lenses" since the forms in which they occur sometimes suggest these terms. It was supposed by some, however, that they might be "replacements" or "contact deposits"; and there are points which might be thought favorable to such a view. Occasionally the deposits have definite walls and a somewhat vein-like form, as near the Orford works, Copper Cliff; and most of the ore bodies have parts that resemble stockworks, where the ore reticulates about fragments of country rock; but in both cases the ore penetrated the small fissures while molten, under pressure from the magma above. The fissures themselves and the crush breccias in which the ore plays the part of matrix were due to the faulting and smashing of the underlying rock owing to the motions of the nickel-bearing magma in reaching its present position.

Again the ore bodies sometimes have a rude lenticular shape, though they are not symmetrical as they should be in typical lenses. The side toward the country rock may be fairly well defined, but the side toward the norite has no definite boundary.

Where secondary action of circulating waters is pronounced the ores have to some extent the appearance of materials deposited by replacement; although this is deceptive, since the ores have not been introduced from without, and have merely been rearranged in practically the place where they originated.

The ore bodies often have the look of contact deposits, lying as they commonly do, between country rock, such as granite or greenstone, and the never failing norite; but they are not contact deposits in the usual sense, implying that the country rock has been a necessary reagent causing the precipitation of the ore.

It is evident that none of the foregoing terms, drawn from studies of ore deposits made by circulating waters, will apply properly to masses of ore having an origin so essentially different as magmatic segregation.

To meet this difficulty the two main varieties of ore bodies in the region were distinguished by the present writer as "marginal" and "offset" deposits, terms having no connexion with those used for water formed deposits.[1]

MARGINAL DEPOSITS.

Many of the more important nickel deposits occur at the basic margin of the norite, lying between it and the adjoining country rock. They are commonly irregular sheets of ore occupying the lowest parts of the country rock, penetrating all its fissures and enclosing blocks of it of all shapes and sizes. They may, however, have a very distinct foot wall where the country rock was not shattered by the influx of ore and norite or where faulting has brought a smooth surface of country rock against the ore.

After a varying thickness of pure ore containing very little of the rock minerals the blending of rock and ore called pyrrhotite-norite occurs, passing finally into norite with a few blebs of ore. The inner and upper margin is very indefinite, being fixed in mining simply where the amount of rock matter present is too great to be profitably worked. The thickness of workable ore may vary from a few feet to 100 feet or more as in the Creighton mine. The length is equally variable, ranging from one or two hundred to seven hundred feet, but is usually several times the thickness. Often the ends thin out without ceasing entirely, and a very rusty rock may connect one deposit with another, as happens with the Elsie and Murray mines, so that more or less ore continues for half a mile or more.

The depth to which marginal deposits go is unknown. The Creighton has been found by mining 700 feet below the surface and is known by the results of diamond drilling to extend to at least 900 feet. Theoretically there is no reason why these ore bodies should not go down indefinitely provided the depression in the underlying country rock continues.

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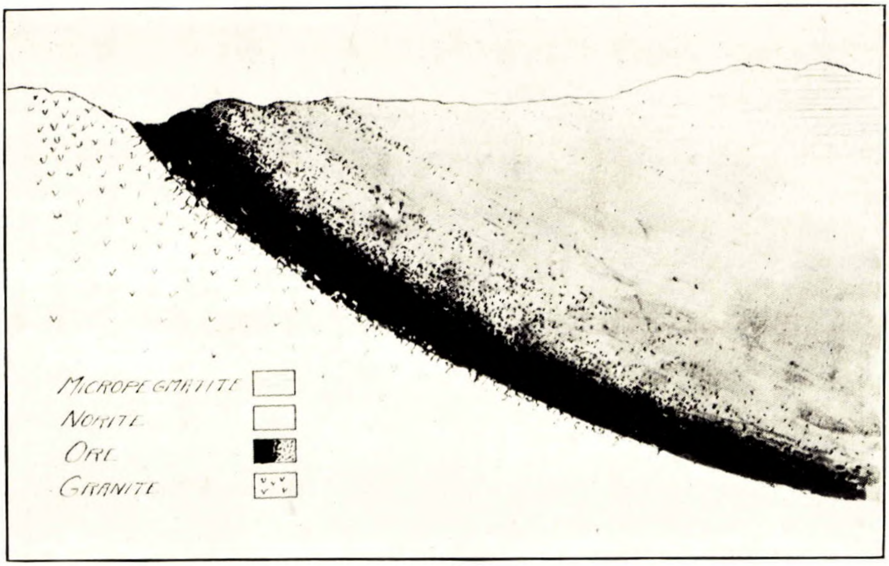
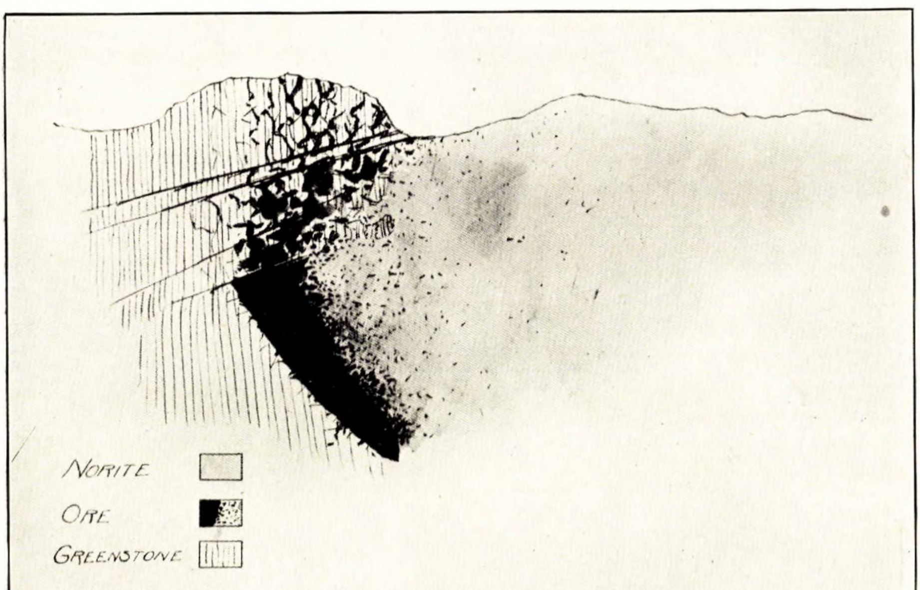
[1] Bur. Mines, Ont., Vol. XIV, 1905, pp. 19, etc.

Plate XII.



Typical marginal deposit.

Plate XIII.



Faulted marginal deposit.

Marginal ore bodies usually dip at moderate angles inwards toward the axis of the syncline, the inclinations commonly observed running from 20° to 65°, with an average of 30° or 35°. At the Creighton mine the dip of the foot-wall is 34° in the upper part and flattens to 32° in the lower levels.

Since there are marginal deposits on all sides of the nickel basin, there are ore bodies inclined in every direction, those of the southern range dipping northward or northwestward, and those of the northern dipping southeastward; those on the east end dipping west, and vice versa. Occasionally faulting interferes with the regularity of the arrangement, but in general the deposits conform surprisingly well with the outline just given.

These ore bodies may be symmetrical to a vertical plane at right angles to the dip, but they are never symmetrical as to their upper and lower sides, since the lower side is generally well defined, while the upper merges into the general body of norite. There is usually a good foot-wall but no definite hanging wall.

FAULTED MARGINAL DEPOSITS.

Since the former survey of the region was made two very interesting deposits have been opened up, disclosing features quite different from those of ordinary marginal deposits, yet so closely bound up with the norite edge as to be marginal in position. These are the Crean Hill and Garson mines.

In each case the deposit was formed, or at least begun, as the usual marginal type, occupying a hollow in the underlying country rock; but later faults of various kinds have carried masses of country rock over or into the basic edge of the norite, greatly confusing the relations and giving rise to ore much richer in copper than that of the regular marginal mines.

During the faulting the country rock was more or less crushed and split into small and large blocks, and the ore wandered into the fissures between the blocks, either at the time as molten sulphides, or later through water transport. As chalcopyrite is everywhere the more transferable of the sulphides, it has entered the fissures more largely than the pyrrhotite. Unusually large amounts of quartz, carbonates, and sulphides of zinc or lead are found in these two mines as a result of circulating waters, and these later processes have played a larger part than in most other ore bodies of the region whether marginal or offset.

OFFSET DEPOSITS.

The term "offset" was introduced to include ore bodies connected with dyke-like projections from the basic edge of the norite, or more or less separate masses of ore and norite not visibly connected with the main body of rock, but almost certainly having underground connexions. Dr. Barlow prefers to separate the isolated ore bodies as a third type, and there is something to be said for this view,[1] but the general character of the two is so much alike that they may be discussed together.

The marginal deposits occupy depressions in the country rock below the norite, but often these bays or depressions end funnel-like in a projection somewhat resembling a dyke, though usually more irregular in shape and boundaries. Because of this irregularity and also because of the frequent interruptions in these bands of norite and ore it seems preferable to use the word offset rather than dyke for descriptive purposes.

One must think of the underlying country rock as having been broken and shattered in many places by collapse during the removal of the molten

[1] G.S.C., Part H, Vol. XIV, p. 120.

rock from beneath, and also by the mechanical action of the laccolithic sheet spreading out above. The fissures and devious channels between the blocks would be flooded by the highly fluid norite and ore acting under the pressure of three miles of overlying magma and solid rock. The bottom norite highly charged with sulphides entered and filled every existing channel and forced its way in places through belts of shattered and weakened rock, enclosing many fragments torn off on the way. Doubtless there was much grinding of one surface upon another in the process, accounting for the many rounded boulder-like rock fragments enclosed in the ore.

Offsets may sometimes extend continuously from the basic edge of the norite for a distance of a mile or two, as at Copper Cliff, first as a funnel irregularly narrowing, then in a dyke-like manner with a width of only 100 or 200 feet. At length it ceases abruptly. More or less ore appears along the funnel-shaped part, resembling in its arrangement the marginal deposits mentioned above; while along the narrow projection from the funnel the norite is highly charged with ore, and small bodies of solid ore occur, but usually not of great importance. When the band of pyrrhotite-norite ends, however, there is apt to be a large and important ore body, a typical offset deposit, as at No. 2 mine, Copper Cliff. It is as though advance was arrested and the sulphides could accumulate.

After a longer or shorter interruption of barren country rock, norite and ore appear again, sometimes as small isolated bodies, at others as elongated outcrops with most of the ore at the outer end.

These separate outcrops may be very definitely aligned, as in the Worthington offset, or may be scattered quite irregularly, as at Copper Cliff; since the arrangement was due to the accidents of the conduits into which the ore and magma were forced. The relationship has been aptly expressed by Dr. Peters as "like sausages on a string, but with a long bit of string between the sausages."[1]

The word offset is used for the whole series of outcrops, which may be short, with only a single ore deposit, or long, including as many as four or five distinct ore bodies, and containing in all hundreds of thousands of tons of ore.

As might be expected, when a depression beyond the basic edge ends in an offset, there are no important marginal deposits, most of the ore having passed on to halt before various obstructions as offset deposits.

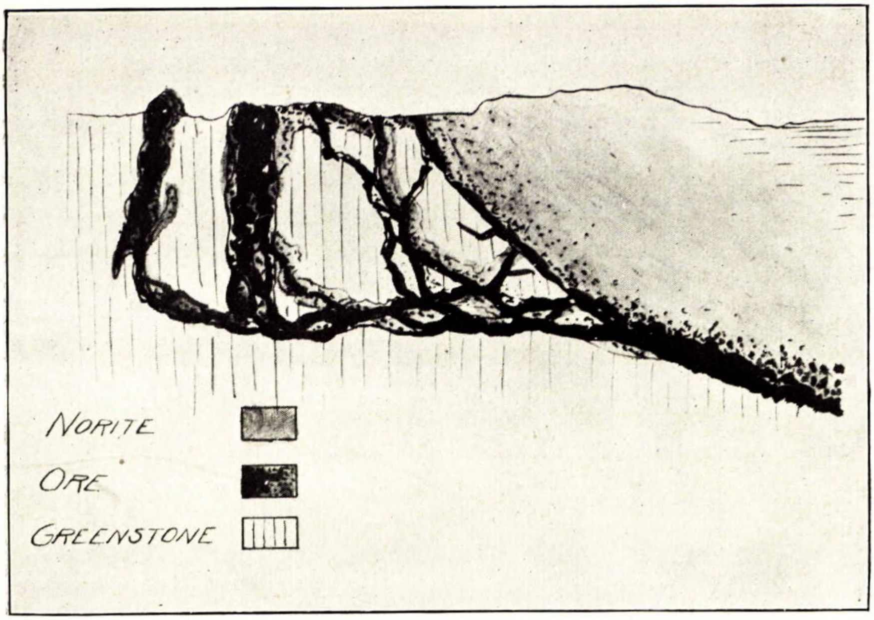
COLUMNAR OFFSET DEPOSITS.

In form typical offset deposits differ completely from the marginal deposits described on an earlier page. They may be fairly symmetrical as they appear on the surface, and have usually a longer diameter in the direction of the offset, and a shorter one across it. Occasionally ore may fill almost the whole width between the walls of country rock, though there is always more or less norite spotted with ore associated with it. When followed down in mining operations they prove to be among the most extraordinary ore deposits in the world, and may be looked upon as quite unique in the light of recent developments.

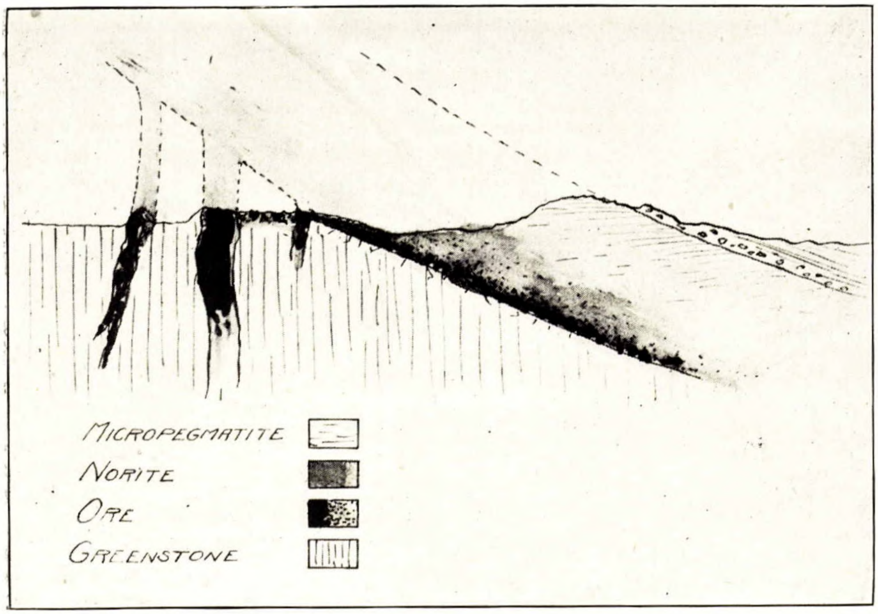
In the last report on the nickel region the Copper Cliff deposit was known to go down for 1,000 feet without interruption as a rude oval pipe with diameters varying from 50 to 200 feet, and a dip of 77½° to the northeast.

Since that time the two ore bodies of Victoria mine, though smaller in diameter, have been followed to the depth of 1,400 feet with no indica-

[1]Mineral Resources of Ontario, p. 104.



Possible arrangement for offset deposit.



Possible a rrangement for offset deposit.

tion that they may not continue indefinitely. These two small cylinders of ore, more than 1,400 feet in length and close together, but never meeting, are not at all easy to account for on any other theory than the magmatic one, and this continuance to so great a depth was not anticipated in earlier studies of the region.

The much larger cylinder of No. 2 mine at Copper Cliff is known to reach a depth of 700 feet, descending nearly vertically. In shape and attitude these curious deposits remind one somewhat of the South African diamond pipes, though with much smaller diameters and with a filling that was much more fluid than the volcanic materials of the diamond fields.

The contents of these pipe-like bodies differ considerably from those of marginal deposits, being more rocky, as might be expected, and containing usually more copper ore, as well as more of the precious metals, gold, silver, platinum, and palladium. The rock matter is mainly spotted norite, but includes also fragments of the adjoining country rocks, often pretty well rounded. There is usually more evidence of water action than in the marginal mines, and often a certain amount of quartz and of rusty weathering carbonates is mixed with the ore, probably as later effects of magmatic waters.

The mode by which these relatively narrow and not far from vertical columns of ore reached their present position must have been completely different from that suggested for the marginal deposits, where the ore settled by gravity as pools in the hollows of the country rock below. It is probable that after such a gravitational separation the lower and more fluid part of the magma was, in a sense, injected into every available opening by the hydraulic pressure of the molten mass above weighted still further by the thick overlying sediments of the basin.

It would be natural to suppose that the heavier and more fluid sulphides sank from above into the openings presented in the country rock, in which case the separate columns of ore might have been fed by overhead conduits now removed by the tremendous erosion to which the region has been subjected. On the other hand, however, it is possible that the most fluid part of the magma, the pyrrhotite-norite, entering all the fissures produced by the collapse of the underlying rock, rose from beneath under hydraulic pressure and was able, in a sense, to drill holes up through the crushed zones of rock above.

The latter explanation is the one that seems to fit best, though our knowledge is not yet complete enough to settle the matter finally. Whatever their cause, these nearly vertical columns of ore must be distinguished from all others as a well-marked type, which may be called "Columnar Offsets."

The word "pipe" would have been more appropriate and descriptive than "column," but its prior use in "diamond pipes" with a definite signification of quite a different sort, made it unadvisable.

PARALLEL OFFSETS.

Another type of offset, with very different features from the columnar type, should be set apart for the greatest mass of nickel ore in the district and in the world—the Frood-Stobie offset. In this case there is no observable communication with the basic norite edge; so far as can be seen on the surface, the band of ore is entirely unconnected with the main nickel range.

The Frood-Stobie offset runs nearly parallel to the basic edge, but at a distance of from $\frac{3}{4}$ of a mile to $1\frac{1}{2}$ miles to the southeast. The ore more nearly resembles that of a marginal deposit than that of the ordinary offsets; and the ore body dips at an angle of 60° toward the basic edge. It is a long irregular sheet enclosing much rock, and its connexion with the edge of the norite is probably at a considerable depth below the surface. The margin of the norite parallel to it shows comparatively little ore, the sulphides belonging to it having been drained off through a complex set of fissures to the Frood-Stobie deposit. The ore is known by diamond drilling to extend northwest beneath the country rocks to a depth of more than 1,000 feet, and at the lower points it distinctly flattens toward the basic edge of the norite. No other deposit of this type has so far been discovered; but the Frood-Stobie belt of ore is so important and so very distinct from the other types that it deserves a place by itself.

The various types of deposits may be summarized as follows:

TYPES OF SUDBURY ORE DEPOSITS.

Marginal—*a.* Dipping toward the axis of the basin—ores with comparatively little rock and more than twice as much nickel as copper.

b. Faulted marginal—irregular in shape and character—usually mixed with much rock and carrying as much copper as nickel, or sometimes more.

Offsets—*a.* Columnar offsets, roughly cylindrical bodies nearly vertical and going to great depths. Ore usually rich in copper and the precious metals.

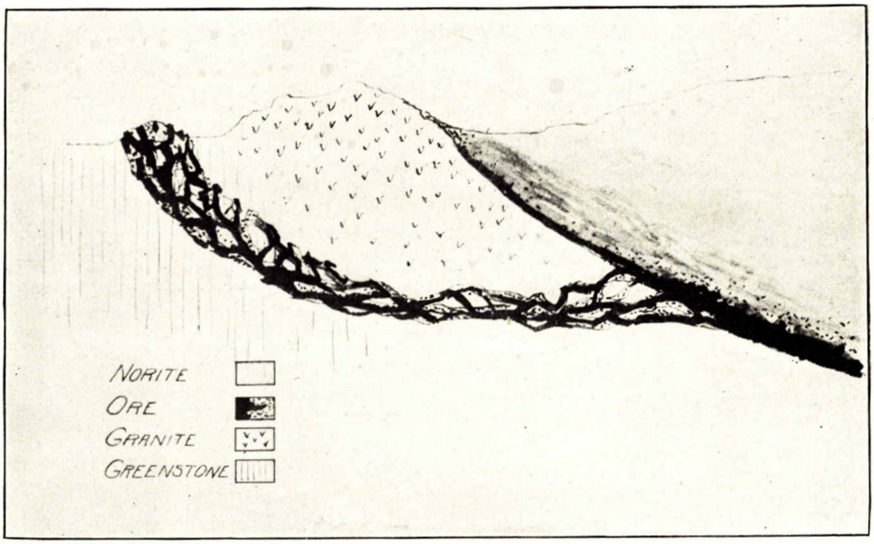
b. Parallel offsets—not columnar, but sheet-like, dipping inward toward the basic edge. Ore like that of the usual marginal deposits.

Individual Deposits of the Sudbury Nickel Region.

Having discussed the general relations of the Sudbury laccolithic sheet to the bodies of nickel copper ore associated with it, and having defined the more important classes of ore bodies found in the district the individual deposits may now be taken up in detail. As they are so closely bound up with the outer or basic edge of the norite it will be desirable to follow this edge from point to point along the margin of the boat-shaped syncline, referring not only to deposits already worked or thought to be of workable extent, but also to other features of interest, some of them not of economic importance, but having a bearing on the history and structure of the region.

For this purpose the different ranges will be taken up not in the order of their importance but in such a way as to give a connected treatment of the whole circumference of the basic edge of the norite. As prospecting and the development of ore bodies are closely bound up with certain features of the geology, these will be described briefly along those parts of the margin where no bodies of ore are known. The survey will begin at the southwest end of the syncline and follow its edge east and northeast along the Southern or Main nickel range; then north along the Eastern range; then west and southwest along the Northern range, finally arriving at the starting point at the southwest end of the syncline.

Plate XVI.



Parallel offset deposit.

THE SULTANA MINE.

At the southwest end of the syncline unusual conditions exist, since the norite feathers out upon hills of older rocks, so that the boundary of the two is almost impossible to fix exactly. The basic edge has, therefore, a much more irregular outline than in most other parts of the nickel region. On the earlier map this portion of the margin was swept in with very little detail, as its importance did not seem to be great and the wooded character of the country exposed comparatively few outcrops. Since then fire and the lumberman have removed most of the woods, and last summer the work could be done in much greater detail.

The country rock on the southwest boundary consists of mixed greenstones, probably Keewatin in age, penetrated by granite, perhaps Laurentian, rising as hills just to the southwest and west of a swampy valley in which a few hills of norite occur. The sides of the hills are here and there plastered with patches of ore in the hollows, and some fine grained norite occurs in patches on the face of the hills, partly as a matrix enclosing masses of the greenstone. Some of these norite patches are hundreds of feet west of the gossan covered ore bodies. Evidently the underlying rock was greatly crushed as the norite and ore pushed outwards above it, so that solid and molten materials were mixed in puzzling ways.

Southeast of the outcrops of ore, an iron post marks the boundary between lots 7 and 8 in con. VI of Drury township, and most of the ore is in lot 8, con. I of the township of Trill. The workings were chained out from this point in a former examination of the property, and it was found that three small shafts had been sunk about 100 yards east of the line between lots 7 and 8, at distances of 13, 19 and 22½ chains north of the boundary between Drury and Trill townships. The deepest shaft is reported to go down 110 or 120 feet, and there is a considerable quantity of ore on the dump beside it. A drill hole sunk to the east of the last shaft showed 30 feet of clay and sand, then norite followed by some ore, and finally greenstone with more or less ore.

In addition to the small ore bodies opened up by the shafts on the side of the hill there are thin bands of ore on the upper slopes, running up 9 chains from a point a little north of the corner post and reaching a height of 117 feet above the valley. Ore occurs at one or two points along the hillside to the south of the concession line, in the township of Drury, also, though not in important amounts; so that gossan or ore extends for 30 chains (three-eighths of a mile) from north to south along the hillside.

The thin irregular sheets of ore dip eastwards at angles running from 12° to 35° or 40°, the latter dips being found toward the foot of the hill.

None of the ore bodies exposed by stripping or in the small shafts seem large, but there is a possibility that more may occur below the swamp which extends eastwards from the foot of the hill. The fact that the norite projects as a considerable bay into the country rock is favourable, but the total width, and therefore the probable thickness of the eruptive at this point, is not very great, which may be looked on as an unfavorable feature. As may be seen from the map, the acid edge of the eruptive runs westward from Cameron lake, giving a width of only about a mile and three-quarters for the whole eruptive, so that the probable thickness of magma from which the ore could settle is much less than in most other parts of the basin.

The Sultana mine is separated from the Sultana East mine by a broad swamp from which a hill of norite projects. Half a mile east of the workings just described a similar hill of mixed greenstones rises steeply from the muskeg, facing northwest and north, with small patches and sheets of gossan and ore along its flanks and at its foot dipping 35° or 40° under the swamp. Some stripping has been done here and there along its slope for about 230 yards. This outcrop is just within the township of Trill, in lots 7 and 6; but the edge of the norite presently bends to the south in lot 6, entering the township of Drury, still showing a few gossan stains but no ore.

On the top of the high hills extending as a promontory northwards into the swamp there are many basal patches of norite, as on the hill west of the main Sultana mine, showing that the nickel-bearing eruptive once covered the whole region, probably to a depth of nearly a mile, as estimated from the dip and width of the outcrop at the Sultana East. This with whatever ore it may have contained has been completely removed by erosion except in the patches mentioned.

The ore at the Sultana, so far as can be seen on the badly weathered dump, was chiefly pyrrhotite, very little chalcopyrite occurring. The houses built when the work was done at the main Sultana have been burnt with the exception of one, now in ruins, but the road out to the railway at Worthington, six miles southeast, has been kept in tolerable repair by the lumber companies working in Trill and other townships to the north.

Leaving Sultana East the basic edge of the norite can be traced, with many small irregularities, for about half a mile to the southeast, when widespread swamps and drift plains hide it from view.

THE CHICAGO MINE.

The boundary of the norite against Laurentian looking granite and gneiss is once more exposed a mile and a quarter southeast, not far from the Chicago, or Travers, or Inez mine, on lot 3, con. V of Drury township. Here, along the road north from Worthington station to Fairbank lake, a low mound of the older rocks rises above the drift, with coarse grey norite, showing some rusty patches, leaning against it. The mine is just beside the road about a third of a mile to the south of the margin. The granitoid gneiss between is largely mixed with greenstone, forming a crush breccia, and the ore bodies occur in the latter rock. As no connexion has been traced between the mine and the edge of the norite, it is evidently a small offset.

To the south and for some distance east and west the greenstone changes to very coarse gabbro, often white and feldspathic enough to be called anorthosite, and mixed with schistose and porphyritic varieties. The workings include a small pit west of the road and an open cut and a shaft said to reach a depth of 160 feet a little to the east. Close by are the small roast beds and just to the northwest is the smelter in which the roasted ore was reduced to matte. The boarding house and office stand near the basic edge of the norite to the north.

The coke and other supplies for the mine and smelter were brought in and the matte shipped out by a mono rail tramway of timber and strap iron, on which a horse could haul cars swung beneath the rail; but the tramway has long ago fallen and is now almost lost beneath the bushes along the road to Worthington, four or five miles to the southeast.

According to Dr. Barlow mining began in 1891, and most of the ore was got from open cuts, one of which was 60 feet long and 30 feet wide and deep, and another 80 by 40 feet with a depth of 30 feet. 3,500 tons of ore had been mined and smelted when the mine closed down in 1892, but in the following year also some ore was raised and turned into matte, before the plant was once more shut down. It was finally reopened in 1896, by the Trill Nickel Mining and Manufacturing Company, under the new name of the Inez mine, only to close again before August 1897.

The ore deposit appears to have been too small to justify a complete mining and smelting plant, probably because the basic edge of the nickel eruptive is here nearly straight with no funnel-shaped depression to accumulate a large body of ore.

FROM CHICAGO MINE TO VICTORIA MINE.

For three quarters of a mile to the southeast of the Chicago mine the norite edge is lost beneath swamps and drift, though hills of the grey, coarse grained rock rise a quarter of a mile to the northeast. The boundary seems to follow the foot of a very steep ridge of greenstones of varied kinds, and near the southeast corner of lot 2, con. V of Drury, norite with some rusty spots once more shows itself, rising as a fairly high hill. Near the line between concessions 4 and 5 the hill slopes south to low ground and the norite becomes mixed with blocks of greenstone. On this hillside there are considerable stretches of gossan, and some stripping has been done.

As the edge of the norite here turns from southeast to nearly east and the band of eruptive is wide, the conditions favor a deposit of ore, and one would expect a larger one than anything disclosed by the stripping and small pits, which extend for 200 or 300 yards. From this point the basic edge runs nearly east to the line between Drury and Denison townships, which it crosses a few paces south of concession V, but beyond this it is lost for half a mile beneath the drift.

In lot 12, con. IV of Denison a sharp ridge of greywacke with a vertical dip and a strike of 60° east of north may be followed for nearly a mile, while norite is found a short distance north, but the two cannot be seen in contact. About a quarter of a mile west of the line between lots 12 and 11, and an eighth of a mile south of con. V the edge of the norite shows against some low lying greenstone as a gossan covered ridge, where ore has been disclosed in several pits on the southward dip of the hill, as in the last case.

In the next lot to the east, near the north end of concession IV and not far from the steep northern end of the ridge of greywacke, there is a larger display of gossan and ore, where half a dozen pits and strippings have been made on a deposit dipping 30° or 35° to the north. Here the arrangement is the normal one, the norite and ore occupying the lower ground and leaning up against the hill of country rock, which is formed of greywacke with greenstone to the east. This mine was worked to a small extent in earlier years, and two large pits were opened up quite extensively, but the ore is a good deal mixed with rock matter, such as greenstones and green schist, with some actinolite and a little quartz.

The coarse norite to the north is in places crushed and sheared into a conglomerate with a schistose matrix; and a quartz vein 10 or 15 feet wide in green schist to the south was mined years ago to furnish quartz for converter linings at Victoria Mines smelter; but a supply for this purpose was obtained later not far from the village, and this mine, a mile and a half west and reached only by a rough road, was abandoned.

The body of ore described above occurs in a small southward bay of the norite, where the boundary bends northeastwards, so that it conforms to the usual rule in the nickel region.

Beyond this point the edge of the norite bends to the northeast, but is largely concealed by swamps, while the rocks to the south, as shown along the wagon road to Victoria mine, are mainly greenstones and greywacke, often intricately mixed. At a point about half a mile north of con. IV on the line between lots 10 and 9 the norite boundary turns southeast, but is once more largely hidden by swamps and drift. Along this inward bend of the contact, as might be expected, no ore has been found, but as one advances southeast toward Victoria mine, gossan shows itself where the norite edge meets the neighbouring greenstones.

VICTORIA MINE.

About a third of a mile northwest of Victoria mine toward the southern end of lot 9, con. V, a good deal of ore outcrops and No. 3 shaft has been sunk; and another outcrop of ore on which some work has been done occurs on the line between lots 9 and 8 to the east of shaft No. 3. In both cases greenstone has been crushed beneath the eruptive, and ore extends fifty feet or more into the fissures beyond the characteristic norite, which dips away from the older rocks; so that a band of gossan covers part of the country rock. Beyond the second gossany surface the edge of the norite swings southeast toward Victoria mine, though the exact boundary is covered by marshy ground enclosing a small lake to the northeast.

Across the marsh and lake a ridge of very rusty rock, mostly greenstone, rises 20 or 30 feet, running northeastwards from Victoria mine, and a number of strippings and pits show very similar relations to those mentioned above for a distance of a quarter of a mile, when low ground covers the margin of the norite once more. To the north of the marsh and pond one finds typical grey, coarse grained norite and this continues with no perceptible change for a mile or two.

On each side of the basin just mentioned we find norite with a fringe of ore dipping inwards on a floor of shattered greenstone, the two bands of gossan converging as a funnel at a point just north of the open pits of Victoria mine. Low ground prevents the tracing of the two sides of the funnel quite to the mine, and it appears to be separated from the main body of norite by a small extent of country rock. This open pit and a smaller one to the southeast of the rock dump represent two small offset deposits, evidently due to the accumulation of ore in the norite funnel to the north.

The rocks enclosing the mine to the west, south, and east are greenstones of various kinds, having the appearance of diorite, hornblende porphyrite, and green schist, followed to the south by slate or greywacke with thick bands of quartzite, the latter rocks being well stratified. On the rock dump at Victoria mine there are fragments of all these rocks, as well as fine grained norite and actinolite probably resulting from its alteration, and it is stated that small diabase dykes cut the eastern ore body between the 8th and 10th levels.

The ore masses on the two sides of the funnel to the northeast and northwest dip at about 45° into the swamp, and are small but characteristic marginal deposits, while the two ore bodies at the mine are equally typical offset deposits, sinking as steeply inclined columns of somewhat irregular shape to a depth, it is said of more than 1600 feet. They are about 169 feet apart and dip uniformly to the east at an angle of about 70°, according to the report of the mine inspector.

The open pits are followed toward the southeast by two small gossan-covered hills reaching for a quarter of a mile, and one of them, where a shaft

Victoria Mine: rockhouse. Ore bucket on cable-way.

has been sunk and a considerable amount of ore obtained, is connected by a tramway with the main shaft house. Whether this offset sweeps a curve to the southwest and continues as the row of deposits near Worthington is not certain though probable. It may also be joined with the Vermilion mine a mile and a half to the southeast, and some of the local prospectors believe that the Worthington row of deposits is connected with Vermilion and Crean Hill mines rather than Victoria mine, though the interval between them is long and without any surface indication of an underground connexion.

The nickel eruptive has a width of a little more than 4½ miles at Victoria mine, which is not surpassed at any other part of the laccolithic sheet, but though the ore of the offset is rich, the amount appears much smaller than the thickness of the eruptive would suggest.

Victoria mine, like most other offset mines, shows evidence of later circulating waters in the presence of quartz and carbonates with the ore; and Mr. H. W. Hixon, former manager of the mine, is firmly convinced that the deposit is entirely due to aqueous action; and, in fact, objects to the theory of magmatic segregation as accounting for any of the nickel ore deposits of the region. The geological evidence in its favour is so overwhelming, however, that all geologists who have studied the district are convinced of its correctness.

The Victoria mine was first developed by Mr. Rinaldo McConnell, by means of strippings and test pits opening up the gossan-covered areas mentioned above, so that the property became known as the McConnell mine.

In 1897 it was one of the properties visited by the geological section of the British Association after their Toronto meeting; and great interest was aroused by the panning of gold and sperrylite from the gossan. Sperrylite had been found previously at the neighbouring Vermilion mine, so that this was the second locality for the mineral, but the McConnell mine was the first distinctively nickel mine in which gold and platinum had been found, since the Vermilion mine was taken up for gold and not for nickel and copper.

During the same year, Mr. G. R. Mickle made an examination of the McConnell mine and demonstrated that gold and sperrylite occurred not only in the gossan, but, as might be expected, in the unweathered sulphides as well. His assays showed that the platinum is mainly associated with the copper pyrites, though the pyrrhotite contains some also. The average of six samples of solid ore gave a little over 3 dwt. of platinum and a trace of gold, while pyrrhotite with little chalcopyrite gave considerably less than the average, and one sample 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.[1]

In 1899 the property was purchased by Dr. Mond and was named the Victoria mine; and in 1901 the mine and smelter came into operation under the management of Mr. Hixon.

The smelter was placed on Fairbank creek, two miles south of the mine, near the "Soo" railway; and the ore was transported to the roast beds near the smelter by a cable tramway 11,000 feet long. Later the roast beds were removed to a flat of old lake deposits half way between mine and smelter; and the surroundings of the village which had grown

[1]Bureau of Mines, Vol. XIV, Part III, p. 161.

up at the railway station began to recover from the desolation caused by the sulphur fumes.

The Algoma Central railway now passes between the mine and the roast beds, and before long the old smelter and the cable tramway will be abandoned and the ore will be taken by rail to the new smelter at Coniston.

A little north of the present smelter a mine or quarry has been opened up for quartzite as a flux and for lining the bessemer converters.

VERMILION MINE.

A mile and a half southeast of Victoria mine, in lot 6, con. IV of the township of Denison, is Vermilion mine, close to the short railway connecting the "Soo" branch at Victoria mines with Crean Hill, and about two miles northeast of the village. The deposit is a small offset more than a mile from the nearest part of the norite, but the character of its ore suggests that it is, or was, probably connected in some way with Victoria mine. A small patch of norite spotted with sulphides rises on a hill made up of a crushed mixture of ancient lava (now greenstone with pillow and amygdaloidal structure), a little felsite, and some greywacke, and these materials have been ground and rolled together into bouldery forms with the norite and ore squeezing up between them.

The Vermilion was first taken up as a gold mine in 1887, and a shaft was sunk by Messrs. Tough and Stobie on a small quartz vein the following year, on the low ground 930 feet north of the present mine and just beyond the Crean Hill railway, the name coming from Vermilion river, which flows 2 or 3 miles to the southeast. A shaft was sunk 40 feet on the quartz vein and some very rich ore (wire gold) was found on the surface and also to some extent in the wall rock. Mr. B. Charlton, president of the Vermilion Gold Mining Co., states that several thousand dollars worth of gold was obtained by means of a three stamp prospecting mill while sinking the shaft.

The rich ore presently ran out and then gold was found in the gossan on the hill at the present mine, which was put through the little mill. The men in charge were puzzled to find the carpet used to collect the coarse gold whitened by shining grains of a tin white mineral, afterwards named sperrylite, as already described on a previous page. Since the owners were in search of gold, and not platinum, the mine was sold in 1890 to the Canadian Copper Co.

It was presently found that the gossan contained palladium, as well as platinum and gold, and the Canadian Copper Company made attempts to dispose of the mineral to various firms dealing in the rare metals, such as Balbach & Co., and Johnson, Matthey & Co. In 1896 the two firms mentioned reported that the ore contained from 6 to 9 ozs. of platinum and from 8 to 14 ozs. of palladium. In 1897 a consignment of 14 casks (5 tons) of platinum sand was made to Johnson, Matthey & Co., who found its treatment a matter of extreme difficulty, "as the ore could not be levigated nor treated successfully by any acid process, and in smelting the palladium contents are sacrificed. The platinum contents could only be recovered by smelting with a large proportion of silver ore, involving considerable cost in its subsequent separation." In 1899 they paid for the ore at the rate of £8 per ton, and after deducting various charges, the net return from the consignment was at the rate of $22 per ton. An offer was made to buy the ore at the rate of £9 5s. per ton if quantities of 100 tons or more were shipped; but no more seems to have been sent to them, probably because the price was so low for ore running on the average 7 ozs. of platinum and 11 ozs. of palladium per ton. Platinum was worth about $16 per oz. at the time.

Negotiations were carried on in 1899 and 1900 with a French company on the basis of 35 per cent of the value of the two metals, palladium to be taken as equal to platinum in value, but apparently without result.

In 1902 a small amount of platinum sand was sent to the Orford works at Bayonne, and in September, according to Mr. A. Wadhams, experiments were carried on under the direction of Mr. Hybinette for the separation of the precious metals. They seem not to have been very successful, and finally the material was turned in with the ordinary nickel-copper matte, so that only a small percentage of the platinum metals was recovered.

In October, 1903, 155·65 tons of "platinum dirt" were shipped to the Orford works, according to official records at Copper Cliff, and Mr. Browne states that 90 barrels of gossan were removed in 1903, containing 6·88 per cent copper, and 2·91 per cent of nickel, with 6·5 ozs. of palladium, 4·1 ozs. of platinum, 4·3 ozs. of silver, and 0·28 oz. of gold per ton.

Since sperrylite and gold are very easily separated from the gossan by panning, there is no doubt that most of the platinum and gold could have been saved by sluices or cradles, and it is surprising to find Johnson, Matthey & Co. stating that the ore could not be "levigated." The source of the palladium is not known, since analyses of sperrylite show only traces of that metal.

In 1902 the Canadian Copper Company began taking out unweathered ore, sinking the main shaft to about 50 feet and drifting in various directions to follow the ore underground, and there is a record of 198·28 tons having been shipped in February, 1905. This was very rich in nickel and copper, averaging 20 to 25 per cent of the combined metals. Assays made, apparently in 1903, show that the ore contained 4 ozs. of silver, 4 ozs. of palladium, 1·5 ozs. of platinum, and $\frac{1}{3}$ oz. of gold per ton.

An assay of clean chalcopyrite, made by Mr. Waern in the laboratory of the Canadian Copper Co., in September, 1909, showed a trace of gold, 0·79 oz. platinum, 3·62 ozs. of palladium, and 3·78 ozs. of silver—a total of 8·13 ozs. per ton of the precious metals.

Assays of its ores gave the following results to the same chemist:

——	Average Ore Sept. 6-11	Average Ore Sept. 12-18.	Polydymite.	
Cu	10·65	11·70	Cu	0·50
Ni	8·80	15·15	Co.	0·50
Fe	18·30	20·70	Ni	42·35
S	19·80	23·10	Fe	12·45
SiO_2	28·45	16·60	S	38·75
	....	Balance Insoluble..		94·55

Within the last three years the mine on the hill has yielded a considerable amount of ore containing much polydymite and running from two to four times as high in nickel and copper as that of most other mines. This ore has in part been smelted separately to avoid loss, but there are difficulties in the way of recovering and separating the precious metals it contains, since the gold and platinum could be saved by ordinary stamp mill methods, but the palladium has not been found associated with any definite compound, like sperrylite, and so would be lost.

The finding of gold and sperrylite in both the Victoria and Vermilion mines affords evidence of a relation between them, though there is no surface indication of this, and there is no positive evidence as to the mode by which the small amount of norite and ore reached its position. However this came about, the ore was greatly enriched in the precious metals before reaching Vermilion mine.

The Vermilion ore is so rich in nickel and copper as to equal some grades of matte, and much of the product of the mine has been sent directly to the converters without a preliminary smelting in a water-jacket furnace. The Bureau of Mines of Ontario reports that 1,229 tons of ore were obtained from this mine in 1910.

THE WORTHINGTON OFFSET.

Small outcrops of ore occur at Victoria mine about 600 yards southeast of the pits near the shaft, and it was believed by the late Mr. M. T. Culbert, my assistant when the region was first surveyed for the Bureau of Mines, that a curved line of gossan stains could be traced up from point to point to the Worthington offset.

The first mining development on the offset is found in lot 10, con. III of Denison township, where two pits have been sunk on ore mixed with spotted norite. A quarter of a mile southwest, just within lot 11, and 50 yards south of a meandering creek, there is a larger pit at the McIntyre mine, where the ore and norite enclose numerous rounded masses of country rock, mostly greenstone, near the foot of a high hill to the south, consisting of greenstone and diabase. Much of the surrounding country is drift covered, but hills and ridges of greenstone, green schist and greywacke frequently rise above the general level. From the high hilltop 50 paces south of the opening one gets a good view of the offset, several gossan-covered hills standing nearly in line with the rockhouse at Worthington, two miles to the southwest.

The next outcrops of ore are at the Gersdorffite and Robinson mines, beyond the northwest end of a small lake; and just past the line between the townships of Denison and Drury, near the north end of con. II, is the Howland mine, where a pit displays an interesting crush conglomerate with greenstone boulders two or three feet through, enclosed in ore. A small diabase dyke cuts the ore body steeply, running northwest and southeast.

From the Howland mine to the Worthington, a distance of a mile, there is a succession of gossan-stained hills, interrupted in one place by an irregular band of later diabase.

This row of small ore outcrops is marked by an interesting set of minerals, including much marcasite, and a little gersdorffite and nickelite, probably deposited by circulating water and accompanied by quartz as a gangue mineral. No sperrylite is known from the offset, but the arsenical nickel minerals with quartz show, perhaps, a further separation of materials, in which heated waters played a large part.

At the Worthington mine, which is much the most important ore body on the offset which takes its name, a low but steep ridge of gossan-covered greenstone rises just to the north of the station on the "Soo" line. The mine, which was discovered during the construction of the railway, like a number of other mines in northern Ontario, became the property of the Dominion Mineral Co., and mining was started, according to Dr.

Boulders of greenstone in pyrrhotite: Howland mine.

Barlow, in 1890, and continued till September 1894, two shafts being sunk, one to the depth of 175 feet and the other to 100 feet. It is stated that about 25,000 tons of very rich ore were obtained, and were sent to Blezard smelter for treatment.

When the mine was opened up for examination some years later, the lower workings were found filled with ice, which had to be blasted out before it could be removed.

It was in ore from the Worthington mine that Dr. Walker first recognized pentlandite, the only important nickel mineral in the Sudbury region; and its ore has been surpassed in richness only by the much smaller deposit at Vermilion mine. In 1891 a shipment of 123 tons contained 10 per cent nickel and 3 per cent copper; and manager Attwood has stated that a considerable quantity of selected copper pyrites was shipped, assaying 18 per cent copper and 2·5 per cent nickel.

As gersdorffite and nickelite, as well as pentlandite, occur at the Worthington, it has the greatest variety of nickel ores known in the region. The rock dump includes very little spotted norite, but a considerable amount of actinolite rock, probably a product of the re-arrangement of norite or some other basic rock, owing to the crushing and shearing which is so pronounced along the offset.

Continuing southwest across the railway from Worthington mine, a shaft 60 feet deep has been sunk on a gossan-covered hill a few hundred yards away, and a good deal of work has been done on the Totten mine, about half a mile away, both in lot 2, con. I of Drury township. Here the pyrrhotite, as in so many other cases, forms the matrix of a crush conglomerate. A quarter of a mile to the southwest the gossan-stained ridge of the Totten mine sinks into a swamp followed by a small lake. On the other side of the lake rusty stains may be followed into the township of Lorne, and these have been traced for perhaps a mile beyond Totten mine, but no ore bodies of any account have been found on this extension.

The country rocks southwest of Worthington vary greatly, including greenstone, greywacke, slate and quartzite; all of which occur as rounded fragments or boulders along a narrow belt of shearing, with fine grained norite and ore as a matrix. This offset has been traced for fully four miles in nearly a straight line, and represents one of the main zones of dislocation at the time the nickel eruptive reached its present position.

Except from the Worthington mine comparatively little ore has been produced from this row of deposits. A few hundred tons have been taken from the Totten mine and used for experimental purposes in two plants west of Worthington station, one of which, on the steep hillside north of the railway, was extensive, but neither process proved satisfactory.

In addition to the ore bodies along the offset a number of small outcrops are known at various other points near by, and several of these on the northern side of lots 5 and 6, con. III of Drury, were visited under the guidance of Mr. Hermann, who gave much assistance also in looking up the properties along the offset. There are about eight showings of ore, small patches of pyrrhotite and chalcopyrite running roughly east and west along a group of high hills of greenstone and greywacke with some diorite. Some pits have been sunk in the ore, and in one case a small shaft; but the amount of ore seen was not important.

Many other small outcrops of pyrrhotite are known from the townships of Lorne and Nairn to the southwest, and one might think of the norite and ore of the offset as having been squeezed through a number of small channels among the dislocated blocks of country rock, channels too narrow to allow any large quantity of the magma to accumulate at one place.

In a general way the direction of the offset corresponds to the strike of the sedimentary and schistose rocks adjoining, and no doubt the plane of fracture and faulting has been much influenced by the structures of the rocks beneath.

THE CREAN HILL REGION.

Beyond the funnel-shaped southward bend of the norite edge at Victoria mine the basic margin continues for about a mile northeastwards, and then bends to the east to Crean Hill (or Krean Hill) mine on the south half of lot 5, con. V of Denison township. Between the two points the country rocks are greenstone, green schist and small amounts of intermixed quartzite. The norite is of the grey, coarse grained variety usual on the southern range, and is sometimes pitted with spots where pyrrhotite has weathered out, though no ore of importance is known along this part of the basic edge.

In lot 6 there is a group of high hills which deflect the Algoma Central railway to the south; but these fall away in lot 5 so that the railway sweeps north near the western edge of the lot and then turns east to Crean Hill mine, which is near the other side of the lot. The line in this part follows the edge of the norite and continues in this relation for a few hundred yards into lot 4.

The Crean Hill mine has the situation corresponding to a marginal nickel deposit, and its western part conforms to the usual characteristics of such deposits. Its southeastern end, however, has features suggesting an offset deposit and presents some very interesting problems. According to the classification of ore deposits given in a former chapter it is a "faulted marginal deposit".

Approaching the deposit from the west one comes upon gossany surfaces of norite against greenstone just beyond a small stream and ravine to the north of the bend in the Algoma Central railway. Here a considerable amount of ore was obtained from an open pit in the early days of the mine and near by is a quartz vein in which free gold was found in small amounts. Beyond this on the southward slopes of a hill sinking into swampy ground, rusty greenstone and norite with strippings and one fairly large pit extend to the main workings of the mine on a separate gossan-covered hill. For this distance, about 1,400 feet, the arrangement is that of a normal marginal deposit.

The eastern hill, where the important part of the mine is found, though gossan-covered and with much ore, consists almost entirely of greenstone and other country rocks; while the norite rising to the north of a small ravine, though somewhat spotted with gossan, contains no ore. The opening up of the mine in depth by the Canadian Copper Co. has provided a solution of the puzzle, which with their kind permission will be given.

Though discovered fairly early in the history of the nickel region, before 1906 it was opened up only by stripping and the sinking of test pits. In February of 1906 the first ore was shipped on sleighs to the "Soo" line and thence by rail to Copper Cliff, but soon after a branch railway was built to connect it with the "Soo" line three miles southwest. In 1910 the

Algoma Central railway reached it from Creighton and gave a shorter haul to Copper Cliff, when the branch to Victoria Mines village was discontinued.

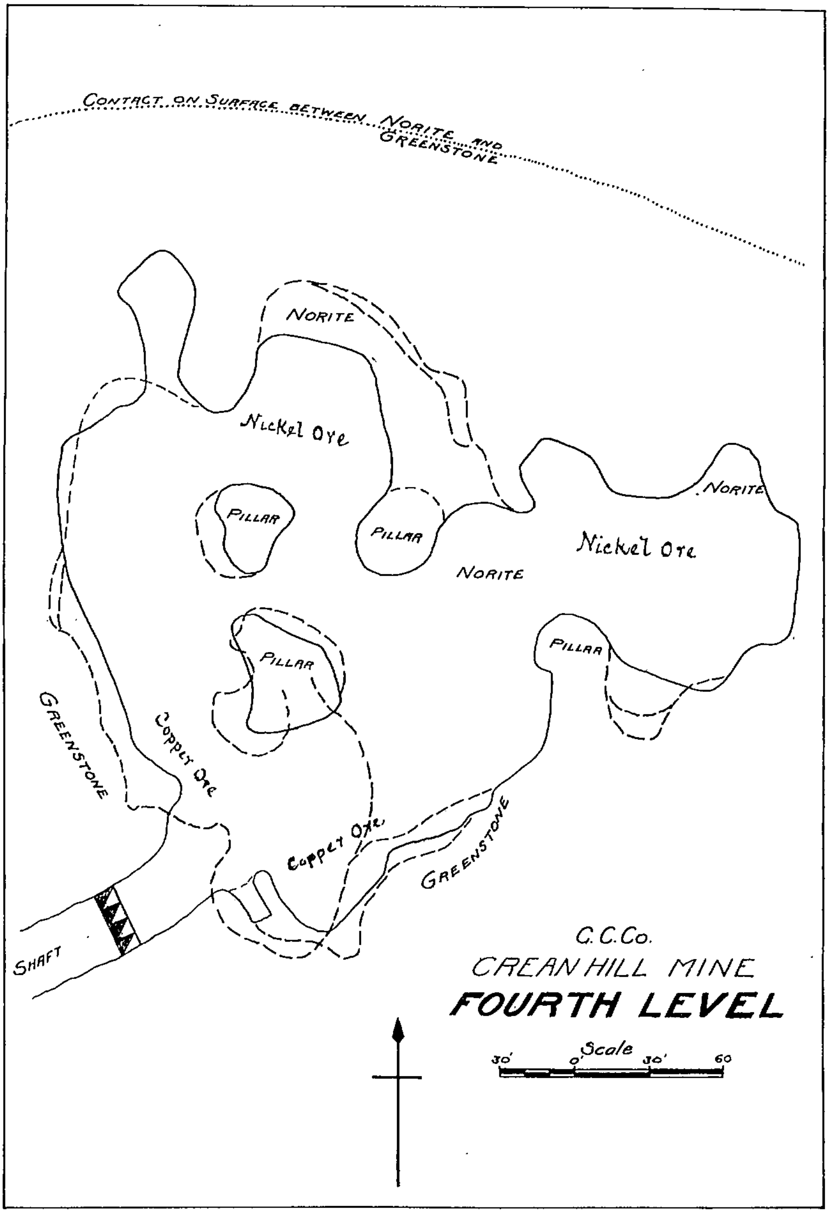


Fig. 1.

Though the mine was worked first as open pits, not long afterward underground levels were begun, and the shaft has now reached the 7th level, about 600 feet below the surface.

The hill itself sinks on all sides with rather steep slopes to lower ground, the top consisting mainly of greenstone and green schist with some bands of greywacke and quartzite, all broken into small or large blocks and often rolled and mashed against one another, with ore surrounding the blocks. Toward the north the crushing has been more complete than toward the south, and northward there is a steep cliff facing a narrow ravine with a gentler slope of norite beyond. In the open pits only the greenstones and the surrounding ore are disclosed, but in the rock dump spotted norite is found also, showing that at greater depths this universal accompaniment of ores in the region is not wanting. The norite is found in place, as shown by Mr. Bedford, at various points on the 4th and 5th levels.

From the geological point of view, as well as from that of the miner, one of the most interesting features of the mine is the occurrence or two zones of crushing about twenty feet apart, indicated by clay slips sloping diagonally upward through the mine, where the rock has been ground into small fragments mixed with clay. These clay slips begin in the shaft 35 feet below the 3rd level and after cutting that level reach the 2nd level toward the northeast side, rising at the rate of 23° 40′ in that direction. The upper of these planes of slipping comes to the surface in the narrow valley northeast of the gossan-covered hill; and the valley evidently shows the line of weakness where this zone of crushing and slipping separates the mixed greenstones of the hill from the norite sloping up towards the north.

The clay slips no doubt represent fault planes having an unusually low angle with the horizon; and it is probable that the many examples of slips and slickensides in other parts of the mine indicate less regular fault planes. It is estimated that the horizontal throw of the fault is not less than 200 feet, and it may be very much more.

When the greenstones and sediments making up the hill were thrust bodily northwards over the edge of the norite there must have been tremendous crushing and grinding among the blocks toward the lower part where there was friction against the norite below; accounting for the brecciated character of the hill.

The presence of the slip planes referred to above caused great difficulty and danger in mining operations because of looseness of the rock, until the workings got below this zone of weakness.

Evidences of the effects of the faulting process just mentioned are found on the rock dump, where there are all gradations from fairly sound and fresh rocks to actinolite and talc representing materials completely rearranged during the squeezing and shearing due to the thrust of the faults. The shaft was still in greenstone at the 6th level and had not reached norite, though this may be expected at greater depths. How deep the crushing and faulting extends has not yet been determined.

Apparently the latest geological event recorded in the bed rocks of the region was the welling up of a great dyke of diabase through all the other rocks, along the southwest side of the hill containing the main ore body. This dyke, 50 or 60 feet wide, and dipping 80° to the southwest, runs nearly due southeast through the norite, jogs a little to the south at the open pit, and pursues an irregular course beyond this. It came into position later than the fault and seems to have been somewhat disturbed in its direction by the confusion resulting from the faulting.

ORES OF CREAN HILL MINE.

There is more variety in the minerals at Crean Hill mine than in most nickel mines of the region, though pyrrhotite and chalcopyrite are more common than other sulphides. The pyrrhotite is often in very platy forms,

Crean Hill mine.

sometimes having cleavage surfaces an inch across; and the chalcopyrite is present in much larger amounts than in any other large mine in the region except the Copper Cliff. Pentlandite occurs in excellent specimens, and a little gersdorffite has been found; but polydymite, so important at Vermilion mine a mile to the southwest, seems wanting.

Among other metallic minerals marcasite is plentiful where water could circulate, as near the clay slips; zinc blende occurs in smaller quantities, and magnetite has turned up in large masses. As gangue minerals quartz and calcite or ankerite are quite common; but often the ore is disseminated among the blades of actinolite so characteristic of the sheared zones between the less changed rock masses. Tourmaline occurs mixed with ore in one specimen, and there has evidently been a large amount of secondary action in this ore body.

Panning of the gossan at several points on the hill disclosed a few fine particles of sperrylite and still fewer and finer colours of gold; but the mine is much poorer in this respect than the Victoria or Vermilion mines to the west and south.

The Crean Hill mine has been a larger producer of copper than of nickel, reversing the proportions of the two metals at Creighton mine, which are about 2 per cent of copper to 5 per cent of nickel. In 1907 Crean Hill ore averaged 4·84 per cent of copper and 2·35 per cent of nickel. Since chalcopyrite contains 34 per cent of copper while the ordinary sulphides of the region average only from 3 to 5 per cent of nickel, it is evident that Crean Hill ore with the above amount of copper will contain far more rock, and hence be leaner in appearance than that, for instance, of the Creighton mine. It may be three-fourths rock and yet run 5 per cent of copper and 2 per cent of nickel.

There is much less regularity in the distribution of the ore at Crean Hill than at most of the mines of the region, and there are not many stopes where more than a few feet of solid ore can be seen. Generally the copper pyrites is more greatly mixed with rock matter than the pyrrhotite. and fragments of various rocks may be enclosed in it, the ore forming a matrix for angular or rounded pebbles and boulders of all sizes. In some stopes well rounded masses of greenstone or hornblende porphyrite three or four feet in diameter may be seen surrounded by narrow belts of sulphides, often making the winning of the ore a serious problem, and rounded pebbles completely encrusted with ore sometimes puzzle the rock pickers when sorting the ore.

The common rule of the region that copper pyrites is present in largest amounts near the country rock is specially well exemplified at Crean Hill since rich masses of copper ore are found on all the levels in the angle between the foot-wall and the barren rock to the southeast, as may be seen from the diagram of the 4th level. The arrangement is roughly that of a right angled triangle with rich copper ore at the apex, gradually passing into pyrrhotite toward the hypothenuse of the triangle. The body of rich ore dips about 60° to the east, so that in the lower levels it is 100 feet or more east of the open pit where the ore body was first opened up. The nickel ore is generally associated with norite, and the copper ore with greenstones and other rocks; and the boundaries of the richer copper ore are pretty well defined to the south and west, but the limits of the nickel ore toward the north and east are much less definite, patches extending to the northeast side of the hill as shown by the strippings.

Though the Crean Hill mine has many of the characters of an offset deposit, it is of an unusual kind, since the movement of ore seems to have been upwards from the underlying norite margin some hundreds or perhaps thousands of feet below, instead of outwards from the basic edge of the norite. In the offset deposits thus far described the norite and ore pushed laterally or downwards through irregular fissures leading off from bay-like projections of the norite into the country rock. Here there is scarcely any visible bay of the norite though there probably is one underground, and the ore ascended to its present position, at least in the upper parts of the mine, unaccompanied by norite, the only instance of the kind known. Whether it came up molten into the fissures between the blocks or was carried upwards later by hot circulating waters is not certain, but that water played a large part is shown by the presence of quartz and carbonates and of hydrous secondary minerals like talc.

As a general rule in offset deposits the longer and more difficult the route followed by the ore in reaching its final position the larger the percentage of copper, since chalcopyrite seems more easily transported than pyrrhotite. Here the distance upwards was probably not very long, but heated waters ascending from the basic edge of the norite below may have effected an unusually complete separation of the copper from the nickel ore. If this is the case one might expect the percentage of nickel to copper in the ore to increase with depth until at length ore rich in nickel as in ordinary marginal deposits is reached. Down to the 6th level, however, there is little indication of such a change.

Up to July 1909 Crean Hill had produced more than 250,000 tons of ore and in 1910 it added 89,211 tons, so that it must be considered one of the great mines of the region. A large part of the copper produced in Ontario, as shown in the statistics of the Bureau of Mines of recent years, must have come from this mine, which has supplied probably 15,000 tons of metal. Of late the proportion of copper to nickel and also the grade of the ore have been falling off somewhat, since in 1909 the percentage of copper was 3·97 and of nickel 2·30.

FROM CREAN HILL TO GERTRUDE MINE.

Beyond Crean Hill the margin of the eruptive remains gossany for some distance and turns northeast, with quartzite as a country rock to the south. About two-thirds of the way across lot 4 it turns southeast and at its edge or in the quartzite close by patches of gossan and ore occur, the occasion for several small test pits in the latter rock to the north of the railway. About on the line between lots 4 and 3, midway in con. V, the basic edge crosses the railway southeastwards and is then concealed for nearly half a mile by a muskeg. Rising above the swamp toward the east as one follows the railway, norite spotted with ore is encountered and about a sixth of a mile south gossan-covered hills can be seen.

The highest hill represents a turning point in the basic edge, having greenstone to the south and granite to the east, the latter enclosing a small lake 200 yards from the slope of the hill. This lake is cut nearly midway by the line between lots 2 and 1 toward the south side of con. V. A considerable amount of stripping has been done on the hills and apparently there is a respectable volume of ore, but it is said to be low grade, and therefore has not been developed by its owners, the Canadian Copper Company.

From this point the boundary of the norite turns northeast with granite as country rock, and no evidence of ore is to be seen for some distance, but in lot 1 of Denison, 400 yards northeast of a sharp southward bend of the railway, gossan surfaces occur and continue eastwards for about 400 yards, passing into lot 12 of Graham township, where some work was done years ago by Mr. Wm. McVittie.

Beyond this the margin of the norite runs somewhat north of east to the low drift-covered ground near Vermilion river and no ore nor gossan was observed along this part of its course. The granite to the south becomes coarse and red and markedly porphyritic as one approaches the river, and is probably older than the norite, though this is not positively proved.

Crossing the Vermilion, granite and swamp extend about 650 paces north of the railway before coarse grey norite of the normal type is found, and along this part of the margin a few spots of gossan occur but no continuous areas. The boundary has minor irregularities but runs on the whole nearly straight to the northeast corner of lot 8, in concession VI of Graham township, when it passes into Creighton township, still following about the same course of 60° east of north. The rocks to the southeast consist of greenstone much cut up by dykes and masses of red granite.

GERTRUDE MINE.

At a small creek on lot 5, con. I of Creighton township the first suggestion of the Gertrude ore bodies shows itself in a small tunnel run into the side of the valley. The norite varies from coarse to fine grained, forming an irregular mixture, and the ore lies against greenstone and penetrates fissures in the latter rock. From this point eastward there is more or less gossan along the norite edge until the main shaft is reached, about on the line between lots 4 and 3, and less than a quarter of a mile north of the boundary of Creighton township.

There are three shafts and several open pits along this line of gossan which extends from west to east for about three-fifths of a mile, and the diamond drill shows that at least one other deposit exists to the north of the main shaft, where in a drill hole reaching a depth of 120 feet, 15 feet of mixed ore and 20 feet of solid ore were found with a dip of from 55° to 67° to the north. The relationships of the two ore bodies are probably due to faulting.

South of the nickel-bearing norite at Gertrude one encounters for the first time a narrow fringe of older, finer grained and more basic norite, apparently an earlier eruption from the same magma, which reached the surface as lava streams instead of cooling at great depths. Henceforth this is found from point to point along the southern range, often in the neighbourhood of important ore bodies, and seems to have opened up the way for the more important laccolithic sheet which brought the ore; though the earlier norite itself seems devoid of ore. Still farther to the south there are hills of greenstone much cut by granite, and in less than a mile granite becomes the predominant rock.

The Gertrude mine was purchased by the Lake Superior Power Co. of Sault Ste. Marie in 1899, and two shafts were sunk, one to the depth of 120 feet and the other to 80. In the spring of 1901 the Manitoulin and North Shore railway, now generally called the Algoma Central railway, reached the mine, making further development possible, so that roast beds could be arranged and a smelter erected, and ore from the Elsie mine, some miles farther to the east, was treated along with that from Gertrude. After a few months run the mine and smelter closed down in 1902, and in the following year the parent company collapsed for the time, putting a final stop to operations at Gertrude[1]. Some of the buildings in the village have been burned, but several of them, including the smelter, are still

[1] G.S.C., Vol. XIV, pp. 39-40.

standing. It is said that the Gertrude ore was very rich in nickel, some of it containing over 6 per cent of that metal and less than 1 of copper.

Just east of the line between lots 3 and 2 the edge of the norite turns north, and then curves east and southeast toward a small lake at the west end of the Creighton hill. 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 no ore and little gossan are to be seen. The rock filling the space to the south of the bend is mainly a fine grained variety of the "older norite" mixed with greenstone, but there are also some granite and re-crystallised arkose.

Near the small lake from which the water supply of Creighton is pumped the surroundings are mostly swamp, though weathered norite crops up at one place, and at another northeast of the lake it is seen in contact with gneissoid rocks dipping under the swamp.

THE CREIGHTON MINE.

Soon after the norite margin turns eastwards a rusty slope of hill rises northeast of the small lake, the beginning of the Creighton outcrop of gossan and ore. The steep hill slopes southeast and becomes more completely gossan-covered as one advances toward the mine itself. Beyond the great open pit of the mine the boundary of the norite turns sharply a little west of north for half a mile, and then bends off to the northeast.

A glance at the map shows an unusual combination of circumstances. The nickel eruptive is here about at its widest, stretching for 4½ miles northwest of the mine, and the mine occupies the best defined bay of the norite, without an outlet into an offset, along the whole southern nickel range. This bay lies between the two largest offsets, those of Victoria mine and of Copper Cliff, and is nearer to the larger of the two, Copper Cliff.

We have here all the conditions for a great body of ore, and find as a result the greatest nickel mine in the Sudbury region or in the world. The great thickness of molten magma provided a large amount of sulphides, and the deep and wide mouthed depression in the country rock furnished a capacious basin into which the ore could settle; while no important fissure in the rocks beneath gave an exit for the melted ore.

The Creighton mine is properly regarded as the typical marginal deposit. The mine is near the west side of lot 10, con. I of the township of Snider, but the band of gossan and probably the ore beneath extend into lot 1 of concession I of Creighton, giving some justification for the name. The mine is about midway between the "Soo" branch and the main line of the Canadian Pacific railway, but is separated from both by rugged, hilly country, so that its only outlets are by the Algoma Central railway, running eleven miles east to Sudbury, or by a wagon road eight miles long to Copper Cliff. The ore is shipped by the Algoma Central to Clarabelle Junction, from which it goes south to the roast beds or the smelter at Copper Cliff.

The Creighton, though the earliest found of the nickel deposits, was one of the latest to be developed, owing to its inaccessibility before the railway reached it. It became the property of the Canadian Copper Co. in 1890, but it was ten years later before it was so far opened up as to ship

Creighton mine: open pit, second level.

ore. From that time to the present the mine has been of great importance, because of the quantity and richness of its ore, so that for some time it supplied almost all the ore used by the company.

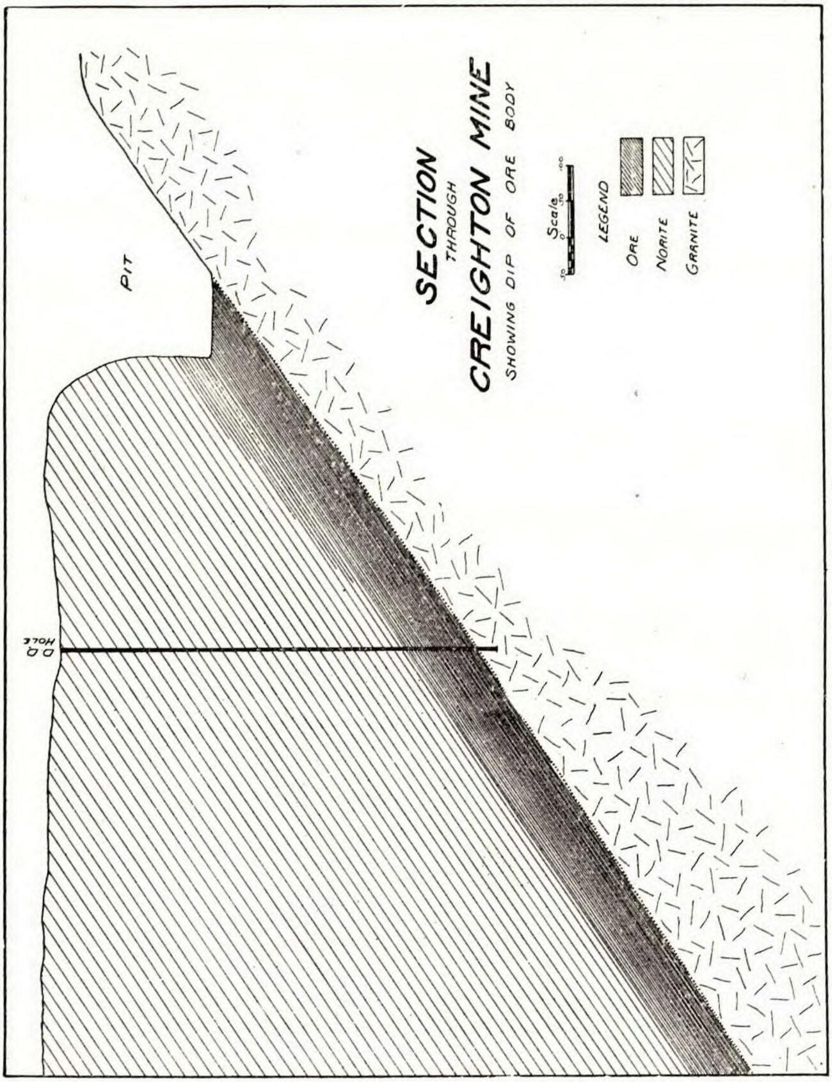


FIG. 2.

GEOLOGICAL ASSOCIATIONS.

As the most important mine in the district its geological relationships should be considered somewhat in detail. The great extent of norite, running for about two miles to the northwest before merging into micropegmatite, is of the typical kind, consisting mainly of labradorite, hypersthene and ordinary pyroxene, with more scattered bits of brown mica and bluish quartz. It is in general coarse grained, but becomes finer grained as it approaches the margin, and half a mile away from the margin it begins to show the round rusty spots indicating blebs of ore, and these increase as the ore body is approached, though not in a very regular way. Near the edge of the steep slope of the hill towards the low ground with its swamps and pond where the great pit was opened, there is a marked tendency for the gossan to occur in several bands parallel to the brow of the hill, as if there were irregular sheets of the rock heavily charged and others less heavily charged with ore blebs.

Near the open pit in earlier days the gossan was thick and continuous except where drift deposits covered the rock. When the somewhat sandy boulder clay was being removed north of the pit in 1904 beautifully polished and striated surfaces of perfectly fresh pyrrhotite were exposed, but these have now been all mined away. The large pit while being opened presented a wall of almost pure sulphides 60 feet high on the north side, a most impressive spectacle when the sun shone upon it.

This great outcrop of ore came sharply against a foot-wall of coarse granitoid gneiss to the northeast and southeast, and a huge block of the same rock was enclosed in ore and pyrrhotite norite on the northeast side of the deposit, probably having slipped in while the materials were still molten, unless it reached its place by faulting at a later time.

Through the granitoid gneiss, the ore and the norite, impartially, a number of diabase dykes made their way at a later time, when all was cold and solid. The diabase, which is beautifully fresh and often porphyritic, cooled very rapidly against the ore, causing a glassy selvage, but less rapidly against gneiss and norite, showing that the solid ore was a better conductor than the rock. The dykes were from a foot or two to twenty feet wide, but often sent off apophyses only a few inches in width, and occasionally curious wen-like or boulder-like projections extended into the ore, having the same chilled surface as the dyke they were attached to. Most of these dykes have now been removed in mining operations. In one case two intersecting dykes completely walled off a large body of ore from the main deposit, but this was obtained by breaking through the walls.

Within the past year or two a large northeast and southwest dyke, formerly hidden by gossan, has been encountered on the north side of the much enlarged open pit. Mr. Hambly, the manager of the mine, states that it descends vertically to the 4th level, and then bends off at an angle of 45° or 50° toward the north.

This tangle of dykes cutting the ore body might be expected to influence it in some way, but there is no evidence to show that this was the case beyond a small amount of faulting and readjustment at the time the dykes made their way in. There seem to be far fewer dykes at other points, perhaps because the angle between the two walls of country rock and the great sheet of ore provided a region of weakness more easily fractured than others.

The general arrangement of norite merging into ore to the southeast, enclosed on two sides by granitoid gneiss, and cut by a tangle of later diabase dykes, was readily observed during the earliest study of the mine, and seemed fairly simple;[1] but during later years as the surroundings were opened up and mining and diamond drilling progressed, the arrangement has been found to be somewhat more complex than was believed at first.

The norite near the ore body contains large bands or blocks of fine grained greenstone and green schist, one which was pierced by the diamond

[1]Bur. Mines, Ont., Vol. XIV, part III, pp. 33-34.

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Creighton shaft houses.

drill having a thickness of 500 feet; and the granitoid gneiss varies in character from granite to syenite or diorite, all cut by later granite redder in colour and finer grained. Part of the foot-wall of the ore consists of a dark green, fine grained rock, which turns out to be "older norite", and must have reached its place and become solid long before the ore arrived. This may be seen at one place on the 1st level near No. 1 shaft house, and the ore encloses blocks of this older norite and of the granitoid rocks to a considerable extent near the foot-wall and penetrates the rock beneath as narrow veinlets.

On the hill southeast of the mine the older rocks are found to be tremendously crushed and mixed up, the coarse flesh coloured gneiss being mixed with masses of greenstone and cut by finer grained syenite or gneiss. There was clearly some faulting and much readjustment among the underlying rocks when the ore and norite pushed their way outward from the centre of eruption toward the edges; but no channel of escape seems to have been opened for the floods of molten materials to distribute themselves along an offset.

THE CREIGHTON ORE BODY.

The minerals of the Creighton ore body are few in number and monotonous in character, including as important constituents only pyrrhotite, pentlandite, and chalcopyrite, pyrrhotite making the bulk of the ore with the other two minerals disseminated through it. On fresh surfaces the pentlandite so much resembles pyrrhotite in colour as to be easily overlooked, while the greenish yellow of the chalcopyrite is readily spotted, but in reality, pentlandite makes up about 15 per cent of the ore and chalcopyrite only 6 per cent. A small amount of magnetite as tiny octahedra rounded on the edges occurs also, and there are everywhere, even in the purest sulphides, particles or crystals of the rock-forming minerals of the norite, especially plagioclase and the pyroxenes. In addition there are insignificant amounts of later, water-borne minerals, galena, pyrite, quartz, and carbonates.

Beside distinct minerals there are always smaller or larger fragments of rock, granite or older norite from the foot-wall or portions of spotted norite from the parent rock in the ore; and near the foot-wall a trifling amount of graphic granite has been found, due to the interaction of norite and granite, and, as a rarety, fluorite. The copper pyrites is present in largest amounts against the foot-wall and as small seams penetrating the country rock, and sometimes considerable masses of it are found in this position.

The ores, like the norite, grow finer grained against the foot-wall and evidently cooled in their present position; and it is important to note in this connexion that perfectly fresh norite, the freshest in the neighbourhood, is found in the open pit beside the ore and spotted with blebs of ore. There has, however, been a little secondary rearrangement by water as shown by the water-borne minerals mentioned above and by the films of chalcopyrite, and less often pyrrhotite, in tiny fissures in the diabase dykes. These sulphides must have migrated into the minute fissures after the dykes had cooled and shrunken a little.

The Creighton ore up to September, 1910, contained on the average 5·08 per cent of nickel and 1·63 of copper with a total for the two metals of 6·71 per cent, making it the richest of the large mines with the exception of Copper Cliff. Crean Hill ore approaches it, but with the proportions of the two metals about reversed. It is also the richest in sulphides of all the large mines, or, in other words, contains less rock matter than the others, 75 or 80 per cent of the ore being sulphides. It has shown a slight falling off in grade since the earlier years, since more rock is now included with the ore, but the sulphides seem to be very uniform in their average contents of nickel and copper. In 1891 when the open pit was begun and almost pure sulphides were mined the percentages were nickel 5·11 and copper 2·19.

If 25 per cent of rock matter be deducted from the ore, the sulphides contain the three metals in about the following proportions:—

Fe—56·44
Ni— 6·77
Cu— 2·17

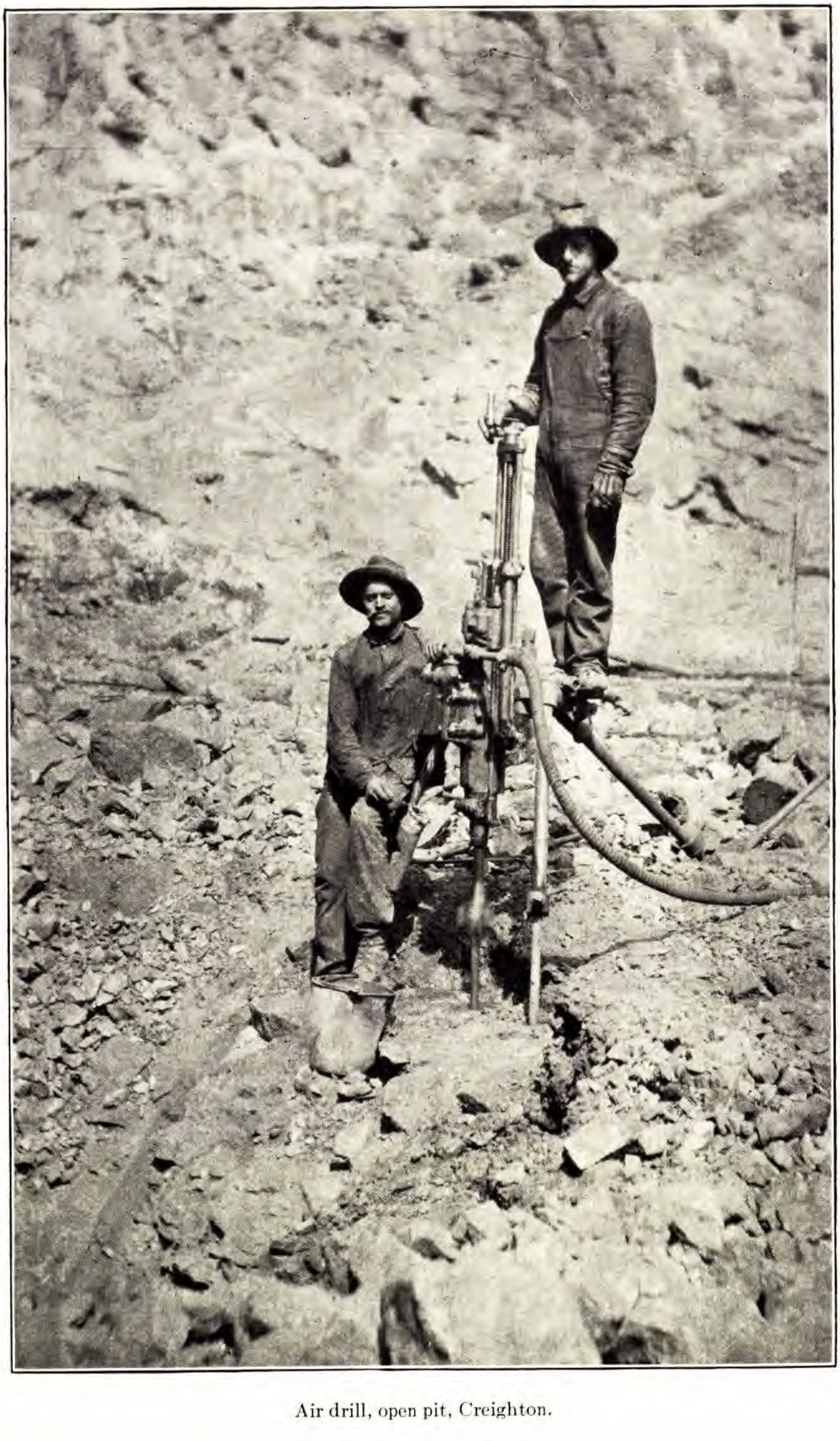
and the sulphides are present to the extent of about 80 per cent pyrrhotite, 20 per cent pentlandite, and less than 10 per cent chalcopyrite.

GENERAL SHAPE OF THE ORE BODY.

Like other marginal nickel deposits the Creighton ore body is unsymmetrical, having quite different features on the foot-wall from those of the hanging wall. It is not a vein deposit nor a replacement, and though it occurs between two different rocks, norite and granitoid gneiss, it is not a contact deposit in the ordinary sense.

On the surface the ore body appeared as a somewhat pear-shaped mass with its broad end toward the northeast. The present open pit has a length of 570 feet from northeast to southwest and a greatest breadth along the plane of No. 1 shaft, of 355 feet, with an average breadth of about 300 feet. Deducting the part of the hanging wall removed in mining operations, the original surface of the ore body must have had about two-thirds of these dimensions, about 380 by 240 feet. Allowing for the dip of the ore body, the width of 240 feet means a thickness of about 180 feet. The pear-shaped cross section shown by the present open pit does not, however, give a very correct idea of the shape or area of the ore body as it appeared in the early workings. The pit down to the 1st and 2nd levels shows a somewhat irregular but quite definite foot-wall of granite with a dip of 42° to the west, while the hanging wall was indefinite, being simply the limit where the mixture of ore and norite proved too low in grade to mine profitably. In the lower levels the dip of the foot-wall has changed to about 34° and the thickness of ore has diminished to about 50 or 60 feet. Below the mine workings the only means of determining the inclination of the foot-wall and ore body are several diamond drill holes, reaching a depth in one case of 672 feet. These data indicate that the dip of the deposit flattens to about 32°, and that the thickness diminishes somewhat, varying from 36 to 52 feet, while the diamond drill work has proved that the ore extends at least 1250 feet in a nearly westward direction. It appears that the ore body thins rapidly in the upper part, and then remains of nearly the same thickness so far as it has been followed by the drill, while the width seems to be increasing at greater depths. It is of interest to find that a new ore body of considerable dimensions has recently been opened up by mining operations at a short distance southwest of the main workings, showing that some deposits have not reached the surface at all.

Since its diminution at the bottom of the open pit, the Creighton deposit has continued so uniformly and regularly, as shown by mining and the diamond drill, that one naturally expects it to extend far beyond



Air drill, open pit, Creighton.

the present known limits, and theoretically there is no reason why it should not go on indefinitely so long as the furrow in the country rock in which it collected continues.

Mr. McCaulley of the engineers department at Copper Cliff makes the interesting suggestion that the remarkable thickening of the ore body at the surface represents a sort of spilling over of the molten ore. It is probable, however, that the ore once extended much higher than the present surface of the country, and that many millions of tons of it have been removed during the ages that have elapsed since weathering removed the edge of the nickel eruptive.

The Creighton has of late years been by far the most productive nickel mine in the world, with its annual output of more than 200,000 tons of ore containing on the average 4·68 per cent of nickel and 1·65 of copper. The total production up to the end of 1910 was 2,088,531 tons, and mining at the regular rate has gone on steadily since that time. The annual production of nickel from this mine has probably surpassed that of all the other nickel mines in the world.

In the month of July, 1909, 32,348 tons of ore were raised, and the cost of production was only 34·4 cents per ton, the output per man employed at the mine being $6\frac{1}{3}$ tons. There are probably few mines that surpass these results for economy of labour and costs.

The Creighton was worked first as an open pit, No. 1 shaft being sunk later on an incline of 59° in the country rock to the southeast to handle the ore. The second and third levels were presently opened up to the first, and the fourth is now opened to the bottom of the pit, which is about 260 feet deep. In order to keep pace with the required output No. 2 shaft was sunk 330 feet to the southwest on an incline of 47°, and most of the third level and the parts below it require underground work, owing to the dip of the ore body mentioned above.

NORTH STAR MINE.

The basic edge of the norite, after turning a little west of north beyond the Creighton open pit, bends northeastward for a mile and a half through swamps and low ground before reaching the North Star mine in the south half of lot 9, con. III, Snider township. The rock to the southeast is mainly coarse granite or syenite, flesh red to grey in colour, and often porphyritic and gneissoid, though there are patches of greenstone, and as one approaches the mine there is some crush conglomerate including blocks of greenstone and an irregular strip of "older norite" like that found near Gertrude and Creighton. The edge of the norite becomes rustier as the structures of the mine come into view. The coarse granitic rocks are older than the norite, since the latter grows finer grained against them, but a dyke of fine grained granite a foot wide can be followed for some distance through the norite, showing that there were later granite eruptions.

The North Star mine was opened in 1902 by the Mond Company, first as a narrow open pit, and later (in 1904) by a shaft 170 feet deep. The deposit has a dip of 75° or 80° toward the northwest, the steepest known in the marginal mines of the region. As reported by Mr. Corliss, then in charge of the mine, the ore is fairly solid and sharply defined against the steep foot-wall, though it contains rounded boulders and angular masses of granite and greenstone; but toward the norite it fades out in the usual way. As the foot-wall is unusually clean cut, and is slickensided, it may be that the steep dip is due to faulting.

The North Star ore when free from rock matter is unusually rich, and it is worthy of note that the great Creighton mine with its rich ore is flanked on each side by smaller deposits, the Gertrude and the North Star, having ore of similar grade; the smaller deposits occupying only slight embayments of the norite edge, while the great ore body was accumulated in a deep depression of the norite into the Archaean substratum.

The North Star which had not been worked for some time, has been reopened in 1912 by the Mond Company.

For a mile beyond North Star the branch and the main line of the railway follow approximately the norite edge, which runs northeastwards and is more or less rusty but shows no ore bodies. The rock to the south is mainly granite, though there are patches of greenstone mixed with it. In lot 8, con. III of Snider township the edge of the norite goes south of the railway and turns to the east; and after a drift-covered stretch ore shows on a hillside of granite, in lot 7. Upon this a test pit was sunk years ago, and apparently abandoned, since it was restaked in 1911 by Messrs. Kirby Thomas and H. L. Carpenter. Not far beyond this a large patch of granite is included in the norite, near its edge; and the country is much more hilly than between Creighton and North Star.

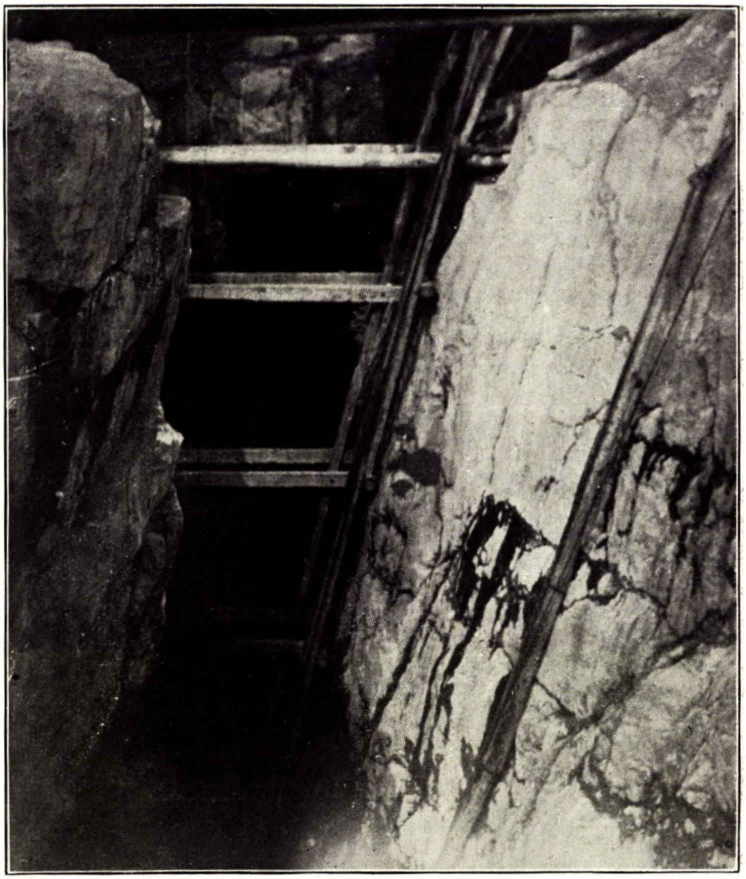
In lot 6, con. III the basic edge once more turns northeast and the amount of greenstone in the country rock surpasses that of the granite. At the shallow bay where the northeastward bend occurs there are several small outcrops of ore on which test pits have been sunk, and a little "older norite" occurs just to the southeast.

The edge now turns nearly east for half a mile, and not far from the line between lots 6 and 5, but probably within the latter lot, there is another northeastward bend with a small outcrop of ore on which test pits have been sunk.

From this point to a small lake near the southern end of lot 5, con. IV, the northeast trend of the norite margin continues, with greenstone as country rock, and no ore in sight. Beyond the lake the margin follows the same direction, crossing the railway and reaching its most northern point nearly on the line between lots 4 and 3, and about a quarter of a mile south of con. V o' the township of Snider. The boundary then turns southeast, crosses the railway in a swamp near mile 5, bends eastward for a short distance, and then south and southeast toward Clarabelle lake.

At its northern point this promontory of granite and gneiss is less than 2½ miles from the acid edge of the nickel eruptive, which is here narrower than anywhere else on the southern range, except near Whitson lake, some miles to the northeast. The almost complete absence of ore or gossan along this part of the basic edge conforms to the rule observed elsewhere. The norite is coarse textured but grows finer grained towards the edge, where it is more or less mixed with fragments of the country rock, mostly coarse porphyritic granite or granitoid gneiss, so that it is evidently the later rock of the two. The granitoid gneiss rises as a group of steep hills in the re-entrant angle of the norite edge, but occasionally at the very edge, the norite forms a hilltop with the granite dipping under it, relations which are well seen near a small lake south of the railway on the line between lots 2 and 3, con. IV of Snider. Southeast of this pond the basic edge may be looked on as merging into the Copper Cliff offset.

PLATE XXIII.



North Star mine, showing dip of foot-wall.

THE COPPER CLIFF OFFSET.

The basic edge of the norite curves southeast from the ba ren region just described, and by walking half a mile eastward along the railway and just to the south of Pump lake one reaches the other side of the norite of the offset, which half encloses a small area of red granite, sending a tongue northeast from the Lady Violet mine. From this mine the margin runs south to No. 6 or Clarabelle mine, close to the north side of the lake of the same name, where the offset is only about 600 feet wide; but just to the southeast it expands again to a width of nearly half a mile, then narrows rapidly once more towards Lady Macdonald lake, where it is not more than 100 feet wide. It sinks beneath the shallow lake, reappears at the east end of Nickel island, is covered by water again for about 1000 feet, and then runs somewhat east of south for half a mile as a narrow irregular band to No. 2 mine.

A gap of about 1500 feet follows in which only drift and a few outcrops of greenstone and greywacke can be seen, after which a small patch of rusty norite appears near a small creek; and then, about 200 feet farther south, the rusty hill of Copper Cliff rises sharply from the drift, runs southward for 400 feet and then bends to the southeast at the mine itself. A wide drift-filled valley separates this mine from the next outcrop 2000 feet to the southwest, after which the rusty norite rises upon a hillside and may be followed with few interruptions for 1900 feet, in a direction somewhat west of south. The southern end of the outcrop sinks beneath bog and old lake deposits once more for 4000 feet, when a low hill of norite mixed with other rocks and gossan-covered, rises at Evans mine, some distance south of the "Soo" railway. Beyond this point no outcrops of the nickel-bearing norite are known.

As the Copper Cliff offset is much the most important known on the circumference ot the laccolithic sheet, as far as amount and grade of ore are concerned, it is desirable to describe its features in detail.

From the account just given it will be seen that the band of norite-micropegmatite is almost at its greatest breadth to the north of the offset, where it gradually curves outward on both sides to form a funnel, a mile wide at the beginning, but narrowing to about 600 feet at Clarabelle lake, then widening and sending a prong to the northeast, before finally shrinking to a width of about 100 feet at Lady Macdonald lake. Beyond this it is seldom more than 200 feet in width and in several places is interrupted, so far as one can see at the surface, by stretches of country rock showing no trace of norite or ore.

It will be noted from the map that after it narrows up the norite of the offset springs from point to point in what seems an erratic manner. The band runs pretty continuously to No. 2 mine, but is next found quite to the west of its former direction, at Copper Cliff mine, and still farther to the west at No. 1 mine. The apparent gaps in the continuity may not be so extensive as they seem, since there may be connecting links beneath the drift, but in some cases the breaks are certainly real, the country rock which interrupts the offset being well exposed. In such cases one naturally supposes underground channels of connexion, though it is possible that the conduit was through overlying rocks, afterwards denuded away. Probably several thousand feet have been removed from the region since Cambrian times when the norite is supposed to have reached its present position.

The length of the offset, measuring from the beginning of the narrow portion at Lady Macdonald lake, is 14,400 feet, of which less than 5,000 feet can be followed on the surface, but perhaps much more is concealed under the lake or the drift deposits. Wherever the band of norite can be followed it is heavily charged with ore. If the offset is assumed to begin where the funnel narrows toward the southeast its length is increased by fully a mile, amounting to nearly four miles in all.

ORE DEPOSITS TO THE NORTHWEST OF LADY MACDONALD LAKE.

On the southwestern side of the funnel where the norite rises against the granitoid gneiss referred to before, ore and gossan seem to be absent; but on the eastern side two ore bodies have been more or less opened up, and there is a large amount of gossan. The difference may be due to the marked widening of the eruptive toward the northeast as compared with the southwest. The first ore body is encountered at Lady Violet mine, to the south of Pump lake in the north half of lot 1, con. III, where in early days the Vivians of Swansea opened two pits at the contact of the norite with greenstone. The deposit is marginal, with coarse grained norite to the west and no suggestions of offset relationships.

Half a mile to the south near the north shore of Clarabelle lake there is another large extent of gossan with two pits, called the Clarabelle, or No. 6 mine. For the distance between the two mines granite forms the country rock in the main, but the gossan-covered hill at Clarabelle is of shattered greenstone merging into chloritic and hornblendic schists. The rock dump, in addition to spotted norite and phases of the country rocks, contains quartz, calcite, dolomite, and actinolite in blades several inches long, indicating considerable secondary action by circulating waters.

During mining operations a mass of about five tons of magnetite was found completely enclosed in the ore at Clarabelle, the magnetite being slightly mixed with sulphides and green silicates, and seeming to be closely related to the regular ores, oxygen replacing sulphur.

Clarabelle mine was for a time connected by rail with Copper Cliff and supplied 4,000 tons of ore containing about 2 per cent of nickel and 1·68 of copper; but for some years it has not been worked, and the rails have been removed, and the mine dismantled. Much of the norite to the southwest of Clarabelle is very rusty, suggesting that more ore may be found when needed.

At the southwestern contact the norite meets granitoid gneiss nearly vertically and grows finer at the edge and is more or less mingled with the granite, penetrating all the fissures in the older rock.

The contact along the railway to the southeast of Clarabelle mine shows patchy norite containing many fragments of a finer grained older norite and of greenstone or green schist, the neighbouring rocks. Beyond this it bends northeast on a steep hill rising about 100 feet above the lake. The hilltop is partly of brecciated rusty greenstone, and on its southward slope beside a tongue of norite there are the large open pits and workings of No. 4 mine. The size of the workings indicates an ore body of considerable dimensions; and years ago the mine supplied 43,500 tons of fair ore containing 3 per cent of nickel and 1·25 per cent of copper, about the normal ratio for a marginal mine. No. 4 is a quarter of a mile east of Clarabelle mine at a point where the offset has widened to about half a mile from northeast to southwest.

On the south side of this expansion of norite there is mainly coarse, porphyritic granitoid gneiss of the Laurentian type; but to the west near Clarabelle lake the granite is intimately mixed with greenstone, and is clearly the later rock. Toward the north there are rugged hills consisting of a mixture of rocks, including hornblende porphyrite with large cleavages of the mineral, hornblende schist, diorite, and portions of a sedimentary rock, greywacke or quartzite all greatly disturbed. It appears that this large bay of norite pushed itself wedge-like along the contact between the granite and the greenstone, which was evidently a zone of weakness.

Where the offset narrows to a point on the northwest shore of Lady Macdonald lake another ore deposit occurs named Lady Macdonald or No. 5 mine, the first of the series of mines on the Copper Cliff offset to be worked. The development consists mainly of an open pit close to the lake at the margin of the norite against a crush breccia of greenstones and granitoid gneiss. The norite and ore at this mine seem to be cut by a later dyke of pegmatite, but the exposure is not satisfactory enough to make this quite certain. The rock dump contains fragments of pegmatite, hornblende porphyrite, hornblende schist and arkose, and a few scales of graphite were found in one mass of gneissoid rock. The mine was at one time connected by a switch with the railway from No. 4 to Copper Cliff, and is reported to have supplied 8,000 tons of ore of moderate grade, containing 2·83 per cent of nickel and 1·06 of copper.

The proportions of the two metals are those commonly found in marginal mines, so that one may assume that the four deposits thus far described belong to the marginal type and therefore that the offset proper begins to the south of this point. Just why all the ore should be on the east side of the bay of norite is not apparent.

THE COPPER CLIFF OFFSET TO NO. 2 MINE.

Lady Macdonald lake has been dammed to provide a water supply, and so hides the relations of the rocks to some extent; but a small island in the northern part of the lake shows gossan-covered norite in contact with granite to the southwest; while rusty norite rises above a bay to the southeast with a width of about 100 feet, broadening to 180 feet a little to the south. For the first 450 feet the band of norite lies between green schist interbanded with greywacke to the east and coarse granitoid gneiss to the west; but from this point on it has both walls of gneiss until No. 2 mine is reached, where greenstone touches it once more.

The whole surface of the band of norite is either pitted with rusty spots where ore has weathered out or covered with gossan, and a succession of open pits, now filled with water, show where small bodies of ore were mined and taken by a short tramway to the rockhouse of No. 2 mine.

The norite here is fine grained and of the offset variety, and it grows still finer grained against the granitoid gneiss, showing its later age. At one point however, about midway between the bay and the open pit of No. 2, a granite dyke 10 feet wide runs diagonally across the norite, so that there were granites of two ages, one older and the other younger than the norite. The later granite is grey and much finer grained than the other. The granitoid gneiss beside the norite has been greatly crushed and sheared and often forms a giant breccia in which the schistose structure is differently oriented in different blocks, while the matrix between the blocks is fine grained and appears to be merely ground up granite of the same kind as the blocks.

Just north of the open pit of No. 2 mine a sheet of drift covers the band of norite and the relations are obscured, but a dyke of greatly weathered diabase about 30 feet wide seems to cut it from east to west.

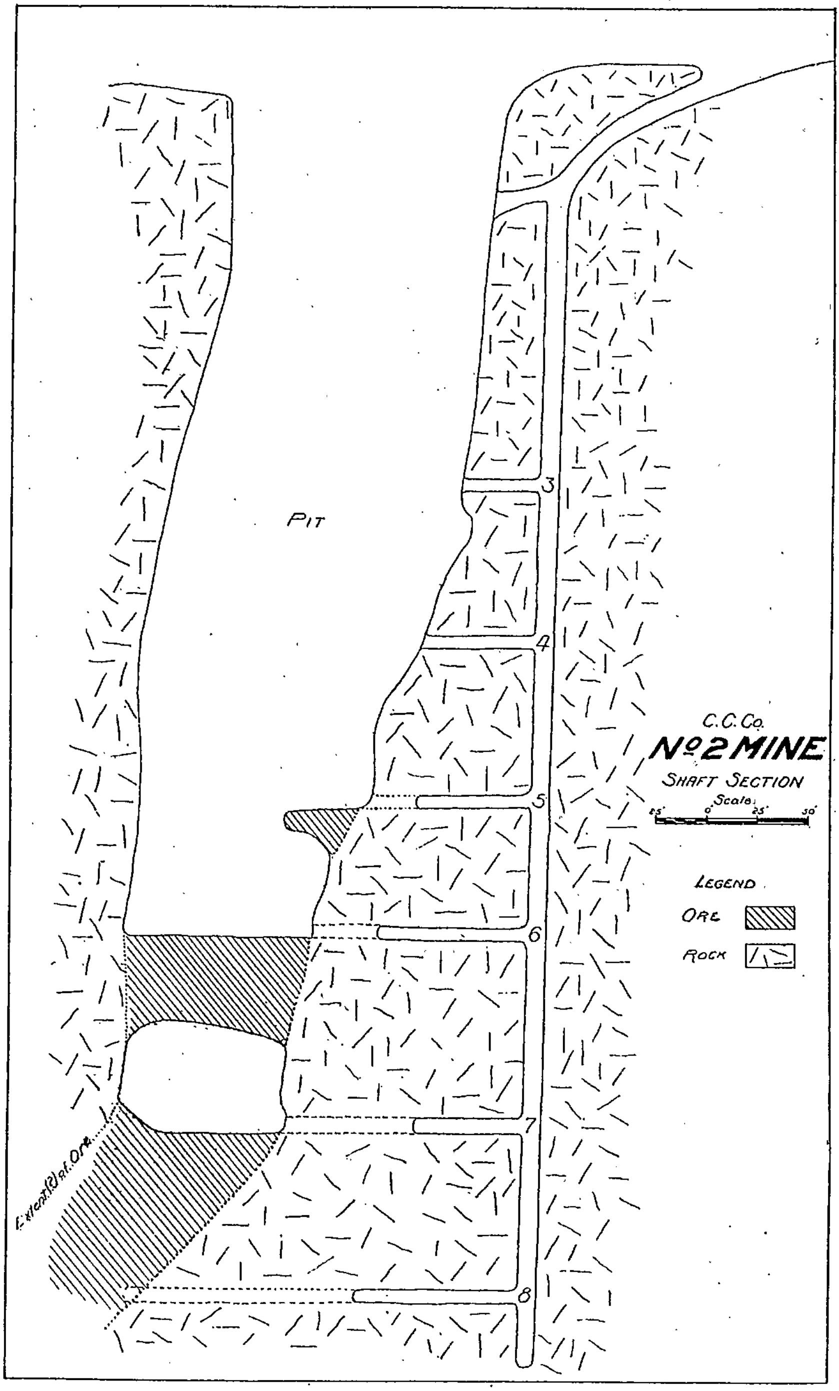

Pit
3
4
5
6
7
8
C. C. Co.
No 2 MINE
Shaft Section
Scale
25' 0' 25' 50'
Legend
Ore
Rock
Extent (?) of Ore

Fig. 3.

The large open pit of the mine occupies nearly the whole width of the offset, showing that ore accumulated here, near the end of a straight band of norite, in much larger amounts than at points with an unobstructed flow from the funnel to the northwest. There is only a small amount of norite spotted with ore left between the pit and the granitoid gneiss.

The pit is about 230 feet long, following the direction of the offset, and about half as broad, but it is not quite oval in shape, since a projection of norite bulges out from the southwest side. The pit is 278 feet deep, and lower down the ridge of norite dies out, the pipe of ore grows more regular in form, and there are underground levels reaching a depth of about 400 feet.

The ore of No. 2 encloses a good many fragments and rounded masses of rock and is of moderate grade, containing 2·70 per cent of nickel and 1·94 of copper, the proportions of the metals being of the offset type, showing more copper than would be found in a marginal deposit.

No. 2 mine was opened in 1898 and produced ore till 1903, when the large output from Creighton mine made it unnecessary to work mines lower in grade of ore, and it was closed down. It is one of the great mines of the region, having furnished 399,000 tons of fair ore during the time it was operated. The mine still contains large amounts of ore, and to meet the increased demand for nickel the Canadian Copper Company began to work it once more in 1911.

COPPER CLIFF MINE.

The small steep hill covered with gossan rising in the midst of the town of Copper Cliff from a wide flat of stratified clay immediately attracts attention, and it is not surprising that so striking a feature was early discovered even in what was then a thickly wooded region. Though not the first nickel deposit found it was the first to be mined on a large scale, and except the Creighton, which was opened up much later, it has been the most important mine in the Sudbury district. It is situated near the northwest corner of lot 12, con. II of McKim township, close to the boundary of Snider township.

The Copper Cliff hill or ridge rises about 400 yards to the westward of the normal extension of the norite band running from Lady Macdonald lake to No. 2; but the trend of the ridge is nearly parallel to its extension. It may be that in a region of so much disturbance they have been separated by faulting on a large scale, so that a great block including the mine has been shifted for a quarter of a mile in a direction a few degrees west of south. It is perhaps more probable, however, that some subterranean channel really connects the norite and ore of the two mines.

The hill of rusty norite 600 feet long and 200 feet wide is enclosed on three sides by drift, but on the east joins a higher hill of sedimentary rock, greywacke conglomerate toward the north and arkose toward the south, both much fractured by the faulting and crushing which prepared the way for the advent of the norite and ore.

The arkose, which is fine grained and flesh coloured, has been so much recrystallized as to look like an eruptive rock, and consequently was at first taken for syenite or felsite; but its relation to undoubted sediments prove that it too is sedimentary. Two small dykes of diabase cut the spotted norite of the hill, and in the arkose just to the east there are two dykes of reddish, grey, medium grained granite, six or eight feet wide, which cannot be traced far owing to the gossan covering of the norite contact. The granite of the dykes is like that of the dyke north of No. 2 mine.

On the rock dump southeast of the mine examples of all of these rocks may be found, and in addition diabase from a dyke, black and fine grained and sometimes twenty-five feet wide, which was followed from the 3rd to the 13th level during mining operations. Diamond drill cores from below the 13th level show spotted norite and ore, diabase, and a dyke of medium grained biotite granite like that cutting the arkose. Beside these rocks, which appear in characteristic forms at the surface, the dump discloses blocks of norite passing into red granite and also forming coarse varieties with large grey cleavage surfaces of plagioclose and coarse grained masses of biotite and hornblende, apparently segregation products of a pegmatitic character. Some of the blocks might be described as anorthosite, when the plagioclase is almost unmixed with darker minerals. While no examples of such differentiation are known from the surface of the offset, very similar occurrences may be seen at Elsie and Murray mines to the north. There is no evidence that either the dykes or the differentiation products have any special relationship to the ore and the dykes were certainly much later in age.

In addition to the pyrrhotite and chalcopyrite of the ore, several other minerals are found on the dump, such as quartz and calcite or ankerite; and along one side of the dyke followed by the mine workings there was a seam of quartz with some ore, and on the other a margin of calcite. Evidently the contact of the dyke with the norite provided fissures in which water could circulate depositing secondary minerals such as quartz, carbonates and galena, but these deposits were formed long after the ore had reached its position in company with the parent norite magma. The circulating waters, so far as the evidence goes, brought in little new material, but rearranged to some extent the minerals of the already existing ore body.

It was largely the study of such later rearrangements of the ores and other minerals from Copper Cliff and neighbouring offset mines which led Messrs. Dickson, Campbell and Knight to consider the nickel ore bodies water-formed deposits due to replacement of the rock minerals by sulphides.

The cross sections of Copper Cliff mine and the plans of the different levels, provided by the kindness of Captain Lawson, show that the ore body is a rude cylinder, narrowing and widening from level to level, and forking about 500 feet below the surface. Its longest diameter varies from 75 to more than 200 feet, following the direction of the hill, and the shorter one runs from 50 to 90 feet. As shown in the vertical section through the shaft, the somewhat flattened cylinder dips very uniformly at an angle of $77\frac{1}{2}°$ towards the east, and reaches a greater depth than 1,000 feet. The earlier shaft following the apparent dip of the outcrop, soon diverged too much from the ore body, and a new shaft was begun at the 3rd level having the dip just mentioned.

In the working of the Copper Cliff mine it was soon observed that when the ore body widened it became richer in nickel, while the narrower parts were especially rich in copper, the first instance of the general rule that the copper ores accumulated near the country rock and the nickel ores farther from it.

The Copper Cliff, as its name suggests, was begun as a copper mine, the nickel contents of the ore being a later discovery. In reality it remained in one sense a copper mine to the end, since out of the 9·53 per cent of the combined metals in its ore, on the average, 5·63 per cent was copper and only 3·90 nickel. In value the nickel was more important, but in amount

PLATE XXIV.

Crush conglomerate south of Nickel range.

25873—8

three-fifths of the output of metal was copper. In this respect it has been paralleled only by the Crean Hill mine, whose ore was, however, much lower in grade.

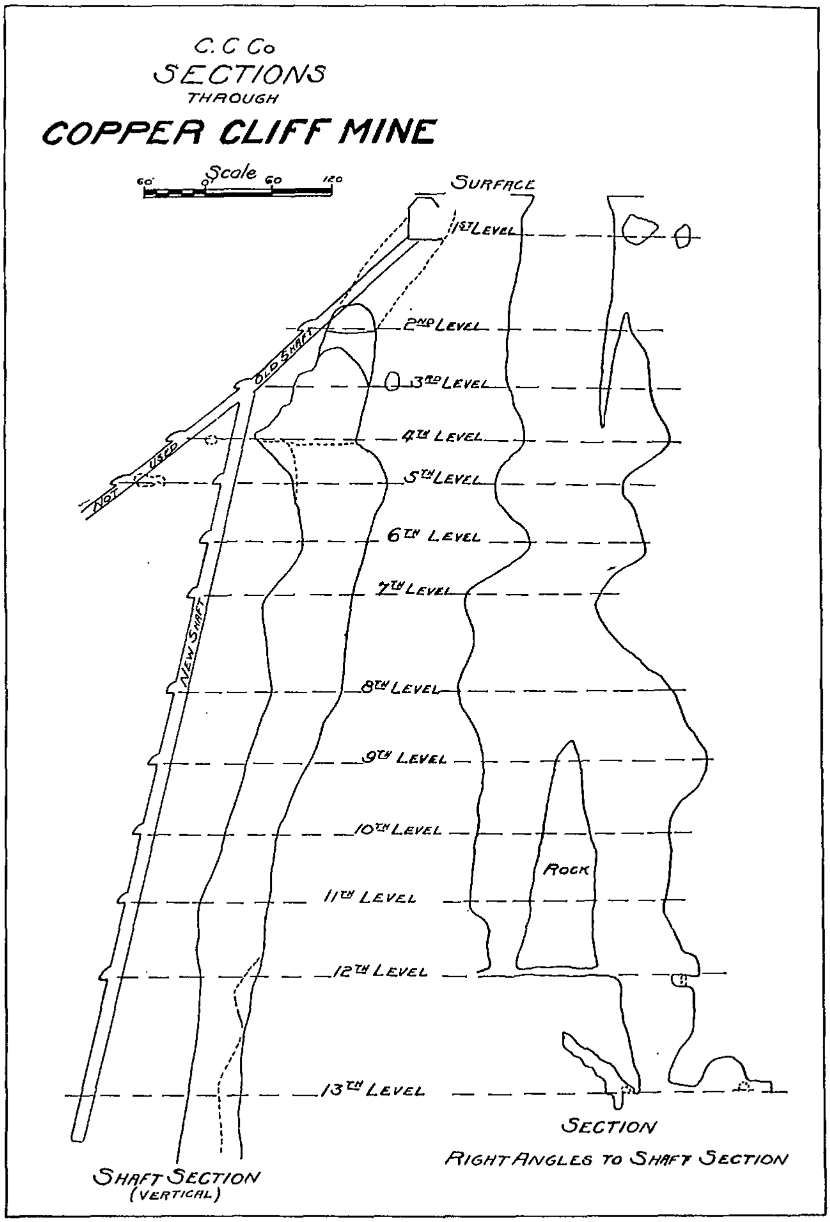


FIG. 4.

During its history from 1886 till it closed down the mine produced 369,000 tons of ore, very rich but containing a good deal of rock, and in its production of the two metals no other mine has equalled it except the Creighton.

When the mine was closed there was still some very rich ore in sight, though the size of the deposit has diminished considerably. In 1910 the rockhouse was torn down, and now little is to be seen at this famous mine except a small open pit and the rock dump. At a few other points on the gossan hill to the north small pockets of ore have been mined and seams of copper pyrites may still be seen in some places.

NO. 1 MINE.

2,000 feet to the southwest of the Copper Cliff mine ore-bearing norite rises above stratified clay on the flanks of a high hill formed mainly of sedimentary rocks, greywacke to the east and arkose to the west. There are three or four small outcrops of ore and rusty norite extending somewhat west of south for nearly 1,900 feet, following pretty nearly the contact of the greywacke with the arkose probably because this was a plane of weakness along which faulting and fissuring took place when the norite was irrupted.

Five pits have been opened on this row of small deposits, No. 1 mine being the most important, but all are now filled with water so that little can be seen except the country rock. The norite and ore in some places ramify between blocks of greywacke, as on the Worthington offset. At the southern pit a small band of dark green hornblende porphyrite shows itself, probably older than the norite; and three dykes of diabase cut both the norite and the country rocks on each side. This part of the offset is narrower than most others and at one or two points the ore occupies almost the whole space between the walls of country rock, much as an ordinary vein might do, and at the southern end it narrows to a width of only ten feet.

For a time No. 1 and its extensions produced high grade ore, the total output reported being 23,000 tons, containing on an average 6·98 per cent of nickel and copper in about equal proportions (Ni 3·56, Cu 3·42). These openings were worked for only a short time about 1898.

EVANS MINE.

Except for a few low projections of greywacke, no rock is to be seen till one reaches the last outcrop of norite, two-thirds of a mile to the south of the one just described, at the Evans mine, where a small and low gossan-covered mound rises above the old lake deposits. Here there are visible only two open pits, filled with water and the rock dumps, showing little that is of geological interest.

The ore must have been somewhat rocky, from the size of the dumps; and one finds norite, partly spotted with ore, actinolite due to thew eathering of some basic rock like norite, diabase, probably from dykes, and greywacke. There is much evidence of shearing and slickensiding in the rocks on the dump.

The Evans mine was worked by open pits to a depth of 160 feet, and afterwards by underground levels to a depth in all of about 250 feet. It was one of the first mines opened in the region, work having begun upon it in 1886, soon after the Copper Cliff mine was started; and, with some interruptions, it continued to furnish ore till the end of 1899. Its massively framed rockhouse was a landmark to the south of the railway until a few years ago, when it was torn down. The Evans mine is reported to have produced 234,000 tons of ore containing 3 per cent of nickel and

2·66 of copper; so that it is one of the important mines of the region, both as to amount and grade of the ore.

A fourth of a mile to the south of the Evans outcrop a hill of gabbro rises through the greywacke, and in my earlier study of the region—before the true relationships of the Sudbury laccolithic sheet of norite had been fully worked out—the question was considered whether it was not really connected with this eruptive mass rather than the much more distant basic edge of the norite. However, the marked difference between the ore-spotted norite at the mine and the pale bluish-green gabbro, devoid of ore, to the south, seemed sufficient to connect it with the offset two-thirds of a mile to the north.

The Copper Cliff offset is much the most important known, with its three great mines—No. 2, Copper Cliff and Evans—not to mention the numerous smaller ore bodies which have been worked. It has produced more than 1,000,000 tons of ore, much of which was unusually high in grade, containing about 35,500 tons of copper and 33,000 tons of nickel; and there is every reason to believe that at least one of the mines, No. 2, will continue to supply ore for a long time to come.

One naturally compares the Copper Cliff offset with the Victoria mine-Worthington offset fifteen miles to the southwest. The latter is quite as long as the former, but is not known to contain any ore bodies of the first rank.

It will be noticed on the geological map that both leave the basic margin of the norite at points where the nickel eruptive has an unusually wide outcrop, with a change of direction of both the acid and basic edges. Both offsets follow directions of great faulting, crushing, and shearing in the country rocks, as if there had been extensive shifting; and this is probably due to the partial collapse and settling down of a great block of the underlying rock as the liquid norite rose from beneath to spread out between the overlying sediments and the more ancient rocks.

If this block lost the support of the molten magma once imprisoned beneath, there must have been important movements at each end, before things were once more adjusted. At Creighton mine there were no such openings provided and the ore was unable to escape.

ELSIE MINE.

Returning to the basic edge of the main range, the contact can be followed northwest from Lady Violet mine, passing to the southeast of Pump lake and then turning east towards Elsie mine. The norite is of the usual coarse grey variety with bluish blebs of quartz and brown spots of biotite, and near Pump lake the adjoining rock is granite, but to the east there is a steep hill of various greenstones and "older norite." The contrast between this rugged mass of the older rocks and the low and nearly flat surface of the norite is very striking, and in the burnt regions to the north one observes how much more rapidly the norite is attacked by the weather than the older rocks to the south. It is being transformed into rounded bouldery masses, partly buried in the coarse sandy materials resulting from the decay of the enclosing rock, the destruction beginning at the joints which permit the water to enter.

The rocks to the south are largely lavas, still showing in places the "pillow" structure and amygdaloids produced where a lava stream has poured into the sea. Parts, however, have been changed from fresh "older norite" into greenstone, hornblende porphyrite and plagioclase porphyrite. With the volcanic rocks were caught up many small and large fragments of greywacke or quartzite, and all of the varieties of rock mentioned appear, more or less gossan-covered, at the southern edge of the ore body, or even enclosed in the ore.

The fresher parts of the "older norite" consist of labradorite with much hypersthene and magnetite, so that the rock is much more basic than the nickel-bearing norite. Just at the Elsie mine the basic edge turns towards the northeast, so that it occupies a small bay, as so often occurs in marginal mines, and the open pit at the mine shows a foot-wall of greenstone and greywacke sloping northwest at an angle of 29°. Twenty feet of clean ore have been stoped out in most places, but the hanging wall of pyrrhotite-norite is very indefinite, and sometimes 40 feet of the mixed rock was thought rich enough to be removed. There has been a good deal of slipping along the foot-wall, and slickensided surfaces could be seen while the mine was working; but everything is now hidden by water, which has filled the underground workings as well as the open pit.

The Elsie mine was opened up in July, 1901, by the Lake Superior Power Co., and ore was shipped to the Gertrude roast yard and smelter for treatment towards the close of the year, a switch curving round the west side of the steep hill to the south of the mine, connecting it with the main line of the Algoma Central railway. The mine closed down, on the financial collapse of the parent company, after shipping 25,700 tons of rather low grade ore.

MURRAY MINE.

The gossan-covered edge of the norite against the greenstones at Elsie mine continues with scarcely a break for about half a mile to the northwest to the Murray mine, the first deposit found in the region and one of the earliest worked. Its geological relationships have been studied by several good geologists, beginning with Baron Von Foullon, who proved the rock accompanying the ore to be norite, and not diorite, as it had been named. Later, Dr. T. L. Walker worked out the geology of the mine and its surroundings in considerable detail while acting as chemist for the Vivian Company[1]; and still later Dr. Barlow studied the region and prepared a map of the geology on the scale of 400 feet to the inch[2]. It will therefore not be necessary to take up details, particularly since the mine has not been worked for a long time and no fresh exposures are to be seen; while the mine itself is full of water, making it impossible to examine it.

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."

This description would apply to a number of the marginal nickel deposits as now known except that for diorite we should put norite to the northwest and hornblende porphyrite variously cut by later granite to the southeast.

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[1]Quar. Journ. Geol. Soc., Vol. LIII, pp. 40-46.
[2]G.S.C., An. Rep., Vol. XIV, Part H.

In addition to the description given above it may be mentioned that acid segregations a few inches or feet in width occur in the norite, in which giant crystals of hornblende and plagioclase occur, often with quartz in the centre. It may be that fragments of quartzite, which occurs with the greenstones near by, have been digested to produce these curious masses in the norite.

Dr. Barlow has shown that the greenstones to the southeast have been greatly shattered and penetrated by a later granite forming a breccia; and he has mapped two great dykes of olivine diabase having a strike of about 120°, cutting the norite and country rock at right angles to the contact. The diabase is very fresh and is much later than the ore body.

The Murray mine was operated by the Vivians of Swansea, Wales, from 1889 to 1894, the smelter having begun work in 1890, but the operations seem to have been carried on at a loss. In 1896 and 1897 the smelter was put to use again in working up about 6,000 tons of roasted ore left by the Vivians, the matte being shipped to Camden, N.J., for the production of nickel.[1]

Dr. H. Winters of Ottawa kindly gives from memory the following information obtained when he was accountant at the mine seventeen years ago. The greatest depth reached in the mine was 225 feet, with drifts of about the same length in each direction at the 100 foot level, and a drift of about 100 feet southwestward at the 200 foot level.

About 200 tons of ore were mined per day of ten hours, but the mine was usually closed for three or four months in the winter as the production of ore was considered more expensive then.

Though the ore was said to contain $2\frac{1}{4}$ per cent of nickel they were not able to obtain more than $1\frac{1}{2}$ per cent from the cupola. About 40 tons of matte, averaging 40 per cent of nickel and 20 per cent of copper, were produced per month, as was impressed on Dr. Winter's memory by the fact that the cash received for payment of wages was dependent on a carload of matte going forward each month, and that there were times when it was difficult to get the carload away. Dr. Winters does not venture to give an estimate of the total amount of ore produced by the mine.

FROM MURRAY MINE TO MOUNT NICKEL.

The gossan belt of the Elsie and Murray mines continues without a break, though in less amount, for a long distance northeast, and at various points test pits have been sunk disclosing more or less ore, but the deposits seem too small to be of importance. For nearly two miles of fairly straight margin one finds small ore bodies or pyrrhotite-norite with enough ore to cause gossan, and the total amount of ore in this distance must be great, but there was no marked depression in the floor into which it might flow so as to form a large deposit such as one might expect where the nickel eruptive shows a very wide outcrop.

For more than three-quarters of a mile northeast of Murray mine the country rock is greenstone or weathered phases of the older norite, often more or less brecciated and pierced by granite; but beyond this in nearly the same direction the country rock changes to granite, flesh coloured and of medium grain, rising as rather sharp hills. Along the granite there is comparatively little ore to be seen until the Cameron mine is reached in lot 7, con. VI of McKim township, though three or four small test pits occur half a mile to the southwest.

[1] Ibid, pp. 30-31.

At the Cameron mine there is a small bay of the norite, and a shaft and some stripp'ngs prove that ore exists. The relations along this part of the boundary are obscured by drift, though there are outcrops enough to show that for about two miles granite is the country rock; but whether it is earlier or later than the norite is not quite certain. The fact that the norite with ore leans up against it suggests that the granite is earlier; but in several cases there is a little greenstone or "older norite" immediately beside the small patches of ore; and it is conceivable that the or'ginal country rock was greenstone, and that the granite is later than the norite, having come up nearly along the old contact.

The relative age of this range of granite hills and the norite is of great practical importance in relation to the probable extent of the ore deposits of the Frood-Stobie offset to the southeast. If the granite is older the Frood deposit may extend much farther to the northwest; whereas, if it is later, the ore and norite are probably cut off from the main range, and the width of the deposit to the northwest will be fixed by the granite mass.

Beyond Cameron mine the basic edge bends somewhat to the east for half a mile to Little Stobie mine, granite rising to the south or southeast for most of the distance. At the Little Stobie, greenstone, green schist and older norite begin; but this part of the region also is a good deal drift-covered, so that relationships are not always clear. The open pit shows hornblende porphyrite and green schist, but the norite near by is so crowded in places with small fragments of "older norite" as to look like a conglomerate or breccia. The Little Stobie was worked for a short time in 1902 by the Mond Company, 1,584 tons of ore being sent to Victoria mine for treatment, but at present things are largely hidden by a second growth of bushes.

About a mile northwest of Little Stobie in lot 8, con. II of Blezard township, a small pocket of ore was found some years ago by the dip needle, and a test pit and a diamond drill hole were sunk by a party sent out by Mr. Edison to explore for nickel ore, without success, however, as no ore was found below the test pit. The drill core showed norite, weathered or fresh, to the depth of 1,030 feet, but interrupted by a band of schist at about 260 feet, and by a considerable thickness of fine grained granite between 900 and 950 feet.

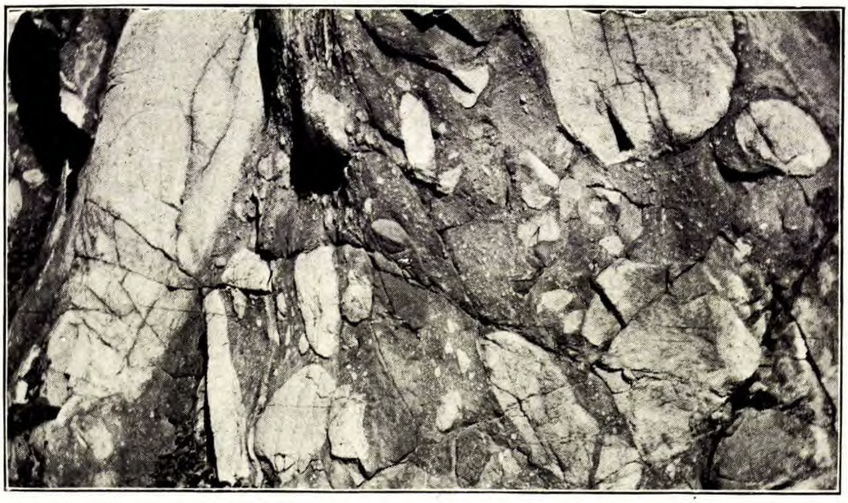
At this distance from the basic edge, if the dip is about 30°, it would probably be necessary to sink 1,500 or 2,000 feet to reach the contact of the norite with the underlying rock where ore might be expected to occur, and the chances would be strongly against finding a remunerative body of ore.

From Little Stobie the contact runs northeast to the north corner of lots 5 and 6, con. I of Blezard, and then east as a small embayment to Mount Nickel mine. Here there has been a considerable amount of development work, including the opening of two cuts and the sinking of a shaft to a depth of 165 feet, some drifting having been done also at the 75 foot level. In these operations an ore dump of respectable size and quality was formed, now largely turned to gossan by weathering. A good deal of diamond drilling has been carried out in addition, some of it in 1911 under the management of Mr. Kirby Thomas; and it is stated that the ore body is fairly large and dips at an angle of about 30° toward the north. In the open cuts one sees first spotted norite with some ore, then a rude breccia of greenstone with ore penetrating all the fissures and serving as a matrix to the rock fragments, the section suggesting that molten pyrrhotite and chalcopyrite were injected into all the openings of the country rock.

PLATE XXV.

Fault, south of Nickel range.

PLATE XXVI.



Crush conglomerate, Copper Cliff.

THE FROOD-STOBIE OFFSET.

Though the nickel eruptive is wide between Murray mine and Mount Nickel, comparatively little ore is found along this part of the basic edge of the norite, partly, no doubt, because the margin bends slightly inwards instead of outwards. This lack of ore along the edge of the norite is atoned for by the immense deposits existing in the Frood-Stobie offset, which runs for nearly two miles somewhat parallel to it about a mile to the southeast, but separated from the main range by the granite hills previously mentioned, extending from south of Murray mine to Little Stobie mine. The Frood-Stobie offset is not quite parallel to the edge of the norite, since its southwestern end is a mile and a quarter from it, and its northeastern end only three-quarters of a mile.

The band of ore-bearing rock may be referred to as a parallel offset, differing so much from other deposits in the region that it should be placed in a class by itself, since there is no surface connexion to be found leading up to the basic edge, and no bay of the norite reaching out towards it, as in most offsets.

It may be assumed that there is, or was, an underground connexion between these two great deposits of nickel ore and the main range to the northwest, so that the ore settling from the great thickness of norite-micropegmatite found its way out through a broad but somewhat intermittent channel or set of intercommunicating channels to its present position, as shown in a diagram illustrating parallel offsets on a former page. This was suggested in my earlier work in the region and has been confirmed by the results of diamond drilling in later years, showing that the ore body dips toward the main range at angles which grow flatter with depth. It is possible, however, that the range of granite hills is later than the norite and has severed a connexion which existed before its eruption.

The general character of the two ore bodies shows an intermingling of the features of offset and marginal deposits, since the ore contains a larger percentage of nickel as compared with copper than in offsets elsewhere, but is more mixed with rock than in a typical marginal deposit. The angle of dip is not far from what would be expected in a marginal mine, and the ore bodies are much longer than broad, both unusual features in an offset mine.

The outcrop rises from swamps and low ground on each side as a very striking ridge of rusty rock on which some pines and other trees grow sparsely, and the highest points reach about 100 feet above the general level, with slopes toward the swamp so steep as to be clifflike. The gossan formed by the decay of the ore is a very resistant material and has largely protected the rocks which it covered from further attacks of the weather.

The band of rusty rock varies greatly in width and the norite is cut completely across at two points, while to the north there are three gaps of from 300 feet to 700 feet before reaching Stobie mine. The widest part of the band of norite and gossan is 900 feet across, a little to the south of Frood mine; and the whole gossan-covered area far surpasses any other in the nickel region, being probably four times as large as the gossan surface at Creighton or Whistle mines, which come next to it. It was an axiom of the early prospectors that a large area of gossan meant an important ore body, and in this case at least their belief was justified.

The ridge rising above the swamps does not consist wholly of norite and ore but includes considerable areas of other rocks, especially greywacke, greenstone, and a gabbro differing considerably from the ore-bearing norite.

The granite separating the offset from the basic edge of the main nickel range nowhere comes in contact with the gossan-covered ridge, more than 800 feet of greywacke and greenstone intervening where swamp does not hide the rock. Most of the adjoining rocks have schistose or bedding structures which run parallel to the norite ridge, and the dip of the sediments is high, generally toward the northwest. The norite seems to have risen through an irregular belt of weakness in the older rocks, especially where the structure permitted an easy separation between the beds of greywacke or of greywacke from bands of greenstone.

As diamond drill cores prove a considerable dip of the ore and norite to the northwest, flattening at the lowest points reached, we must suppose either that the eruptive cuts across the structures in depth, or that the structural planes of greywacke and schist bend rapidly to the northwest below the surface.

It was thought at first that this offset might be connected with the main range near Blezard mine two miles to the north, the connexion following perhaps a series of marshes; but later study of the region opposes this, since greenstone and "older norite" are continuous in low outcrops across the supposed connexion.

FROOD OR NO. 3 MINE.

The southwestern ore deposit is generally spoken of as the Frood mine, so named for an early prospector, though the Canadian Copper Company, which owns most of it, refers to it as No. 3 mine. The gossan surface begins nearly on the line between cons. V and VI of McKim township, 1,800 feet west of the boundary between lots 7 and 6, the norite spreading irregularly on a ridge of greywacke and schist, the greywacke sometimes containing large pseudomorphs after staurolite. The norite extends 1,500 feet in a northeasterly direction, with a width of about 200 feet; but at this point there is a narrow depression across the ridge, when greywacke reaches from side to side cutting off the ore-bearing rock. It is interesting to note that the diamond drill has shown that this surface interruption only goes down a short distance, suggesting that the norite extends as a continuous sheet at lower levels.

Rising again rapidly the ridge of norite broadens to about 400 feet with a steep slope of greywacke to the southeast, and a belt of brecciated rock to the northwest, consisting mostly of angular blocks of greywacke, with some ore coming out between them at many points. Beyond the breccia, to the northwest, low knolls of greenstone rise from the swamp and still beyond are the high granite hills.

After 700 feet of continuous norite one reaches the broadest and highest part of the gossan ridge, where an older gabbro is the principal rock, perhaps an earlier effusion from the nickel-bearing magma. It resembles the true norite in many ways and is sometimes charged with fine particles of sulphides, but thin sections show little or no hypersthene.

This older eruptive rock seems to have been shattered so that the later norite with its sulphides could penetrate in all directions, but the masses of ore pushing through it are only small, though the whole hilltop is gossan-covered to a width of 900 feet It was found impossible to separate the two rocks in mapping These two eruptives make the

Plate XXVII.

Frood or No. 3 mine, 1910.

Plate XXVIII.

Garson mine.

whole width of the ridge at this point and the greywacke disappears on each side, though some mounds of coarse greenstone or porphyrite show to the northwest.

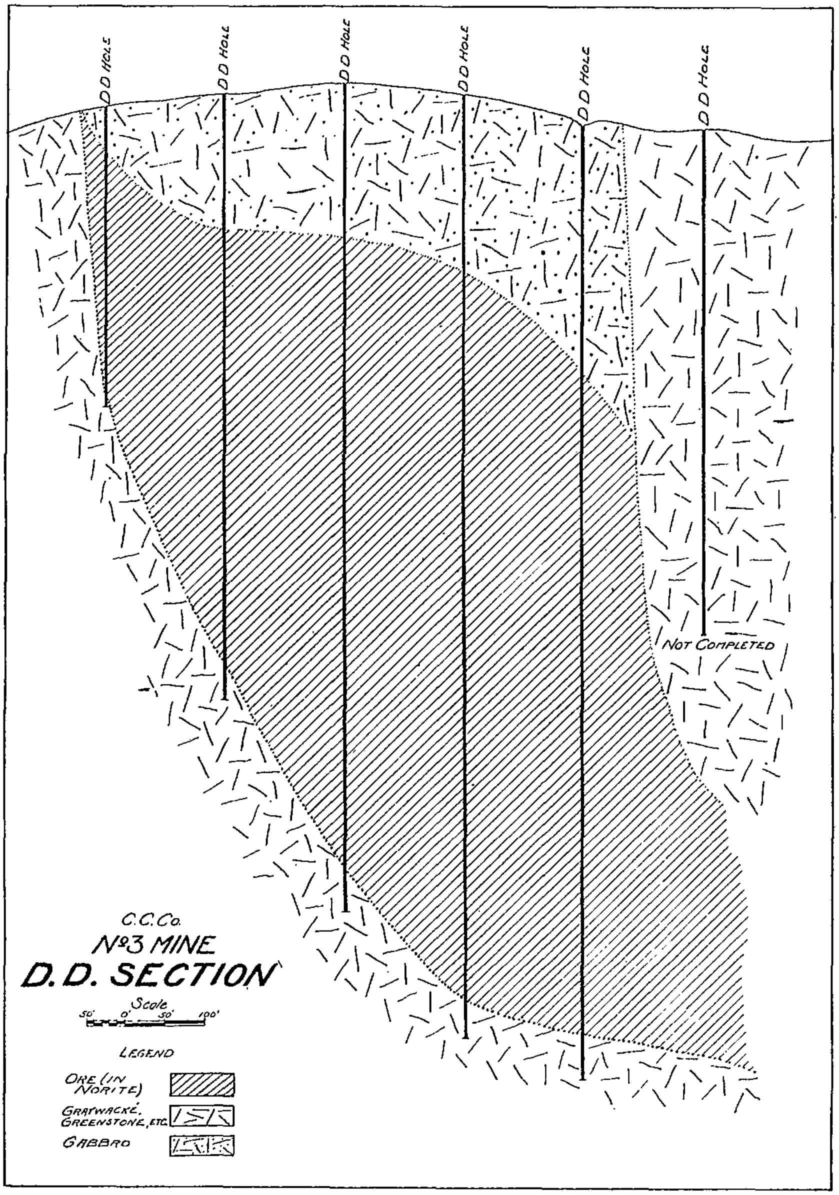


Fig. 5.

While the top of the ridge shows only small masses of ore in the test pits which have been sunk for exploration, the northeast side was in early days the most productive part of the deposit and two large pits show where thousands of tons of ore were mined. The edges of the pits are partly formed of gabbro, but there is also much norite spotted with ore.

Later the mine was worked by a shaft, and since the ore was much mixed with rock, the large rock dump extending toward the swamp gives an idea of the fresher materials obtained in mining. One finds mainly spotted norite and greywacke, but some blocks of actinolite and talc show that these have been secondary changes resulting from shearing and solution. There are also angular and rounded masses of rock enclosed in the ore, some large, others only pebbles; and these may be so well rounded as to suggest water action. One pebble found was of white quartzite like an outcrop about a mile away, but it is probable that these fragments were due to crushing and that they have been rounded by rolling between faulted surfaces.

To the northeast of the open pits the norite sinks suddenly and is nearly cut off by greenstone, but it presently widens and rises again, showing ore in a number of test pits. It may be followed for 2,400 feet northwest of the large pit, with some crush breccia on each side, and is then cut off by greenstone, though small patches of norite rise a little beyond.

The whole length of the Frood portion of the offset is 6,500 feet, and the gossany surface (somewhat wider than the norite) is estimated at an average width of 300 feet, giving an area of gossan not far from 35 acres. More or less ore exists almost everywhere on this surface, though most of it, no doubt, is too much disseminated through the rock to be workable.

Though No. 3 mine was found early in the history of the region, it was not worked, beyond some stripping and the sinking of pits, until 1899. In the following year a railway switch from the Stobie mine gave an outlet for ore from the mine, but four years later in 1903 the mine was closed down after 107,942 tons of ore had been sent to the Copper Cliff smelter. The ore ran 2·66 per cent of nickel and 1·39 per cent copper, the two metals making up 4·05 per cent, so that it was considerably richer than its neighbour, the Stobie mine.

The results of systematic diamond drilling across the ore deposit by the Canadian Copper Company have since proved the amount of ore of a similar grade to be enormous, certainly 35,000,000 tons. The ore body dips in its upper part about 65° to the northwest, as shown by drill holes reaching about 1,000 feet; while later holes, deeper and farther toward the northwest, show that it continues in unimpaired volume but with a flatter dip, so that the amount of ore within reach by shafts of reasonable depth is very great, perhaps greater than the known reserves of ore in all the other mines of the Sudbury district.

Almost the whole of the Frood ridge is the property of the Canadian Copper Company, but a small corner of it is included in the north half of lot 7, con. VI, formerly the property of Messrs. Cochrane and McVittie. Four drill holes were put down near the southeast corner of this property by the Mond Company, who were satisfied as to the amount of ore available and purchased the property. In order to work it a shaft is now being sunk to a depth of 800 or 900 feet. The Canadian Copper Company also is sinking a three compartment shaft to a depth of 500 feet and building a direct railway to Copper Cliff, giving a much shorter connexion than the former roundabout route past Stobie and Sudbury. It may be expected that this greatest of known nickel deposits will soon be sending ore to the smelters of the two producing companies, and adding greatly to the available supply of the region.

STOBIE MINE.

From the end of the nearly continuous band of norite and gossan of the Frood or No. 3 mine most of the distance to Stobie mine is swamp or drift-covered, though patches of rusty norite show themselves from point to point among greenstones and crushed greywacke. The mine is on lot 5, con. I of Blezard township, just to the north of a steep and high hill of greenstone sloping down to the open pits. The stretch of gossan rises steeply just west of the pits, showing comparatively little norite, since most of the surface consists of a confused mixture of rocks, green schist, hornblende porphyrite and greywacke, all more or less brecciated, with a small patch of granite also on the south side. Through the spaces between the masses of older rocks norite and ore have been squeezed from beneath as if through a colander. The extent of gossan is about 1,000 feet from east to west with half that width, but the numerous test pits on the hill itself show no large bodies of ore, so that in many respects it is like the corresponding gossany hill at Frood.

To the north there is swamp and to the west greywacke, to the south the higher hill of green schist and hornblende porphyrite, and to the east the mine openings, rock dumps and rockhouse, concealing most of the surface; though on the low ground there are outcrops of hornblende porphyrite, and also of greywacke containing a band of pebbles, evidently water-formed, since the pebbles are well rounded and are of several different kinds of rock. The dump shows spotted norite, gabbro, greywacke, and quartzite. The magnitude of the openings at this mine is impressive and plans of the mine show large irregular ore bodies having a dip of 65° toward the west, somewhat as in No. 3 mine. The earlier mining was by open pits, though later work was done in underground levels reaching a depth of about 250 feet.

The Stobie mine, which was one of the earliest discovered, began to produce in 1887 and was closed down in 1901, after supplying 418,991 tons of ore, the largest amount obtained from any mine in the region except the Creighton. The ore contained 2·13 per cent of nickel and 1·58 of copper, or 3·71 per cent of the combined metals, so that it was of comparatively low grade; but it was rich in sulphides and made a good fluxing mixture with the high grade but rocky ore of Copper Cliff mine, which was then producing largely.

The mine was closed because that class of ore was not required after the Creighton mine began to work on a large scale, and it is stated that the ore is far from exhausted. Occurring in such a similar way to the Frood and along the same strike, it is probable that this ore body also will be found to extend with a flatter dip toward the northwest. The Frood and Stobie together have provided 535,933 tons of ore, an amount surpassed only by the total from the Copper Cliff offset and the Creighton.

The rocks in the neighbourhood of Stobie show the greatest variety found in the Sudbury district, including both eruptives and sedimentaries. To the north beside the greenstone and hornblende porphyrites mentioned above there are rugged hills made up of "older norite", orbicular diorites, pillow lavas, and what seems to be hornblende schist crowded with bean-shaped patches of white quartzite perhaps once an amygdaloid.

The sedimentary rocks are mostly greywacke and its modifications, sometimes very well preserved and displaying lamination and cross-bedding on weathered surfaces, at others modified into schistose forms or even fine grained gneiss by the effects of adjoining eruptives. Often they are crowded with pale staurolite crystals of all sizes up to four or five inches in length, which are found under the microscope to be pseudomorphs consisting of sericite and quartz. One variety of greywacke is studded with masses of quartzite from the size of a pea to diameters of three or four inches, the larger ones usually suggesting an eye and eyebrow, as if a crescent-shaped shell had split off and separated itself a half inch from the oval mass. In addition there are bands of conglomerate and a few small outcrops of grey or white quartzite.

All of these rocks and also the bands of eruptives penetrating them have the regular strike of from 40° to 55° east of north and usually high dips, nearly vertical or steeply inclined to the northwest. They run parallel to the norite offset just described and probably forced their direction upon it when the norite and ore made their subterranean escape from the margin of the main nickel range.

BLEZARD MINE.

Returning to the main nickel range at Mt. Nickel, the basic edge bends gently towar d the northeast for three-quarters of a mile to Blezard mine in lot 4 con. II of the township of the same name. The actual edge is largely drift-covered and for some distance the outcrops of rock are few and low, the norite forming a plain a mile or two wide with only gentle ridges rising above the drift. There are also swamps along the branches of a sluggish creek lowing northward into Whitson (or Blezard) lake, which cuts across the acfld edge of the eruptive two miles and a half to the northwest. The basic edge at Blezard is of the typical sort for the southern range, dark grey norite with bluish quartz and some plates of biotite, and part of it is very fresh and supplied to Prof. Walker some of the earliest specimens of undoubted norite found in the region.

At the mine the country rock rises as rough ridges of greenstone and quartzite to the southeast, but owing to the dumps and gossan the surroundings are greatly hidden. The pit seems almost entirely enclosed in country rock and is now full of water, so that Dr. Bell's account of the deposit as seen in early days 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-coloured greywaçke, the weathered surfaces of which present raised reticulating lines. Immediately to the northwest of the shafts there is a dyke from 30 to 50 feet wide, of dark brownish grey crystalline diabase, weathering at the surface into rounded boulder-like masses, which scale off concentrically." The "dark quartz-diorite" is norite, and the "ash-colored greywacke" with "raised reticulating lines" is, no doubt, "older norite", which occurs from point to point along almost the whole of this part of the basic edge."

It is said that the pit is 60 feet deep and that the lower workings of the mine reach a depth of 172 feet. A short distance west of the mine and connected with it by a tramway is the smelter with its roast beds and a platform made by dumping slag. As reported by Dr. Barlow the Dominion Mineral Company commenced operations here in 1889 with a capacity of 120 to 150 tons daily, and mining operations ceased in 1893, though the smelter was kept running till July, 1895, chiefly on ore from the Worthington mine, owned by the same company.

The total production of ore from Blezard mine is reported to be at least 100,000 tons and the sulphides of the ore ran about 4 per cent of nickel and 2 per cent of copper.[1] It is probable, however, that the ore as smelted contained a good deal of rock and would run considerably below this.

The Blezard is the last mine of the southern range that has been worked on a large scale until Garson mine is reached five miles and a half to the east.

FROM BLEZARD MINE TO GARSON MINE.

The basic edge is lost to sight in the low ground along the creek for about half a mile northeast of Blezard mine, and when it reappears there are few indications of ore until one reaches the Sheppard mine in the south half of lot 1 con. III of Blezard township. The road which leads from Blezard to this property is now hard to follow from the growth of bushes. There is perhaps a small southeastward bay opposite the end of a little lake along the road, but no ore was seen at this point.

The Sheppard, or Beatrix, or Davis mine has been somewhat carefully prospected and a shaft was sunk in early days, as I am informed by Mr. Kirby Thomas, to a depth of 110 feet, where two drifts were run. There is a considerable area of gossan, and a dyke of diabase ten feet wide cuts diagonally across the contact. The shaft seems to have been sunk in greenstone a little south of the basic edge, and "older norite" occurs near by. According to Mr. Kirby Thomas seven carloads of the ore shipped out by sleighs in March and April of 1892, amounting to about 125 tons, averaged 5·75 per cent nickel, and of two other carloads one contained 5·50 per cent of nickel and 0·32 per cent of copper, and the second 5·60 per cent of nickel and 0·38 of copper. At the time of my first visit to the mine in 1904 the sulphides were in general not yet greatly weathered but included a rapidly attacked mineral which was thought to be polydymite. If polydymite is present it may account for the high percentage of nickel as compared with copper in the ore as shown by the average assays mentioned above. At present the mine is difficult of access owing to the burning of a bridge across the creek, and the sulphides are too deeply weathered to afford much information.

Beyond the Sheppard mine the basic edge passes into the township of Garson, becomes schistose and contains fragments of the adjacent green eruptives sheared out into short narrow bands. Evidently pressure at right angles to the edge or faulting with a horizontal throw have occurred to cause the structure. In Garson the edge turns east and presently a little south of east, and at the crossing of the Canadian Northern railway it is of the normal kind, unsheared and containing a few blebs of ore, the actual contact being concealed by drift, though greenstone rises a little to the south, showing its approximate position. The nickel eruptive is unusually narrow where it passes into Garson township, having a width of only 2 miles, but from this point eastward the width gradually increases until Garson mine is reached.

East of the railway and just beyond the line between lots 11 and 10, some gossan and ore occur at a point one-third of a mile north of con. II, where a test pit has been sunk by Malbeuf and Martin. To the south of the pit well stratified greywacke forms low hills rising through clay soil taken up as farms. The norite from this outcrop eastwards is pale grey in colour and, but for its continuity with the typical norite near Blezard

[1]Dr. Barlow, G.S.C., Vol. XIV, Part H, p. 33.

mine, might not be recognized as the nickel-bearing rock. No further ore or gossan was encountered until the Kirkwood mine was reached in lot 8, but the margin was mostly concealed under drift, so that the low norite hills to the north were often widely separated from the greenstones to the south. The latter sometimes display the pillow structure and amygdaloids characteristic of ancient lavas, and are in part "older norite".

At the Kirkwood mine, toward the southeast corner of lot 8, con. III, a good deal of work was done in earlier times, including the sinking of two shafts about an eighth of a mile apart, and a considerable amount of stripping, but fire has destroyed the mine buildings and the shafts are full of water.

The western shaft is on a low gossan-covered hill of greenstone, the norite appearing at the foot of the hill fourteen paces north, while the eastern shaft is just at the margin. The norite here is greatly crushed and sheared and of the pale grey colour found in this part of the region. The rocks to the south include greenstone, greywacke and quartzite, often crushed to a breccia or conglomerate; and at one point half a mile to the southeast a small patch of rusty norite is seen on a hill near the northeast corner of lot 7, con. II and is sometimes called the McConnell mine. Here a shaft full of water is said to be 60 feet deep, and a small rock dump contains rusty norite spotted with ore. The hill rising to the west shows greywacke interbanded with quartzite and water-formed conglomerate, having a strike of 100° and a vertical dip. These sedimentary rocks have been more or less crushed and faulted; but their strike runs parallel to the edge of the norite an eighth of a mile to the north. This small deposit is evidently an offset, but a drift covering to the north hides any connecting links there may be with the basic edge, which here forms a shallow bay.

Farther toward the east the norite edge is lost under drift and swamp until the Garson mine is reached, while the norite itself rises out of the low ground as fairly high hills to the north of the boundary, though for nearly a mile no rock is visible to the south. This is a complete reversal of the arrangement farther west, where the norite usually forms the low ground and the country rock to the south rises as hills. A partial explanation of this difference is probably to be found in the shearing and alteration of the norite in this eastern section of the range into a rock containing a secondary hornblende instead of the easily attacked hypersthene, thus increasing its power of resistance to weathering.

GARSON MINE.

The Garson mine, formerly called the Cryderman mine, toward the southern end of lots 5 and 4, con. III of the township of Garson, is much the most important known deposit of the southern range west of Blezard mine, and likewise one of the most interesting of the Sudbury mines from its complex geological relationships.

When it was visited in 1904 and described under the name of the Cryderman mine the large showing of gossan was noted, but little work had been done beyond stripping and the sinking of test pits. Since that time it has been acquired by the Mond Company, who have cleared the adjoining land and established a neat village on the sand deposits to the south. A branch of the Canadian Northern railway, leaving the main line a mile north of Sudbury Junction, has been built northeast for about 3½ miles to the mine, to transport the ore to Victoria mine at the present ime, and to Coniston whenthe new smelter is constructed there.

The norite to the north is of the grey variety customary in this part of the range, rather coarse and here and there spotted with sulphides, and rising as hills in contrast with the country rock to the south, which is largely hidden by sand plains. On the hill a quarter of a mile north of the mine a few dykes of grey, fine grained granite cut the norite from east to west, but no diabase or other dykes were noticed at the mine, a rather unusual circumstance in the region.

The mine itself is on a small hill projecting southwards into the sand plain, dipping steeply down to the west with a gossan-covered slope, and to the east more gently to a narrow pond and stream valley running west of south. The rockhouse stands near the western side of the hill, and the railway embankment and a large rock dump hides much of the rock.

The gossan-covered surface is peculiarly shaped, forming a rough quarter of a circle sweeping from south to northeast and finally east, with a broad projection northwestwards from the center of the curve. Just to the north of the gossan, after a short downward dip of the norite of the hill beyond, there is a band of highly schistose rock grey and fine grained with nearly vertical dip so far as can be seen. This runs from a small ravine on the west for a hundred yards eastwards, after which it is drift-covered and blends into the norite to the north without a break. It is evidently a sheared portion of that rock similar to schistose phases of the norite edge which have been noticed in a number of places along this part of the range.

To the south of the schistose band there is a very rusty surface, mainly of greenstone, but a good deal mixed with norite, extending, where not hidden by drift, 350 yards eastward, i.e., as far as the ore is known to exist. The eastern extension of the gossan and greenstone has been opened up by four test pits, while just to the north a band of quartz may be followed for some distance in the narrow valley mentioned before. South of the small gossan-covered ridge spotted norite appears again and extends down the hill slopes for a hundred yards till lost under drift beside a pond. This is the only known instance of a considerable stretch of norite beyond an ore body, and naturally aroused doubts in regard to the origin of the deposit.

The band of gossan running out toward the northwest covers norite, partly schistose, mixed with greenstone, passing toward the southwest into greenstone and green schist reaching down the slope till lost under drift. The curve of norite and gossan to the west of the rockhouse ends against greenstone containing blocks of greywacke, and is no doubt the actual margin of the norite.

In mining operations the ore has been found to enclose great masses of country rock, chiefly greenstone, in a way suggesting that the rock was shattered into large blocks which were shifted so that the ore could ramify into the fissures and spaces between. Along the north side of the ore body a large band of quartz occurs, about in the plane which is occupied by the schistose norite and quartz in the narrow valley between the gossan and the norite on the surface. The same band of quartz, but even broader, appears in the first level of the mine with a length of forty feet or more, and a continuation of the mineralized quartz reaches to the third level, 300 feet below the surface. The quartz is in large enough quantities to be used as converter linings at the Victoria Mines smelter.

There are several quite unique features displayed in this ore deposit. As has been mentioned, much of the ore occurs to the north of a large extent of norite, the only instance of the sort known on the southern range; while the mine workings and diamond drilling have proved that the ore body dips southeastward under this area of norite beyond the mine. This and the peculiar curved shape of the deposit with its projection to the northwest are unprecedented features in the nickel region. It may be added that the ore has entirely the character of that from an offset deposit, though Garson mine occurs partly at the margin of the norite and partly enclosed by norite on both sides.

These anomalies appear to be explained by extensive faulting in which either the norite on the north side, beyond the zone of schist and quartz, has moved horizontally eastwards; or the norite to the south of the ore has shifted westwards, the latter being perhaps the more probable supposition. The amount of horizontal thrust must have been at least 750 feet, since the band of greenstone and ore extends to that distance eastward between the norite to the north and that to the south, and the plane of faulting must have been inclined considerably to the south.

In this process the blocks of greenstone now arranged roughly as a quarter of a circle must have been dragged out of position and more or less rotated. One may imagine that in the beginning the greenstone boundary of the ore body now found west of the rockhouse was 750 feet farther east and continuous with the greenstone and ore at the east end of the deposit, the whole making an outward curve or bay, as so often happens in marginal deposits. It is probable that at a considerable depth an ordinary marginal deposit underlies the whole faulted section and that according to the regular rule workings of a sufficient depth will encounter ore richer in nickel than in copper.

It is unfortunate that everything to the south of the mine is drift-covered so that the margin of the norite cannot be seen. The deepest drill hole, sunk on an incline, shows that ore extends for several hundred feet to the southeast of the outcrop of norite, and Mr. A. L. Sharp, manager of the mine, states that under the village there is quicksand to a depth of 80 feet, so that the final solution of these problems must await the results of mining operations.

On the whole the situation suggests that of the Crean Hill mine, described on a former page, though in that case the place of faulting was flatly inclined and the motion such as to drive the greenstone northwards over the norite; while here part of the norite edge was thrust sidewise beyond the ore and greenstone. The large horses of greenstone enclosed in sulphides, resulting in a very rocky type of ore unusually rich in copper, are found in both mines, showing that they have much in common.

It is only fair to say that Mr. Hall, who has general charge of the mining operations of the Mond Company, does not accept the interpretation of the complex relationships of the Garson mine, given above; but a study of the Crean Hill mine, a somewhat less complicated example of a similar type, makes the explanation probable. It is, of course, not advanced as a final solution of a very difficult problem, but rather as a working hypothesis to help in explaining the facts.

The Garson mine has been worked to the 7th level, the levels being of 100 feet each, and a diamond drill hole shows ore to 1,300 feet, dipping to the southeast under the village. As a result of the faulting described above there are many seams of clay and of quartz in the mine and a few veins of galena apparently without silver. The working of this mine with its comparatively narrow bands of ore encircling great horses of rock, the whole arranged in a rude quarter circle, with a dip to the southeast on its eastern prong, but more to the east on its southern bend, has presented great difficulties, which have been skilfully met. The arrangement of the mine workings is made beautifully clear in the office by plans of the different levels, prepared on sheets of glass so supported as to bring out the dip of the ore body.

At the time of my visit the mine was producing 350 tons of ore a day, and was raising about twice as much ore as Victoria mine, on which the company depended for its chief supply in former years. The Bureau of Mines reports that 93,542 tons were mined during the year 1910 as compared with 42,488 tons from the older mine.

For three-quarters of a mile to the east of Garson mine the basic edge of the norite is hidden by the widespread sand plains of an old glacial lake, and the actual margin is first found against greenstone in lot 3, nearly a quarter of a mile north of the most southern point of norite to be seen near the mine. There is evidently a very pronounced bay of the norite here, and this with the greater width of the nickel eruptive at this point, probably accounts for the much larger amount of ore at Garson mine than at any other known deposit within the township. Low hills of coarse greenstone may be followed somewhat north of east for a quarter of a mile, about to the line between lots 3 and 2 of Garson; while norite of the pale grey, squeezed variety, with few suggestions of ore, rises as much higher hills ot the north.

Less than a mile east of Garson a road runs northwards, following the grade of an old railway made by the Emery Lumber Company, giving a section of the nickel eruptive; and a branch of the road may be followed to Wanapitei lake, making another section across the whole width of the eruptive, but with comparatively few outcrops of rock.

Beyond the line between lots 3 and 2 swamp and rolling surfaces of drift hide the basic edge for nearly three miles, though there are several outcrops of norite along a lumber road turning eastwards toward some old workings in the township of Falconbridge. This fact and the continuous stretch of the acid edge on the north side of the belt of eruptive show that the outcrop of the laccolithic sheet is unbroken here as elsewhere. Not far to the south of the probable basic edge there are exposures of Huronian quartzite, which resists weathering better than the greenstone, rising as hills in a few places, above the wide spread sand plains.

In all there are about three miles of the basic edge on the east side of Garson township and the west half of Falconbridge where the actual edge of the norite is concealed, but it may be that exploration through the Pleistocene beds along this supposedly barren stretch will in the future disclose valuable ore bodies.

The Eastern Nickel Range.

About on the line between lots 8 and 7 and nearly half a mile north of con. III of Falconbridge a hill of greenstone rises to the southeast, but separated from outcrops of norite to the north and northwest by swampy ground, so that the contact is not seen. It is evident that here the boundary makes a sharp turn from nearly east to a direction somewhat east of north.

From this outcrop of greenstone the bush road turns about 30° east of north, mostly over drift deposits for half a mile, when rock shows once more with a thick coat of gossan near the line between concessions IV and V and half way across lot 7. From this point for half a mile northwards ore and gossan are frequently found and several claims were taken up in early years. The most important showing of ore is where the northeasterly trend of the norite edge changes to nearly due north, forming the bay necessary for a marginal deposit of ore, on the west half of the north half of lot 7, con IV. Several of these properties have been acquired by the Dominion Nickel Copper Company, of which Messrs. J. R. Booth and M. J. O'Brien of Ottawa are prominent shareholders, and I am much indebted to their manager, Mr. J. A. Holmes, for aid in visiting them and for useful information regarding the region. This is the most easterly point of the norite-micropegmatite sheet.

The norite is of the rather pale variety commonly found east of Blezard mine and the edge is generally against greenstone mixed with some granitoid and gneissoid rocks, though in one place a small area of quartzite shows beside the norite.

On the southern outcrops the former owners did a good deal of stripping and sank a small shaft, but the Dominion Nickel Copper Company are now testing the properties with the diamond drill. The ore is a good deal mixed with brecciated, fine grained, greenstone, and blends eastward in the usual way into pyrrhotite-norite. The drill holes show that in at least one place the ore goes down nearly vertically for 800 feet so that the ore body has not the inward dip usual in marginal ore bodies, probably because of faulting. The evidence for a large body of ore at this south-eastward bay of the norite is strong, conforming to the general rule in the region and balancing the large Whistle ore body at the northeast corner of the basin.

Beside the series of strippings and test pits extending for more than 200 yards near the co cession line between IV and V, there is an interesting outcrop a half mile to the north, beyond marshy low ground, recently opened up by stripping and test pits by Mr. Cryderman. The associations are the usual ones of norite against greenstone, with some bands of ore ramifying between the crushed blocks of country rock. It is stated that in this part of the eastern range coarse grained platy looking ore is richer than fine grained ore; and though the minerals to be seen on the dumps are the usual pyrrhotite and chalcopyrite, some of the ore is rich in nickel, showing that pentlandite also must be present.

To the north of Cryderman's prospect for nearly three miles no ore has been found by prospectors, and the basic edge is lost under the thick deposits of drift covering most of the region. That there is no break in the nickel eruptive is proved, however, by outcrops toward the west where the micropegmatite makes an irregular band of pale pinkish grey hills.

The next known deposit of ore is at Boland's claims just southwest of Massey bay of Lake Wanapitei, on an area of gossan not known during our earlier examination of the region, showing that discoveries are still being made. The stripping has been done mainly on lot 8, con. II of Maclennan township, 20 chains south of the corner post and 100 yards west of the line between lots 8 and 7; and the outcrop is near the top of a steep hillside sloping toward the bay, in greenstone with green schist enclosing a little arkose or quartzite. The actual edge of the norite may be on top of the hill where drift covers everything for nearly half a mile to the west, though it is possible that the ore belongs to an offset. The ore in sight consists of fine grained pyrrhotite with some chalcopyrite, either in solid seams or ramifying into the rock; and the amount exposed is not very large.

THE BLUE LAKE REGION.

Beyond Boland's the drift once more hides the margin for a mile, after which the superficial beds thin out and the country consists of rocky hills separated by narrow valleys often filled with a lake. The basic edge in this part trends about northwest for six miles; and this stretch may be called the Blue Lake region. Owing to the good rock exposures this belt was early taken up as a series of claims, which run without a break for the whole distance. They are at present rather inaccessible, since the only road that exists is in very bad condition and it stops entirely at Blue Lake; beyond which travel must be on foot over very rugged country, or by a chain of lakes very poorly connected by portage paths, at least during low water seasons, such as the summer of 1911.

In the earlier survey this part of the nickel range was worked out by my assistant the late Mr. M. T. Culbert; and during the examination made in 1911 it was not found necessary to make any changes in his mapping, except in the way of minor details.[1] There has been little advance in conditions since 1905, no work having been done later on any of the properties; and the weathering of the ore and rock dumps has proceeded so far that fresh specimens can only be obtained by breaking large masses. Most of these properties belong to the Lake Superior Corporation or to Cochrane and McVittie.

The wagon road from Sudbury to Blue lake branches off from the road described as going north across the nickel eruptive not far from Garson mine, and turning northeast crosses Massey creek, which flows ultimately into Massey bay near Boland's. At this point the road approaches the margin of the norite after passing for two or three miles over sand plains, and it presently goes down into a narrow valley followed by a small tributary of Massey creek. This tributary stream with the ponds and marshes into which it expands marks almost exactly the basic edge of the norite, and for at least a mile and a half the road, which follows the creek, is scarcely a hundred yards from the edge. The norite has weathered much more rapidly than the granite and greenstone to the northeast and also than the intermediate rock and the micropegmatite of the acid edge to the southwest, so that a trough perhaps a quarter of a mile wide has been opened up all along its outcrop.

The first four claims, WD4, WD6, WD3, and F8 show no large bodies of ore, though the norite is nearly everywhere spotted with gossan where it touches the fine grained greenstone or Laurentian granite which forms the country rock.

F7 and F6 were taken up on the east shore of a small lake running north and south, and WD7, an unusually large location, covers its west side. This small body of water was called Moose lake by the early prospectors, but as there are already two other Moose lakes in the district, it has been named Pyrrhotite lake on the present map. The name is appropriate, since almost its whole eastern side is covered with gossan, and a number of large test pits, as well as two or three small shafts, show sulphides, mainly pyrrhotite.

Most of the pits are near the shore, which rises rather steeply for 20 or 30 feet, but others extend for about 100 paces farther up the hill. The workings are all old and the sulphides of the faces of the pits and on the dumps have largely changed to gossan, but in several places there are thicknesses of five or six feet of solid ore to be seen. Generally, however, the ore is a good deal mixed with rock, partly spotted norite, but more often a crush conglomerate of greenstone, which makes the country rock. There has been a vast amount of crushing and shearing of this greenstone and occasionally also of granite, which has penetrated the older rock as dykes. The foot-wall of rusty greenstone has a very uneven surface, from which much of the ore and norite have been weathered, leaving rounded

[1]Bur. Mines, Vol. XIV, Part III, pp. 73-4.

mounds and hollows, the whole dipping westward under the water of Pyrrhotite lake at angles varying from 15° to 45°.

This dipping of the gossan and ore into the lake suggest that there may be considerable deposits under its bed, especially since very little norite can be seen above or mingled with the ore in the pits. The norite observed is dark grey, medium to fine grained, with small crystals of biotite and looks very like the norite of Creighton mine, and thin sections under the microscope show that the composition is the same, except for the change of hypersthene into hornblende. This dark grey norite seems confined to the immediate vicinity of the ore, and a quarter of a mile to the west, on the other side of Pyrrhotite lake, the rock has the usual pale grey of the eastern norite. Microscope sections of this norite show a little more quartz and no biotite.

The nickel eruptive is unusually narrow here, the width being only a mile and a half, of which about a third may be considered norite and the rest quartz diorite or a dioritic syenite with micropegmatitic quartz.

Not far to the south the eruptive has a width of about a mile and a quarter and one would not expect a very large body of ore to segregate from so moderate a thickness of magma; nevertheless the gossan and ore at Pyrrhotite lake extend for 1,200 feet, following the shore, and for 760 feet in a straight line, with a breadth in places of 200 feet, so that surface indications are favourable, and the ore is unusually coarse grained and rich.

Beyond the lake towards the northeast in location F5 several pits and a small shaft on a steep hill beside a pond display a good deal of gossan, though not much ore can be seen; and beyond this is a steep hill rising from the shore of Blue lake with gossan on its slope and two curious deposits on top. The larger one, 75 feet long from north to south and 35 feet wide, is completely enclosed in greenstone and seems to be a columnar offset deposit, though only a short distance from the edge of the norite; the other one is a few yards to the southeast. Seven years ago the Lake Superior Power Company did some diamond drilling on Blue lake, proving the existence of a considerable body of ore, but the lack of railway connexions prevented them from working the mine.

Blue lake consists of two parts joined by a narrow strait, and the ore deposits just mentioned occur to the east of the strait and south of the northeastern part of the lake, the southwestern expansion being wholly within the nickel eruptive. Across the northeast expansion a small outcrop of ore occurs about opposite those just described in location W 1. From this point the edge of the norite runs northwest to the eastern side of Clear lake, in W 2 and W 3, where there are strippings and small pits showing ore, mostly close to the water's edge, but sometimes 100 or 150 yards up the hillside. The country rock northeast of Clear lake rises with very steep slopes to a rather narrow ridge of greenstone and crush conglomerate running northwest and southeast parallel to the lake, which is about a mile long and less than a quarter of a mile wide. The lake basin was evidently formed by the weathering out of the basic norite with its fringe of ore.

The outlet of Clear lake is over morainic materials, and the solid rock is covered to Emma lake, the next little lake or pond, so that the position of the norite margin is doubtful. A short distance north of Emma lake there are hills of coarse granitoid gneiss, so that the basic edge evidently continues northeast under the drift towards a bay of Ella lake. Like Blue lake, Ella lake is double, with northeast and southwest expansions having a narrows between; but most of the northeastern shore is of granite or greenstone mixed with granite, and in location WR 11, no ore was observed.

Just northeast of the outlet of the lake in WR 10 where a small stream flows north toward West bay of Wanapitei lake, a considerable patch of gossan is seen and a large test pit has been sunk showing ore mixed with rock, and gossan with norite and ore occurs in a ravine northeast of the end of the lake in WR 2. WR 9 and WR 2 are within the township of Norman.

Between this point and Waddell lake there is much difficulty in placing the edge of the norite, since the hill seems to be the plane of contact of norite and ore against the underlying greenstone. The whole surface is a crush conglomerate and here and there scattered over it are gossany spots and small patches of norite spotted with ore. Mr. Culbert mapped the norite edge as bending northeast toward a bay on the east side of WR 2, and there are undoubtedly rusty portions of norite extending as far as that, but they seem to be only remnants projecting a little deeper into the foot-wall rock than usual, and hence of no importance as indications of an ore deposit. On this account it has seemed better to carry the boundary nearly straight north to Waddell lake. Along its shore much the same difficulty is met, since granite occurs at its southeast corner in WR 23, followed by greenstone farther north, partly covered by a fringe of norite and gossan running up into WR 7, where a small outcrop of ore occurs northeast of the end of the lake, probably a short offset, since older rocks occupy the northeast shores beyond this.

THE WHISTLE MINE.

The Whistle mine has long been looked upon as the most important ore deposit on the eastern side of the nickel basin because of the great extent of gossan displayed and also since ore was disclosed in numerous test pits sunk in earlier years. At the time of the former mapping of the region it was not easily accessible except by a canoe route following the chain of lakes referred to as leading northwest from Blue lake, but at present it is reached by the Nickel Range railway, running three and a half miles east from Nickelton Junction on the Canadian Northern.

The mine is mainly on lot 6, con. IV of the township of Norman, but the deposit extends a little way into lot 6, con. V, just to the north, and beyond it the mining village of Nickelton is rising on a plain of old lake deposits. It belongs to the Dominion Nickel Copper Company and is, so far as known at present, the most important in tonnage of ore of their numerous properties on the eastern and northern ranges.

Coming up from the south there is a fringe of barren norite along the east shore of Selwyn lake, cut by its eastern bay, and running with a very irregular edge along low hills at the outlet of the lake into Post creek. A few hundred yards down Post creek a tributary comes in from the northwest in a broad marshy tract which hides the boundary for a short distance. To the north of the junction of the two streams near a road leading northwestward to the mine, gossan is seen extending up the hillside to the east, on what is called the Wildcap deposit. With few interruptions gossan and ore can be followed irregularly along the steep hillside or on top of the hill to the point where the main workings have been carried on near the shaft house, a distance of more than a third of a mile. Here the boundary suddenly turns westward, crossing the railway an eighth of a mile northwest of the rockhouse, which is about 180 yards southwest of the shaft house.

From end to end the gossany edge of the norite and ore extends for half a mile, with a width of 250 yards where widest, and lying up against a steep hill which rises 230 feet above the valley, the rusty surface is most mpressive. Ore or gossan extends quite to the top of the hill and may be followed down the slope to a small tract of swamp at the bottom. Many test pits were sunk from point to point in early days showing shallow or deep ore deposits at the Whistle mine, and since passing into the hands of its present owners a large amount of diamond drilling has been done on a systematic plan, so as to explore the property more thoroughly. A drift has been run into the hillside half way up, cutting a body of ore for 432 feet and resulting in the incidental production of several thousands of tons of ore. In one drill hole in the swamp below the hill ore was found at a depth of 893 feet; showing that the hillside does not display all the ore in the deposit.

The Whistle mine is a typical marginal deposit, formed where the norite edge makes a sharp bend from north to west, so that it follows the general law in the district, of a large ore body where there is a pronounced bay of the norite extending into the country rock. The shape of the deposit is very complex, since the floor of granite and greenstone is uneven with projections and also hollows into which the ore could settle. A distinct rise of the Archaean floor separates the Whistle from the Wildcat to the south, and the Whistle itself is divided into almost separate deposits by projections of the rock beneath, one mass dipping at 45° toward the west, and another passing into the flat at the southwest.

Except close to the ore the norite near the Whistle mine is coarse grained and unusually pale grey in colour, as may be seen where it rises as a steep-walled hill a little to the west of the rockhouse. The norite close to the ore, however, is very fine grained and is sometimes mixed with fragments of other rock, greenstone and granite or gneiss as a crush conglomerate, an arrangement found at many other nickel mines. It is probable that this long known mine will be producing ore on a large scale within a year or two.

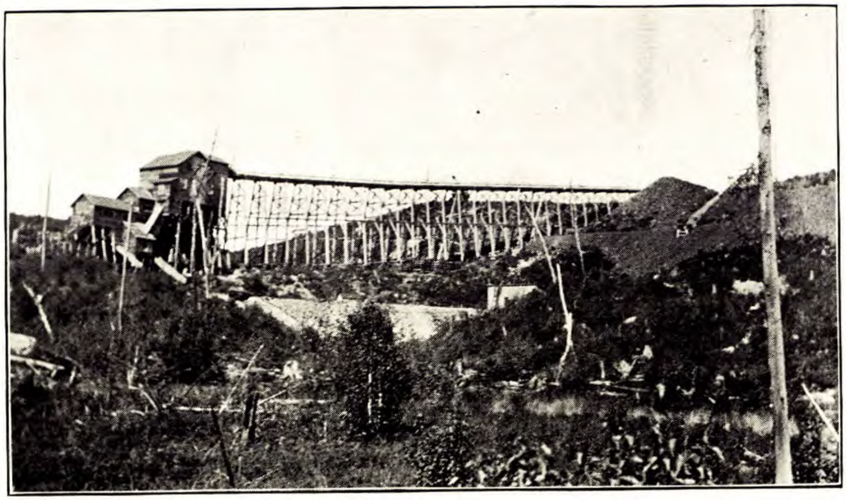
To the west of Whistle mine the boundary of the norite, with its gossan, is lost in the creek valley, and for a quarter of a mile the contact has not been seen, since the hill which it crosses is largely covered with drift and forest. Half a mile to the west, following the railway, small pits on a gossan-covered surface show some ore a hundred paces south of the track, and less than a quarter of a mile beyond gossan is seen, a little to the north of the railway.

Broad lake deposits hide the basic edge for some distance beyond this, but here and there norite with little evidence of ore rises against hills of granite enclosing some green schist. About two and a half miles west of the mine, following the railway, a path leads a quarter of a mile northwest to a ravine between a steep hill of norite toward the southwest and of Laurentian toward the northeast. On the flanks of the latter hill there is ore to be seen at a small shaft, whose dump consists mainly of crushed conglomerate mixed with ore. Beyond this to Vermilion river no outcrops of gossan or ore are known.

The Northern Range.

The edge of the norite at Vermilion river is largely drift-covered, and no actual contact was observed near the river nor along the Canadian Northern railway at Nickelton Junction; the coarse, rather pale, grey norite found for a quarter of a mile north of the junction passing out of

Plate XXIX.



Whistle mine.

Plate XXX.

Crush breccia under norite, Trill.

sight several hundred feet before the reddish Laurentian gneiss rises in a rock cut. From this point southwest for two miles kames and morainic deposits deeply cover the bed rock in most places, but the norite edge can be seen rising as hills against the Laurentian near a small lake at the corner of lots 2 and 3, cons. III and IV of Wisner township. There is no ore nor gossan to be seen and prospectors have taken up no claims until lot 4 is reached in the third concession. A well beaten path leads from Nickelton Junction over the hills just mentioned, and then follows the chain of claims running westward across four miles of the width of the township, in places widened or replaced by a lumber road.

The basic edge from lot 4 to Joe's lake follows mainly a creek valley with swampy margins, where the actual contact of the norite with the older rocks to the north is usually hidden, and no gossan nor ore was observed, though prospectors have taken up half a dozen claims along this part of the range. The edge bends inward here, so that ore in quantity would hardly be looked for; but toward the west side of location WR 14, northwest of Joe's lake, and adjoining part of WD 16 to the west there is a promising outward bend, mainly within the latter claim. Here the norite boundary is gossany against crushed greenstone, and in WD 16 test pits and diamond drill holes show the presence of a considerable amount of ore.

The boundary curves southwest in this location, and then west once more in WD 13, where some gossan and ore are seen in test pits. Ore has been found in WD 15 also, where the norite turns a little south of west before passing out of Wisner township.

In Bowell township the basic edge extends diagonally from con. III on the east side to the southwest corner, just north of the township of Lumsden. Ore may be seen on WD 13 and on WD 208, but the most promising deposits are near the middle of the township, where a long offset extends toward the west. Gossan begins to show itself against granite hills near the northeast corner of location WD 35, but is found in much larger amounts on a hill slope in WD 155, which may be taken as the beginning of the offset.

THE FOY OFFSET.

The Foy offset, as it may be called, runs past Nickel lake in a northwesterly direction, then turns west, passing another small lake, and ends just north of a pond almost exactly in the middle of Foy township. It is six miles long and fairly continuous, though the norite narrows and widens and is not always easy to distinguish from certain grey basic rocks rising here and there in the Laurentian. The rock is heavily charged with ore for the first mile, and there is a distinct ore body in location WR 5, often called the Ross mine, at the western end, but the stretch between shows little gossan, though its whole length has been taken up by prospectors.

Gossan is widespread on the locations near Nickel lake, and test pits and drill holes show that ore occurs at a number of points on WD 155, where the adjoining rock in some places is so largely made up of white plagioclase crystals that it might be called anorthosite, and there are small seams of magnetite as well as sulphides. Similar relations continue to the northwest, in WD 150. Beyond Nickel lake the band of norite narrows and becomes greatly mixed with boulders and angular fragments of a coarser grained norite and of the country rocks, which are grey gneiss, greenstone, and a white rock with porphyritic feldspars not unlike the anorthosite mentioned above. The whole conglomerate is more or less gossan-covered, and quite similar conditions are seen near the next little lake, where gossan and the band of crushed rock rise above the water.

The Laurentian along this part of the offset is coarse red granite, something unusual in the region, where it commonly consists of grey gneiss with streaks or patches of greenstone. Little gossan or ore is to be seen beyond this along the offset, until the Ross mine is reached, where two outcrops rise from the muskeg borders of a small lake against the usual hillside of Laurentain gneiss; but even here the amount of ore to be seen is not large. It is reported to assay only 2·75 per cent of nickel, so that it is not high grade.[1]

The crushed and brecciated character of the rock along this offset resembles that on the two other long offsets, at Copper Cliff and Worthington, and may be accounted for as in the other cases by collapse and faulting during the advent of the nickel eruptive. This offset is, however, more continuous than the others, scarcely showing any interruptions, though its width varies from 20 feet to 500 feet in different places. Except in the earlier part, near Nickel lake, there is no reason to expect any large body of ore on this northern offset, and the low content of nickel at the Ross mine is not specially attractive.

Beyond the Foy offset the boundary of the norite follows the south shore of Roland lake and then turns southwest to another narrow lake which lies between the norite and hills of Laurentian to the north. The next point of interest is in location WD 238, where a small offset projects northward from the edge, running up a narrow valley in location WD 37 and showing gossan and ore as exposed by strippings. Gossan is found at several points to the southwest, and a few test pits show ore on locations WD 231, WD 241 and WD 251, the last being at the southwest corner of the township. The country rock along this part of the basic edge is gneissic Laurentian rising often as very steep ridges or hills, with the ore generally toward the bottom of the slope. At several points, however, the margin is in low ground and covered with drift and swamp.

Taking the northern range as a whole, the number of ore bodies of promise is not great, though at least two portions, northwest of Joe's lake and at the beginning of the Foy offset, are known to contain deposits of importance. The ore is not usually high grade and differs considerably from that of the southern range in containing less copper and more magnetite. In one location there is only 0·15 per cent of copper with 50·57 per cent of iron. About 10 per cent of this ore is magnetite, and sulphur is present to the extent of only 30 to 32 per cent, so that by simple roasting an excellent ore of iron could be prepared containing all the nickel. The amount of copper present is so small that apparently the roasted ore could be used directly in the production of nickel steel, the plan proposed years ago by the Lake Superior Corporation for the ore from the Gertrude mine.

BASIC EDGE IN MORGAN AND LEVACK.

The basic edge of the norite, more or less ore-bearing as it runs diagonally to the southwest corner of Bowell township, loses its ore almost immediately after entering Morgan township. South of a small lake at this point there are two patches of gossan on which a little stripping has been done, while to the north of the lake there is Laurentian granitoid gneiss. The edge of the nickel eruptive shows neither gossan nor ore from

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

this lake to the boundary of Levack township, at the north end of concession IV, so far as our researches go, and no locations have been taken up by prospectors, whose keen eyes never fail to discover an outcrop of gossan. The reason for this is probably to be found in the fact that the eruptive is here at its narrowest, having a width of only three-quarters of a mile in lot 2, concessions V and VI, and not exceeding a mile and a half till the margin bends westward toward the Levack ore deposits.

In accord with this narrowing of the eruptive is the petrographic character of its outer edge, which is pale reddish grey, with the composition of syenite rather than norite. Comparison of specimens from the two edges shows very little difference, and one may fairly conclude that the basic, or norite, part of the eruptive is wanting here, the acid or micropegmatite phase making the whole width, so that under these circumstances the lack of ore for six miles is not surprising.

The country rock, where examined at every half-mile or oftener across the township, is coarse granitoid gneiss of the Laurentian type with many bands and masses of hornblende schist or greenstone enclosed in it. The gneiss strikes about east and west and usually has a vertical dip, and the boundary of the eruptive always shows a crushing and brecciation of the Laurentian beneath.

Owing to its barren character, it does not seem necessary to describe in detail the margin of the eruptive in this part.

The northern part of Morgan township is almost devoid of roads and has been left in a very rough condition by the lumbermen; but it may be reached by canoe on Moose and Trout lakes and by a lumber road over sand and gravel plains to an old camp near the forks of Sandcherry creek.

THE LEVACK AND STRATHCONA MINES.

As the nickel eruptive widens north of Moose lake, near the eastern boundary of Levack township, its outer edge once more becomes grey, though not of a deep tone, and may be called norite again. The widening continues through the first two lots of Levack township and reaches nearly two and a half miles opposite the Strathcona and Big Levack mines. Near the north end of lot 1, con. IV of Levack, 150 yards west of a small lake, gossan and ore are to be seen in some small test pits, and 100 yards farther west stripping shows a considerable extent of gossany surface, the latter probably in lot 2. The country rock is of granite or of granitoid gneiss and a hill of these rocks projects south, separating the stripping just mentioned from the much larger exposure of ore and gossan commonly called the Big Levack mine. Here the margin of the norite and ore is very irregular and is spread out over a length of 130 yards from north to south and a breadth of 70 yards. The underlying surface of granite is hummocky with depressions and projections, so that the ore sometimes reaches down several feet, as shown by test pits, while in other places the bare rusty surface of granite intervenes. The dip of the basic edge is, therefore, very variable, averaging about 20° or somewhat more.

It appears that most of the norite and ore has been weathered away, leaving only what was protected in the hollows of the harder rock beneath. It may be, however, that the swamp at the foot of the gentle slope hides the thicker parts of the ore body.

A swamp-covered gap separates the Big Levack property from the Strathcona mine in lot 3, where the norite edge projects a short distance to the west. Here, as on the Big Levack, the ore and norite are widely but very irregularly spread, as seen in numerous test pits. Mr. Ernest A.

Sjöstedt, who examined the property some years ago, when the workings were fresh, 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 of 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 hillside 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, 1 foot from bottom	D. C. Schuler			0·57	2·78
" " piece from dump	E. A. Sjöstedt			1·35	3·55
" " 2, from dump	D. C. Schuler			0·70	3·85
" " 25 feet depth	"	5·03		2·11	3·54
" " piece from dump	E. A. Sjöstedt			0·14	4·65
Pit A, surface	D. C. Schuler			0·67	2·24
" B, surface	"			5·47	2·02
" B, bottom	"	6·10		1·54	3·37
" C, surface	"			0·33	2·40
" C, trench	"	3·40		1·24	3·27
" C, 13 ft. pit	"			0·28	2·72
" D, low ground	"	4·00	50·4	0·30	3·21
Diamond drill hole, near A, 26 ft.	A. B. Wilmott			0·65	3·80
Diamond drill hole, near A, 40 ft.	"			0·58	2·60
Shafts, all over dumps	R. H. Aiken	5·01	54·3	2·23	3·15
Near norite wall	"			1·49	1·68
Near norite wall	"			2·43	1·70
Average		4·71	52·3	1·31	2·97
Samples taken by Messrs. Cohen and Bradley, experts for J. R. De-Lamar, N.Y.				1·99	2·67
Total average				1·70	2·82

The ore is evidently widely spread in these two mines, which are really one series of deposits, but a very large part of it has been removed during the lapse of time, so that only remnants now remain on the exposed surfaces. What may still be preserved beneath the swamps and drift to the southeast remains to be proved.

The ore as shown in Mr. Sjöstedt's table averages lower in grade than that of the southern nickel range as a whole, though it equals that of two or three large mines which have been worked profitably. Rather pale grey norite rises as hills to the south of the chain of ponds and swamps representing the basic edge of the norite.

At the Levack mine a wagon road begins, following the basic edge rather closely southwestwards to the crossing of Onaping river, in lot 9, on the southern side of Levack township. Beyond this the road keeps to the west side of the river, which here runs south, to the Canadian Pacific railway at Levack, a distance of a little over five miles along the nickel range, followed by about two miles southwards across the more acid phases of the eruptive.

The basic edge runs for two miles southwest from Strathcona mine, then bends south for two-thirds of a mile past a small lake in lot 6 on the boundary between concessions II and III. No ore has been found at the northwestward bend, where one might have expected it, but gossan shows on a hillside sloping steeply down to the lake at its southern end. It may be that the boggy floor of the valley to the north conceals ore which does not show itself on the rocks which rise above it, and no doubt with the idea that an ore deposit may exist below the marsh and lake, a claim has been staked by Mr. Black at its outlet.

The test pits near by show very platy pyrrhotite enclosing small crystals or rounded blebs of rock matter, and the same is true of a large deposit, generally called the Tough and Stobie property, two-thirds of a mile to the southeast, where the road passes over the gossan close to the foot of a high hill, on which several test pits have been sunk.

The Laurentian background of granite, gneiss and fine grained greenstone, has been very little brecciated at this point and dips fairly uniformly at an angle of 33° to the southeast, under the usual swamp; while hills of grey norite rise across the creek a quarter of a mile away. All of the Levack properties suggest remnants of once important sheets of ore leaning up against the Laurentian gneiss, with a possibility that the original thickness of the deposit may yet be found preserved beneath the drift or swamp that regularly covers the base of the hills.

To the southwest of this point plains of sand and gravel begin to spread out along the river valley and the basic edge is mostly hidden for the next two or three miles.

The short stretch of the basic edge included in the township o' Dowling between Onaping river and Windy lake, is largely drift-covered and no ore is known to ex'st along it. Near the Canadian Pacific railway on the northeast shore of Windy lake grey dioritic norite is seen, but the precise boundary between it and the Laurentian is under the drift. The Laurentian beyond is gneiss with darker schistose inclusions.

Windy lake itself cuts out two miles of the basic edge, the only example of a large body of water occurring on the circumference of the basin. A promontory stretching out from its northwestern shore is crossed by the norite margin, but here it is obscured by moraines and esker ridges and a small bay pushing north from the end of the lake forms another interruption, followed by wide swamps to the southwest in the direction of Mink lake. The shore of Mink lake is entirely Laurentian, and the portage path between it and Mosquito lake to the southwest crosses only coarse granitoid gneiss and drift. On the southeast side of the small stream draining Mink lake into an arm of Mosquito lake norite rises as a steep wall of rock, which continues along the shore of this northeast arm and also borders the main body of the lake. A narrow southern arm of the lake probably marks the boundary there, but no rock was seen on its shore.

A point projecting from the southwest side of the main lake consists of spotted norite against Laurentian and it is stated that ore was found in two pits a little lower down on the point and on a small island off shore; but at present a dam at the outlet of Mosquito lake has so far raised the water as to cover all of the openings. The work was done many years ago by Messrs. McConnell and Tough, and the small ore dump visible is turned to gossan. Mr. W. Stephens, a trapper well acquainted with the region, says that a narrow band of rusty rock with some ore is found also on the shore of a long southeastern arm of Ministique lake (locally called Mistic lake), but for lack of a canoe at the proper time this was not visited. The small deposits on Mosquito and Ministique lakes seem to be parts of an offset.

The southern end of Mosquito lake passes into the township of Trill and a portage leads west, mostly over drift, to the northeast end of Armstrong lake in that township. Including the water stretch of Windy lake there is a gap of about nine miles between the last outcrops of ore in Levack and the one just referred to in Cascaden, the longest blank known on the basic margin of the nickel eruptive. The next longest blank is in Morgan township to the northeast, where the eruptive is narrower than anywhere else. The Windy lake part of the eruptive is not unusually narrow, so that some different explanation must be looked for in this case; and it may simply be that ore bodies exist but are under the water of the lake or are covered by the widespread drift and swamp which hide the solid rocks over much of the region.

THE NICKEL RANGE IN TRILL.

For about two miles south of the last norite seen on Mosquito lake the basic edge appears to be lost under drift deposits, though a cliff of norite was found at about the middle of the south side of lot 9 in con. V. The boundary apparently runs near the west side of a small unnamed lake, where granite hills rise just to the west, but the first actual contact was found in lot 10, con. V, 200 or 300 yards south of the lake just mentioned, on a hill sloping east, where a little norite occurs in patches on the Laurentian. The boundary can be traced, with drift-covered interruptions, for half a mile southwest on the same hillside. About a quarter of a mile south of con. V, on the line between lots 10 and 11, the slope of the hill becomes steeper and turns west, and on its south side gossan appears in considerable amounts and some test pits show more or less ore. Beyond this the boundary is once more vague, spots of norite occurring in the brecciated gneiss for some distance up the hill beyond the solid eruptive, and presently the basic edge bends to the south for three-quarters of a mile, and then southeast. There is much drift over this portion so that the precise boundary is not certain, and a little north of the only house left standing there is a small inlier of Laurentian, apparently a mound rising island-like through the surrounding norite.

The contact of norite and the mixed granite and greenstone of the Laurentian is unusually flat in this great westward bay, often having a dip of not more than 5° or 10°, and many scattered shreds of norite, very fine grained and sometimes spotted with ore, are found as outliers upon the older rocks, even hundreds of yards beyond the edge of the solid norite. At the corner post between lots 10 and 11 and concessions III and IV a hill of greenstone rises steeply facing northeast and along its flanks ore occurs in several places at the Trillabelle or Gillespie mine, where in former years a considerable amount of work was done in stripping, opening pits and sinking shafts. The old buildings have all disappeared and saplings are growing up among their foundations, but the gossan-covered dumps of rock and ore may still be studied.

The rocky hillside consists largely of the crush conglomerate so often found beneath the norite, with fine grained norite and ore as the matrix of the large and small fragments of greenstone; and the dip of the contact is from 35° to 45° to the northeast, in strong contrast with the gentle dip of the country rock a little way to the northwest. It seems that the steep slopes beneath the norite, here and also three-quarters of a mile to the north, halted the molten mass and allowed the ore to separate, while the easier slope between these two points permitted an unobstructed motion.

A quarter of a mile farther southeast there is an isolated pit with ore, and 200 yards south of it another pit of considerable size. Beyond this to the south the margin of the norite is generally drift-covered and no more ore nor gossan was observed, though in several places granite with patches of greenstone, or greenstone free from granite can be found to the west, and norite to the east of the valley followed by the road to Worthington. At two points there are outliers of norite with Laurentian all round them.

A bald ridge of pale grey norite rises as a landmark on the line between lots 9 and 10 near the south end of concession III, just to the west of the marshy valley of Cameron creek and sinks out of sight a quarter of a mile farther south. After a half mile of swamp norite again rises on the hillsides west of the creek near its eastward bend and continues to the middle of lot 9, con. I, the farthest point toward the southwest reached by the nickel eruptive. No ore nor gossan was observed along this belt of norite, probably because the actual edge is everywhere drift-covered, though in such a bay-like projection ore might have been expected.

Around the bend of Cameron creek everything is lost under dead water and swamps owing to a dam just beyond; and here a puzzling problem arose. From the last undoubted norite to the nearest ore deposit of Sultana mine is less than a mile in a direction a little south of east; but all trace of the norite seemed to be lost in the space between. To the north of the creek beyond the dam a reddish somewhat schistose rock rose as hills and to the south an even steeper group of hills consisted of greenstone. By careful following up of the nickel eruptive from Sultana mine, so as to make sure there was no break in the continuity, it was proved that the basic part of the eruptive is wanting here and that the reddish schistose rock passes directly into the acid phase of the eruptive. It has, however, been sheared or squeezed against the greenstone across the creek and perhaps cut off by faulting. Owing to the covering of drift to the southwest the relations in that direction could not be seen, but it seems certain that the southwest end of the boat-shaped syncline is partly split open by a mass of greenstone half a mile long and a quarter of a mile wide.

In the former mapping of this part of the region the township of Trill was covered with heavy timber, and outcrops of rock were not easy to find, so that the norite boundary was made too regular. Since that time the splendid pine has been cut off by the lumberman and the region has been mostly burnt over very effectually, so that the following of the rock boundaries has been comparatively easy except where swamps or stony morainic ridges hide everything. The present map, therefore, shows much more irregularity in the basic edge than the former one at the extreme west of the nickel basin.

In the work around Trillabelle mine much assistance was received from Mr. Kirby Thomas, who was examining the property as a mining engineer.

In order to give a more complete idea of the nickel-copper contents of the ores from various parts of the ranges not well represented in the averages quoted the following assays are appended. The samples were taken as fair specimens of the ore in each case, but it will be understood, of course, that they are individual samples and may not represent the average ore from the deposits mentioned.

No.	Locality.	Insol.	Cu.	Ni.	Co.	In pure Sulphides.		
						Cu.	Ni.	—
1	Sultana mine	10·27	0·26	2·68	....	0·29	2·99	
2	Mt. Nickel mine	7·62	0·31	3·07	....	0·33	3·33	
3	Whistle mine	6·60	0·10	2·76	....	0·11	2·96	
4	Chicago (Travers) mine	9·80	0·24	2·50	....	0·26	2·77	
5	Levack mine	1·50	0·84	4·76	....	0·85	4·83	
6	W. D. 150, Northern range of Bowell tp	9·52	0·10	2·51	....	0·11	2·77	
7	Worthington mine	17·00	0·56	6·45	....	0·67	7·77	
8	Totten mine, Worthington offset	29·52	0·08	6·41	3·07	0·11	9·09	Co. 4·35
9	Blezard mine	13·42	2·42	3·90	....	2·80	4·50	
10	Victoria mine	0·62	0·70	7·95	....	0·70	8·00	
11	North Star mine	10·09	0·26	4·56	....	0·29	5·07	
12	Elsie mine	31·84	3·38	1·26	....	4·96	1·85	
13	Little Stobie mine	6·32	0·20	1·58	....	0·21	1·69	
14	W. D. 155, Northern range of Bowell tp	7·47	0·32	3·57	....	0·34	3·86	
15	Gertrude mine	8·75	0·14	3·88	....	0·15	4·14	

The Acid Edge of the Nickel Eruptive.

When it was discovered by Professor T. L. Walker that the norite connected with the nickel ore at Murray mine merged into a more acid rock, micropegmatite, toward the north, and that the norite near Windy lake passed into a similar rock toward the southeast, a clue was given toward the explanation of the whole problem of the nickel ranges and their relationships Under the instructions of the Director of the Bureau of Mines of Ontario the work of mapping the nickel ranges as fully as possible was undertaken by myself and my assistants, including Messrs. Culbert and Moore. In following up the different nickel ranges there were numerous and sometimes wide gaps where no ore had been found by prospectors. Often these gaps proved to be caused by swamps or drift deposits; in other cases the norite could be followed unbroken but with an inward curvature that did not permit the ore to collect.

To avoid the uncertainty occasioned by these gaps, it was decided to map the acid edge of the nickel eruptive also, though in a rougher way; and from time to time as occasion allowed the inner margin of the micropegmatite was traced. This boundary was touched as far as possible at every half mile, and often much more frequently, so that its position as given on the map is believed to be reasonably accurate, though it has not been worked out in great detail.

The results of this work have given greater certainty in regard to the continuity of the nickel ranges, especially in tying together loose ends, for example near Sultana mine to the west and Falconbridge to the east. As the work progressed it was recognized that another valuable result was obtained. It was found that great width of the eruptive was accompanied by large ore bodies, and medium width by smaller ore bodies, while the narrowest parts of the eruptive had no ore bodies on their basic edge.

The basic edge of the eruptive had usually been found to carry ore at outward bays, which was explained by supposing that the heavier sulphides settled by gravity into the hollows. On this theory no ore was to be expected on the acid or upper margin of the eruptive, and actually no nickel ore and very little copper ore has been found on this margin, though there are a considerable number of small ore deposits of another kind either at the acid edge or in the overlying sediments which have been more or less metamorphosed by it. Up to the present none of these deposits have proved large enough for development as mines, though it is possible that more important ones may be found when the acid edge has been as carefully scanned by prospectors as the basic edge.

In mapping the acid edge unexpected difficulties were encountered. It was found that the edge was often overrun, even for a hundred yards or more, because of the great resemblance of the micropegmatite to the overlying Trout lake conglomerate, which was often so completely metamorphosed by hot fluids emanating from the eruptive as to be itself largely transformed into micropegmatite of a somewhat ruder sort, near the eruptive margin. Only the larger granite pebbles and boulders of the conglomerate resisted this process and remained as cloudy patches of coarser or redder granitoid material.

Another difficulty was encountered in the variety of phases presented by the micropegmatite itself, which was sometimes rather coarse, red and granitic or syenitic looking, while at others it was gneissoid in appearance, and at still others it formed a fine grained cleavable green schist. In the field the one variety was traced into the other, but hand specimens of the extreme types would never be recognized as the same rock. Thin sections under the microscope, however, always showed the characteristic intergrowth of quartz and feldspar called micropegmatite.

ACID EDGE OF THE SOUTHERN RANGE.

The inner edge of the nickel eruptive on the southern range begins toward the southwest in a sharp bend on lot 7, con. II, of Trill township, the prow of the boat-shaped syncline, from which it may be followed eastward to Cameron lake and beyond that to the north bay of Fairbank lake. In this part of its course it is fine grained, schistose and dark greenish in colour and does not suggest syenite or granite in the slightest degree, though its chemical composition and its micropegmatite structure, as seen under the microscope, show that it is the equivalent of these rocks. A little to the south it passes into hills of reddish syenite which is unmistakeable.

After continuing a mile and a half eastwards the acid edge bends northeast to Gordon lake, whose south side it follows and then turns suddenly southwards for a mile, before turning to the northeastward direction. Its boundary against the conglomerate is as indefinite here as that of the norite against the Laurentian in Trill, and for a similar reason; since the dip of the micropegmatite beneath the sediment is very gentle and the edge of the conglomerate feathers out irregularly upon the surface of the eruptive.

There is another feature of interest near this great bay of conglomerate; the pebbles are more or less rol ed out in a schistose way and the cleavage of both micropegmatite and schist conglomerate has a strike of 65° or 70°, i.e. not parallel to the direction of the eruptive contact, while the dip is about 45° to the southeast This does not correspond to the bedding, which is shown by vague layers having few or many pebbles to dip 25° or 30° toward the northwest.

It is probable that these features are to be connected with the long Worthington offset of the nickel range, which begins four or five miles to the southwest. The flattening and widening of the conglomerate, the direction of the schistose structure and its dip to the southeast, as well as the complex lines of brecciation along the offset, may all be accounted for by supposing that a great block of the Archaean supports slipped down beneath the molten sheet of norite-micropegmatite, the plane of faulting and shearing running from southwest toward northeast.

After the remarkable southward bend of the acid edge, it once more assumes the normal northeasterly direction, crossing Vermilion river and reaching Lake Emma about in the middle. From this it follows Levey creek rather closely to its exit from Whitewater lake The canoe route is seldom more than a quarter of a mile from the edge, and it is evident that the contact of the acid eruptive with the overlying sedimentary rocks furnished a plane of weakness in which the valley could be cut, though the actual course of the stream is generally a little north of the Trout lake conglomerate in the Onaping tuff. The acid edge is still schistose with syenitic looking hills rising immediately to the south and trends about 80° east of north. Just beyond the edge the northwest quarter of lot 4, con. V has been taken up as a zinc claim.

Whitewater lake makes an interruption of three miles in the outcrop of micropegmatite, which somewhere beneath its waters bends more to the north than along Levey creek. A promontory on the north side of the lake consists of quite schistose conglomerate, having a strike of 60° or 70° parallel to the average direction of the nickel eruptive, and the cleavage dips 45° in the direction southeast.

Old lake clays hide the solid rock for half a mile north of Whitewater lake near Azilda, but syenitic looking rocks rise toward its east end and there is a rocky hill a half mile northwest of the station just north of the railway, which displays the acid eruptive in contact with the conglomerate. Both are pale redd sh and decidedly schistose, the cleavage having a strike of 15° and a dip of from 15° to 30° to the east, though the boundary between the two rocks runs 30° east of north and west of south.

There is evidently a well marked bend of the acid edge from 75° or 80° to 30° east of north, though the point where the change of direction begins is under the lake; and it will be noted that the bend takes place just opposite the bay of norite leading into the great Copper Cliff offset, a coincidence which is almost certainly not accidental.

This is in fact the opposite end of the great block of underlying rock which slipped down during the advent of the nickel eruptive and which was referred to in connexion with the sharp southward curve of the acid edge opposite the Worthington offset. It is an impressive fact that this settling down of a block of the earth's crust 10½ miles long on the acid edge and 15 miles long on the basic side should begin and end with important offsets of norite and ore pushing into crushed and faulted regions of the older rocks, and that it should include the great Creighton ore deposit.

The acid edge in Rayside township runs northeast across its southeast corner, and in lot 2, con. III is accompanied by several small deposits of galena and zinc blende which have been taken up as a mining location. The ores are associated with pyrite, quartz, and ankerite and occur in irregular fissure veins which have been stripped and opened up by test pits. The veins are in the somewhat schistose micropegmatite or the adjoining schistose conglomerate and tuff. The cleavage of the sedimentary rocks has a strike of 80° east of north, conforming to the changing direction of the nickel eruptive, and a dip of 57° to the south.

Passing into Blezard township the acid edge turns nearly east and the whole eruptive narrows considerably from its widest part, opposite the Frood-Stobie offset. It is no longer schistose after passing the crisis of the fault plane, but granitic or syenitic in appearance, and this character continues to Whitson lake toward the east side of the township.

Beyond Whitson lake the acid edge runs in a direction 80° east of north through Garson township near its north side and finally bends suddenly north at the southwest corner of Maclennan township. In part the micropegmatite with the adjo ning conglomerate and tuff rises as steep east and west hills, in other parts the edge is hidden by swamps or small lakes. About half way across Garson the eruptive rises as a red cliff, felsitic in texture and penetrated by many small quartz veins, but on lot 4 it is greyish and schistose, the cleavage having a strike of 125°, much more to the southeast than the general trend of the eruptive itself.

It is worthy of note that at a certain distance on each side of the fault planes bounding the central block supposed to have slipped down the slaty or schistose structures turn southwards, on the west side toward the southwest, on the east side toward the southeast, the whole region having been subjected to strains and shearing, resulting in structures with this roughly semicircular curve.

The various types of rock displayed in this part of the acid edge were formerly mapped as Laurentian by the Geological Survey, and frequently their field characters would justify this if one were not aware that they pass by insensible gradations into the norite of the nickel range toward the south and southeast.

ACID EDGE OF THE EASTERN AND NORTHERN RANGES.

The acid edge of the Eastern range was studied mostly by my assistant, Mr. Culbert, who found that the micropegmatite phase begins within a short distance of the basic side of the eruptive, as might be expected where the whole is unusually narrow. He describes it in general as flesh coloured and rather coarse grained, but where examined by myself, in lot 1, con. III of Capreol township it is rather fine grained and faintly reddish grey, pale on the weathered surface and darker on fresh surfaces. It shows none of the schistose structure so common on the southern band.

The acid edge of the eastern range curves gently to the west near the southwest corner of Norman township, and where crossed by the Canadian Northern railway is rather fine grained and more like diorite than syenite or granite in appearance. It runs across Wisner township in a nearly westerly direction and its contact with the conglomerate is beautifully exposed near the shore of the south end of Joe's lake, where a wave and ice worn surface provides an ideal section. The acid phase of the eruptive is granitic looking and sends irregular projections into the conglomerate with quite vague edges, so that it is by no means easy to fix the boundary. The micropegmatite blends with the conglomerate as if it were continuous with its matrix, though patches of redder coarser granite represent boulders not completely digested. About 400 feet south of the edge tuff replaces the conglomerate.

One of the most interesting contacts of the two rocks is found on the south shore of Trout lake (in Bowell township) where some islets and a small peninsula show an even better section, the granitic phase penetrating the conglomerate for 100 yards or more.

East of the southeast bay of Trout lake a small test pit sunk in dark green rock, probably a variety of the conglomerate or tuff, shows a little ore, and near the southwest bay in location WD 252 a certain amount of mining has been done on a larger deposit in conglomerate with dark green matrix. Here there are distinct veins containing zinc blende, galena, and a little copper pyrites with quartz as gangue, the latter occurring partly as well formed crystals projecting into the ore, which was evidently deposited later. A small shaft has been sunk but the amount of ore to be seen does not seem very encouraging. These deposits at the two ends of the lake are both in the Trout lake conglomerate a little south of the greatly altered contact phase described above.

The acid edge beyond Trout lake passes southwest across a corner of Lumsden township, with relationships like those described. Near Nelson river it is covered by drift for some distance, but on a small unnamed lake to the west it is a grey green rock more like a variety seen on the southern range, though not schistose. About midway across Morgan township the eruptive is narrowest with a breadth of a little less than a mile, and the acid phase seems to extend right across so that specimens from the two sides look much alike.

At the southeast point of Moose lake the acid edge is flesh coloured and granitic looking with small veins of green epidote, and similar roundish patches of green epidote with a little flesh coloured feldspar occur in the matrix of the conglomerate not far off. On the railway near Onaping river the edge is greenish grey and fine grained, with platy development of the feldspars, while not far to the northwest railway cuttings show coarse reddish syenite. Southwest of Windy lake the acid phase is flesh coloured and granitic or gneissoid looking while the conglomerate at the contact looks like a coarse variety of Laurentian gneiss in places and was so mapped in the earlier surveys of the region.

Beyond this the acid edge bends more to the south, crossing the ends of Ross lake and an unnamed lake in lot 7, con. III of Trill township, its character remaining much the same along the whole southwestward portion of the margin. The acid part of the eruptive is here much wider than the basic part, rises as hills of rather coarse grained syenitic looking rock, and at the edge against the conglomerate becomes finer grained and usually grey rather than flesh coloured; but it is seldom schistose, having evidently undergone much less squeezing and shearing than on the southern range. There seems to have been no great collapsing of the older rocks beneath the eruptive on the north range to correspond to the arrangement between Victoria mine and Copper Cliff on the south.

It is probable that a good deal of the overlying conglomerate has been stoped down and absorbed in some places, bringing the upper edge of the eruptive almost in contact with the base of the next formation, the Onaping tuff and at such points the colour of the acid edge is darker and greenish, as if it had digested some of the more basic material. Where the conglomerate band is wide the colour of the acid edge is generally paler and with a tinge of pink.

Economic Minerals of the Interior Basin.

Ores of zinc and lead with more or less pyrite and chalcopyrite have been mentioned at a few points on or close to the acid margin of the nickel eruptive and others have been reported by prospectors, but were not visited owing to their unimportance economically. There are similar deposits, usually with more pyrite in the rocks of the interior basin at a greater distance from the micropegmatite and yet probably to be brought in connexion with it. As the geological work undertaken in the region had especially the nickel ores and their associations in view, other deposits were visited only incidentally.

The one which has attracted most attention is the Creighton gold mine in lot 11 of the fourth and fifth concessions of Creighton township, where in 1892 to 1895 Mr. J. R. Gordon attempted to work a large quartz vein in the tuff. A company with a capital of $1,000,000 was formed, a shaft was sunk 200 feet and the quartz was explored by a good deal of drifting and diamond drilling. It is said that free gold was occasionally found in the quartz, but it was on the whole of much too low grade to pay for working, and after a short run of the small Crawford mill which had been erected, the mine closed down.[1]

A similar deposit was prospected on lot 2, con. IV of Fairbank township about two miles to the west, but in this case much less work was done[2] and small quartz veins like this have been found at several places, but have not attracted much attention and need not be mentioned in detail.

At Stobie Falls, on Vermilion river, in lot 10, con. VI of Creighton township, a considerable deposit of zinc blende with pyrite occurs in the Onwatin slate, and has been opened up on a small scale near the river bank.

It will be observed that all of these deposits lie along an extension of the zone of shearing and faulting on the west side of the block, which slipped down during the incoming of the nickel eruptive, as described on former pages.

Small deposits of pyrite and pyrrhotite (almost free from nickel) are found at other places in the slate, e.g. north of the Canadian Pacific railway a mile or two west of Larchwood and at the east end of Lake Onwatin, the latter having been taken up as a nickel property, though it contains only traces of the metal. Mr. R. R. Rose informs me that test pits have

[1]Bur. Mines, Ont.; Vol. II, p. 236, Vol. III, pp. 47 and 7; Vol. IV. p. 233 and Vol. V, p. 261.

[2]Ibid, Vol. III, p. 47.

been sunk on a deposit of galena, sphalerite, and pyrite with much quartz, on lot 9, con. V of Balfour township.

The most interesting deposits in the Onwatin slate are, however, the veins of anthraxolite which cross it at various points, giving rise to reported finds of coal, the best known of these being the one on lot 10, con. I of Balfour township, not far north of Stobie Falls and along the same belt of faulting. It has been reported on by the present writer and by Dr. W. H. Ellis,[1] and may be described briefly as originally a vein of bitumen, derived from the enclosing black slate, which contains from 6·8 to 10 per cent of carbon, as determined by Dr. Ellis. The material has, however, now lost almost the whole of its hydrocarbons and oxygen and has much the composition of anthracite. Samples anaslyed by Dr. Ellis show the following composition:

———	Average.	Selected.
Moisture	4·00	4·00
Volatile matter	1·30	1·80
Fixed carbon	74·20	90·10
Ash	20·50	4·10
	100·00	100·00

As the ash is quartz, which occupies the shrinkage spaces due to the loss of volatile matter, it is possible to obtain small shining cubical masses of the anthraxolite with still less ash. Such a specimen gave the following results on ultimate analysis:

Carbon	94·92
Hydrogen	0·52
Nitrogen	1·04
Sulphur	0·31
Ash	1·52
Oxygen	1·69
	100·00

Subtracting ash in both cases, Dr. Ellis compares the Balfour township anthraxolite with Pennsylvania anthracite, as follows:

———	Volatile matter.	Fixed Carbon.
Anthraxolite	1·98	97·02
Anthracite	7·83	92·17

showing that the loss of volatile constituents has gone farther in the anthraxolite than in the anthracite.

The finding of the Balfour anthraxolite naturally roused hopes of an important coal region a few miles north of the nickel mines, and so-called experts on Pennsylvania hard coal declared the rocks similar and prophesied

[1] Ibid, Vol. VI, pp. 159-166.

the development of valuable coal deposits. The original mine was soon abandoned, since the anthraxolite in it is mixed with 20 or 30, or even more, per cent of quartz and considerable pyrite, and all the anthraxolite in sight would not amount to more than a few thousand tons, at most.

Coal has been sought for at several other points in the same general region, and a company was formed to exploit a recent find on lot 4, con. II of Balfour township, which has been opened up within the last two years. The pure anthraxolite is a concentrated carbon, which would make a strong but slow burning fuel if it could be obtained free from the intermixed quartz and pyrite. It is decidedly improbable that it will be found free from these impurities, however, owing to its origin by the volatization of hydrocarbons, leaving contraction spaces to be filled later by circulating water.

It is likely that the Onwatin slate was highly charged with bituminous matter in the beginning, like the oil shales of Scotland and other places, and that the heat of the nickel eruptive when it spread out beneath, first drove part of the petroleum or pitch into fissures in the slate and then volatilised the hydrocarbons, leaving only the fixed carbon.

Quartz Mines.

The smelting processes employed on the Sudbury ore require quartz and sometimes limestone as a flux, under certain conditions, and also quartz for lining converters, so that fairly pure silica is necessary. This has been mined at various points by the companies which have smelted the ores to matte. The Mond Company first used quartz from a large vein a little south of a nickel ore deposit two miles west of Victoria mine, but of late they have provided their quartz from a bed of quartzite north of the present smelter. The quartzite beds stand nearly vertical with a strike of about 110°, and the supply of material, averaging 88 per cent of silica, is inexhaustible.

The Canadian Copper Company has operated several mines, the earliest one conveniently placed about a mile south of Copper Cliff on the top of a range of gabbro hills along the north shore of Kelley lake. It had the appearance of a gigantic segregation out of the gabbro, since the pure and glassy quartz was mixed at its edges with an intergrowth of white feldspar, forming "graphic granite." Around this came a coarse rock consisting of the white feldspar and green crystals of hornblende and finally the green-grey gabbro.

There are a number of large white masses of the same sort along the crest of the hill, but apparently none so large as the one worked, from which for a time a daily output of 100 tons was obtained. It is possible, and perhaps probable, that these quartz masses, with their rim of pegmatitic-looking acid rock, were originally great blocks of quartzite, "roof pendants" when the laccolithic gabbro pushed its way up, and in that case the feldspathic rock enclosing them is in reality a "reaction rim."

When this supply became exhausted, another quartz mine was opened in the Huronian on lot 8, con. IV of the township of Waters, about one and a half miles northeast of Naughton station on the "Soo" branch from which 150 tons of quartz per diem were produced in 1907.

In 1910 a new quartz deposit was opened up in the township of Dill, near the station of the Canadian Northern railway named Quartz, and about ten miles south of the Canadian Pacific. This deposit is in a region always mapped as Laurentian, though its immediate associations suggest the Grenville series rather than the ordinary gneisses of the Laurentian.

Somewhat to the west of the mine there is a hill of coarse, reddish gneiss, much crumpled and characteristically Laurentian, with a strike of 60° to 80° and a vertical dip; but after crossing a creek near the railway fine grained grey gneiss rises as a low ridge well stratified and looking like the Grenville gneisses, with a strike of 150° and a dip of 45° or 50° to the east. Apparently the two are separated by a fault in the drift-covered bed of the creek. With the grey sedimentary rock there are some beds of green hornblende schist cut by small dykes of granite, and in a cutting of the railway to the east there is a band of coarse and crystalline quartzite, followed by some coarse grey gneiss, with a strike of 20° and dip of 45° to the west.

Beyond the railway to the east is the open pit of the mine, with coarsely granular quartzite parted by some narrow sheets of mica schist, striking 150° and dipping 45° to the east. The structure seems to be anticlinal, but the relationships are too much disturbed to be easily interpreted. To the east of the wide band of quartzite of the mine a steep ridge of coarse pegmatite, of later age than the quartzite, since it has carried off blocks of it, runs north and south, and beyond it there is quartzite again dipping 45° to the east. Five hundred feet east of the hill there is a parallel band of grey gneiss.

The age of these bands of quartzite is not certain, but they are much more crystalline and metamorphosed than the Huronian or Temiscaming quartzites a few miles to the north. They are distinctly older than the pegmatite which cuts them, and their association with gneisses like the Grenville and the presence of some crystalline limestone not far to the north make it probable that the whole series of sedimentary rocks here is more ancient than the Huronian. The Dill quartz mine bids fair to last longer than the others and furnishes pure silica to the extent of 300 tons a day.

Limestone for fluxing purposes is brought in from a distance. The crystalline limestone occurring in Laurentain amphibolites about two miles north of the quartz mine, in a cutting on the Toronto branch of the Canadian Pacific railway, is not extensive, and an analysis shows only 76·87 per cent of $CaCO_3$, so that it is too impure to replace the flux now in use. This comparatively small outcrop is the only limestone in the Sudbury region, and if larger and purer deposits could be found they would meet with a considerable local demand.

Composition of the Sudbury Nickel Eruptive.

In a former section it was shown that the nickel-bearing eruptive consists of micropegmatite on its inner, or acid edge, passing gradually into norite on its outer, or basic edge, the more basic part having settled to the bottom of the basin, where in bays or offsets it becomes mixed with ore as pyrrhotite-norite and ends with solid masses of ore containing only a few crystals or fragments of the rock-forming silicates.

It is of interest to trace the transition, and for this purpose the following analyses, largely made by Prof. T. L. Walker,[1] but partly taken from a Bureau of Mines Report, [2] may be quoted.

[1]Quar. Journ. Geol. Soc. Lon., Vol. LIII, p. 56.
[2]The Sudbury Nickel Field, Vol. XIV, Part III, pp. 116 and 117.

———	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.	No. 11.
SiO_2	10·10	9·90	51·52	56·89	60·15	68·48	64·85	61·93	68·95	69·27	67·76
Al_2O_3	6·85	16·32	19·77	19·39	18·23	12·70	11·44	13·03	12·74	12·56	14·00
Fe_2O_3	(Fe) 44·68	....	·47	·38	1·51	2·41	2·94	·5	·46	2·89	....
FeO		13·54	6·77	7·11	6·04	4·50	6·02	8·00	5·15	4·51	5·18
MgO	1·40	6·22	6·49	2·11	3·22	·74	1·60	1·76	1·57	·91	1·00
CaO	1·19	6·58	8·16	8·11	4·01	1·41	3·49	4·02	1·72	1·44	4·28
Na_2O	....	1·82	2·66	3·31	1·28	3·72	3·92	3·18	3·80	3·12	5·22
K_2O	....	2·25	·70	1·04	1·68	3·36	3·02	2·80	3·28	3·05	1·19
H_2O	....	·76	1·68	1·35	·55	1·13	·78	1·95	1·50	·76	1·01
TiO_2	....	1·47	1·39	·43	1·34	·61	....	·84	·43	·78	·46
P_2O_5	....	·17	·10	·11	·23	·20	·24	·32	·20	·06	·19
MnO	....	trace	trace	·30	·29	·05	trace	·18	·13	trace	trace
BaO	....	....	....	....	·25	....	....	trace	trace	....	....
LiO	....	....	....	....	·14	....	....	....	....	....	....
NiO	(Ni) 5·62	....	....	....	·17	....	....	....	....	....	....
Cu	1·77	....	....	....	·16	....	....	....	....	....	....
S	27·48	....	....	....	·54	....	....	·19	....	....	....
Total	98·99	99·03	99·71	100·53	99·79	99·31	98·30	98·76	99·93	99·35	100·29
Specific gravity	....	3·026	2·832	2·834	....	2·673	2·788	2·757	2·694	2·724	2·709

In the above table of analyses No. 1 is of ore from the Creighton mine, on the authority of Mr. David H. Browne.[1] Nos. 2 and 3 are from the basic edge of the southern range near Blezard mine, analyst Dr. T. L. Walker. No. 4 is from near the basic edge of the northern range at Onaping, analyst Mr. E. G. R. Ardagh, Chem. Dept. University of Toronto. No. 5 is from the basic edge near the Creighton mine, analyst Mr. M. T. Culbert. No. 6 is a syenitic looking specimen taken from the middle of the Onaping section, analyst Dr. Walker. No. 7 is from the middle of the Blezard-Whitson lake section, analyst Dr. Walker. No. 8 is from the acid edge of the Onaping section, the rock being greenish grey, analyst Mr. Ardagh. No. 9 is from near the acid edge on the north shore of Fairbank lake, the rock being dark greenish grey and somewhat schistose, analyst Mr. Ardagh. No. 10 and No. 11 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. 10 and Dr. Walker of No. 11.

The analyses are so arranged as to give first the most basic material, the ore, next the norite (Nos. 2-5), then the micropegmatite at various stages to the acid edge. In the table No. 5 from the basic edge near Creighton mine, is not typical, since it appears to have absorbed some of the adjacent granite and contains some micropegmatite and microcline, while thin sections of other specimens close to the ore are almost free from this mineral.

In the cases of No. 6 and No. 8 also, there is an anomaly, since the so called acid edge (No. 8) contains less silica than the middle of the eruptive (No. 6); the relations being accounted for probably by the absorption of basic material from the overlying tuff in No. 8, giving rise to its greenish colour as compared with the red syenitic looking specimen from the middle of the eruptive.

Omitting analyses No. 5 and No. 8 we have Nos. 2, 3 and 4 representing the basic side of the eruptive and Nos. 6, 7, 9, 10 and 11 belonging to the acid side. It is of some interest to get the average composition of the norite and micropegmatite, which works out as follows:

——	Basic average.	Acid average.	Average composition
SiO_2	52·770	67·862	62·831
Al_2O_3	18·493	12·688	14·623
Fe_2O_3	0·283	1·740	1·254
FeO	9·140	5·072	6·428
MgO	4·940	1·164	2·423
CaO	7·617	2·468	4·184
Na_2O	2·597	3·956	3·503
K_2O	1·330	2·780	2·297
H_2O	1·263	1·050	1·121
TiO_2	1·097	0·456	0·670
P_2O_5	0·130	0·178	0·162
MnO	....	0·036	0·024
Total	99·760	99·450	99·520
Specific Gravity	2·897	2·718	....

Along the southern range the basic portion (norite) extends over about a half of the width, but on the eastern and northern ranges it makes up less than a quarter of the whole. On this account in computing the average

[1]Economic Geology, Vol. I, p. 471.

composition of the eruptive, the acid (micropegmatite) portion was considered to have twice the contents of the basic portion, with the results given in the third column.

It will be observed that silica and the alkalies are present in smaller amounts on the basic side of the eruptive than on the acid side, while iron, magnesium, and calcium have increased in amount. It would be easy to continue the series beyond the average Creighton ore into pure pyrrhotite, where the iron might make 60 per cent of the whole. Every gradation could be obtained from a rock with 69 per cent of silica and 4 per cent of iron, to ore, which may be looked upon as the most basic phase of the rock, with 60 per cent of iron and no silica.

Along with the concentration of the sulphide of iron in the hollows beneath the norite went the concentration of nickel, cobalt and copper sulphides, and also of the precious metals, gold, silver, platinum, and palladium, and in a general way the longer the distance traversed by the materials the more complete the separation, so that offset deposits are much richer in the precious metals than marginal deposits. The segregation has not alone separated micropegmatite from norite and norite from ore, but has tended to concentrate the heaviest materials of all in the offsets.

Though the ore is only the heaviest constituent of the magma, and so is in reality an ultra basic phase of the rock, its total amount, so far as known, is relatively insignificant. If it were once more mixed with the barren rock it would be almost imperceptible.

The total amount of ore mined in the region up to the present is roughly 5,500,000 tons, of which probably 4,000,000 were actually sulphides, containing perhaps 2,400,000 tons of iron and its associated metals, nickel itself amounting to only about 133,000 tons. The greater part of this ore has come from open pits 200 feet or so in depth. If evenly distributed along the 40 miles of the southern range it would mean 100,000 tons of sulphides per mile. This is of course far below the real amount, since only the better grades of ore are worked and the vast amount of sulphides in the pyrrhotite-norite have not been touched. More than half the total has come from the few hundred feet of margin at the Creighton mine, so that things are very unequally distributed.

Including the great Frood-Stobie offset there are certainly 30,000,000 of tons of workable ore still to be mined on the southern range above a depth of 1000 feet, and very probably much more. All told it is not unreasonable to assume that there are 100,000,000 tons of sulphides, workable and unworkable, along the whole range, which amounts to about 2,500,000 tons per mile.

The average width of the nickel eruptive in the southern range is a little over 3 miles and the average dip of the foot-wall 30° giving a thickness of the eruptive of 10,000 feet to provide the amount of ore estimated above. Assuming this thickness of magma, and a 1,000 feet of base, each mile of the sheet would contain about 52,800,000,000 cubic feet of rock, or 4,400,000,000 tons, and the 2,500,000 tons of ore per mile works out to 0·057 per cent. The probable amount of ore in the southern nickel range formed then a quite negligible part of the whole sheet of molten matter as far as percentage goes, though an extremely important part from the point of view of the miner. There is far more iron combined with silica in the pyroxenes of the rock or with oxygen in its magnetite than with sulphur in the ores, since the analyses show from 5 to 13½ per cent of iron, and the sulphides so far as known amount to only 0·057 per cent, of which less than 60 per cent is iron. This minute proportion of sulphides seems, however, to have concentrated in itself most of the valuable metals as if in a minimum of matte from an overwhelming amount of slag.

PROPORTIONS OF METALS IN THE SUDBURY ORES.

It has been shown that the known amount of sulphides in the original magma was very small so far as percentage is concerned though of great practical importance when concentrated in ore deposits. In these ore deposits themselves under the present conditions of smelting by which the iron is entirely sacrificed, the amounts of the valuable metals recovered represent only a small fraction of the whole, as appears from the table of statistics given above. The nickel reported averages 2·69 per cent and the copper 1·85 to which should be added the amount of loss in roasting and smelting, variously estimated at from 10 to 20 per cent of the metals contained in the ore. If 15 per cent of loss is assumed the proportions of metals in the ores will be 3·09 of nickel and 2·12 of copper, with a total of 5·21 per cent.

Iron is present then in much the largest amount in the sulphides and probably averages not far from 45 per cent in the ores as mined, followed by 3·09 per cent of nickel and 2·12 per cent of copper. Next comes cobalt, which is present in all the ores, though scarcely represented in the statistics, since it makes only a fraction of a per cent of the ore and is so readily slagged off as to appear only seldom in analyses of matte. The few analyses recording its presence show from 1·40 to 1·133 as much as cobalt as nickel.

The Precious Metals.

The precious metals occur in still smaller quantities, bessemer matte containing $2\frac{1}{2}$ to 7 ozs. of silver per ton, 0·17 to 0·5 ozs. of the platinum metals and 0·02 to 0·3 ozs. of gold per ton.

MATTE ANALYSES.

The results of the most complete analyses of bessemer or other high-grade mattes available are given in the following table:

——	I.	II.	III.	IV.	V.	VI.
	p.c.	p.c.	p.c.	p.c.	p.c.	p.c.
Nickel	48·82 (Nickel and Cobalt)	41·58	40·37	41·18 (Nickel and Cobalt)	39·96 (Nickel and Cobalt)	41·88
Cobalt		0·71	0·78			0·33
Copper	25·92	24·99	24·95	44·87	43·36	37·37
Iron	2·94	9·82	9·64	0·94	0·30	1·07
Sulphur	22·50	....	....	11·62	13·67	....
	oz.	oz.	oz.	oz.	oz.	oz.
Gold	0·02	0·15	0·10	0·30	0·1 to 0·2	0·66
Silver	3·14	....	2·50	5·10	7·0	4·87
Platinum	0·13	0·50	·0·44	....	0·25	·40
Iridium	0·02	....	....	....	....	....
Osmium	0·02	....	....	....	....	....
Rhodium	trace	....	....	....	....	....
Palladium	trace	....	....	....	....	....

I is by T. L. Walker, of Murray mine bessemer matte.[1]

II and III are by Donald Locke, of Ontario Smelting Works matte[2] mainly from Creighton ore.

IV is by J. W. Bain, of Copper Cliff matte in 1899, from Stobie, Copper Cliff and Evans mine ore.[3]

V is by Titus Ulke, in 1894, of Copper Cliff and Evans ore, probably with some ore from Stobie.[4]

VI is by Donald Locke, of Victoria Mines bessemer matte.[5]

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 the precious metals increase when there is more copper in the matte, and that offset deposits, which always contain more copper than marginal deposits, are also much richer in gold, silver and the platinum metals. The latter increase, however, in a much greater ratio than the copper, as if the lighter metals were more or less left behind in the wanderings through devious ways from the norite edge to the offset deposits.

Reckoning back the amount of the precious metals in a ton of matte, to the corresponding amount of sulphides required to furnish the matte, the following results are obtained:

——	Silver.	Gold.	Platinum metals.
	oz.	oz.	oz.
I. Murray	0·13	0·0009	0·007
II and III. Creighton mine, etc	0·21	0·0083	0·037
IV. Copper Cliff, Stobie, etc	0·28	0·0166	....
V. Copper Cliff, Evans, etc	0·583	0·0125	0·0146

Nos. II and III included some ore from the offset mines of the Canadian Copper Company, and do not represent the Creighton alone.[6]

It will be noted that in the analyses of matte given above only one shows palladium and then only a trace. It came therefore as a surprise to learn that for several years more palladium than platinum was recovered from the Canadian Copper Company's matte during the process of refining it at Constable Hook. In 1902 no less than 2,375 ozs. of platinum and 4,411 ozs. of palladium were recovered doubtless partly belonging to ore mined in previous years. If it all came from the ore mined in 1902 there were 0·0102 ozs. of platinum and 0·0189 ozs. of palladium or 0·0291 of the combined metals, per ton of ore. In 1903 the amounts were 0·0077 of platinum and 0·0144 of palladium, and in 1904 0·0052 ozs. of platinum and

[1]Am. Journ. Sc. Vol. 1, 4th Series, 1896, p. 112.
[2]Dr. Barlow, p. 206.
[3]Bur. Mines, 1900, p. 218.
[4]Min. Industry, Vol. III, p. 460.
[5]Dr. Barlow, p. 206.
[6]Bur. Mines, Vol. XIV, Part III, p. 153.

0·0093 ozs. of palladium; showing a rapid falling off, due probably to the fact that Creighton ore (marginal) had largely replaced the ores from the Copper Cliff offset.[1]

Since 1904 no platinum or palladium has been reported, though the recent working of the Vermilion mine, so very rich in sperrylite, must have provided a considerable amount of platinum at least.

It has been shown in a former chapter that the Vermilion ore may contain as much as 8·13 ozs. of precious metals per ton, consisting of gold a trace, of platinum 0·79 ozs., palladium 3·62 ozs., and silver 3·78 ozs. It is worthy of note that the Vermilion mine is the smallest offset deposit yet worked and that it is far from the norite edge and with no suggestion of a direct connexion with it.

Since the Victoria mine in early days contained so much sperrylite and gold that they could be panned from its gossan it is probable that the Clydach refinery in which its bessemer matte is treated must separate important amounts of gold and platinum and also of palladium, though there is no published account of the production of the metals.

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	1·98	0·97
Copper	16·40	23·00
Iron	10·87	(13)
Sulphur	19·58	(20)
	oz. per ton	oz. per ton
Gold	0·0145	0·029
Silver	2·46	4·06
Platinum	0·075	0·09
Iridium, Osmium } about	0·003	....

From the table of analyses of Sudbury mattes given on a previous page, it will be seen that the proportions are quite like those of 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

[1]Ibid, Part I, pp. 5-8.

to 5,000 of nickel.[1] 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.

Other Canadian Nickel Deposits.

The only nickel deposits worked in Canada belong to the Sudbury laccolithic sheet, but numerous occurrences of pyrrhotite containing more or less nickel are known from other parts of the Dominion, especially in Ontario. The townships adjoining the nickel ranges have naturally been carefully scanned by prospectors, and small low grade outcrops of ore have been found in a number of places, especially beyond the east and west ends of the known areas of norite. Near Nairn Centre, 8 or 10 miles southwest of Worthington, several small deposits occur, perhaps distantly connected with that offset; and a little stripping has been done upon some of them but without important results. Ore containing 1·95 per cent of nickel is reported from lots 1 and 2, con. III of Nairn township, and a little is known to occur in Lorne township, southwest of Worthington.

To the east of the nickel eruptive, northeast of Lake Wanapitei, several locations were taken up for nickel years ago, and 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 of these deposits have a possible connexion with the main nickel eruptive, since they occur within a few miles of it in rocks which have been a good deal disturbed and faulted.

A number of deposits of low grade nickel ore have been reported from more distant localities in Ontario and also from other provinces. Dr. Barlow gives a sufficiently complete account of them, as far as known up to 1904;[2] but since most of those mentioned by him have been proved to have no economic importance it will not be necessary to describe them here. The deposits at St. Stephen, N.B., are associated with a weathered basic eruptive, probably gabbro, and resemble those of the Sudbury region, but contain much less nickel, assays of two samples of ore showing the following contents:

—	I.	II.
Nickel	1·72	1·82
Cobalt	0·16	0·17
Copper	0·31	0·33

For further particulars Dr. Barlow's discussion of the subject may be consulted.

Since his report was issued the famous Cobalt silver region has risen to its climax, furnishing as a by product a considerable amount of nickel ore, and an interesting nickel deposit has been found in an area of serpentine in Dundonald township in northern Ontario. These two possible sources of

[1]Zeitschr. für prakt. Geol. Year 1902, pp. 258-60.
[2]G.S.C., Vol. XIV, 1904, Part H, pp. 147-166.

nickel may be briefly referred to, though up to the present, neither has proved of great importance.

NICKEL ORES OF THE COBALT SILVER REGION.

One of the earliest minerals found in the Cobalt region was nickelite (Ni As), and chloanthite ($NiAs_2$) also occurs, as well as millerite (NiS), and the gossan mineral annabergite ($Ni_3As_2O_8+8H_2O$) is frequent.[1] Nickelite was one of the earliest minerals deposited in the silver veins, and the total amount occurring in the mines is very considerable. For a full account of the geology and mineralogy of the region Dr. Miller's excellent report should be consulted. Mr. T. W. Gibson, Deputy Minister of Mines, estimates that in 1910 the 34,282 tons of ore and concentrates shipped from Cobalt contained on the average 1·47 per cent of nickel. The year's output of the metal is estimated at 604 tons and the total output at 2,601 tons.

Probably a portion of this was recovered in various metallurgical plants after the silver had been separated, but there is no record available as to the amount, since the nickel in the ore is not paid for. It may be mentioned that the three Canadian smelting companies at Copper Cliff, Deloro and Thorold, up to the end of 1910 had treated 28,013 tons of the ore. It may be added that cobalt, usually so much rarer a metal, was present to the extent of 6·76 per cent.

The Cobalt ores in their small narrow and very irregular veins form a very striking contrast with the huge masses of solid ore at Sudbury and in origin the two are equally different, the Cobalt ores being derived from circulating waters and the Sudbury ores from magmatic segregation. The nickel is found combined with arsenic in the Cobalt ores as compared with the sulphides almost free from arsenic in the Sudbury ores.

THE ALEXO MINE.

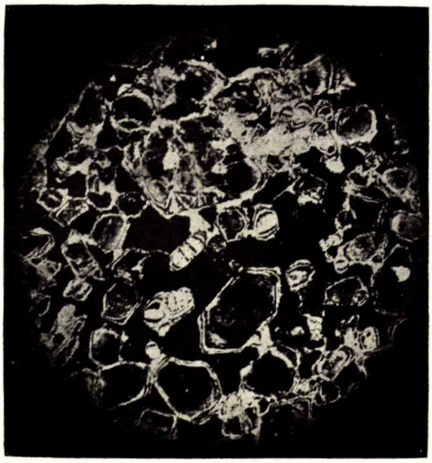
The most promising recent find of nickel ore in Canada, aside from the Sudbury deposits, is the Alexo mine in Dundonald township, near Matheson in northern Ontario, where pyrrhotite with chalcopyrite is associated with serpentine, originally peridodite, in exactly the same way as the sulphides are with norite in the Sudbury region. The serpentine with its margin of ore leans against a face of older rock, apparantly andesite, though it is too badly weathered to make entirely sure of its original composition[2]; and dips at angles of from 45° to 60° to the north, as shown by diamond drilling, just as marginal deposits do near Sudbury.

There is every gradation from nearly pure ore, through intimate mixtures of ore and serpentine, to pure serpentine; and sharply formed crystals of olivine, now transformed to serpentine and magnetite, are seen in thin sections completely surrounded by ore with no hint of secondary attacks upon the enclosed pseudomorphs. Beyond the narrow outcrop at the foot of the hill of andesite drift deposits cover the serpentine, and

[1]Bur. Mines, Ont., 1905, Part II.

[2]Mr. Uglow in Bur. Mines, Vol. XX, 1911, Part II, pp. 34-38, calls the serpentine the oldest rock in the district and speaks of the hill to the south as rhyolite; however, the serpentine seems to cut the other rock in a dyke like way and the freshest specimens of the rock from the hill consist of lath-shaped plagioclase feldspars and hornblende, with no quartz, so that the rock comes nearest in mineralogical composition to ande ite.

PLATE XXXI.



Olivine crystals (changed to serpentine and magnetite) enclosed in pyrrhotite: Alexo mine.

the area and general relationships of this rock are unknown, except that it appears to be later than the andesite.

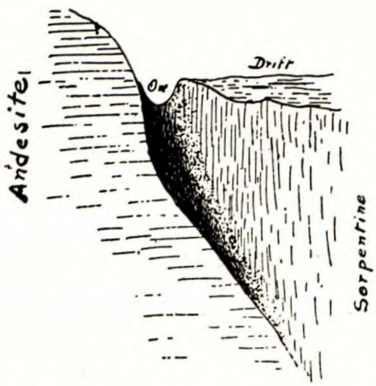


FIG. 6. Section of Alexo mine. Scale, 100 feet=1 inch.

The ore crops out for about 200 feet, with about 6 feet of solid ore at the widest place, followed by several feet of mixed ore and rock, and finally by serpentine with only a few specks of ore. Below the surface the solid ore thins out and at 100 feet depth there is only mixed ore and rock against the foot-wall.

The ore is high grade, a specimen taken by myself assaying 5·79 per cent, while specimens assayed by Mr. W. L. Uglow averaged 7·08 per cent. The latter gentleman studied polished surfaces of the ore, finding delicate stringers and veins of pentlandite in it, so that the association of minerals is precisely that found in the Sudbury ores.

The total amount of nickel ore disclosed by the diamond drill work of the Canadian Copper Company was not sufficient to justify the purchase of the property, and later drilling done by the Mond Company confirms this conclusion, so that the new nickel field will not rival that of Sudbury unless larger deposits are somewhere hidden by the widespread drift deposits.

The analogy between the Alexo mine and the Sudbury marginal deposits is so close that one naturally turns to the same theory in explaining its origin; seeking the probable source of the ore in magmatic segregation from the original olivine rock, now transformed to serpentine.

Mr. Uglow, from the study of polished surfaces of the ore concludes that it is of secondary aqueous origin, but some of the reasons assigned for that view really favour the magmatic theory; and his other points simply show that the ore has been rearranged by water action at a later time, as is so often the case in offset deposits at Sudbury. The ore occupies a bay in the andesite but is confined to the serpentine and diminishes downwards, showing that its source was from above and not from beneath, as the replacement theory seems to demand.

Fuller accounts of the Alexo deposit may be found in Economic Geology,[1] by the present writer, and by Mr. Uglow in the paper mentioned above.

[1]Econ. Geol. Vol. V, 1910, pp. 373-376.

Nickel Deposits in the United States.

The Gap mine in Lancaster county, Pennsylvania, was begun, like the Copper Cliff mine of Sudbury, as a copper mine; but met with little success, until in 1852 it was discovered that nickel was present in the ore. It was not, however, until 1862 that work on the mine began in earnest, when it had passed into the hands of David Wharton. It became the largest nickel producer of its day and remained active for many years until it was finally closed in 1891 because of the increasing competition of New Caledonia.

The associations are closely like those of Sudbury, the visible ores consisting of pyrrhotite and chalcopyrite connected with a lens-shaped mass of amphibolite, once, no doubt, gabbro; and the ore occurs only at the edges of the eruptive mass against the country rock of mica schist.

As compared with the more important Sudbury deposits it was quite insignificant but yet supplied the demand for nickel in the United States for a number of years. The ore body worked was nearly vertical and was followed to a depth of 250 feet, with a greatest width of 30 feet, and the ore contained 1·3 per cent of nickel, 0·25 to 0·75 per cent of copper and 0·05 to 0·15 per cent of cobalt.[1] Its total production is given as 2,000 tons, but its importance as introducing the use of nickel and as aiding to develop the methods of treatment of these difficult ores of nickel and copper, has been considerable.

Sulphide ores associated with basic rocks have been found at other places in the United States, as at the Key West mine in Nevada, where diabase intrusive into crystalline schists contains sulphides running 3·5 per cent of copper, 2·5 per cent of nickel, 1 to 3 ozs. of silver and 0·25 to 0·30 ozs. of platinum per ton. The ore occurs in lenses 10 to 50 feet thick and 50 to 600 feet long, and one deposit is estimated to contain 150,000 tons; but up to the present no nickel has been smelted from these deposits[2].

Somewhat similar deposits, though of lower grade ore, are reported from Floyd and Roanoke counties in Virginia, where the United Chemical and Nickel Corporation is developing pyrrhotite ores said to contain 1·75 per cent of nickel, less than 1 per cent of copper, and less than 0·4 per cent of cobalt.[3] It is doubtful if ores as poor as this can compete with those of Sudbury.

Most of the other nickel deposits of the United States are of a quite different kind, being formed by the weathering of slightly nickeliferous peridotite or serpentine, thus forming superficial residual sheets or pockets, like those of New Caledonia. Of these the Webster mine, Jackson county, North Carolina, is a good example, known for a number of years and described by Dr. Barlow[4].

The ore is genthite, much like the New Caledonia garnierite, a hydrous silicate of nickel and magnesia of a pale green or apple green colour, resulting from the weathering of dunite; but it is reported not to contain more than 2 per cent of nickel; so that its only possible utility will be in the direct production of nickel steel. In 1909 it was reported that it was being smelted in an electric furnace in lump form with about

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[1]Barlow, G.S.C., Vol. XIV, Part H, pp. 174-5, and Kemp, Ore Deposits of U.S. and Can., III Ed., pp. 432-4.

[2]Eng. Min. Journ., Vol. 86, July-Dec. 1908, p. 73.

[3]Ibid, Vol. 92, 1912, p. 884; also Trans. Am. Inst. Min. Eng., Vol. XXXVIII, 1908, pp. 683-697.

[4]G.S.C., Vol. XIV, Part H, p. 176; also Journ. Can. Min. Inst., Vol. IX p. 3 3. etc.

10 per cent of coke to produce a silicate of nickel and iron, which was afterwards to be reduced to nickel steel.[1]

Similar ore has been known for many years in southern Oregon, having been discovered in 1864, but as the deposits have not yet produced any large amount of ore, it may be concluded that they are not likely to compete seriously with New Caledonia or Sudbury.[2]

Practically all the nickel obtained from native ore in the United States since the closing of the Gap mine has come as a by product in the mining and smelting of lead ores in Missouri, first from Mine la Motte, which produced in 1899, 22,500 lbs., but gradually fell off to 5,748 lbs. in 1912[3]. In 1905 the North American Lead Company of Fredericktown, Mo., began to supply, as an accompaniment of its lead ore, 50 tons per day concentrated sulphides averaging 5 per cent of copper and 3 per cent each of nickel and cobalt. In 1906 it was reported that a special smelting and electrolytic refining plant had been erected; and in the following year a first shipment of 10,000 lbs. of nickel, 98 per cent pure, was made. In 1908 and 1909 its output was estimated at 500,000 lbs., for each year; but in 1910 it passed into the receiver's hands and was sold to the Dominon Nickel Copper Company of Ottawa, mentioned earlier in this report as developing mines on the northern and eastern nickel ranges at Sudbury[4].

The process of separating and refining the nickel-copper ore is that patented by Mr. Hybinette and successfully used on matte from Norwegian ores at Kristiansand; and it is expected that the mine will soon be producing lead, nickel, and copper again under the new management.

A small quantity of nickel is obtained also from complex western ores coming from Omaha, which sends blister copper to the American Smelting and Refining Co. of Perth Amboy, near Baltimore, for final treatment; but taken all together the total amount of nickel produced from ores of the United States is insignificant as compared with that prepared from Sudbury matte.

Nickeliferous Iron Ore in Cuba.

One other country in the Western Hemisphere may prove to be of importance in the production of nickel steel, since the vast iron ore deposits of the eastern end of Cuba are believed to carry enough of that metal to add to the value of the steel produced from its ores. As reported by Mr. Dwight E. Woodbridge[5], the deposits are of the nature of laterites, brown ores high in moisture and alumina and low in silica and phosphorus, with an average of 0·8 per cent of nickel, the extremes being 0·44 and 1·28 per cent. A typical analysis of these ores dried at 212° Fahr. is about as follows:

Silica	3·37
Iron	43·67
Alumina	13·07
Chromium	1·745
Nickel and cobalt	0·8025
Phosphorus	0·008
Sulphur	0·107
Combined water	11·59

[1]Mineral Industry, Vol. XVIII, 1909, pp. 544-5.
[2]G.S.C., Vol. XIV, Part H, p. 178.
[3]Ibid, p. 179.
[4]Min. Industry, 1905, p. 461; 1906, p. 589; 1907, p. 735; 1908, p. 663, 1909, p. 545; and 1910, p. 501.
[5]Can. Mining Journal, Vol. XXXII, 1911, pp. 738-741, also from Iron Ore Resources of the World, Vol. II, p. 795.

It will be seen that these deposits will not furnish nickel ore in the strict sense, but that the small amount of nickel present would represent 1·86 per cent if included in the 43 per cent of iron. The ores exist as a soil in comparatively thin, widespread sheets and from the presence of nickel and chromium it is naturally inferred that they arise from the decay of a basic eruptive rock, probably peridotite, since some serpentine is found with the deposits, and so may be compared with the New Caledonian ores.

Nickel Ores in Europe.

Nickel has long been obtained from European deposits, which were naturally the first sources of the metal to become known to the scientific world, though nickel alloys had been used by the Chinese long before. The first recognition of the metal was by Cronstedt in ores containing nickelite associated with cobalt minerals from Helsingland, Sweden; and a small amount of the metal has since been obtained in Sweden, though much less than in the neighbouring country, Norway.

The European deposits hitherto worked on any important scale are in Scandinavia and are associated with norite, thus resembling the Sudbury mines; and those of Norway may be taken as typical.

These deposits were examined and described by Prof. J. H. L. Vogt of Christiana long before the Sudbury mines had attracted much attention, and his working out of the magmatic theory of their origin was of great assistance in the study of the Sudbury region by Canadian geologists. A statement of his results may be found in various numbers of the Zeitschrift für Praktische Geologie[1], including brief accounts of most of the Norwegian mines, as well as references to other European localities where the same type of deposit is found and to Sudbury, New Caledonia, etc.

There are no less than 40 outcrops of nickel ore known in Norway, scattered over different parts of the country, mostly in Archaean schists but always accompanying areas of norite or of a gabbro too much weathered to make sure of its original constitution.

He describes the ore bodies in the best mines as not reaching a greater length than 200 metres, and as being usually not more than 120 to 150 metres long, with a greatest thickness of 15 metres and an average thickness of 3 metres (about 10 feet). The ore averages 1·5 to 2·5 per cent of nickel, though the pure sulphides often run considerably higher than this.

Vogt discusses interestingly the relations between the size of the ore bodies and the areas of norite with which they are connected, reaching the conclusion that large ore bodies are generally in large areas of the eruptive rock and vice versa, though there is no strict relation between the two. This may be compared with the results of mapping in the Sudbury region, where the largest deposits are at bays of the norite, where the width of the nickel-bearing eruptive is greatest.

The Flaad mine in Säetersdal, sometimes called the Evje mine, from the village three miles to the south where the smelter stands, is the only nickel mine working in Norway, or in Europe, and was visited in June, 1911, for the sake of comparison with the deposits of Ontario.

The mine is situated on a steep hill rising several hundred feet above the valley and was opened in the beginning as a copper mine, like Copper Cliff, and was only later discovered to contain nickel.

The ore is at the edge of a mass of norite six miles long now weathered so that no hypersthene remains in thin sections and greatly resembling

[1]Vol. I, 1893, pp. 125, 257, and Vol. II, pp. 41, 134, and 173.

Flaad mine, Saetersdal, Norway.

coarse weathered norite from the southern nickel range at Sudbury. The country rock is hornblendic gneiss or amphibolite penetrated by coarse and fine grained granites. The norite close to the ore body is thickly shotted with spots of ore, a true pyrrhotite-norite, merging into ore on the one side and norite free from ore on the other. The sulphide minerals collected are pyrrhotite and chalcopyrite, the latter tending, as at Sudbury, to follow the crushed edges of the country rock. Some magnetite was observed in the wall of the shaft, an unusual mineral in the Sudbury mines, but every feature of the deposit and its surroundings could be matched at some point in our nickel region.

Dykes of aplite from a few inches to a foot wide penetrate the country rock and also the ore, and a dyke of pegmatite 30 feet wide cuts the norite but some ore penetrates the aplite in thin seams, as happens in the diabase dykes cutting the ore at Creighton mine.

The ore deposit, which has been followed down on an incline of 45° to a depth of 530 feet, began on the surface with a length of only 67 feet, but in depth it has increased to 330 feet. The ore often encloses rock matter as small or large masses, sometimes angular and sometimes rounded.

Selected ore, at the time of my visit, ran 4·6 per cent nickel and 1·5 per cent copper, but the average was stated to be 2·3 per cent nickel and 1·2 per cent copper, much above the results reported from year to year in the Mineral Industry; e.g. in 1909, when 6,600 tons of ore were mined, resulting in 168 tons of matte and 70 tons of nickel. 115 tons of ore were mined per day and were sent down by cable tramway to the smelter at Evje, 4·8 kilometers to the south, the ten horse power needed for this work being generated from a fall in Otra river at the smelter.

The ore dump at the smelter was very rocky and looked no richer in sulphides than some rock dumps near Sudbury; but costs of mining and smelting are so low in Norway that the ore appears to be worked at a profit.

I am indebted to Mr. B. Thorkildsen, M.E., of Evje, for guidance about the mine and for much valuable information.

The Flaad mine is small when judged by Canadian standards, having produced altogether only 35,000 tons of ore up to 1893, as reported by Vogt, while its largest annual output as reported in the Engineering and Mining Journal has been 6,600 tons, in 1909, as mentioned above[1].

The nickel deposits of Sweden and Finland appear to be all of the same type as those referred to in Norway, and as they have been less productive and none of the mines are now working, it will not be necessary to mention them specially.

A number of other European deposits connected with basic eruptive rocks and probably formed by segregation like those of Sudbury have been described, such as the deposit of Varallo in Piedmont, and others near Horbach and Totmoos in the Grand Duchy of Baden, where pyrrhotite containing 12 per cent of nickel is reported, but as they are not now of economic importance it will not be necessary to mention them further; nor are the Russian or Spanish deposits now producing ore in any quantity,[2] though the one near Bilbao in Spain is reported to carry ore containing 6 per cent of nickel, 7 per cent of copper and 3 of cobalt.

One of the most interesting nickel deposits in Europe, on the Grecian island of Locris, east of Athens, is at present attracting attention and may prove to be of value in the future. This was not visited by the writer owing to lack of time; and there appears to be no description of it in print.

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[1]E.M.J., Vol. 89, p. 1271.
C., Vol. XIV, Part H, pp. 171-3.

Through the kindness of Dr. Mohr, of London and Mr. V. Hybinette of Kristiansand, Norway, brief accounts of the mine were given me, as well as specimens of the ore. The mine was opened for hematite and has been worked as an iron mine; but below the iron ore a somewhat rich ore of nickel is found, dull brownish and earthy in appearance, but with some bands or spots of apple green material suggesting genthite or garnierite.

A complete analysis made for the Kristiansand nickel refinery shows the following composition:

SiO_2	37·00	
Al_2O_3	9·81	
Fe_2O_3	28·37	(Fe=19·86 per cent)
MnO	2·85	(Mn=1·92 per cent.)
CaO	0·39	
MgO	1·91	
S	0·06	
As	0·15	
CuO	0·07	(Cu=0·06 per cent.)
NiO	9·17	(Ni=7·22 per cent.)
Co	Traces	
P_2O_5	0·09	
Loss on heating	8·50	
Cr_2O_3	1·37	
	99·74	

From its appearance the ore suggests the weathering of a basic eruptive rock, such as peridotite or serpentine, with the accumulation of the nickel toward the bottom of the products of weathering, and so may be compared with the New Caledonian deposits, though with much less of the green nickel magnesia silicate, garnierite.

This ore deposit has been examined by the Mond Company and the Norwegian Company, and the latter have made use of a shipload of the ore, some of which is still to be seen at the Evje smelter. A portion of the nickel produced at the Kristiansand refinery is therefore not from Norwegian, but from Grecian ore.

So far as known at present none of the European nickel deposits are of sufficient magnitude or of sufficiently high grade to be serious rivals of the Canadian and New Caledonian mines; and much the largest part of the nickel refined in Europe comes from these two regions.

Nickel Ores of New Caledonia.

Next to the Sudbury region the French penal colony of New Caledonia, 900 miles east of Australia, in lat. 22°, is far the most important source of nickel in the world. 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 in French and English, the most complete being the description of the mines and their conditions by M. E. Glasser who reported on them for the French government[1]; though good accounts of the nickel region are given by Dr. Barlow[2], Mr. G. M. Colvocoresses[3] and others. The following account is mainly drawn from Mr. Glasser's report, as translated for the Bureau of Mines of Ontario, by the present writer[4].

The island consists of ancient schists and Mesozoic sediments, penetrated by numerous eruptives, of which the most important is a very

[1]Annales des Mines, 15 Series, Tome IV, 1903, pp. 299-392 and 397-536.
[2]G.S.C., Vol. XIV, Part H, pp. 180-6.
[3]Eng. Min. Journ., Vol. 84, 1907, pp. 582-5.
[4]Vol. XIV, Part III, 1905, pp. 147-150.

basic rock, peridotite, consisting of olivine and enstatite, now more or less transformed into serpentine. Deposits of nickel, cobalt and chromium are asssociated 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 content 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 colour 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 coloured with iron oxide, and forms the larger part of the ore mined. There are also siliceous masses of a green colour, containing, however, only 9 to 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.
	p.c.	p.c.	p.c.	p.c.	p.c.	p.c.	p.c.
SiO_2	42·61	35·45	44·40	37·78	38·35	37·49	47·90
NiO	21·91	45·15	38·61	33·91	32·52	29·72	24·00
MgO	18·27	2·47	3·45	10·66	10·61	14·97	12·51
Al_2O_3 Fe_2O_3	0·89	0·50	1·68	1·57	0·55	0·11	3·00
FeO	....	....	0·43	....	....	....	....
CaO	....	....	1·07	....	....	....	trace
H_2O	15·40	15·55	10·34	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 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 half a 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 labour 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.

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 103,908 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 neighbourhood 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 favourable than those of our colony." He goes on to show that the Sudbury ores are sulphides 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. 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.

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 favourable 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."

The New Caledonia ore has one apparent advantage for purposes of treatment 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 is smelted with coke, which always contains 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 by methods 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.

Since 1903, when the above account was written, conditions have somewhat changed in regard to the New Caledonian mines, and ores of slightly lower grade, containing 6·5 per cent of nickel, are now being shipped to Europe. One serious handicap for the New Caledonian ores is the length of the voyage, half round the world, before they can be marketed and hence the heavy freight rates which have to be met.

To diminish this expense it was natural to attempt the first smelting to matte on the island, but early efforts in this direction were unsuccessful. In 1909, however, a new electrolytic process was introduced and in 1910 a furnace of this kind was at work, so that 769 tons of matte figure in the export statistics, while two other furnaces were nearly ready for operation. The output of ore has for some time been standing still at 80,000 to 120,000 tons, and it is suggested that a heavy tax be placed on unworked nickel lands in the island, so as to force the owners, especially the greatest owner, the "Société le Nickel," to work more actively the mines leased from the government. How much result will flow from these measures remains to be seen.

The International Nickel Company is stated to own nickel mines in New Caledonia, but at present works only its Sudbury mines, which furnish nearly the whole nickel supply of America; while the New Caledoniaoresare employed in France, Germany, and Scotland in the numerous small smelters and refineries operated by branches of the Société le Nickel. The Mond Company uses Canadian matte, and the Scandinavian Company uses mainly Norwegian ore.

It is interesting to note that the New Caledonian ores practically never contain sulphur, the only instance of a nickel sulphide reported by M. Glasser being a little millerite found in the Esperance chromium mine; so that these southern ores, due to the weathering and surface concentration of basic olivine rock, form an extreme contrast with the sulphide ores segregated from norite, a much less basic rock, in the Sudbury region. The two types of ore deposit are about as opposite in character as could be imagined, the latter being formed directly from the molten mass, largely separated by gravity; while the former results from two very slow processes, the transformation of olivine into serpentine by hydration and the weathering of serpentine into clay, with the accumulation of the minute quantity of nickel in the original rock as a secondary deposit of the hydrous silicate of nickel and magnesia called garnierite.

Nickel ore has been reported from one or two points in Australia also, the most interesting locality being at Trial Harbour, north of Macquarie harbour in Tasmania, where sulphide ore was found in a mine opened for asbestos, evidently in serpentine, so that the deposit is more like that of Alexo mine in Ontario than the New Caledonian mines. It is reported in 1904 that 136 tons of this ore, valued at £554, were exported from this mine, but as no further references can be found to the deposit, it has probably not proved to be of importance.[1]

Nickel Ores of Cape Colony.

Nickel ores were found at Insizwa, Cape Colony, many years ago, but have only recently attracted much attention. As described by Mr. Du Toit of the Cape Survey, they resemble rather closely the Sudbury deposits, consisting mainly of pyrrhotite with chalcopyrite and pentlandite, though a few other nickel and copper minerals occur also, as well as the metal platinum. The ores accompany gabbro or norite which forms a basin-like sheet as at Sudbury. The sheet is 2,000 or 3,000 feet thick.

Two trial shipments of the ore, of some five tons each, sent to Messrs. Johnson, Mathey and Co. in England for examination, are reported to run as follows:[2]

——	1.	2.
Copper	3·40 per cent.	3·50 per cent.
Nickel and cobalt	4·90 per cent.	5·25 per cent.
Gold (per ton)	6 grains.	6 grains.
Platinum	2 dwt. 12 grs.	12 grains.
Silver	10 dwts.	12 dwts.

If the ore sent represents the average of the deposits, they seem to be of high grade, and if the ore is present in large amounts the region may be of importance.

[1]Eng. Min. Journ. Vol. 78, 1904, pp. 95 and 382.

[2]Dept. of Mines, 15th An. Rep. Geol. Com., Cape of Good Hope 1910, pp. 111-142.

STATISTICS OF NICKEL PRODUCTION, SUDBURY DISTRICT.

Year.	Ore.		Nickel.			Copper.			Cobalt.		
	Tons raised.	Tons smelted.	Tons Ni.	Ni. %	Value $	Tons Cu.	Cu. %	Value $	Tons Co.	Co. %	Value. $
Before 1890	100,000	...	...	...	...	...	...	...	...	...	...
1890	130,278	59,329	...	...	...	...	...	...	...	...	...
1891	85,790	71,480	...	...	...	...	...	...	...	...	...
1892	72,34	61,924	2,082	3·36	590,902	1,936	3·19	234,135	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	3¼	·0037	1,500
1895	75,439	86,546	2,315¼	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	...	...	...
1897	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
1905	284,090	257,745	9,503	3·69	3,354,934	4,524	1·76	688,993	...	...	...
1906	343,814	340,159	10,776	3·17	3,839,419	5,260	1·55	806,413	...	...	...
1907	351,916	359,076	10,602	2·95	2,270,442	7,003	1·95	1,020,913	...	...	...
1908	409,551	360,180	9,563	2·65	1,866,059	7,501	2·08	1,062,680	...	...	...
1909	451,892	462,336	13,141	2·84	2,790,798	7,873	1·61	1,122,219	...	...	...
1910	652,392	628,947	18,636	2·96	4,005,961	9,630	1·53	1,374,103	...	...	...
	4,832,387	4,311,744	116,108½	...	30,787,682	79,584¼	...	9,951,498	...	...	...

The above statistics are taken from various reports of the Bureau of Mines of Ontario. In regard to the amount of nickel produced in 1910, a table summing up the production since 1906 reads as given; but the general statistics for 1910 show 19,140 tons of the metal, since 504 tons estimated as contained in Cobalt ores shipped to various smelters are included. Probably not much of this extra amount was actually refined, however.

Of the amount of ore mined in 1910, 391,575 tons came from the Creighton mine, 89,219 from the Crean Hill mine, 26,381 from No. 2 and 1,229 from the Vermilion mine belonging to the Canadian Copper Company; while the Mond Company produced 93,542 tons from the Garson mine, 42,488 tons from Victoria No. 1, and 7,958 tons from Victoria No. 4.[1]

It is probable that 15 per cent of the two metals is lost in roasting, smelting and refining the ores, so that the original contents of the ores were 15 per cent larger than the amounts given in the table.

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	6,292	324,800	812	537
1883	6,881	6,768	248,000	620	615
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		317,203	2,388	
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	
1903	77,360				
1904	98,653				
1905	125,289				
1906	130,688				
1907	101,708				
1908	120,028				
1909	82,937				
1910	115,342				

[1]Bur. Mines, Ont., Vol. XX, Part 1, 1911, p. 26.

In the table given above the statistics up to 1902 are taken from M. Glasser's report on New Caledonia[1] and the later ones from the Mineral Industry.[2] The value of the ore and its contents in nickel are not given in the later years, but the average contents of the ore is stated to be 6½ per cent. In comparing these statistics with those of the Sudbury district an uncertain amount of loss in smelting should be allowed.

The output of nickel from Norway and other countries has of late years been nil or very small as compared with the two great producers of which statistics are given above.

If the contents in nickel of the new Caledonia ores be put at 6½ per cent, its output of the metal in 1910 was 7,497 tons, from which possibly 15 per cent should be deducted for loss in smelting; so that Sudbury produced 2½ times as much of the metal as its nearest rival.

Methods of Prospecting and Exploration.

The scour of glaciers during the Ice Age must have swept most of the nickel deposits bare of gossan, leaving clean surfaces of unchanged sulphides; but after the retreat of the Labrador ice sheet some thousands of years ago weathering processes became active again. Pyrrhotite is one of the most easily attacked sulphides, and where unprotected, fresh surfaces quickly become rusty and within a few years the surface is changed to limonite and little or none of the original ore is to be seen. Glacially scoured surfaces may, however, be hermetically sealed by a sheet of boulder clay left by the ice; and when this is stripped, as was the case some years ago at Creighton, the clean surface of pyrrhotite and chalcopyrite with distinct striae is found unchanged.

Probably in almost all cases there are parts of the ore body exposed to weathering and gossan formation, and in the beginning prospectors naturally looked for such gossan-covered surfaces. It was soon found that only gossan connected with a particular rock, "diorite" as it was then called, indicated good ore. In only a few years after 1883, when the Murray mine was discovered, every deposit known to be important had been found, so alert had the prospectors become to the indications of ore.

In many cases the deposits rose as rusty hills or covered steep hillsides, so that they thrust themselves on the attention and could hardly be missed in walking through the woods. Copper Cliff, Murray mine, Creighton, the Frood, and other deposits, which have since become famous, chalenged the eye with their rusty brown surfaces rising from the green of swamps, and it required no great skill to locate them once the general trend of the nickel ranges had been discovered so as to keep the work within reasonable bounds. But a number of other outcrops occur in low ground largely covered with drift or swamps, and here more patience was required.

It may be that important deposits remain undiscovered beneath such drift areas or muskegs where no gossany point rises above the concealing mantel. Up to the present, however, there have been scarcely any finds of this sort made in the region.

It was soon noticed by the prospectors that the compass is useless near nickel deposits, since pyrrhotite (magnetic pyrites) causes local attraction; and it was naturally thought that magnetic disturbances might help out

[1]An. des Mines, 10 Series, Tome IV, p. 512.
[2]Vol. XIX, 1910, p. 505.

in the discovery of these ores. In a number of instances the dip needle was used over swampy ground and in the case of Mr. Edison's parties a wide range of country was swept by such a magnetic survey, with little or no reference to the geological relationships, and with no results of value, since after months of work not a single ore deposit was located. The method was thereby unduly discredited.

A serious difficulty in the use of magnetic survey methods is found in the variable amount of magnetism in pyrrhotite, which in some localities is feeble and in others strong, though never so strong as that of magnetite. Since its attractive force is usually not great the presence of a rock containing a small amount of magnetite may affect the dip needle as strongly as a considerable body of ore, and stripping has sometimes proved this to be the case.

More careful methods, using the Thompson-Thalen magnetometer were later introduced by Mr. Nystrom, a Swedish engineer who had received his training in the old world, and have later been applied by other engineers in the region. For a complete and scientific account of the method and its underlying principles reference may be made to the "Location and Examination of Magnetic Ore Deposits by Magnetometric Measurements" by Dr. Eugene Haanel.

Although magnetometric methods have distinct limitations they have proved of great service, not so much in discovering nickel deposits as in defining the boundaries and giving an idea of the amount of ore in known deposits. At least two of the companies interested in the region systematically carry out such a survey before going on to more expensive methods; and the regularly arranged pegs used for the purpose may be found blocking out the surface at most of the still unworked deposits.

USE OF THE DIAMOND DRILL.

The magnetometric survey is looked on as an inexpensive preliminary method of examining a property, but before purchasing usually a more thorough examination is made with the diamond drill; and diamond drilling is used also to determine the reserves of ore in working mines and to fix the most suitable position and inclination of shafts for exploiting the deposit. In fact the extended use of the diamond drill is one of the most striking features of modern methods in the nickel region. Formerly when a drill was used the positions and directions of the holes were decided on rather at haphazard, but of late the work has been carefully systematized by the more important companies, the holes being planned so as to come at regular distances apart and along definite planes, giving more or less complete cross sections of the ore body, from which the amount of ore may be worked out with a good deal of certainty. The drilling is now usually carried out with careful reference to the geology, especially in marginal and parallel offset deposits, and thus more valuable results are obtained with fewer barren holes. In earlier days holes were frequently put down in country rock where no ore could be looked for, but the relations of norite to ore and country rock are now better understood, and the drill holes put down give far more effective information.

The Canadian Copper Company, for example, have developed a complete system, not only for the placing of holes, but also for the examination of the cores and the classification of the materials, with carefully planned forms for entering the results so as to be available for immediate reference. Cross sections of ore and country rock are easily prepared from these records and give reliable results as to the amount and grade of the ore present, so that mining can be carried on with almost complete certainty.

All the companies examining or operating mines in the region within the last few years have made great use of the diamond drill, and the two most important companies have sunk many thousands of feet of drill holes to determine the value of properties or to decide on the most efficient method of developing them.

Methods of Mining.

Every variety of development is illustrated among the mines of the Sudbury district from prospects on which a little stripping has been done, to great and carefully planned mines, like the Creighton, raising and shipping more than 1,000 tons of ore a day; and the methods employed vary accordingly.

Many of the deposits have never got beyond the prospect stage in which the superficial limits of the ore have been disclosed by trenching or costean pits, and the presence of a certain amount of ore proved by test pits of greater or less depth. This point has been reached by dozens of properties, not only on the southern, but on the eastern and northern ranges, from which no ore has been shipped, though in a few cases hundreds or sometimes thousands of tons lie in the ore piles exposed to the weather and rapidly changing to worthless gossan. In many cases also shafts have been sunk from a few feet to 200 feet to show the extent of the ore body or in preparation for mining operations which never materialized. Sometimes hundreds of feet of drifting have been done at one or more levels with the same object in view.

The number of mines which have actually produced ore on the commerical scale is, however, not large, scarcely exceeding 20; and only 9 appear to have supplied as much as 100,000 tons and so to have reached the rank of important mines. On the other hand one mine has provided more than 2,000,000 tons of ore.

Usually the mines have passed through two more or less distinct stages requiring different mining methods, beginning as open pits and ending with underground mining, with an intermediate stage of mixed methods connecting them.

During the prospecting stage man-power or horse-power is employed, often succeeded later by temporary steam hoisting plants and drills the fuel frequently being wood from the adjoining forest. When the mine begins to supply ore a more elaborate steam plant is usually installed for hoisting and air drills, the fuel being coal, which is very expensive at Sudbury. Finally, in all the present important mines, the costly steam plant is replaced by electricity supplied from water powers, which may be as much as 25 miles away, and the steam plant is held in reserve in case of accident to the turbines or transmission plant.

In the earliest stage of opening up a mine the work is practically quarrying, but presently it becomes necessary to sink a shaft in the country rock close by at a suitable angle to keep within easy distance of the ore body. The ore quarried in the open pit is loaded by hand in cars which run on narrow gauge moveable tracks radiating from the short tunnel leading to the shaft, where the ore is dumped into skips and hoisted to the rockhouse which stands just behind the shaft.

In the case of the Creighton mine No. 1 shaft with two hoisting compartments and a ladder way, was sunk on an incline of 59° in granitoid gneiss just southeast of the open pit, to the first level at a depth of 60 feet. Later the shaft was extended to the second level at 140 feet and a drift was run into the ore, which was then stoped out to the first level, making a great open pit of that depth with a length of 500 feet by a breadth of 300. Meantime No. 2 shaft was being sunk 330 feet to the southwest since the ore was dipping in that direction. Stoping was carried on at the third level from both shafts and the eastern part of the ore body was stoped out to the floor of the second level, deepening the open pit to 190 feet; the same method being continued at the fourth level. Below this depth the workings are underground. A brief general description of the mine may be taken from an account by Mr. G. E. Sylvester.[1]

There are two shafts in parallel planes about 330 feet apart.

No. 1 shaft, inclined 59°, has two hoisting compartments and ladderway. It is still served by the original timber framed rockhouse with the interior somewhat modified.

No. 2 shaft, inclined 47° has, besides the ladderway, three hoisting compartments, one of which is intended more particularly for development work and hoisting barren rock, leaving the other two for the ordinary work of hoisting ore, without interference.

The rockhouse, 45 feet by 90 feet, is of reinforced concrete up to and including the bin bottoms. The bins, which are in three rows, served by three tracks running underneath, are 12 feet by 15 feet by 14 feet deep, built up of 3 inch by 10 inch plank laid flat and lined with 2 inch plank. The structure above the bins is of heavy timber framing with double wooden sheeting.

The ore is dumped on grizzlies at a height of about 70 feet above surface level. From the foot of the grizzlies, it is carried by massive curved chutes directly into two 18 by 30 inch jaw crushers, which are large enough to take anything that can be handled into tramcars underground. These chutes are removable in case ore should be encountered which would require sorting on the crusher floor. The wearing plates of the crushers are manganese steel. Each crusher discharges into a trommel screen, 36 inches by 10 feet, fitted with manganese steel plates with one-inch perforations throughout, as only two sizes of ore, fines and coarse, are separated.

The coarse ore from each screen falls upon a 36 inch rubber picking belt, 50 feet long between centres, in two sections. There is also a screen and picking belt under the grizzlies. From these belts the ore and rock are distributed to their respective bins. The crushers, screens and belts are operated by two 50 horse-power constant speed induction motors. The rockhouse has a capacity of about 1,200 tons in 24 hours. The picking floor is steam heated. A few steam coils in the fines bins, covered with a false lining of steel plate, effectually prevent the freezing and hanging up of damp fines.

The tracks under both rockhouses are on a grade, so that empty cars can be placed on the upper side, then dropped through by gravity, and loaded without any further attention from a locomotive.

In the mine the drilling is practically all done with $3\frac{1}{8}$ and $3\frac{1}{4}$ inch standard type rock drills, and the blockholing by small hand air drills of the hammer type. The pressure at the drills runs about 95 pounds.

The tram cars are 18 inches gauge and 18 inches wheel base. The front and back journal boxes on each side are rigidly connected in a single steel casting, bolted under the side frame, ensuring a permanently true

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[1]Journ. Can. Min. Inst., Vol. XII, 1909, pp. 220, etc.

Air-operated chute gates.

alignment of the axles. The wheels are 14 inches diameter, of manganese steel, one fast and one loose on each axle. The cars weigh 2,000 pounds and hold about three tons.

The skips are 46 inches gauge, and hold a full tram carload. The wheels are of manganese steel 14 inches diameter, with broad treads on the rear wheels for dumping. The track stringers are 8 by 10 inches, shod with 3 by $\frac{5}{8}$ inch steel straps. Guard timbers are 6 by 8 with $2\frac{1}{2}$ by $\frac{3}{8}$ inch straps.

The shafts and stations are lighted with incandescent lamps and equipped with electric hoisting signals, but in the stopes large acetylene torches are used, with individual lamps for drifts and confined spaces.

The mine pumps are of the vertical single acting, three cylinder, crank type, geared to 15 horse-power motors.

The engine house is 93 feet by 39 feet, with brick walls on concrete base. Steel columns built into the walls support a crane runway and steel roof trusses. The roof covering is 3 by 3 dressed lumber with tarred felt.

A high tension switch tower of brick, 10 feet by 11 feet, adjoins the building in one corner, and a transformer room 8 feet by 20 feet is walled off inside. A 10 ton hand-power travelling crane runs the full length of the engine room. The floor is of reinforced concrete surfaced with cement tiles.

The equipment is as follows:—

Two electric driven mine hoists, a two drum for No. 1 shaft, and a three drum for No. 2 shaft. The drums are 60 inches in diameter, and have a capacity of 1,000 feet of one inch cable in one lap. The drums are arranged to hoist singly or with any pair in balance. Each hoist is geared to a 150 horse-power variable speed induction motor, the hoisting speed being 600 to 800 feet per minute.

A 1,650 foot cross-compound compressor, direct connected to a 300 horse-power induction motor at 120 r.p.m. delivers air at 100 pounds pressure. An after-cooler is provided as well as an extra large intercooler. In addition to this, the condensed moisture is trapped in a special leg in the air line in the shaft.

A 1,000 gallon, 6 inch, 4 stage turbine fire pump, direct connected to a 150 horse-power induction motor, furnishes fire protection for all the mine buildings; and a 250 gallon, 3 inch, single stage turbine, with 5 horse-power motor, circulates cooling water to the transformers and compressor.

The office and warehouse are in one building, 30 feet by 60 feet in dimensions. The walls are of brick, on concrete base, with steel roof trusses and roof covering of hollow book tile with tar and gravel. The floor is of reinforced concrete. In the basement is situated the steam heating plant for all the buildings.

The dry, or men's change house, is 36 feet by 80 feet in size, of similar construction to the warehouse building. It is equipped with basins, shower baths, hot and cold water, closets and urinals. There is a 12 by 16 open steel sanitary locker for each man and a private room is provided for foremen. The building is thoroughly heated and lighted and has a caretaker always in attendance.

The water for the various buildings and for fire protection is pumped from a small lake about 3,000 feet distant, into a steel tank holding 60,000 gallons, situated just outside the engine room. The pump is a 250 gallon 4 inch, 2 stage turbine with 20 horse-power motor, in a small concrete building.

The tank is connected directly with the suction of the fire pump, and furnishes a gravity supply for the buildings generally.

CREAN HILL MINE—METHOD OF MINING.

The mine, in the first stages, was developed with a view to removing only the high grade copper ore along the foot-wall, which is fairly regular and well defined, the presumption being that the various patches of low copper and higher nickel ore cut by the diamond drill holes in the hanging wall side of the deposit could, probably, not be worked profitably. Subsequent development work, however, showed the ore to be fairly continuous and that the enclosed rock occurred in masses, sometimes very large, and usually not intimately mixed with the ore. The question then arose—how to win this nickel ore at an economically possible cost. It was evident that a very large percentage of the ground broken would consist of rock, which would necessarily require to be disposed of in the stopes, quickly and cheaply.

Following is a brief description of the method now employed:—

At each level the ground is blocked out by exploratory drifts, which are carried to the boundary of the mineralized section. Wherever an enrichment occurs, these drifts are widened and raised to a height of about 16 feet, and then carried as breast stopes.

In breast stoping the richer portions only are removed, in order to avoid handling rock, but on the back stopes, where the rock can readily be disposed of, pretty much all rock containing mineral is broken and handled, except the very large masses, which are left as pillars, care being taken to lay out the pillars where rock occurs.

Until sufficient space has been provided in the breast stopes, all rock as well as ore must be hoisted, but, as soon as practicable without hampering work at the breast stopes, the rock is piled up along the walls of the stope.

Masons are then employed to build the dry stone walls, which take the place of drift sets to maintain the tramways. The walls are built about 4 feet thick and 7 feet high, reinforced at intervals with round timber. These walls are stronger and less expensive than drift sets. In the walls are built ore chutes and manways. The latter commence at the floor, of rectangular form, and large enough to admit a tramway. In them are placed ladders and drill chutes.

The ore chutes are built up solid to the bottoms, which are formed of wood lined with steel or cast iron plates. The chutes are circular in form, above the roof of the drifts, which, where manways and chutes occur, are about 12 feet high. The main tramways are double tracked, covered with round tamarac or pine lagging.

No effort is made to fill to the top of the walls with rock from the breast stopes, the deficit being supplied by returning through chutes provided for the purpose, waste rock from the surface, all rock hoisted direct or rejected in the ore house being returned to the mine. The first fill is made to within 8 or 10 feet of the back and is carefully levelled off with crushed rock from the surface to form a smooth floor.

Back stoping is commenced on top of the fill by slicing and raising until the back has reached a height of 35 to 40 feet above the filled floor, the stope being then carried as a breast stope, but having the advantage that the bottom is cut away. By this means maximum footage is attained by the drillers and maximum tonnage from the drilling.

Drilling is performed on bars, on top of the muck, and the drill holes, after the proper height has been attained, are nearly all underhand or wet holes (the latter a very important advantage in such hard ground). The roof is easily accessible for scaling, and but little delay occurs after blasting

Dry wall, Crean Hill mine.

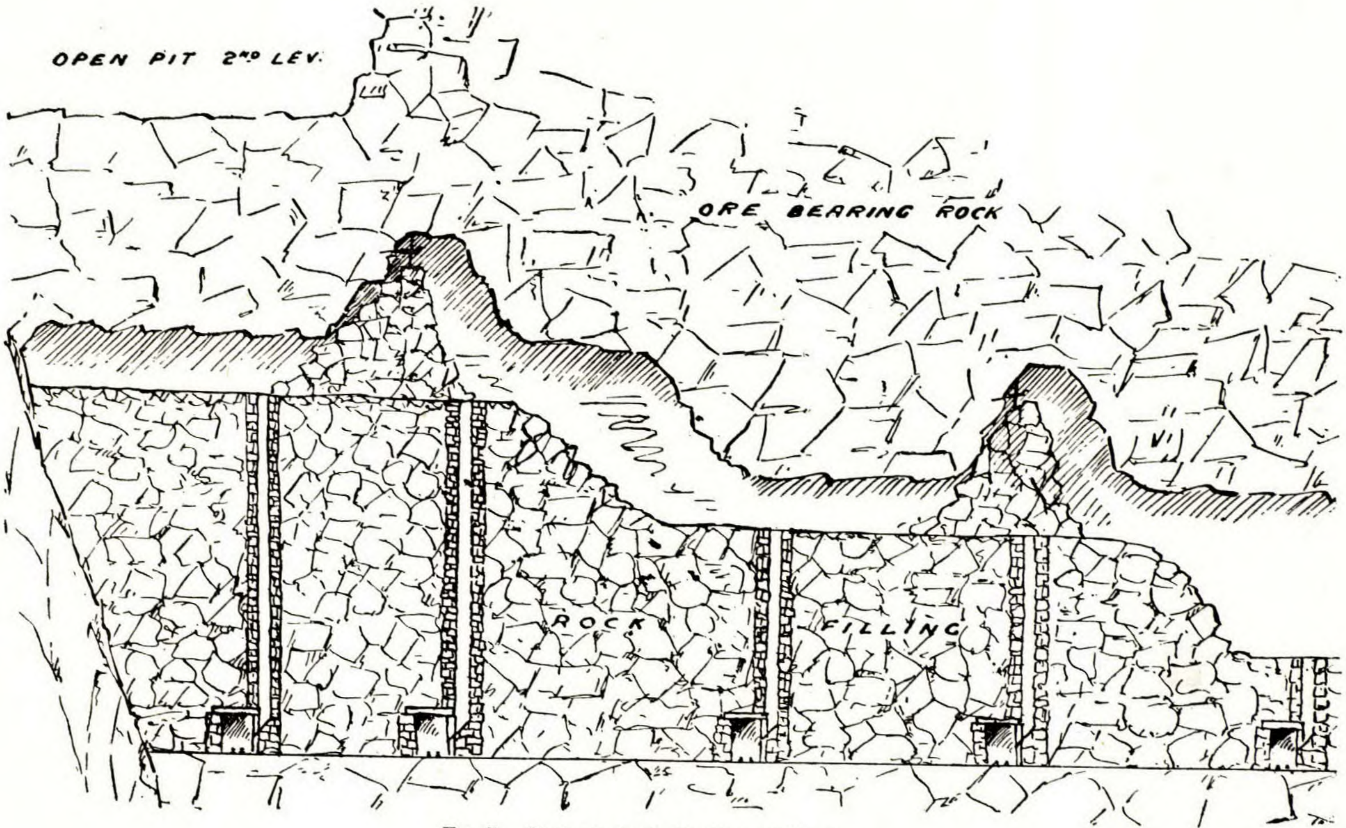


FIG. 7. Back stoping in the Crean Hill mine.

before the machine men can again start to set up their machines. The trammers also can begin work promptly at the beginning of the shift.

On a new fill considerable waste of fine ore is inevitable, but, by dropping a slice 30 feet thick and handling it on one floor, this waste is minimized.

Some careful engineering is required to provide convenient dumps for the rock rejected on the back stopes. With this object in view the stopes are carried one ahead of the other (i.e. one higher than the other) in the form of terraces, the stopes being advanced in opposite directions to the fills, the reject of one stope forming filling for the succeeding one.

The ore bearing rock is transferred from the chutes to the tramcars by means of air operated gates. The gate is hung radially to the lip of the chute, on a square shaft placed underneath the bottom of the lip, and held in position by means of arms which are integral parts of the gate. The bottom of the lip is about a foot above the side of the tramcar. When the gate is opened it swings under the lip. The stream of ore flows into the car until it blocks. The car is filled to its full capacity and heaped up, but not overflowing. The air is turned on and the gate cuts up through the pile of coarse rock, separating the rock in the car from that in the chute. No adjustment of the load is necessary, and no delay occurs, unless the chute happens to be blocked. The whole operation of loading usually does not consume longer than one minute.

Tramcars and skips have each a capacity of three tons.

CREIGHTON MINE.

In all levels of the mine below the 3rd, and all of the western part of all levels, the method of mining is similar to that pursued at Crean Hill, except that the walls and filling consist entirely of ore. By this means a large reserve of broken ore is always available in case of a shortage of labour, or a sudden demand for increased tonnage. The latter emergency was met last winter by withdrawing filling from part of a stope in which stoping has been completed.

Treatment of the Sudbury Ores.

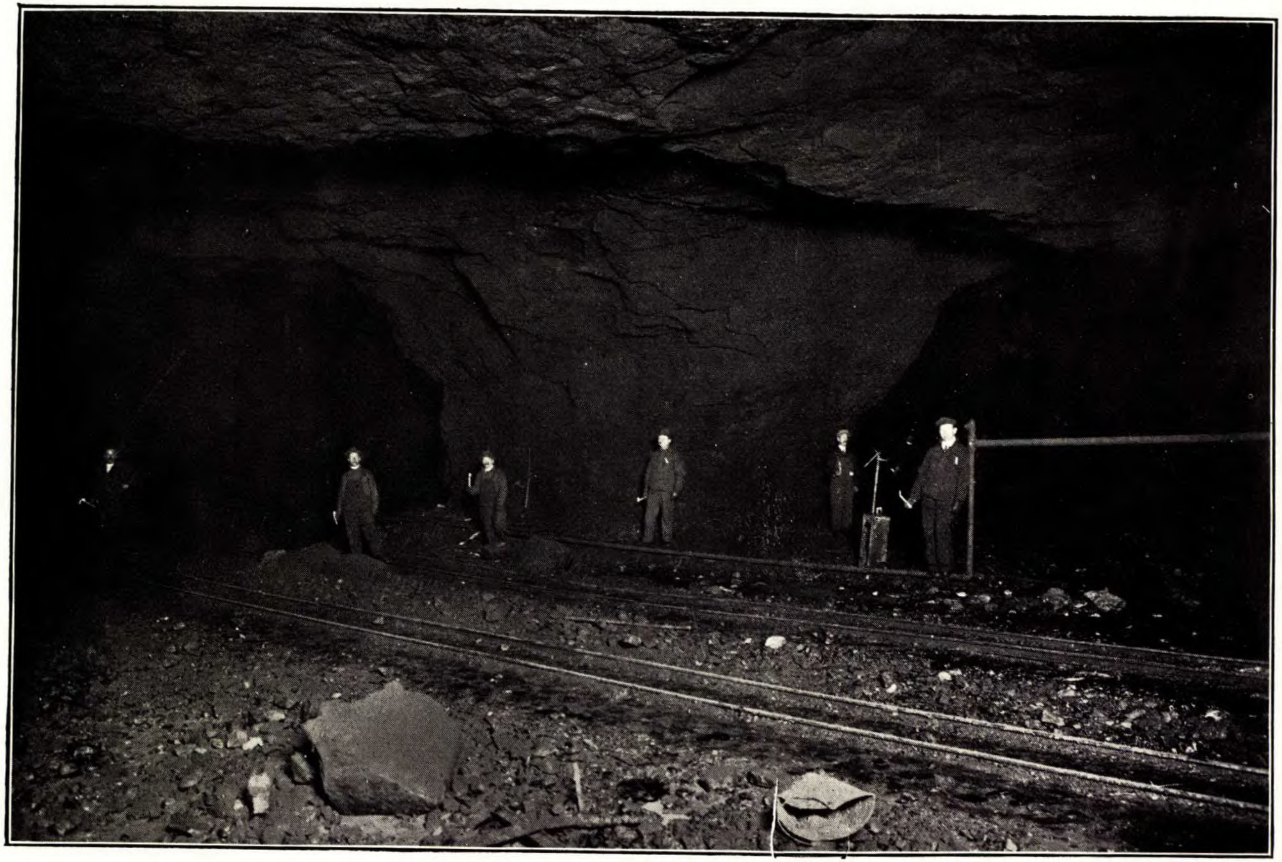
MECHANICAL.

The Sudbury ores include essentially only four ingredients, a magnetic sulphide of iron, which is practically free from nickel and copper· a sulphide of nickel and iron, which is nonmagnetic; a sulphide containing equal parts of iron and copper, which is nonmagnetic; and a variable amount of rock matter which may be of several different kinds, in the main nonmagnetic, norite or the products of its weathering predominating.

The valuable constituents of the ore are nickel and copper, the former being much more valuable than the latter; and these two metals must be separated first from the useless materials and afterwards from one another.

Some of the ores are low in copper and high in iron, and if these could be selected so as to contain only a minimum of copper the large amount of iron present in the ore could be utilized directly to form ferro-nickel, and the costly separation of the copper could be avoided. This would, of c ourse, be the ideal method to pursue, but the only attempt to put it into practice on a large scale, by the Lake Superior Power Co. on Gertrude ore, proved a failure because of the presence of too much copper.

25873—13½



Fourth level, Crean Hill mine.

The fact that the components of the ore include a mineral which is magnetic, while the others are not, or only feebly so, suggests a natural means of concentrating it, by crushing and passing the crushed ore through a magnetic separator. This has appealed to a number of investigators who have occupied themselves with these ores and their treatment, and a large amount of ingenious experimentation has been performed in search of an economic method of magnetic separation, hitherto without success. The fact that pyrrhotite varies greatly in the strength of its magnetism adds to the difficulty of separation.

The question of magnetic separation is fully discussed by Dr. Barlow, who gives fairly complete references to the literature of the subject as well as an account of experiments carried out at McGill University under his direction for the purposes of his own report.[1] Careful work along this line has been done by Mr. David Browne, the well known metallurgist,[2] Dr. C. W. Dickson,[3] and Mr. W. M. Ogilvie,[4] the latter gentleman working on ores provided by Dr. Barlow.

Mr. Browne gives the following table of the results which he obtained from three important mines of the Canadian Copper Company, using picked nickel ore:—

COPPER CLIFF MINE, 7TH LEVEL.

Analysis of total ore.		Magnetic.	Analysis.	Nonmagnetic.	Analysis.	Nickel in magnetic part, Pyrrhotite	Nickel in nonmagnetic part, Pentlandite
Cu	0·00	78·6	0·00	21·4	0·00	34·00	66·00
Ni	11·00		4·62		35·05		
Fe	50·40		55·70		29·80		
S	38·01		38·58		34·35		

STOBIE MINE.

Analysis of total ore.		Magnetic.	Analysis.	Nonmagnetic.	Analysis.	Nickel in magnetic part, Pyrrhotite	Nickel in nonmagnetic part, Pentlandite
Cu	0·00	97·175	0·00	2·825	0·00	72·00	28·00
Ni	2·75		2·15		34·70		
Fe	58·00		57·00		29·90		
S	35·35		36·10		33·90		

EVANS MINE.

Analysis of total ore.		Magnetic.	Analysis.	Nonmagnetic.	Analysis.	Nickel in magnetic part, Pyrrhotite	Nickel in nonmagnetic part, Pentlandite
Cu	trace	84·04	0·00	15·96	0·00	35·47	64·53
Ni	9·02		3·82		34·12		
Fe	51·50		56·00		29·95		
S	39·28		40·18		35·43		

The results of Dr. Dickson's experiments on representative examples of pyrrhotite ground to pass through sieves of varying mesh are shown in the following table, No. I giving the original contents of nickel; No. II that of the magnetic concentrate after passing through a 100 mesh

[1]G.S.C., Vol. XIV, Part H, p. 132, etc.
[2]Eng. Min. Jour., 1893, p. 566.
[3]Trans. Am. Inst. Min. Eng., 1903.
[4]Dr. Barlow, Rep., pp. 136-140.

sieve; No. III the same samples crushed first coarsely and then more and more finely, with magnetic concentration in each case; and No. IV the final concentrate after a similar succession of crushings ending with grinding in an agate mortar.

The table is of interest also as showing the nickel contents of approximately pure pyrrhotite plus pendlandite from various mines.

Mine.	I. Ni and Co	II. Ni.	III.	IV.	Description of sample.
1. Elsie mine........	2·44	2·22	0·98	....	Fine grained pyrrhotite.
2. Stobie mine.......	3·05	2·14	0·68	....	" " "
3. Frood mine........	2·40	2·07	1·05	0·65	Coarse " "
4. Mt. Nickel mine...	3·06	2·14	0·75	0·70	Medium " "
5. No. 2 mine, Copper Cliff............	4·00	2·00	0·70	....	Coarse " "
6. No. 4 mine, Copper Cliff............	3·30	2·32	0·83	....	" " "
7*a*. Creighton mine...	2·32	2·25	1·20	0·70	" " "
7*b*. Creighton mine...	4·15	....	....	0·45	Fine " "
8. Gertrude mine.....	4·00	2·30	1·10	....	Massive " "
9. Victoria mine......	3·40	2·46	0·80	....	Fine " "

It will be seen that by successive magnetic separations, in which the materials are crushed finer and finer, the nonmagnetic portions being removed, the amount of nickel in the magnetic portion is greatly reduced though not entirely lost even after very fine grinding.

The experiments carried out by Mr. Ogilvie in the mining laboratory at McGill University for Dr. Barlow's report were more elaborate, and included ores from the Creighton, Victoria, Garson (Cryderman) and Mt. Nickel mines, and from the Tough and Stobie property in Levack township, and the Cochrane property near Blue lake. The ore came from widely distributed localities, mainly from the southern range, but some also from the eastern and northern ranges so as to represent the marginal deposits of the region very fairly. The work was done with a Wetherill magnetic separator which permitted various adjustments of the strength of the current, of the distance between the two magnets, and of the speed of the belts conveying the powdered ore. It was found that the material varied much in magnetic properties, ore from the Creighton being least magnetic and that from Blue lake being most magnetic. For details of the process Dr. Barlow's report may be consulted.

The work done resulted in the separation of three products, magnetic, feebly magnetic, and nonmagnetic; and it was found, in the case of Creighton ore, that from 40 to over 50 per cent of the nickel remained in the magnetic portion, which represented from 75 to 90 per cent of the whole sample, while the rest was contained chiefly in the feebly magnetic portion. The copper also was found to be largely concentrated in the feebly magnetic or nonmagnetic parts. The results from the other ores were similar, showing that pentlandite is largely left behind in the magnetic separation, but that too much of it is carried over with the pyrrhotite to make the process a commercial success.

A glance at the photomicrographs of polished surfaces of ore from some of these mines, as illustrated by Campbell and Knight, shows clearly why magnetic separation is so incomplete, since pentlandite and also chalcopyrite ramify through the pyrrhotite in the most minute and intricate way.[1] It appears, therefore, that under present conditions magnetic

[1]Jour. Can. Min. Inst., Vol. X, 1907, pp. 274, etc.

separation is out of the question as an economic process for the ordinary Sudbury ores. In any case this mode of separation would leave the rich ores of nickel and copper mixed, so that the most difficult and costly process would still have to be carried out.

The other useless ingredient of the ore is the intermingled rock matter, which could be removed by suitable concentrating mills, since the sulphides have a much higher specific gravity than plagioclase or pyroxene; but up to the present this has not seemed necessary.

At most of the mines a certain amount of selection of the ore is carried out by hand picking, either in the mine itself, or on travelling belts or otherwise in the rockhouse, so that stony masses below a certain grade are removed. Usually, however, the waste dumps display a considerable amount of ore, especially in the very rocky mines, like the Crean Hill, where much of the ore is copper pyrites. In some cases there are on the dumps hundreds of thousands of tons of waste rock which contains 1½ or even 2 or more per cent of the metals, mostly copper, deposited there because a certain standard of ore is demanded for the smelter. Some of these dumps run as high in copper as do ores worked on a large scale in western mines, e. g. in the Boundary country in British Columbia; and it is to be expected that at some time these rocky low grade ores will be put through concentrating mills so as to recover the large amount of sulphides contained in them. This may not take place, however, until there is no longer a sufficient supply of ore from high grade mines like the Creighton.

Ore almost as rocky and low grade as the rock dumps of some of the Sudbury mines is being smelted, apparently at a profit, in the Evje valley in Southern Norway, as will be shown later.

The mechanical separation of the sulphides from the rock can never be very complete because of the intimate mixture of the two in the pyrrhotite-norite, into which the solider ore usually passes. The crushing of the tough rock fine enough to set free the enclosed ore must result in a great amount of fines with such soft and brittle minerals as pyrrhotite, pentlandite and chalcopyrite; and the later treatment of fines is troublesome.

Metallurgical Processes.

The usual metallurgy of the Sudbury ores includes four distinct processes, (1) roasting to remove part of the sulphur, (2) smelting in water jacket furnaces to produce furnace or standard matte, (3) resmelting the standard matte in converters to make a matte of 75 or 80 per cent of nickel and copper, and (4) the separation and refining of the nickel and copper.

At least six companies in the Sudbury region have produced standard matte, the Drury Nickel Company at the Chicago or Travers mine, the Mond Nickel Company at Victoria mine, the Lake Superior Corporation at Gertrude, the Canadian Copper Company at Copper Cliff, the Vivians at Murray mine, and the Dominion Mining Company at Blazard mine. In addition several plants have been formed for experimental purposes without reaching the point of producing any large amount of matte or metal. All of the companies which have used smelters have followed the practice of heap roasting and smelting in a water-jacket furnace to matte, the general methods employed not differing greatly in principle, though the size and equipment of the various plants have differed immensely.

Beyond this stage there have been considerable variations in methods of producing the high grade matte, Manhés furnaces having been used by the Vivians, ordinary acid lined converters by the Mond Company and formerly also by the Canadian Copper Company, while a reverberatory type of furnace was used for some years by the Orford Company to raise the Copper Cliff standard matte to high grade matte.

Within the past year the Canadian Copper Company has introduced immense basic lined converters, which will be described later by Mr. David Browne. In addition they are supplementing the usual furnaces with reverberatory furnaces to treat fines and flue dust, which have accumulated to a considerable tonnage.

The processes thus far mentioned are all carried on in the Sudbury region itself, and the methods are well known, so that there is no attempt at secrecy in the smelters. The last set of operations, in which the metals, nickel and copper are reduced from the 80 per cent matte, and separated from one another, are carried on in other countries by methods which have been partly patented but are in part kept secret.

The divergences of method up to the stage of high grade matte are unimportant, at least as regards the principle involved; but the final separation and refining of the two metals are carried on by totally different methods.

Canadian matte from Copper Cliff is treated by special smelting methods at Bayonne, N.J., by the International Nickel Company, while Canadian matte from Victoria mine is treated by the Mond process at Clydach, Wales, in which the reduced metals are acted on by carbon monoxide, and the nickel removed from the copper as a volatile compound which is later decomposed, setting free the nickel. Finally Norwegian matte, very similar to the Canadian converter matte, is separated electrolytically by the Hybinette process, at Kristiansand, Norway.

There are, then, three ways of obtaining and separating nickel and copper from the high grade matte, each absolutely different from the others, and not merely variations of a single method. All three processes seem to be commercially successful and able to compete with one another and with the somewhat different process used in the treatment of New Caledonian ores. In this respect nickel is unique among the metals produced on a fairly large scale.

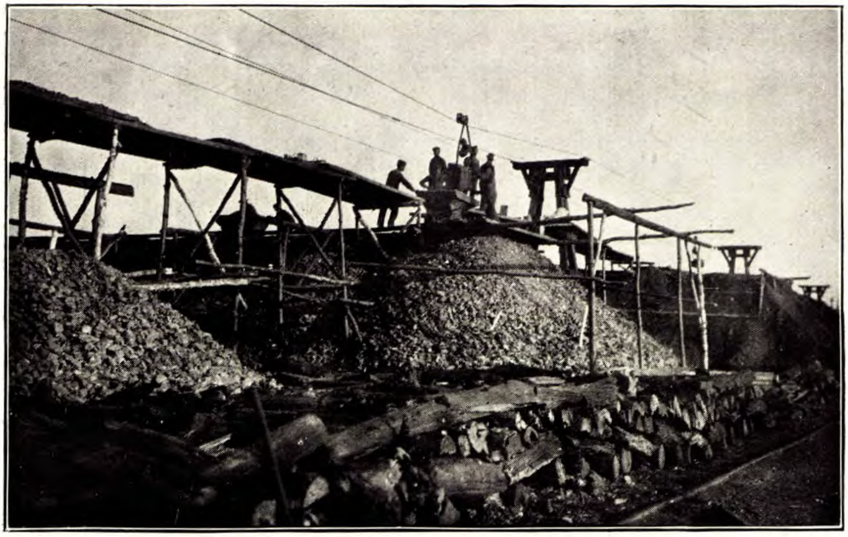
ROASTING THE ORE.

All the Sudbury nickel-copper ores contain much more sulphur than is required in standard matte, so that a large part of this element must be driven off before the matte is obtained. Up to the present, most of the sulphur has been removed by the simplest possible method, heap roasting. Attempts have been made to introduce pyritic smelting by the Canadian Copper Company, but with little success, so that the greater part of their ore is still roasted in heaps[1]. All the other companies which have produced matte have roasted a large percentage of their ore. It has often been suggested that a more scientific process of roasting should be adopted, including the manufacture of sulphuric acid to prevent waste of the sulphur and to preserve the adjoining country from the action of the

[1]Pyritic smelting of Sudbury ores is discussed at length in the Engineering and Mining Journal by Mr. G. T. Beardsley, who carried out experiments for the Canadian Copper Co. (Vol. 84, 1907, pp. 343, etc.); and Mr. Hixon (Ibid. p. 507); while others give their experience in the pyritic smelting of copper ores in the same volume (Ibid. pp. 601, 749 and 837).

Canadian Copper Co.: roast yard, Copper Cliff.

PLATE XXXVII.



Building roast beds: Victoria Mines.

PLATE XXXVIII.

Roast beds, Copper Cliff.

Canadian Copper Co. steam shovel at roast yard, Copper Cliff.

fumes of sulphur dioxide. However, there is little demand for sulphuric acid in the Sudbury region and freight rates would be a serious item if so cheap a product was shipped to a distance; and the country just around the roast beds is usually of small value as farm land, so that the simpler and cheaper method of disposing of the sulphur will probably continue in use for some time to come.

For heap roasting a flat surface that can be drained is prepared, swampy tracts or old lake terraces being generally chosen for the purpose, though some of the smaller plants have used flat surfaces of rock. The general principle involved in the roasting is that the sulphur in the ore itself serves as a fuel when ignited, so that it is simply necessary to provide wood enough to start the fire, and then to make sure that the combustion goes on uniformly over the whole pile.

In preparation for a roast heap a layer of cordwood or of dead pine from the neighbourhood is laid down to a depth of a foot or eighteen inches, the spaces between the larger sticks being filled in with smaller pieces to make a somewhat uniform level surface. Small channels filled with kindling wood lead at intervals of eight or ten feet toward the center of the pile, so as to light the whole heap uniformly. On this bed coarse ore is placed, either by barrows or by dumping from cars running on a rough trestle, making up about two-thirds of the whole. This is followed by medium sized ore and then all is covered with fines, the whole amounting in most cases to 2,000 or 3,000 tons, arranged in a trim rectangular shape with a nearly flat top and sides sloping at the angle of stability for the material.

The wood is set fire to, and according to Captain McArthur, burns out in about 60 hours, after which the sulphur of the ore is well ignited and will continue to burn without further aid, though rapid combustion at any given point is checked by covering it with fines. The usual large heaps require 3 or 4 months to burn, when all but 10 or 11 per cent of the sulphur has passed off and the iron is more or less completely oxidised, so that the heap takes on a reddish colour.

In the earlier stages a good deal of sulphur is sublimed from the lower part of the heap and condenses as a pale yellow coating on the cooler upper part, but later this too is burnt away. The fumes of SO_2 are heavy and do not rise readily, but condense moisture from the air forming a cloud which drifts with the wind low along the ground, making a choking atmosphere to breathe, though it is apparently not found unhealthy by the men who work in the roast yards.

These regularly shaped heaps are built in parallel rows only a few feet apart, and north of Copper Cliff, for instance, one may study heaps at every stage from the process of building to cold burnt out ones which are being loaded on cars for the smelter.

During the roasting process, especially when rains come on, various sulphites of iron, nickel and copper are formed as green stalactitic masses in the cavities between the pieces of ore, and a not inconsiderable amount of the metals may be leached out and lost. An old pick or shovel immersed in the greenish water of some hollow or ditch is gradually replaced by copper, giving ocular evidence of the loss due to this cause.

The roasted ore is usually somewhat sintered together and may be fused into such solid masses as to need explosives to break them up. While the surfaces of the bits of ore are well roasted and rusty looking, there still remains a certain amount of unroasted sulphides within the blocks.

The effects of the sulphur fumes on the surrounding vegetation are disasterous, especially to coniferous trees, so that soon after a roast yard is established the nearby cedar swamps show only bare trunks, and many plants are killed even two or three miles away in the direction of the prevalent winds. It is of interest to note that the maple stands the sulphur fumes best of all the trees, so that small clumps may be seen springing up on many of the bare hillsides near Copper Cliff since the roast yard has been removed a mile to the north behind a group of hills. Mr. Turner, President of the Canadian Copper Company, has tested a large number of plants in his garden and finds that some flowers stand the effects of the sulphur much better than others. If carefully looked after, grass forms a turf once more at Copper Cliff and a good field of indian corn thrives just behind the hospital.

An interesting geological effect results from the roasting process, since the destruction of the plant life covering the old lake beds in the vicinity exposes the clay to rain erosion, which is going on very rapidly.

The roast beds send hundreds of tons of sulphur dioxide into the air every twenty-four hours, and it is perhaps surprising that this active reagent does not accomplish more destruction than can be observed. Fortunately there is practically no arsenic in the ore, so that the gases, though sometimes distressing to breathe, are not poisonous. Perhaps the most injurious effect is on iron or steel, which are rapidly corroded, so that wire fences and telegraph wires last only a short time within reach of the fumes.

NICKEL-COPPER SMELTING PLANT AT COPPER CLIFF.

After heap roasting the next operation is the smelting of the ore in water-jacket furnaces to standard matte. A concise description of a smelter and its equipment as used by the Canadian Copper Company at Copper Cliff was given by Mr. G. E. Sylvester, of that company, in 1909[1]; and the present account is essentially his, though modified to bring it into accord with modifications introduced since 1909. Information as to these changes has been furnished by the kindness of Mr. D. H. Browne, whose notes have been used in rewriting the earlier account.

The blast furnaces and the basic converters employed in the two smelting processes used at Copper Cliff are in adjoining buildings and the general arrangement is described first.

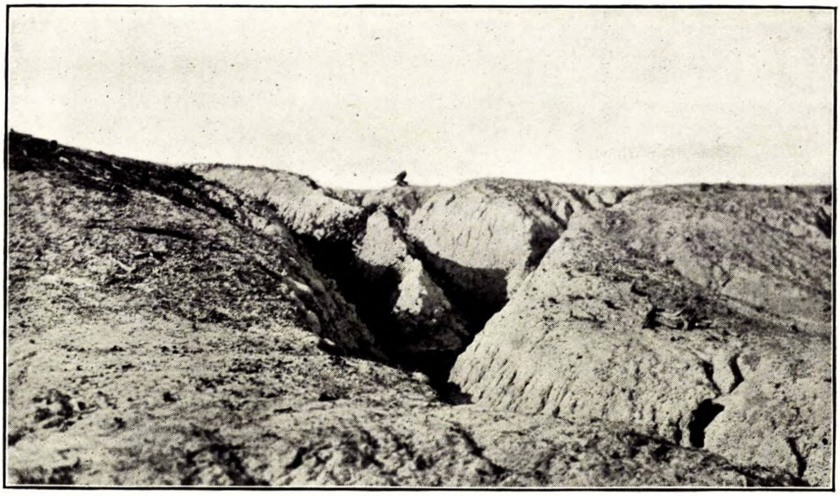
"The site of the present smelter was decided upon after a careful contour survey covering all the available ground in the vicinity. The grade of the receiving track, on top of the storage bins, having been fixed at 67 feet above the smelter yard grade, it was necessary to fit these two governing levels into the topography in such a way as to give the easiest possible railway connection to each, and at the same time to obtain a good slag dump, with sufficient area and depth to last for many years without elevating slag. These several conditions are all met in the present site as may be seen from the accompanying drawing.

The storage bins, dust chamber, stack, sampling building, and laboratory are all built on solid rock, and the furnace building, steam power house, and electrical substation almost entirely so. The other buildings were constructed later, on 15 or 20 feet of poured slag.

The storage bins are of massive timber construction with bents 6 feet centres on masonry footings. They are 700 feet long, 30 feet wide and 32 feet high, carrying two standard gauge tracks at 15 feet centres. The bins are covered with a running shed having a continuous louvred

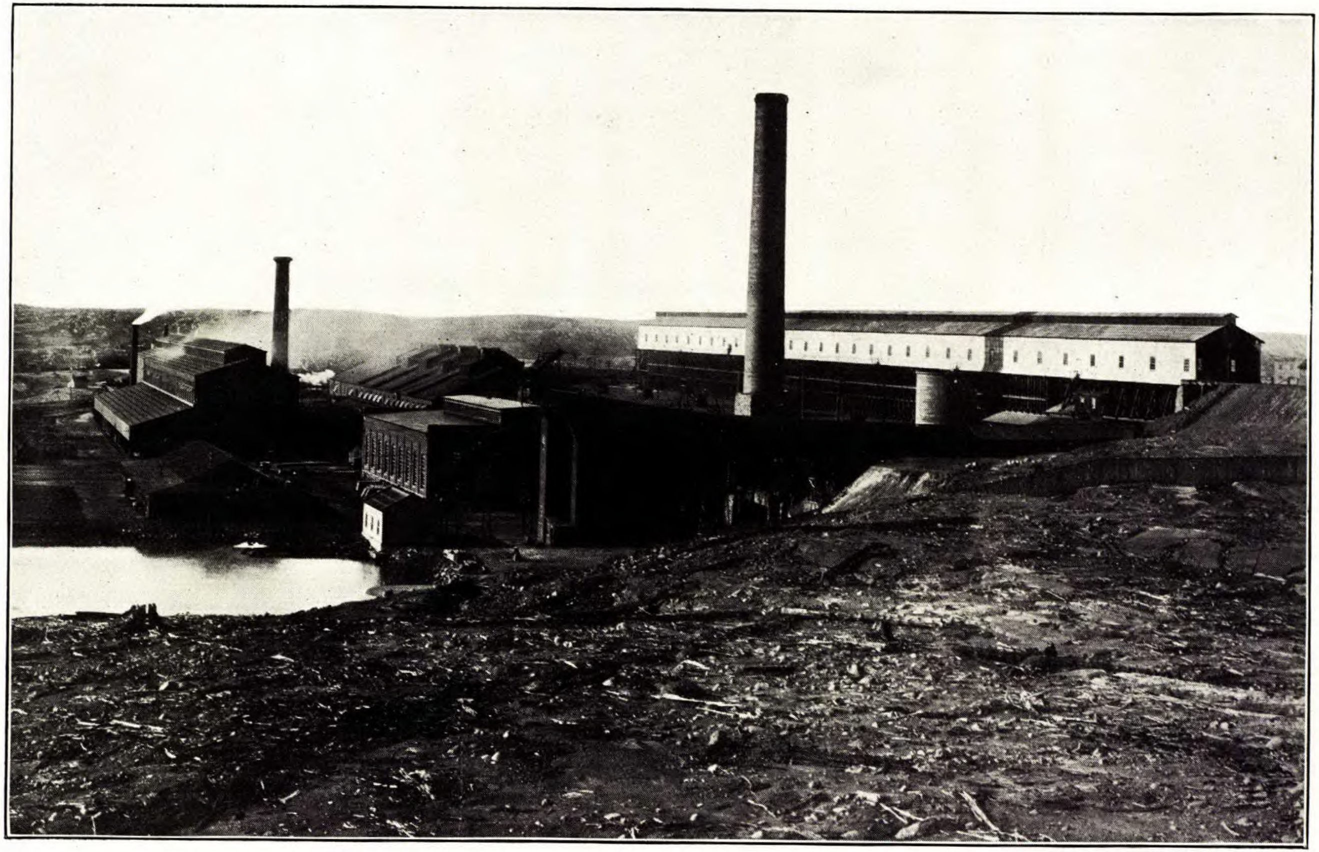
[1]Jour. Can. Min. Inst., Vol. XII, 1909, pp. 218-239.

PLATE XL.



Rain erosion where vegetation has been killed by sulphur fumes, Copper Cliff.

25873—14½



Canadian Copper Co. smelter, Copper Cliff.

ventilator, and sheeted and roofed with $\frac{3}{16}$ inch asbestos lumber. The total storage capacity is about 400,000 cubic feet. Under the bins and

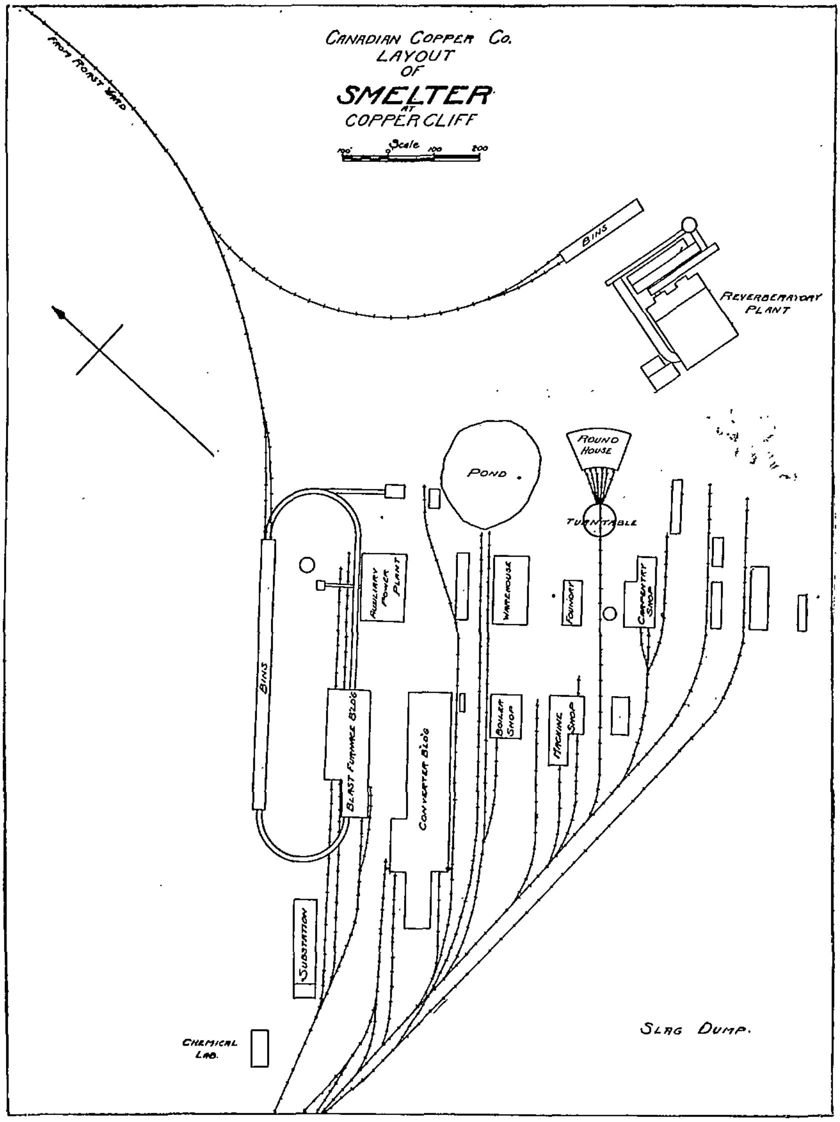


Fig. 8.

on the same level as the furnace charge floor run two parallel tracks, 36 inch gauge, and 15 feet centres. The bin bottoms are double hoppered with discharge gates every 6 feet, directly over each of these tracks. The gates are of a patented type, convex on the under side and operated by geared cranks.

At one end of the bins are three-ton suspended track scales on each track, with the beams and weigh check houses between the tracks. Alongside are small open bins for adjusting the components of the charge. Two more of these scales will be installed near the centre of the bins to relieve the pressure on the present ones.

The centre line of the ore bins is parallel to that of the furnace building and 200 feet distant from it. The tracks under the bins are carried round in a semi-circle at each end and through the furnace building, one track on each side of the furnaces, thus forming a double track belt line, with crossovers at convenient points. These tracks are covered between buildings with a wooden shed, and for a considerable distance along the furnace slag track are carried on a trestle resting on 14 foot masonry piers. This prevents danger of fire from slopping of hot slag from the cinder cars. In this trestle, under the charge tracks, are coal pockets with chutes which discharge in front of the boilers in the steam power house, described later. There are also two cooling pockets for locomotives. The trestles mentioned above are of wood but are to be replaced by steel structures.

Around this belt line the five furnace charging trains are operated, running always in the same direction. Each train consists of eight or nine side dumping steel ore cars, weighing about 1,500 lbs. and holding about 3,000 lbs. of ore, hauled by a 5 ton electric locomotive with 1,200 lbs. draw bar pull at 6 miles per hour, equipped with overhead trolley and using direct current at 250 volts. The tracks are 56 lb. steel, copper bonded throughout. The charge cars are 6 feet long over all, this being also the length of the furnace charge doors, and the centre to centre spacing of bin gates. The charging trains also supply the coal pockets referred to above, the coal being weighed in transit.

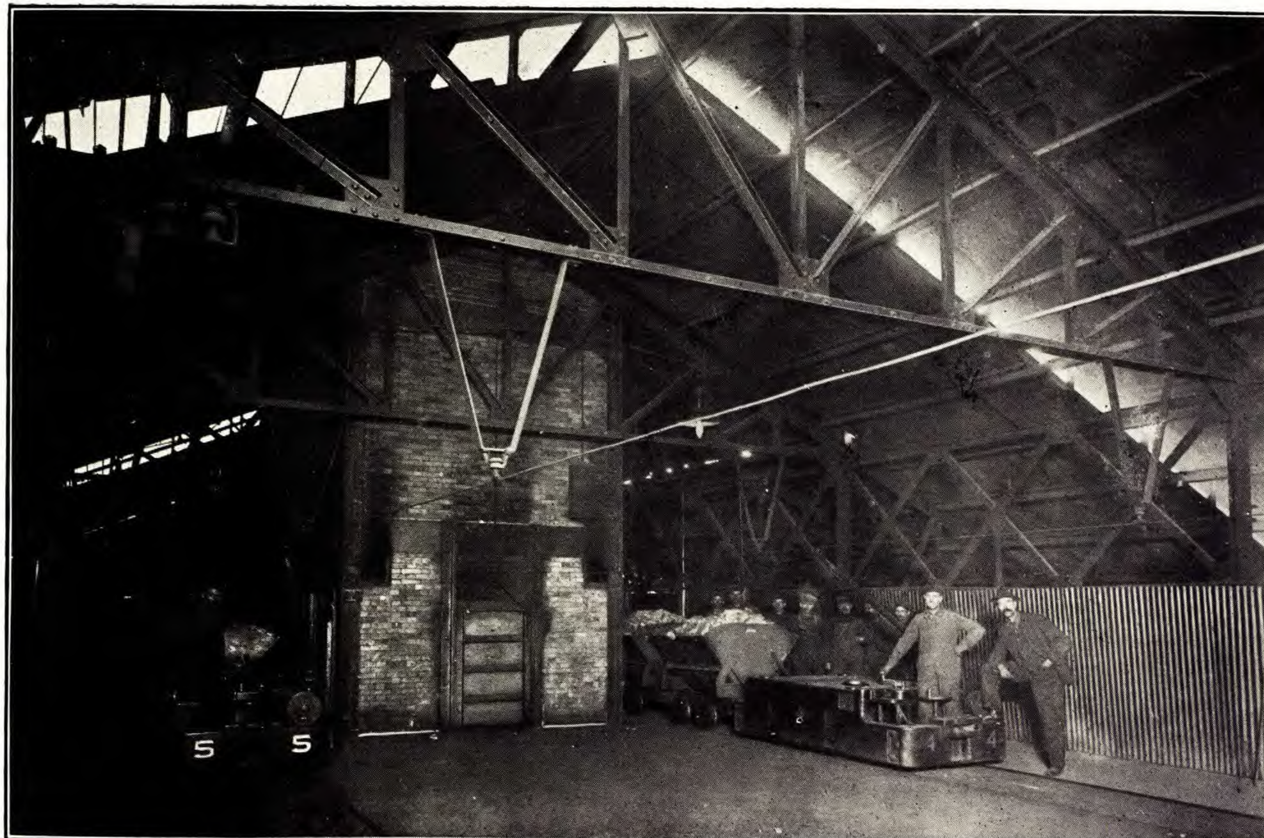
The furnace building is 370 feet long and 80 feet wide, with a lean to shec 30 feet wide and 280 feet long on one side. It is of steel construction throughout, except one side wall of brick, with heavy pilasters, which carry one track of the crane runway, and having 8 feet arched doorways every 20 feet. The roof covering is reinforced tile. A section of roof 12 feet wide in each space between furnaces is raised two feet above the general level for ventilation. A monitor, enclosed with louvres, is also carried up 8 feet above the main roof around each furnace. The lower part of the building is divided longitudinally into three portions or bays, as follows:—

a. The slag floor at the back, 33 feet wide, served by two standard gauge through tracks.

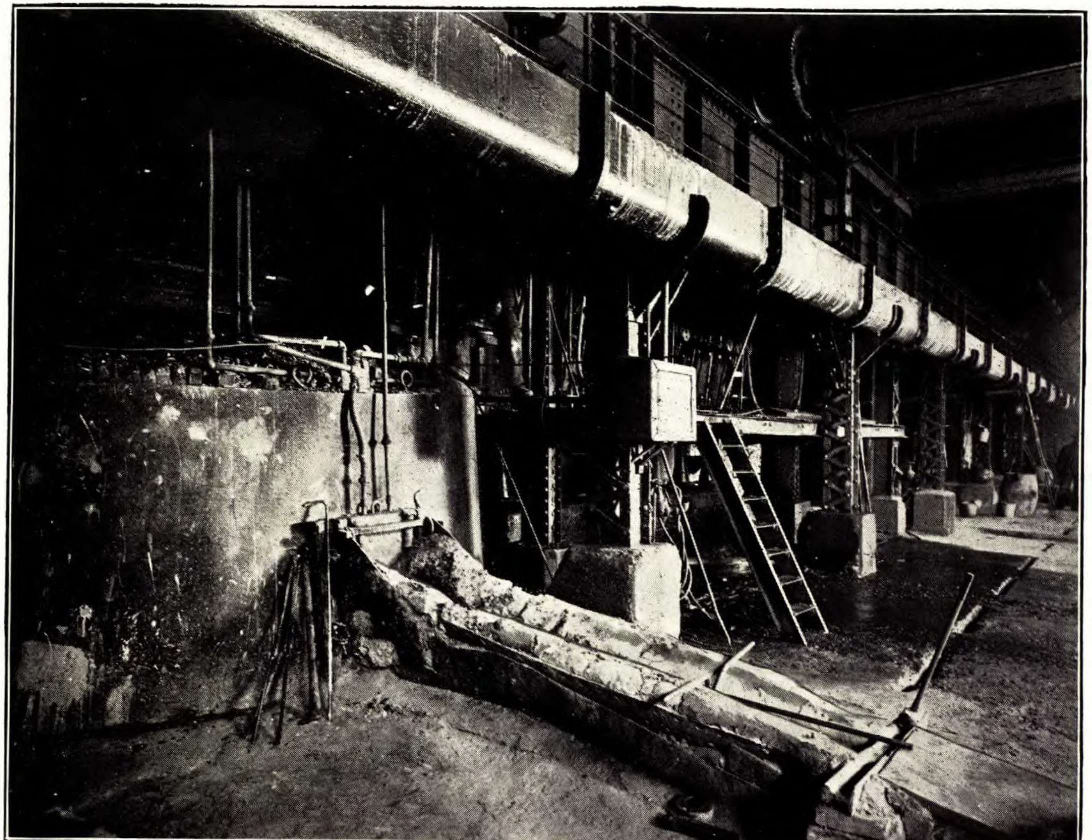
b. The matte floor in front, 33 feet wide, served by a 50 ton and a 20 ton electric ladle crane of 32 feet 10 inches span, and by a railway track running about 80 feet into one end of the building.

c. The furnace and settler floor in the centre, 20 feet wide and 10 feet above the balance of the floor. The raised portion consists of massive masonry walls, and for the columns which carry the charge floor and crane runway. These walls are filled in between and floored over with concrete, which is carried out over the matte floor about 9 feet on steel supports, forming a continuous tapping platform and furnace runway. The charging floor is 35 feet above the matte and slag floor, and 25 feet above the furnace floor. It is 30 feet wide, of reinforced concrete on heavy steel framing, with sides sheeted up to the roof, forming a separate enclosure.

The blast furnaces, five in number, are of the rectangular water-jacketed type, 50 by 204 inches inside at the tuyeres, 19 feet high from the hearth plate to the charging level, and rated at 500 tons per day. They are spaced in line, at 61 feet 6 inches centres, with their longitudinal centre



Charging floor: Canadian Copper Co. smelter, Copper Cliff.



Settler: Canadian Copper Co. smelter, Copper Cliff.

line coincident with that of the building. The supporting frame is of heavy steel construction, the charge deck of cast iron. The hood or superstructure above the charge deck is of firebrick, with 18 inch walls, built into a skeleton of very heavy structural steel. The end walls unite in a catenary arch to form the roof, the top of the arch being 33 feet above the charging level, making the total height of the fur ace 58 feet above the tapping platform. The side walls are vertical and in one of them is the down-take opening, with its centre 27 feet above the charge floor.

The down-take is 8 feet in diameter, lined with 4 inches of firebrick for the first 20 feet. It inclines 30 degrees in a straight line from the furnace to the dust chamber, passing over the slag tracks. The design of hood on these furnaces has given great satisfaction in the way of perfect draft, and almost absolute freedom from scale. The hearth plate is supported on jacks on a concrete pedestal. There are two tiers of water jackets, the lower or tuyere jackets 8 feet, and the upper 6 feet 4 inches high. Cast iron tuyere jackets have been substituted in the lower tier for the ordinary steel plate type formerly used; and they have water circulating pipes cast into an otherwise solid slab, with stiffening flanges.

A new blast furnace, now in construction (1912), is of the same style but somewhat larger, having diameter of 50 inches by 255, and tuyeres arranged in the same way but 50 inches longer. All the tuyere jackets used for the past 3 or 4 years are of cast iron with the circulating pipes for water cast in, as mentioned above. The settling wells which were originally round and 16 feet in diameter with a height of 5 feet 6 inches, and the settlers, furnace hearth, and spout are lined with chrome brick. The present type of settler is oval in shape and larger, having diameters of 16 feet by 19 feet 6 inches, with two top jackets for matte. The larger size settler gives slag lower in copper and nickel by from 0·1 to 0·15 per cent of the metals; and having two tap holes, if one becomes clogged the other may be used, or can be repaired while the other is in use.

Water cooled cast iron slag spouts on the settlers discharge into 25 ton cinder cars, with sectional cast iron bowls, rack and worm geared, on standard gauge trucks. Small catch pots, operated by compressed air crawls, receive the slag streams during cinder car shunts.

The matte from the settlers is tapped into 7 ton steel plate ladles, clay lined, which are placed by the travelling cranes on low transfer trucks and hauled by a compressed air winch across into the converter building.

The water-jacket overflows into two continuous cast iron launders, on either side of the furnaces, sloping both ways from the centre furnace, and thence flows through 20 inch drains to an open cooling reservoir.

As the water supply is limited and the furnaces alone use about 1,000 imperial gallons per minute each, most of this is pumped back from the reservoir and used over and over. For this service three pumps are installed, two 8 inch, 1,500 gallons, and one 14 inch, furnishing 5,000 gallons. All are single stage turbines direct connected to constant speed induction motors. These discharge through an 18 inch flanged cast iron pipe into a reinforced concrete tank 25 feet in diameter and 32 feet high. Duplicate cast iron mains connected with this tank run on either side of the furnaces just under the charge floor. The tank is also connected with the smelter supply main, the static head of the latter being just balanced in the tank. This arrangement gives a very steady pressure on the furnaces, the head being 28 feet above the jackets.

The dust chamber is of $\frac{5}{16}$ steel plate of the balloon type, 20 feet in diameter, 34 feet high and 500 feet long, supported on steel columns with expansion joints about every 60 feet. The only lining is in a section about 12 feet square opposite every down-take opening. The bottom has hoppers and clean-out doors every 6 feet, discharging the flue dust directly into cars on a continuous track beneath.

The stack is 210 feet high and 15 feet inside diameter at the top. The upper 150 feet is circular, built of perforated radial stack brick; the base is 24 feet square, of granite masonry, with a circular lining of firebrick. This stack accommodates also the steam power house boiler.

SMELTING IN THE BLAST FURNACES.

The present blast furnace practice is described by Mr. Browne as follows:—The ore when properly roasted contains about 10 or 11 per cent of sulphur. It is lifted from the roast heaps by a steam shovel and placed in steel drop-bottom 50 ton cars and taken to the ore bins from which the furnaces are supplied.

The five ore trains mentioned above as running on the oval track connecting the bins and furnaces include eight or nine side dumping steel ore cars, the first three carrying the coke charge, which is adjusted at the scales to a certain percentage of the weight of ore and flux, the amount varying from 10 to 12 per cent. The three cars behind the coke contain the ore, usually about 9,000 or 10,000 lbs. of roasted ore forming a charge. Another car carries 2,000 or 3,000 lbs. of Crean Hill ore, which being low in sulphur (12 to 14 per cent) does not require roasting. Sometimes if the ore is well roasted 2,000 or 3,000 lbs. of Creighton green ore can be used in the charge. The furnace scrap, when used, is carried in a separate car, as is the quartz, the amount of the latter used varying from nothing to 2,000 lbs. per charge according to the silica in the ore.

If the furnaces are choked by siliceous ore or fine ore, lime may be used for a few charges instead of quartz. The coke is dumped in the furnace first, then the ore with its flux, and then the scrap or floor screenings. The blast is normally 24,000 cubic feet of free air per furnace at about 25 to 35 ounces pressure. If the furnaces are choked by fine ore the blast will form blow holes, throwing the heat to the top of the furnaces and forming incrustations or blocks of half fused material. In this case the blast is reduced and a "clean-out" charge of green ore and lime is given. This melts easily and carries the heat to the lower part of the furnace, undercutting the blocks, which are then easily removed by barring.

There is no regular rule for the operation of the furnaces, the charge varying from day to day, often changing from hour to hour as the ore changes in quality chemically or physically.

The five blast furnaces smelt from 40,000 to 45,000 tons of ore per month, the amount of green ore varying with the condition of the roast ore. The charge may be two parts roast ore to one part of green ore if much of the Crean Hill ore is used; or it may be four parts of roast ore to one of green ore, if the Crean Hill ore is not received in sufficient quantity.

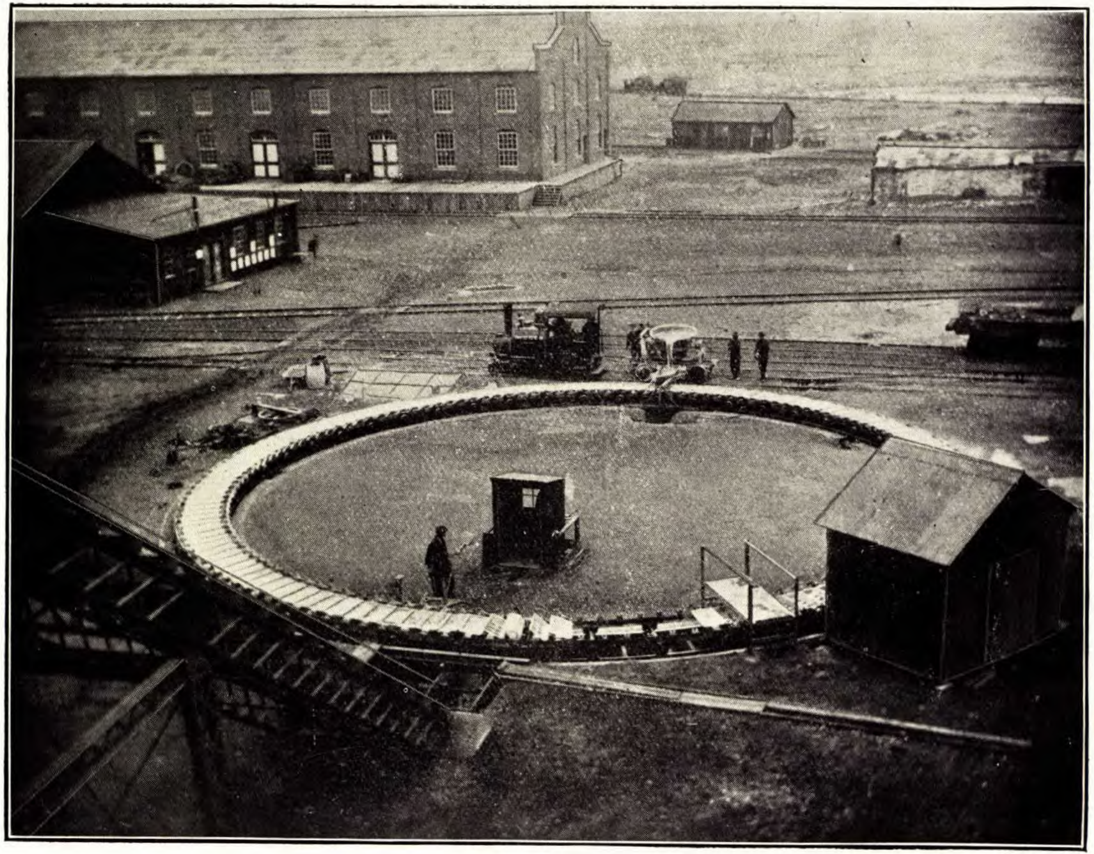
Green ore alone could be used in the blast furnaces, but this would make a very low grade of matte and would throw a great amount of work on the converter department.

A comparison of the amount of work necessary to convert matte of different grades into bessemer matte is interesting. To make 100 tons of bessemer matte per day from a 10 per cent furnace matte would require 14 basic converters; from 15 per cent matte would require 7 converters; from 20 per cent matte, 5 converters; from 25 per cent matte 4 converters, and from 30 per cent matte 3 converters.

Interior blast furnace building: Canadian Copper Co. smelter, Copper Cliff.

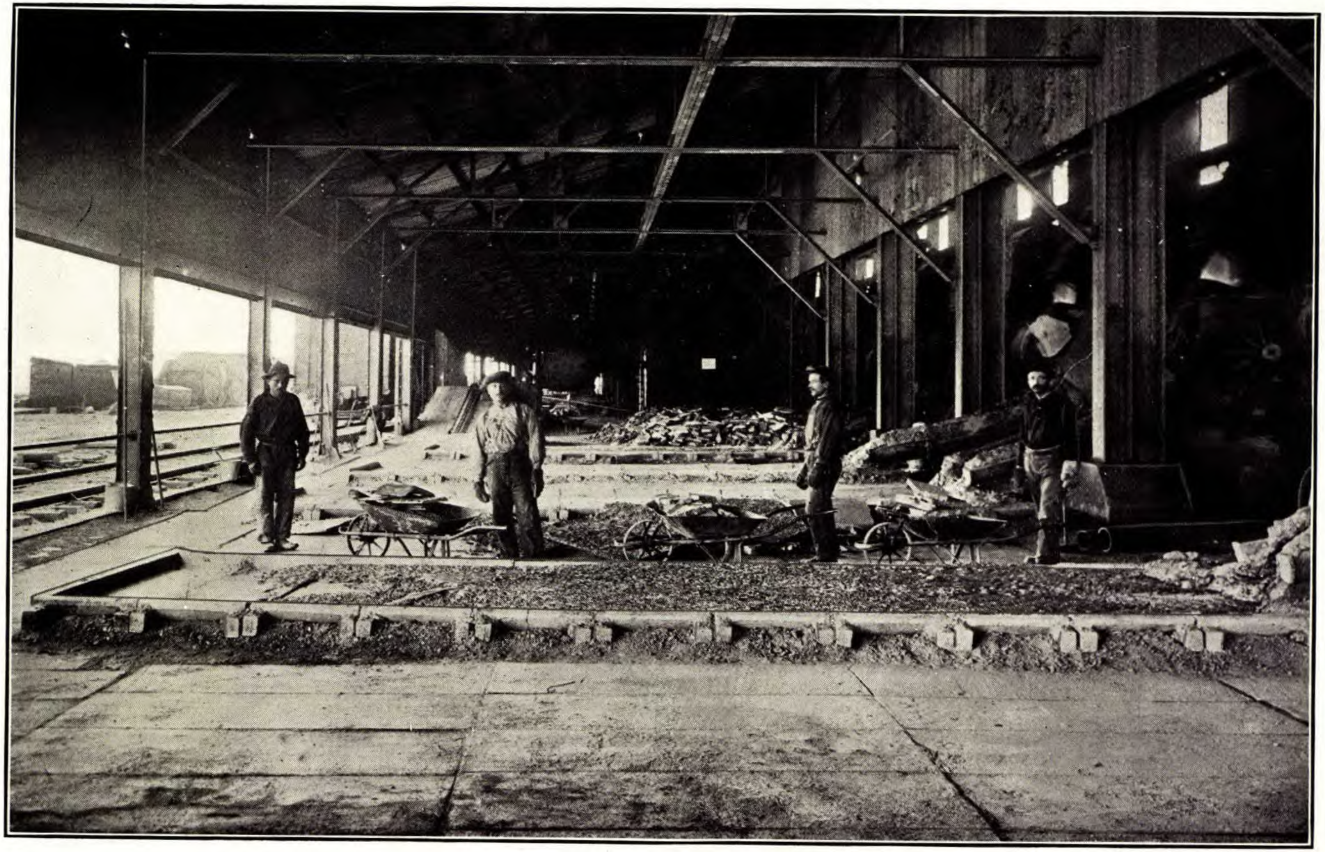
Pouring slag: Canadian Copper Co. smelter, Copper Cliff.

25873—15

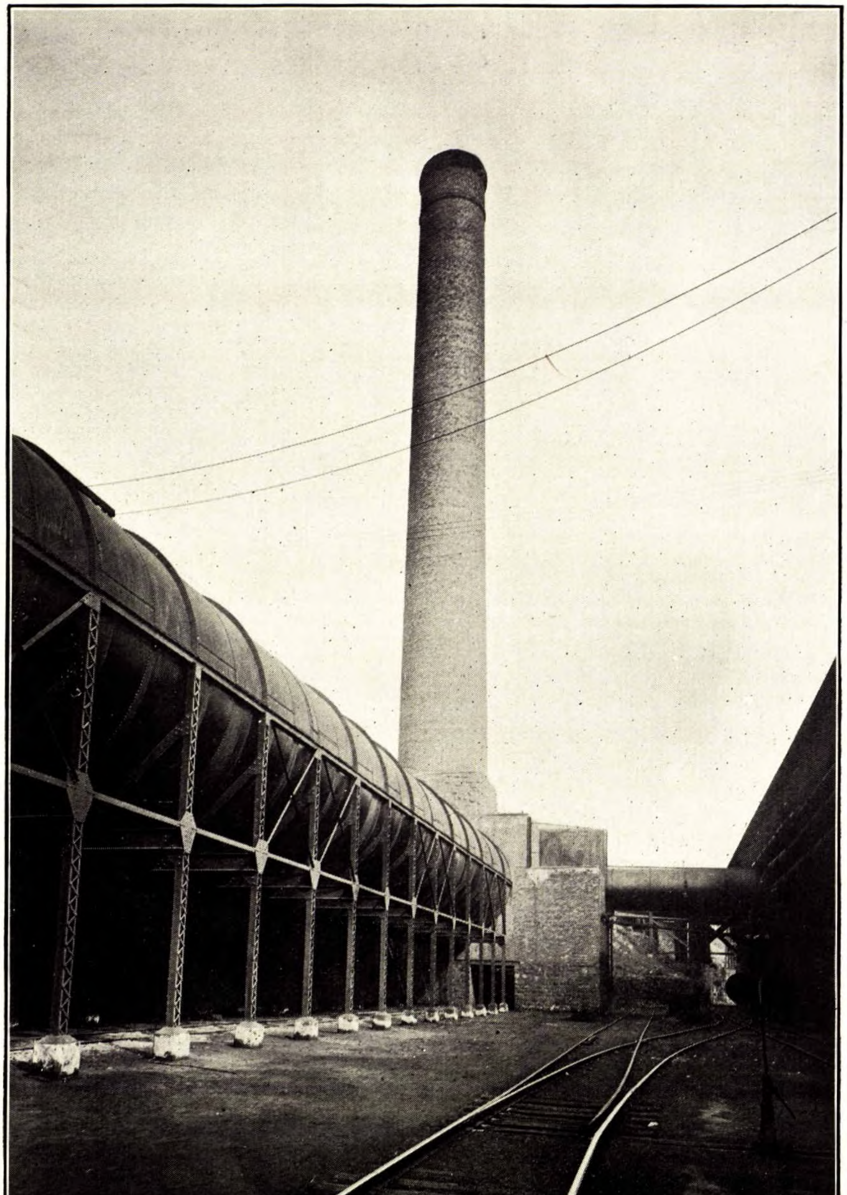


Slag cooling machine: Canadian Copper Co. smelter, Copper Cliff.

25873—15½



Matte shed: Canadian Copper Co. smelter, Copper Cliff.



Blast furnace flue: Canadian Copper Co. smelter, Copper Cliff.

The whole smelting operation requires very careful balancing. At present five converters are being installed, which should allow the use of a 20 per cent furnace matte.

THE CONVERTER BUILDING.

This building is of steel construction throughout, extra braced on account of the heavy travelling cranes. The main building is 552 feet long, 60 feet wide and 47 feet to the roof trusses, with lean to sheds 30 feet wide, 392 feet long on one side and 112 feet on the other. A monitor 24 feet wide and 8 feet high, with louvres, runs the entire length except the end bays. The roofing is of reinforced concrete tile and the sheeting of galvanized corrugated iron, except 130 feet toward the southern end which is covered with cement plaster on metal, giving greater protection against frost. The building contains different departments; 280 feet in length being provided for blowing, while the rest is used for drying and crushing quartz, etc. Formerly this was employed in drying, grinding and crushing quartz and clay for relining the acid converters, and in the slow process of relining them. The introduction of large basic converters, as described by Mr. David Browne, has made great changes in this respect.

RECENT IMPROVEMENTS AND ADDITIONS TO THE SMELTING PLANT OF THE CANADIAN COPPER CO.

(The following account is taken unchanged from a paper prepared by Mr. Browne for the Canadian Mining Institute, 1912).

In the year 1910 the Canadian Copper Company had in operation ten stands of acid converters. The shells were 84 inches by 126, and were lined with the usual mixture of quartz and clay. In each shell were eight tuyeres, one inch in diameter, and six inches apart. The center or mould, around which the lining was rammed was oval in shape, 3 feet 4 inches high, 5 feet by 2 feet 6 inches at the top and 4 feet 6 inches by 2 feet at the bottom. Each shell consumed about 3,000 cubic feet of free air per minute at 9 to 11 lbs. pressure.

The production of matte from these shells depended largely on the grade of furnace matte with which they were supplied. On a 36 per cent furnace matte one lining lasted for about eight hours blowing time and produced seven tons of finished bessemer matte, 80 per cent copper-nickel. On a 30 per cent furnace matte one lining was good for about 5·3 tons bessemer matte.

As the amount of metal lost in furnace slag depends very much on the grade of furnace matte made, this pointed to the desirability of producing lower grades of furnace matte with cleaner slags, throwing on the converters every year an increasing burden. The converters received lower grade furnace mattes, containing not only less copper-nickel but more iron In a 40 per cent furnace matte one pound of copper-nickel is accompanied by 0·88 lbs. iron, in a 30 per cent matte by 1·28 lbs. iron, and in a 20 per cent matte by 2·4 lbs. iron.

As this iron is removed by oxidation and combination with silica to form a slag, and as the amount of air passing into the converters is a fixed factor, practically 3,000 cubic feet per minute, it is evident that lower grade mattes take longer to blow than higher grades. When using a 36 per cent urnace matte about one hour and five minutes blowing is required to produce a ton of 80 per cent bessemer matte, while with a 30 per cent furnace matte an hour and fifty-five minutes is required.

Furthermore the amount of scrap, or material thrown out of the mouth of the converter while blowing is a factor of the time of blowing. The amount thrown out by the blast is about the same per hour. Therefore as the furnace matte becomes of lower and lower grade the production of the converters becomes less and less, first, because they have more iron to remove and need longer time to do it, and second, because during this longer time they slop out more and more material on the floor.

These considerations decided the Canadian Copper Company to discard this type of acid converters and to substitute basic converters, such as had been installed by Smith and Pierce at the Garfield plant of the American Smelting and Refining Co.

A basic converter is simply a cylinder lined with magnesite brick. The function of the converter is exactly the same as in the acid converters. Air blown in through the tuyeres passes through melted matte and oxidizes iron. The oxide of iron combines with silica and forms a slag. The difference lies in the fact that in the acid converters the siliceous material is rammed in to form the lining of the converter. The iron attacks this lining and melts it off to get at the silica, so that after a few hours blowing the lining is all cut away and the shell must be relined. In the basic converter the lining consists of basic bricks and the quartz or other siliceous material is dumped into the converter on top of the matte from time to time as the converter requires it. The magnesite bricks which form the lining are very slowly worn away above the tuyeres, but a basic converter will make three or four thousand tons of bessemer matte before it requires repair, while an acid converter requires relining after making six or seven tons.

In March 1911 the first basic converter was blown in. During the remainder of the year the acid stands were taken out and basic converters put in their place. At present all the acid converters have been removed and their place taken by five basics.

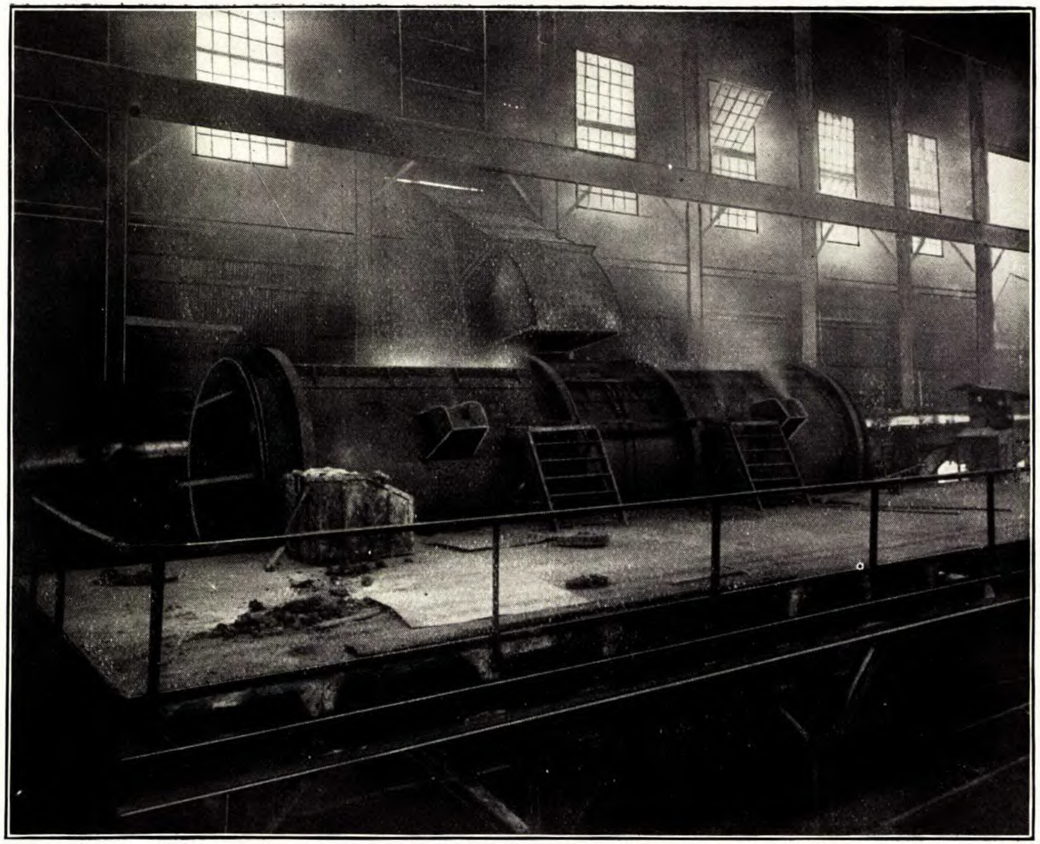
These basic converters are 37 feet 2 inches long by 10 inches in diameter, outside measurement. They run on four tread rings 12 feet in diameter. The stack or opening in the roof for the escape of gas, is in the centre of the cylinder instead of at the end, as in the Garfield plant. There are 44 tuyeres, 1¼ inches in diameter and 7 inches apart. There are no tuyeres directly under the stack. The length inside the lining is 33 feet 3 inches. The bottom is 2 ft. thick, the back or tuyere wall is 18 inches and the front 15 inches thick. The roof is a 12 inch arch. The brick directly around the tuyeres is 24 inches thick.

These converters have two openings or spouts in the front wall opposite to but above the tuyere line. The shell is turned down to pour slag and matte from these openings or turned back to blow by means of two wire ropes which surround the shell on either side of the central stack. These ropes are fastened to a hydraulic piston working in a horizontal cylinder, having a stroke of nine feet.

As the usual hydraulic equipment would not be suitable to the climate of Northern Ontario, oil is used instead of water, since oil remains fluid at low temperatures.

This is moved in the cylinders by air pressure. Two tanks are provided, one for regular use, one for emergency. These tanks are of ¾ inch steel 4 ft. diameter by 15 ft. high. Into these tanks a small amount of oil is pumped, and the space above the oil is filled with air at 75 lbs. pressure.

Old acid converter plant, Copper Cliff.



Basic converter: Canadian Copper Co. smelter, Copper Cliff.

Basic converters, Canadian Copper Co. smelter, Copper Cliff.

An electrically driven pressure pump now forces more oil into the cylinders, compressing the air to 300 lbs. pressure. At this pressure the pump automatically stops. When it is desired to turn down the converter a valve is opened on the converter platform, allowing the oil to pass to one side or the other of the hydraulic cylinder, moving the piston and so by means of the rope tackle turning the converter as desired. In this operation the air in the tank above the oil expands and loses pressure. When the pressure in the tank falls to 200 lbs. the oil pump starts automatically pumping oil into the tank till the pressure rises to 300 lbs.

As the entire equipment of the plant is electrically driven it is manifest that if for any reason the power went off the line the converter blower would stop blowing air into the tuyeres. The matte would then run back through the tuyeres, as the mechanism for turning the converter down, being also electrically driven, would be useless. To avoid this a spare tank always contains oil under 300 lbs. pressure. This spare tank is connected to the hydraulic cylinder by a valve which is held closed by a solenoid brake. The fly wheel of the converter blower is of sufficient size to keep the engine turning over and delivering air for perhaps 15 to 20 seconds after the power goes off. The solenoid brake is actuated by the electric power, and the moment the power goes off the solenoid brake drops, opening the valve, and admitting oil to the proper side of the cylinder to turn the converter down.

It sometimes happens that a thunder storm twenty-five miles from Copper Cliff will cut off the current on the power line. The safety device above described, being absolutely automatic and entirely separate from the regularly used turning device, has proved quite satisfactory.

The basic converter takes an initial charge of about 60 tons of furnace matte. About 10 per cent of quartz rock, previously dried is dumped into the converter, and the blast is turned on. Blowing is done entirely by the clock. The charge is blown from one-half to three-quarters of an hour and is then turned down to skim slag. While the slag is being poured off, 5 or 6 tons of furnace matte are poured into the converter. After the slag is poured about 3 tons of quartz or siliceous ore and quartz are added and the shell is blown for another fixed time. The length of the blow, the amount of slag removed, the weight of matte added after each skim, and the per cent of flux required are all factors of the grade of matte and have to be determined by experience.

The blowing and the addition of matte is kept up until there remains in the converter 70 or 80 tons of finished product. This may require from 300 to 400 tons of furnace matte and from 30 to 50 hours blowing time depending on the matte grade. The finished matte is then cast into moulds, and the cycle of operations re-commences.

The basic converter has several advantages over the acid converter. The units are very much larger. This simplifies the problem of dealing with large quantities of matte. There is practically no material slopped out of the converter during the blow, hence less furnace matte is required to produce a ton of bessemer matte. The slag made is lower in silica which means economy of flux. The converter slag contains less copper-nickel than the acid converter slag, but since all the converter slag has to be re-treated, this of itself, is not material. As a whole the operation of converting has been much simplified by the change.

THE REVERBERATORY FURNACE.

During the last few years about fifty thousand tons of flue dust have been recovered from the blast furnace dust chambers. Several attempts have been made to briquette or sinter this flue dust so as to make it useful as a blast furnace charge, but these have proved ineffectual, either by failure of the method or by extravagant cost. The flue dust has therefore been set aside in piles to await the building of reverberatory furnaces. There has been a similar accumulation of green ore fines from the mines, material under ¼ inch diameter which is too small for the blast furnaces.

In the year 1911 the Canadian Copper Company commenced the erection of two large reverberatory furnaces. The first of these was blown in at the end of December, 1911.

These reverberatory furnaces are interesting as being the first designed to burn pulverized coal. Experiments in the use of pulverized coal have been previously made by Chas. Shelby at Cananea, and by S. S. Sorensen at the Highland Boy smelter, but while these experiments proved that this method of coal firing could be used, local conditions prevented its adoption. In neither case were the furnaces specially designed to meet the requirements of this fuel.

The furnaces built at Copper Cliff are 112 feet by 19 feet hearth area. The side walls are 27 inches thick. The roof is 20 inches thick for the first 35 feet near the coal burners and 15 inches thick for the rest of the way. The extreme height inside is 6 feet. The bottom is an inverted arch of magnesite brick with a spring of 12 inches. The spring of the roof arch is 19 inches, one inch rise to the foot.

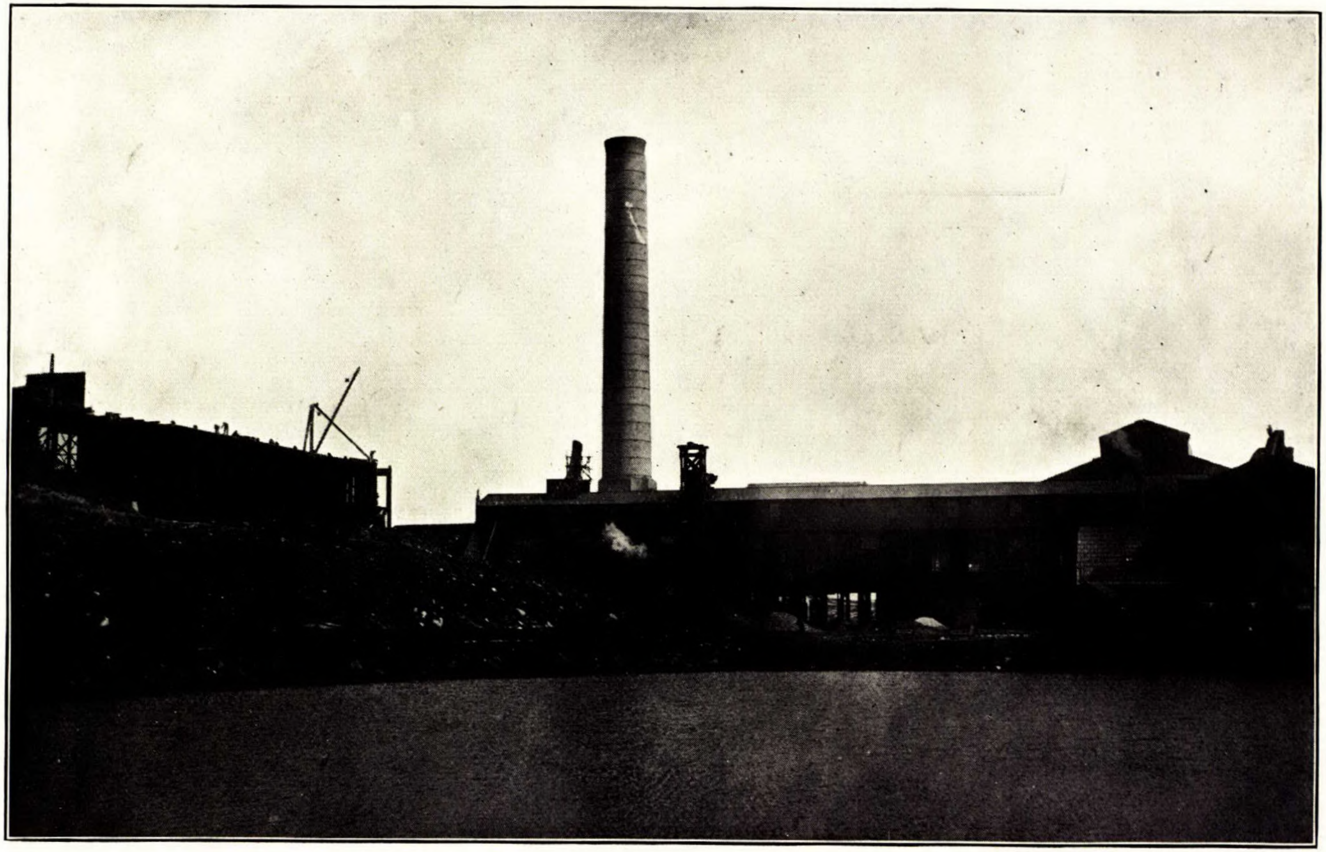
The foundation of these furnaces was made by building a trestle about 14 feet high, and pouring furnace slag from this, to build up within the outer walls a solid block of slag ten feet high above the yard level. On this foundation the side walls of the reverberatory furnaces were built. Slag was poured inside these walls to form a hearth or furnace bottom about two feet thick. By this means a solid mass of slag about 12 ft. thick was formed under the furnace. Between the furnace openings were formed by concrete retaining walls, so as to leave tunnels entering the slag foundation at the yard level, at either side of each furnace. Through these tunnels the melted converter slag is brought to the reverberatory and matte is taken back.

The hearth of the furnace is formed by levelling up the poured slag bottom with concrete so as to provide an inverted arch of the same curve as the magnesite brick lining. On this form one layer of firebrick was laid flat, 2½ inches thick. Over this 2 inches of ground chrome ore was laid, and on this the final bottom of 9 inches of magnesite brick was laid. This brick hearth was laid in a mixture of ground magnesite and linseed oil. Expansion strips of wood were placed between every six courses. The expansion allowed is ¼ inch to the foot.

The side wall is of silica brick 18 inches thick. On this the roof rests. Inside this wall a flash wall of magnesite 9 inches thick is built. This does not support, but is brought close up to the roof. The tap hole is so placed as to retain 12 inches of matte in the hearth, so that the bottom is always protected by a pool of matte.

Slag is removed, not at the front of the furnace as is usually the case, but at either side where the side walls commence to narrow in, about 11 feet from the front of the furnace. The space at the front usually occupied by the slag door, slopes up gradually from the hearth to form a straight

25873—16



Reverberatory furnace plant: Canadian Copper Co. smelter, Copper Cliff.

PLATE LIII.

25872—16½

Interior reverberatory furnace building: Canadian Copper Co. smelter, Copper Cliff.

outlet for the products of combustion. The area of the throat is about 27 square feet. The gases meet no obstacles whatever, but pass straight into a cross flue 6 feet by 9 feet, which is covered by cramps. This flue is 70 feet long, and leads to the main or dust chamber flue. The main flue is 15 feet by 19 feet by 200 feet, and connects with the stack. The stack is 17 feet 2 inches in diameter at the bottom, 15 feet 4 inches in diameter at the top, and 200 feet high.

At the fire end of the furnace two sets of charging bins are provided. These are used to drop flue dust, ore fines and other pulverized material into the furnace. Each bin has five hoppers, discharging by slide gates through the roof.

The most interesting part about the reverberatory is the method of firing. Coal is dropped from the trestle into storage bins. Out of these bins it passes through a coal cracker on to a conveyer belt. This coal $\frac{1}{2}$ inch in size, and under, is carried by this conveyer belt to the coal grinding room and dropped into a bin. From this bin it is fed by a screw conveyer to a Ruggles Coles dryer. The dry coal is elevated into bins from which it drops into two Raymond impact pulverizers, which grind the coal to the finest powder, most of it passing a 200 mesh screen. The pulverized coal is sucked up by a fan into a separator on top of this building, passed by screw conveyers into the reverberatory building, and dropped into bins at the end of the furnaces. From these bins it is taken by five variable speed screw conveyers 4 inches in diameter which deliver the coal into five burners, dropping it in front of nozzles which carry air from a fan. The air blast sends the coal into the furnace in the form of a cloud or spray of dust which burns just like fuel oil. Each burner can be run independently and the amount of coal or air can be varied at will.

The converter slag from the building is brought to the reverberatory furnace in ten ton pots by a locomotive, which enters the tunnels between the furnaces. Through openings in the roofs of these tunnels the reverberatory cranes pick up the slag pots, and pour the slag through an opening in the roof into the furnace. The slag skull being left in the pot, the pot is set back on its truck in the tunnel, and reverberatory matte is tapped into it, and taken back by the locomotive to the converter building to be charged into the basic converters.

The reverberatory building was put in operation before the bins were completed. At present flue dust and green ore fines are charged through the side doors by hand and as the charge is wet and frozen the amount charged is at present low. The coal firing system however is quite satisfactory and no difficulty is experienced from coal ash. A small amount of ash settles in the flue near the end of the furnace, and is removed through doors about twice a week.

As the plant has been in operation only a few weeks and under abnormal conditions, no comparisons can be made with western practise. It may be stated however that the system of firing is quite satisfactory, and that with the charge put in through the bins it is expected that this method of firing will prove much cheaper than burning coal on a grate. There is no loss of fuel efficiency, since all the carbon in the coal is consumed. The ash offers no difficulty and the heat of the furnace is maintained uniform.

After the furnace has been in operation a few months under normal conditions some comparisons may be instituted. Present indications are that these comparisons will show that this system of firing has many advantages over the grate firing of coal which has heretofore been the customary practise.

The Power Plant of the Canadian Copper Co.[1]

When the present smelter was blown in, the construction of a hydro-electric plant had not been considered. The various mines and shops, etc., had their individual steam equipments, and for the first two years the smelter was operated by steam generated power.

The steam power house is 100 feet by 160 feet. The walls are brick with masonry foundations. Steel trusses support a roof of hollow book tile covered with plastic slate. A longitudinal brick fire wall runs through the centre of the building and divides the engine room from the boiler room. The floors are of reinforced concrete.

There are two pairs of 400 horse-power water tube boilers furnishing superheated steam at 160 pounds pressure, and the necessary feed pumps, feed water heaters, hot well pump, dry vacuum pump, and a 24 inch barometeric condenser. In the boiler room are also a 1,000 gallon underwriter pump, 700 gallon duplex furnace feed pump, and a cross-compound 18 × 11 × 18 compressor.

As all the water used at the plant contains from 15 to 20 parts per million of acid, it was necessary to install a purifying plant. This supplies also the locomotive water tank.

In the engine room is the following equipment:—

Two furnace blowing engines, cross-compound Corliss steam, 13 × 25 × 42, duplex air, 57 × 42, giving a pressure of 60 oz. Capacity 20,000 feet per minute at 85 r.p.m.

One converter blowing engine, cross-compound steam, 15 × 30 × 42, duplex air, 40 × 42, giving blast pressure up to 15 lbs. Capacity 10,000 feet per minute at 85 r.p.m.

Two generator sets, each consisting of 350 horse-power tandem compound Corliss engine, 13 × 26 × 24, 200 r.p.m. direct connected to 200 k.w. 600 v. 3 phase, 25 cycle generator, with 11 k.w. belt driven exciter.

One 30 k.w. motor generator set, delivering direct current at 250 volts.

All this equipment is kept as a reserve in case of serious accident to the hydro-electric plant. One boiler is kept under steam, banked in summer and supplying steam heat to the various buildings in the vicinity in winter.

For lack of room in the electrical sub-station, there is installed in the steam power house also one 300 foot rotary furnace blower, rope driven by two 225 horse-power induction motors. There are three speeds, the maximum giving 30,000 cubic feet per minute.

The water power referred to above was developed by a subsidiary company, formed for this and other purposes, known as the "Huronian Company". The site is at High Falls on the Spanish river in the township of Hyman, about 4 miles from the "Soo" line of the Canadian Pacific railway, at a point about 23 miles west of Copper Cliff station. It is connected with the railway by a spur line from Turbine station.

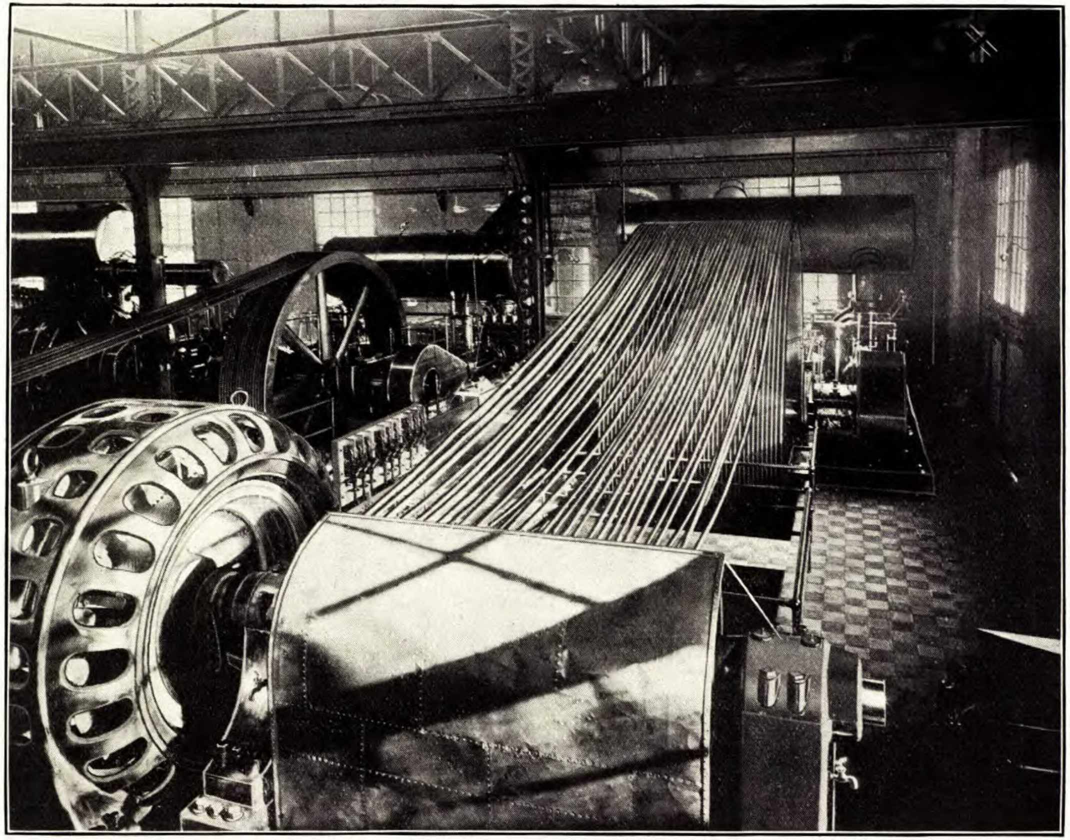
Work was begun on this spur line in the spring of 1904, and on the power development proper in the following September. Power was turned on at Copper Cliff in February, 1906. The power house is situated on the lower point of an island in the river, across which the water is carried. The natural head was 67 feet, which has been raised by the dams to 85 feet. The effective watershed is upwards of 2,000 square miles, practically all unimproved, containing a large area of lakes.

The dams are all of concrete construction on solid rock. This work was carried on continuously throughout the winter of 1904-05. Log slides

[1]Canadian Mining Institute, Vol. XII, 1909, pp. 231-239.

Canadian Copper Company's power plant, High Falls of Spanish river.

Canadian Copper Co. generators at High Falls.



Substation: Copper Cliff.

and booms had to be provided, to handle the very large cut of timber which is annually driven down the Spanish river.

From the bulkhead wall, three 9 foot steel penstocks for the generators, and one of 3 feet for the exciters, are carried down the slope to the power-house, which is of brick on a concrete substructure, with steel roof trusses.

The roof covering is 2 × 4 lumber on edge, sheeted with galvanized iron. The building is 106 feet long by 71 feet wide, with an annex 33 × 30 at one end for workshop and heating boiler. The blow system of heating is used.

The generator room is 55 feet wide, leaving 16 feet along one side for the transformer rooms and switch tower, which are separated from it by fire-proof brick walls and steel doors.

There is space for four generating units, three of which are installed. Each unit consists of a 2,000 k.w. generator, 3 phase, 25 cycle, 2,400 volts, direct connected to the shaft of a 3,550 horse-power turbine, on which are mounted two 34 inch bronze runners in a single case.

The head is 85 feet and the speed 375 r.p.m.

There are two exciters of 200 k.w. each, either of which can furnish excitation for four generators. Each exciter is driven by a small turbine, direct connected.

Three sets of transformers, of three each, step up the voltage from 2,400 to 35,000, at which it is transmitted.

The operators' bench board occupies a central elevated position in front of the switch tower, giving a full view of the generator room, and the switching operations in the tower. All switches are distantly controlled, and there is nothing higher than 125 volts on the board.

A small motor driven air compressor is installed for cleaning purposes, and for handling oil by air pressure.

For fire protection there is a 500 gallon 2 stage turbine pump, direct-connected to a 50 horse-power d.c. motor, operated from the exciter. The pump suction is connected to the penstocks.

No trouble has been encountered in this plant from frazil, there being no rapids upstream for six miles. The penstocks, bulkhead gates, and screens are housed, and the use of a small amount of current at critical points effectively prevents the building up of ice in the tubes.

Transmission Line:—The main transmission line is about 30 miles long, from the power house at High Falls to the sub-station at Copper Cliff, for the most part on its own right-of-way, 100 feet wide, all cleared. It is of double cedar pole construction, with poles at 8 feet centres, bolted to a common crossarm, the pole stands being placed 120 feet apart.

There are two independent 3 phase circuits of No. 1 wire, arranged in two equilateral triangles, 4 feet apart, and 4 feet to a side. One circuit is transposed and the other straight.

Branch lines of single pole, single circuit construction, run from the main line to Crean Hill mine and Creighton mine, each being about 3½ miles in length. These are both connected to the same main circuit with aerial switches.

Lightning arresters, of the horn type, are provided outside the power house and the sub-stations at Copper Cliff, Creighton, and Crean Hill.

A telephone line runs direct between the switchboards in the power house and smelter sub-station, along the transmission line. It is carried on a short crossarm, 6 feet below the main crossarm, with wires transposed every fifth pole. It gives perfect service.

A second telephone line, carried for the most part on the poles of the Canadian Pacific Railway's telegraph, connects the terminal stations with the Copper Cliff central, and also with Crean Hill and other points between.

Smelter Sub-Station:—This is the main distributing station of the system, and supplies motors in the building itself, and elsewhere, having a total capacity of over 7,700 horse-power, besides arc and incandescent lighting for the smelter, shops, etc., and the town of Copper Cliff. Most of the circuits in the furnace and converter buildings are placed underground in fibre conduits, laid in cement.

The building is 92 feet wide, by 194 feet in length. The foundations, walls and floor are of concrete. Steel roof trusses are carried on a central row and two outer rows of steel columns, the latter being built into the concrete walls. Two ten ton hand-power cranes are carried on two parallel runways extending from end to end of the building. The roof is of hollow book tile, covered with tar and gravel.

The transformer rooms and high tension switch tower are arranged along one side, separated by fireproof walls.

The following equipment is housed in this building:—

Two banks of transformers, three each, 667 k.w., 35,000 to 2,400 volts.

Three transformers, 175 k.w. each, 2,400 to 575 volts.

Most of the motors outside this building operate at 550 volts.

Fifteen panel switchboard.

Storage battery for controlling switches.

Four furnace blowing engines, duplex, radial valve, 70 × 42, capacity about 24,000 cubic feet of air per minute, delivered at 50 oz. pressure with 75 r.p.m. These are driven with fourteen $1\frac{1}{2}$ inch ropes, English system, two by 600 horse-power and two by 500 horse-power motors. The motors have special pole changing controllers giving three speeds.

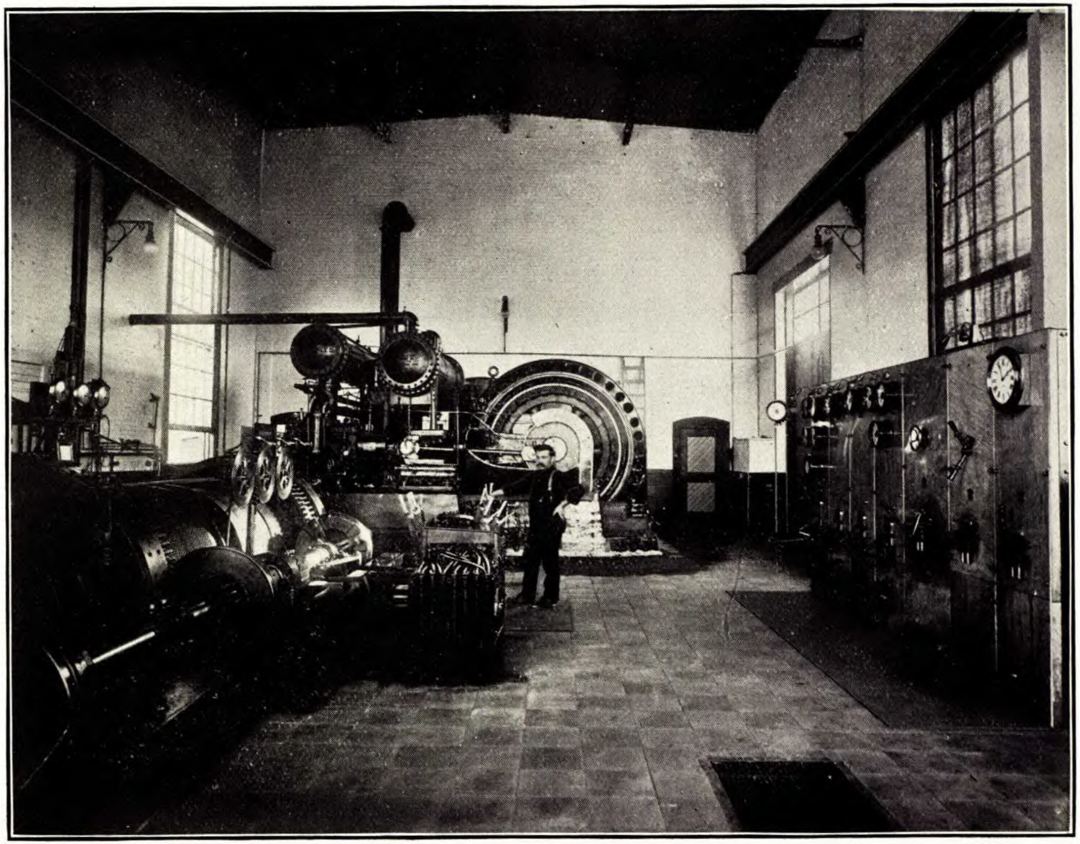
Each of these blowing engines is connected to one or more furnaces by a 48 inch blast pipe, carried on steel trestles. Two of these blast pipes are carried through, past the furnaces, to the steam power-house where they are connected to the rotary blower, and the two steam blowing engines previously referred to. Each blast pipe is equipped with a 22 inch multiple spring blow-off; and each engine with automatic gravity oiling system, revolution counter, recording pressure gauge, etc.

One converter blowing engine, duplex, Corliss valve, 40 × 36, capacity 10,200 cubic feet of air per minute at 12 lbs., 100 r.p.m., supplying four converter stands, driven by 500 horse-power motor with sixteen $1\frac{1}{2}$ inch ropes.

One converter blowing engine, duplex, Corliss valve, 60 × 48, capacity 20,700 cubic feet per minute at 12 lbs., 70 r.p.m., supplying 8 converter stands, driven by 1,200 horse-power motor, with forty-two $1\frac{1}{2}$ inch ropes. An additional blowing engine of the same kind has been installed for the new basic converter.

These two engines are each equipped with automatic unloading device, gravity oiling system, recording gauge, etc. They both discharge into a common receiver, from which a 36 inch blast pipe is carried on a steel trestle to the converter building.

One cross-compound 100 lb. air compressor, 15 × 24 × 24, capacity 1,500 cubic feet per minute, direct connected to a 300 horse-power motor at 120 r.p.m. The air from this machine is piped all over the plant, and is used for various purposes, such as blowing out motors, tamping converter linings, shell drying, operating air lifts on furnace doors and elsewhere, driving air winches and hoists, air tools of various kinds, forges, etc.



Power plant, Crean Hill mine.

One 1,000 gallon 6 inch 4 stage turbine fire pump, direct connected to a 225 horse-power motor. This pump, as also the underwriter pump in the steam power house, is connected to a series of dry fire lines, which are laid around the smelter buildings, with hydrants and hose houses at frequent intervals. A closed circuit electric fire alarm system is in service.

One 100 k.w. motor generator set, 575 a.c. to 250 d.c., operating the electric locomotives for furnace charging. This is the only direct current used anywhere in the system.

One 75 k.w. frequency changer, delivering 60 cycle alternating current for arc lighting. About 50 enclosed arc lamps are used for lighting the furnace and converter buildings, and the smelter yard, and 25 are supplied to the town of Copper Cliff for street lighting.

The building is heated by air, blown over coils by a motor-driven fan and distributed through ducts and floor registers. With the blowing engines removing usually over 100,000 cubic feet of air per minute, any ordinary means of heating would be futile, were it not so arranged that the engines receive their air direct from outside the building, through a large cold air duct in the basement, to which all the intake valves are connected.

A complete system of electric signals, with gongs and coloured lights, for the operation of the various blowing engines, connects this building with the furnace floor and the converter pulpits.

This sub-station, in addition to serving the smelter, is also the distributing point for No. 2 mine, for the shops, for municipal and domestic lighting, and for the cobalt smelter, which plant does not come within the scope of this paper.

The sampling plant is a three storey building, 30 × 48 feet. The upper floor is on a level with the furnace charging tracks, to which it is connected by a track carried on a trestle and forming a tangent to the curve at one end of the belt line. There are 24 bins, into which samples can be dumped direct from cars brought in by electric locomotive. These bins discharge into small tramcars on the crusher floor below. Two small jaw crushers are used, with "Duplex" samplers. Two laboratory crushers with riffle samplers form the next step, from which the material goes to various grinders and pulverizers for final division.

All the discard goes to a common bin at the bottom of the building from which it is hoisted in regular furnace charging cars by an electric elevator at the end of the building. This serves also to hoist to the crusher floor, samples which originate on the lower yard level.

The crushers and elevator are operated by a 15 horse-power motor, and the smaller machines by a 5 horse-power motor.

The laboratory is 34 feet by 79 feet, of concrete, brick and steel construction, with book tile roof. Care was taken to make it fireproof, as two laboratories had previously been destroyed by fire.

The building consists of one storey, with 9 foot basement. The main floor contains an analysis room, 32 × 40, and four smaller rooms, each 13 × 18, which are the head chemist's office, the balance room, the H_2S room, and the bacteriological analysis room, which also contains an assay furnace. All partitions are brick. The large room is open to the roof, and in each gable is a bull's eye window with an electric ventilating fan.

The hood is of down draft construction, with top light. It is made of concrete, iron and glass, and is ventilated by a suction fan in the basement. Electric hot plates are used, with the temperature controlled by plugs. Acetylene gas is used for the Bunsen burners.

In the basement, which has a separate outside entrance, are the store rooms, lavatory, private research room, photographic dark room, and the heating system, which is similar to that in the sub-station.

Warehouse:—A central warehouse building has been constructed at the smelter, which serves as the main distributing point for supplies for the various plants and mines. The building is 60 feet by 150 feet, two storeys and basement, built of concrete, steel and brick, with concrete tile roof. The floors are of reinforced concrete, designed for 300 and 150 pounds per square foot. There is an unloading platform 20 feet wide the full length of the building, and a three ton electric elevator serving all three floors. In this building are also the purchasing office and the electrical repair shop.

The Shops:—These include machine, locomotive, blacksmith, boiler, car, carpenter, and pattern shops; foundry and pattern storage. These buildings are at present rather inconveniently situated, and quite inadequate for the machines installed, and the volume of work done. As mentioned above, larger ones of modern construction are to be built. Most of the ordinary repairs and renewals for all the plants are executed here, including car and locomotive work.

Water Supply:—The general water supply is obtained by gravity from two small lakes. A heavy concrete dam has been constructed at their outlet, forming a very considerable reservoir, from which a 16 inch cast iron main leads directly to the smelter. Other mains supply the shops, etc., and the town of Copper Cliff.

Transportation:—To furnish efficient transportation service to the various departments, considerable equipment and organization is necessary. There are about 25 miles of tracks in service, mostly laid with 80 pound steel. Two standard hundred ton track scales are installed, one at the roast yard, and the other in the main yard near the shops. Both are properly housed, the latter containing also the transportation offices.

The motive power consists of nine locomotives. Four of these are 117 ton, six wheel switching engines. Two others are about 90 tons each, and three about 60 tons. There are also a 15 ton capacity locomotive crane, and two gasoline motor cars. The rolling stock includes twelve 50 ton dump cars, 125 flat cars, and 125 five ton dump cars, besides test car, wrecking tool car, and flanger.

For housing the motive power there is provided a six stall round house of steel, brick and concrete construction, with concrete floor and pits. This is served by a standard 70 foot, half deck steel turntable, with concrete foundations.

A complete telephone system, with twenty-four hour service, connects the general office with all departments, including the outlying mines and the power plant.

For the physical well being of the employes, there is a thoroughly equipped modern hospital, with a staff of physicians and nurses. There is also an accident insurance fund administered by a committee of the employes.

From the assurance of eminent authorities from almost every country who have visited this plant, the Canadian Copper Company feel justified in believing that, after the completion of the new shops, they will have, while not the largest, at least, all things considered, one of the best smelting plants in the world."

The Orford Process of Separating Nickel and Copper.

The bessemer matte produced in the basic converters at Copper Cliff is shipped to the Orford Copper Company's works at Bayonne, New Jersey, for final treatment. The method used is that of smelting the matte with coke and an alkaline sulphate, usually sodium sulphate, which dissolves the sulphides of iron and copper, allowing the heavier sulphide of nickel to go to the bottom. The different layers of molten materials may be tapped off at different levels; but the process is not complete at one melting, and must be repeated until the nickel sulphide is satisfactorily freed from the iron and copper.

As the Orford company do not permit an examination of their works, no detailed account of their methods is possible beyond the statements included in their patent, a copy of which is printed at the end of this volume, as appendix.

THE MOND PROCESS.

The bessemer matte produced by the Mond Company at Victoria Mines is shipped to Clydach, a suburb of Swansea, Wales, for final treatment by one of the most ingenious processes imaginable. It was discovered in 1889 by Dr. Carl Langer, working in conjunction with Dr. Ludwig Mond, that carbon monoxide, passed at a temperature not exceeding 80° centigrade over finely divided nickel, combined with the metal to produce a gas, nickel carbonyl, which could be decomposed again at a temperature of 180° C., thus depositing the nickel. The process was patented and an experimental plant was erected in 1892 at Smethwick, near Birmingham, to test it. As described by Roberts-Austen in 1899, the process was developed during some years of patient work, in which the plant had several times to be reconstructed to make it a practical success.[1]

Essentially five operations are required in order to produce the nickel, (1) dead roasting to drive out as much of the sulphur as possible; (2) the extraction of about two-thirds of the copper by sulphuric acid, the resulting sulphate of copper being sold in that form; (3) the reduction of the nickel and remaining copper to the metallic state by water gas or producer gas rich in hydrogen in an apparatus called a "reducer", the temperature of which is under perfect control, so that 400° C is never exceeded; (4) from this apparatus the substance, now reduced to the metallic state, is taken through air-tight conveyers and elevators into another apparatus called a "volatilizer" in which it is subjected to the action of carbon monoxide gas at a temperature not exceeding 80°C; (5) the nickel carbonyl thus produced passes into the "decomposer", a tower or horizontal retort heated to 180°C so as to release the nickel in the metallic state.

The process is not complete in one passage through the five stages, however, and the materials are made to circulate for a period varying from 7 to 15 days between stages (3) and (4) until about 60 per cent of the nickel has been removed as carbonyl. The residue from this operation, amounting to about a third of the original calcined matte and not differing much from it in composition, is returned to the first operation and follows the same course as before.

In operation (5) the carbon monoxide is released and is returned to the volatilizer to take up a fresh charge of nickel. When the operations are in progress the carbon monoxide gas and the partially reduced oxides of nickel and copper are continually revolving in two separate circuits

[1]Minutes of the Proceedings of the Institution of Civil Engineers, Vol. CXXXV, pp. 29, etc.

which join and cross each other in the volatilizer (4). The nickel is deposited on granules of ordinary commercial nickel which are automatically removed after reaching a certain size; and the product contains between 99·4 per cent and 99·8 per cent of nickel.

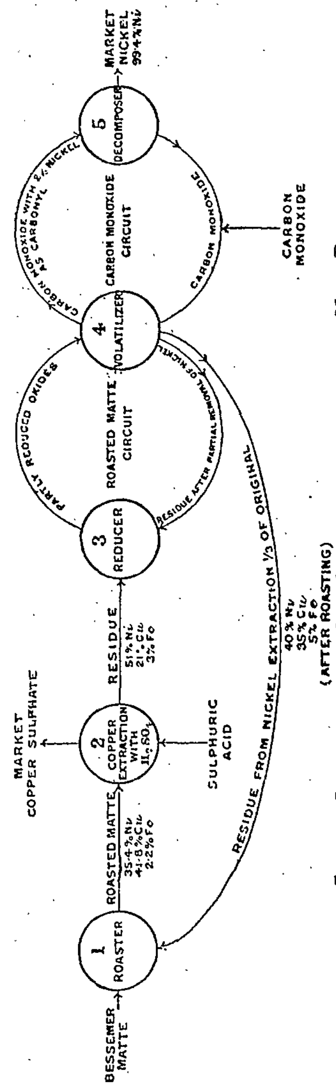
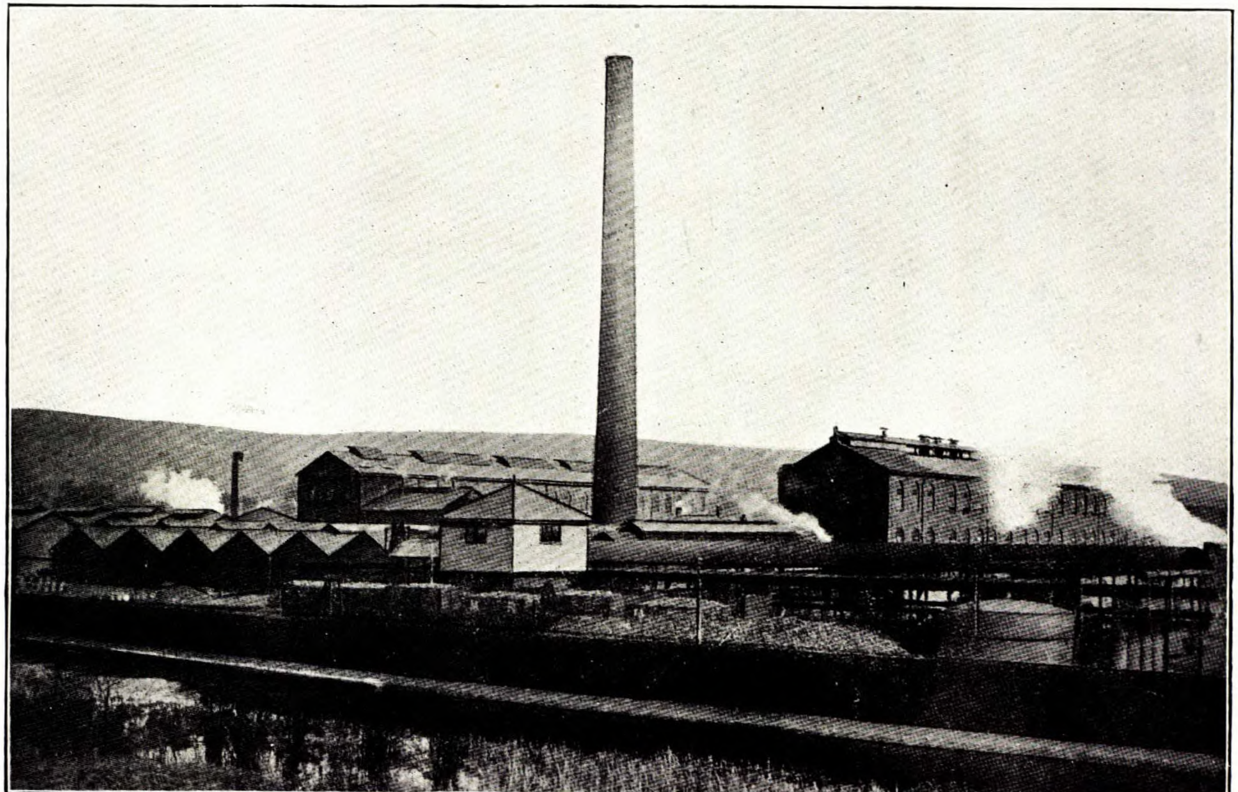


Diagram Illustrating the Five Operations Involved in the Mond Process.

Fig. 9.

Roberts-Austen describes the process as he observed it at Smethwick as follows:—

"The material under treatment during the author's visit was of Canadian origin, and had been received as calcined bessemer matte containing 35·4 per cent of nickel, 41·8 per cent of copper, and about 2 per cent of iron. This material was first passed through a ball mill and dresser with a sixty mesh riddle, and was then treated in quantities of 3 cwt. in a small lead lined mixer with 200 lbs. of ordinary sulphuric acid



General view of the Mond Nickel Works, Clydach, near Swansea.

which had previously been diluted with about 20 cubic feet of mother liquor from previous operations. These appliances are shown in the right-hand portion of the plan and elevation, Fig. 10. The temperature of the mixture soon rises by the action between the copper oxide and the sulphuric acid, and is kept, by means of a steam jet, at a temperature of about 85° C, for half an hour. From this mixer, the charge is run out into a centrifugal hydro-extractor, provided with a filtering cloth, in which the solution of

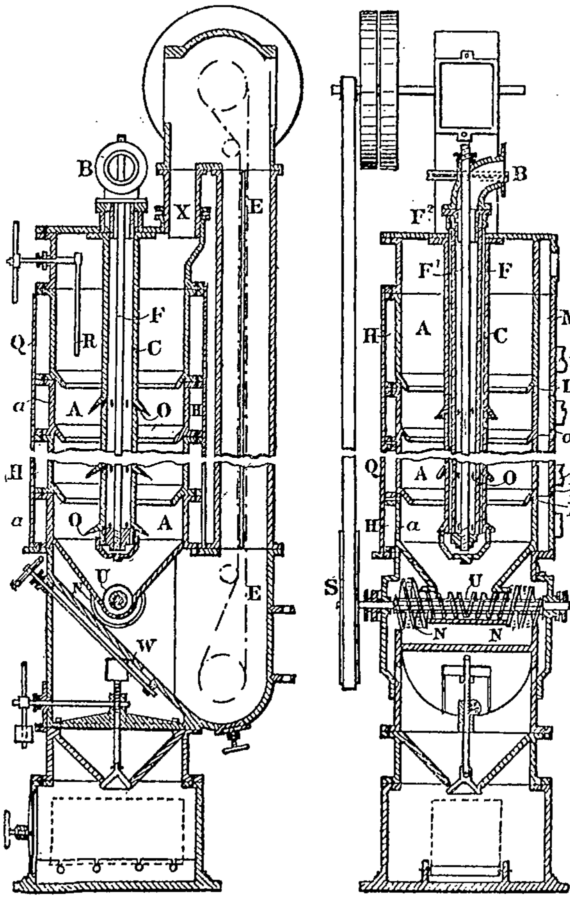


FIG. 10. Vertical sections through the decomposer: Mond process.

copper sulphate is separated from the solid residue containing the nickel. After the filtration of the charge is finished, the speed of the hydro-extractor is increased, and the residue is thus rendered sufficiently free from the liquor.

The solution containing the extracted copper runs from the hydro-extractor into a well, from which it is pumped into the crystallizing vats shown on Fig. 11. After a period of about 8 days to 10 days, the crystals of copper sulphate are taken out of the vats and the mother liquor is mixed with fresh acid and is again used for the extraction of copper. As already mentioned, a small amount of nickel and a little iron are also dissolved in the sulphuric acid during the copper extraction, so that the mother liquor from which the copper sulphate has crystallized becomes gradually contaminated with these two metals. It is therefore necessary to replace some of the mother liquor from time to time by fresh water, and to recover the nickel from the solution. The simplest method is to evaporate the solution to dryness and to roast the nickel and copper sulphates so obtained. The oxidized material is again introduced into the main process. The copper sulphate crystals from the crystallizing vats are charged into a second hydro-extractor, where they are washed with a little clean water to remove all acidity; they are then dried and are ready for packing. The copper sulphate thus obtained is sufficiently pure for market, as it contains only 0·05 per cent of nickel and 0·048 per cent of iron.

The residue from the copper extraction is taken from the hydro-extractor and stored in a bin until a sufficient quantity has been collected to make up a charge of 5 tons to 6 tons for the nickel extracting plant. It now contains 52·5 per cent of nickel, 20·6 per cent of copper, and 2·6 per cent of iron. The material is charged by hand at the rate of half a ton per hour into a feeding hopper, described as the matte inlet in the lower part of the plan, Fig. 11, which communicates, through a rotary valve, with the conveyer, consisting of a tube enclosing a revolving spiral, which transports the material to an elevator. This lifts the material to the top of the reducing tower, and discharges it through another rotary valve into this reducing tower.

The reducer and the volatilizer (shown in the centre of Figs. 12 and 13) in which the treatment with carbon-monoxide takes place, are fully described in Dr. Mond's patent (No. 23,665 of December 10th, 1895). The reducer consists of a vertical tower about 25 feet high, containing a series of shelves, which are hollow so as to admit of their being raised to a temperature of 250°C by producer gas. The roasted matte falling on these shelves from above is stirred and made to descend from one shelf to that below it by rabbles actuated by a central vertical shaft. Water-gas passes up the tower to effect the reduction of the material. There are about fourteen of these shelves or trays in the tower. The five lower shelves are not heated by producer gas, but are cooled by a stream of water in order to reduce the temperature of the roasted and reduced matte to the temperature at which the volatilizer is worked.

The volatilizing tower resembles the reducer, but the shelves are not hollow, as there is no necessity to heat them. The reduced nickel requires a temperature of only 50°C, to enable it to combine with carbon monoxide and form a volatile compound, and the matte and gas are sufficiently hot to maintain this temperature. In the plant at Smethwick the volatilizer was made the same size as the reducer, but in the new plant it is somewhat smaller.

The decomposer has been devised with much care, and has, in its present form, only recently been patented. The nickel is deposited in it, from its gaseous compound with carbon-monoxide, on granules of ordinary commercial metal. The arrangements by which this is effected are very ingenious, and may be described almost in the words of Dr. Mond's latest patent. The object is to obtain metallic nickel from nickel carbonyl in the form of pellets, which are specially suitable for the production of nickel alloys. For this purpose gases containing nickel carbonyl are passed through granulated nickel, which is kept at the temperature required for the decomposition of the carbonyl, about 200°C. The nickel which thus separates from the carbonyl becomes deposited on the granulated nickel, which consequently increases in size. In order to prevent cohesion of the granulated nickel, it is kept in motion. When a number of the pellets have attained a convenient size, they are separated by sifting without interrupting the depositing operation, the smaller granules being returned to receive a further deposit from the nickel carbonyl. A convenient form of apparatus for effecting the process described is shown in Fig. 10, which represents vertical sections of the apparatus on planes at right angles to each other. A is a cylindrical vessel, preferably built up of short cylinders, a a, bolted together; it contains a central tube, C, provided with gas outlet holes O, through which the gas containing nickel carbonyl, entered at the gas inlet, B, passes into the vessel which is filled with shot, or small granules of nickel. The gas permeates through the interstices between these granules, and is brought into intimate contact with them, and when the nickel carbonyl is decomposed, the nickel is deposited on the granules.

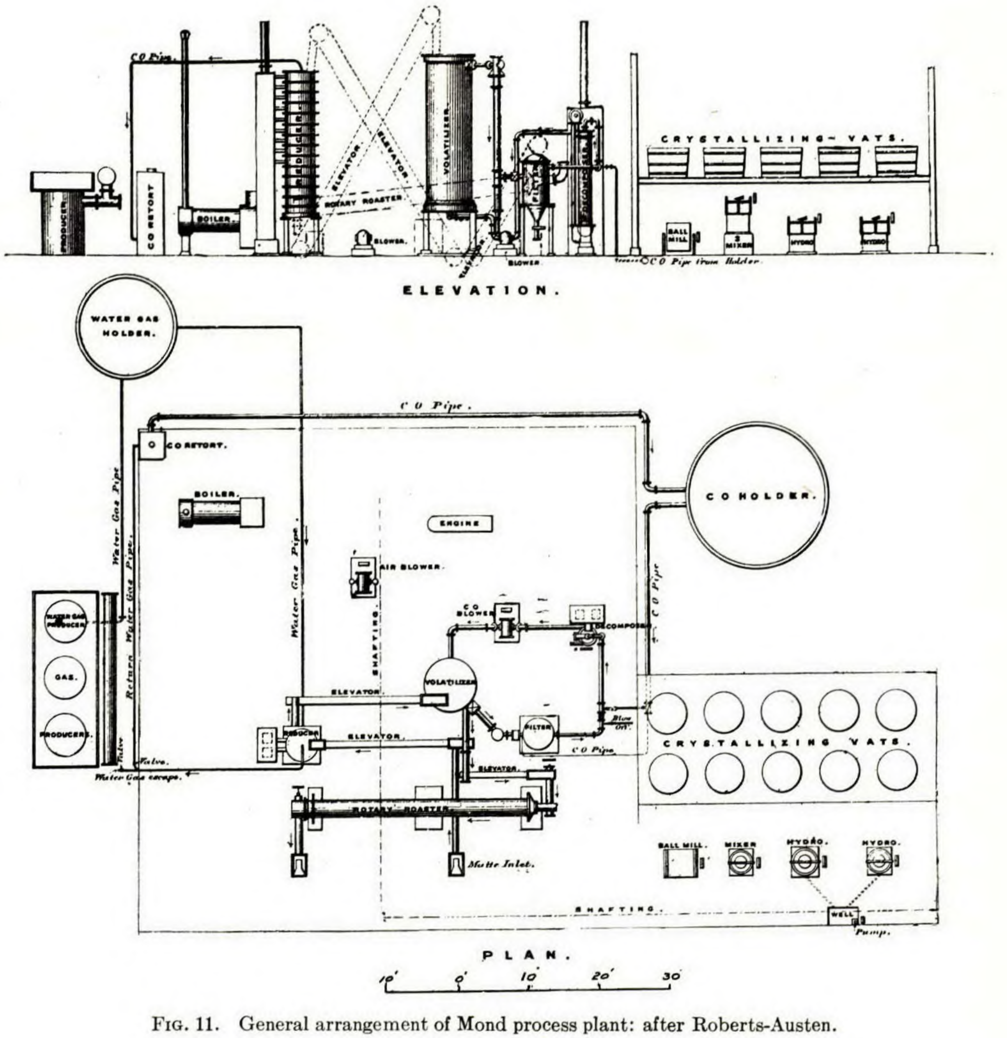


FIG. 11. General arrangement of Mond process plant: after Roberts-Austen.

The gases finally escape through the outlets, L, into the gas exit pipe M. In order to prevent the granules from cohering, they are kept slowly moving by continuously withdrawing some of the granules from the bottom of the cylindrical vessel, A, by means of a right and left-handed worm conveyer, U, which delivers the granules into two sifting drums, N. The smaller granules fall on to the inclined plane, W, and collect at the base of the elevator, E, which conveys them again to the top of the cylinder, A, and feeds them through the feeding-hole, X. In order to avoid the deposition of nickel from the nickel carbonyl in the central tube, C, it is kept cool by causing water to circulate down the tube, F, and up through passages, F, formed in the central tube, to the water outlet F^1. The cylindrical vessel, A, is surrounded by a wrought iron casing, Q, which forms heating-spaces, H, communicating with heat flues, P, which are so arranged that the temperature of each cylinder can be separately regulated by dampers, so as to maintain the temperature of the granules of nickel contained in the vessel, A, at about 200°C, at which temperature the nickel carbonyl is decomposed. With a view to ascertain whether the cylinder, A, is full of granules, a rod, R, is fixed to the spindle of an external handle, which can be turned partly round, so that if the operator feels resistance to the motion of the R, it is certain that the granules extend to that height. The appliance used for depositing the nickel originally consisted of a series of retorts lined with tin steel sheets, on which the nickel was deposited in layers. It was found, however, that the metal so obtained was very difficult to cut, and the apparatus above described was accordingly devised.

A magnified section of a granule of nickel, shows a core of nickel with a crystalline and convoluted structure surrounded by concentric layers. The central core is ordinary commercial nickel, and the layers are nickel deposited from its carbonyl. In some cases granules of deposited nickel are found without any central core. These have grown from minute fragments of deposited nickel which have become detached during the course of deposition.

The water gas used in the reducer is generated in gas producers, three of which are shown on the left of the plan, Fig. 11. Anthracite is used to decompose the steam, and the water gas is collected in a gas holder, whence it is taken to the reducing tower, to which reference has just been made. This gas contains on entering the reducer, about 60 per cent of hydrogen.

The reducing operation is so regulated that only a small quantity of hydrogen remains in the escaping gas, as a rule not more than 5 per cent to 10 per cent. This waste gas is subjected to the action of a fine water spray which condenses the steam generated by the combustion of the hydrogen in the water gas. Part of this waste gas is used for making the carbon-monoxide required in the volatilizer, by passing it through the CO retort charged with incandescent charcoal, Fig. 11, which reduces the carbon-dioxide contained in the waste gas, and this increases the amount of carbon-monoxide in it. The gas issuing from this retort contains about 80 per cent of carbon-monoxide, and is stored in another gasholder, which communicates with the main circuit of the carbon-monoxide gas. This main circuit of the carbon-monoxide passes through the volatilizer already referred to, where the nickel is taken up. The carbon-monoxide, now charged with nickel, passes through a filter to separate the fine particles of matte-dust from the gases, then through an apparatus called the decomposer, and so described in the figure. In this decomposer the nickel taken

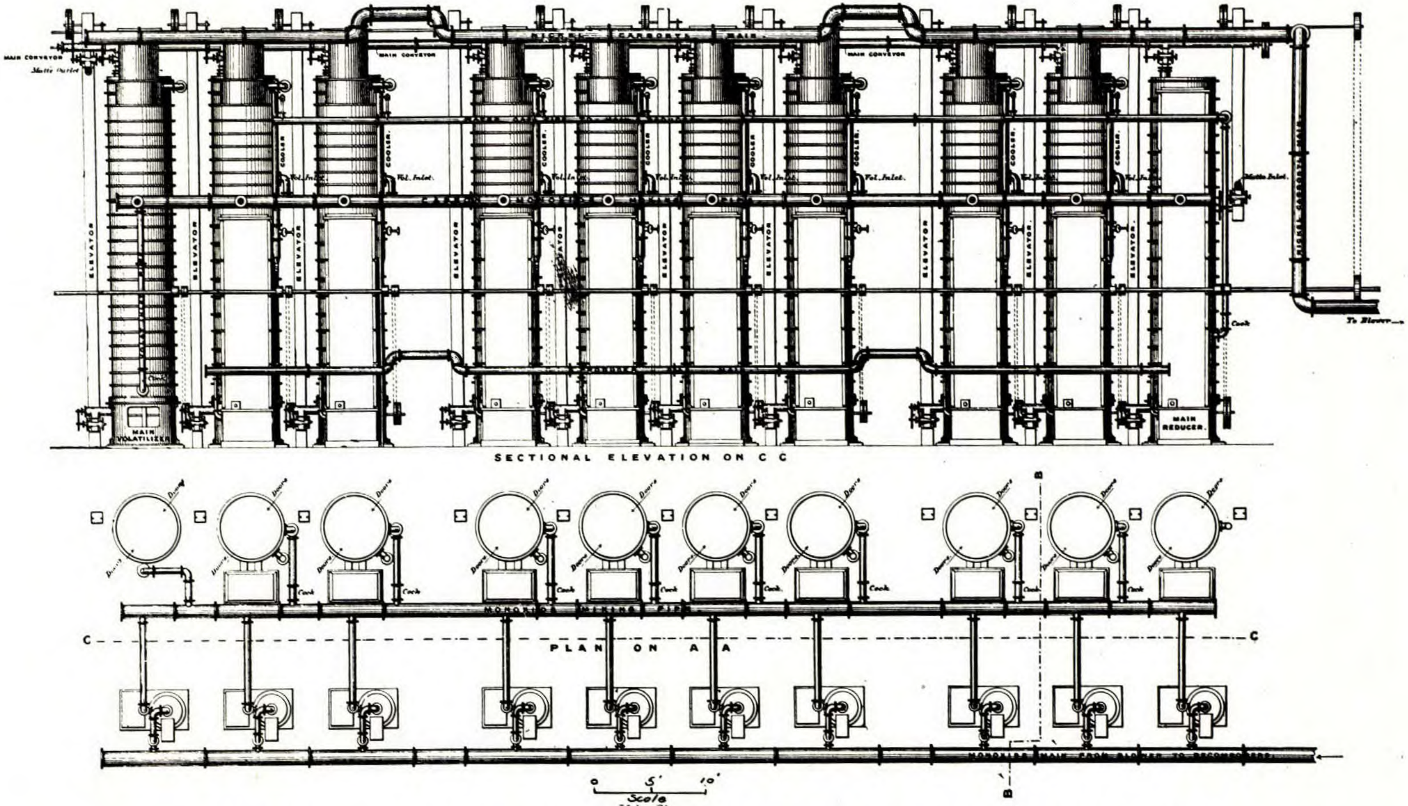


Fig. 12. Arrangement of reducers and volatilizers for extraction of nickel: Mond process: after Roberts-Austen.

up in the volatilizer is deposited. The gas now deprived of its nickel passes to the CO blower, Fig. 11, which sends the carbon-monoxide to the volatilizer in order that it may take up a fresh charge of nickel.

The solid material from which the nickel is being extracted is kept circulating through the reducer and volatilizer for a period varying between 7 days and 15 days, during which time the oxides are gradually reduced to the metallic state and the nickel volatilized. When the material originally charged in has had the bulk of its nickel extracted it is run out through a rotary calciner roaster, Fig. 11, which converts the metals into oxides, so that they may be treated for the second time with sulphuric acid and carbon-monoxide. The ratio between the nickel and copper in the residues from the nickel extraction is practically the same as in the calcined bessemer matte, with which the operations were started, but the amount of iron has increased by the removal of the copper and nickel, as the following figures show:—Original matte contains, nickel 35·27 per cent, copper 41·87 per cent, iron 2·13 per cent. After the first treatment of copper and nickel extraction, the quantities are, nickel 35·48 per cent, copper 38·63 per cent, iron 4·58 per cent; and after the second copper and nickel extraction, nickel 35·83 per cent, copper 35·56 per cent, and iron 7·82 per cent. The amount of nickel extracted in these two cases was, after the first treatment, 61 per cent, and after the second treatment 80 per cent of the nickel present in the original matte. It must be remembered, however, that in the second treatment only one-third of the original amount remains to be treated, while the final residue is only one-tenth. To avoid the formation of iron carbonyl, the temperature in the reducer has to be kept very low, and if this is done, the nickel extracted from a matte originally containing as much as between 6 per cent and 10 per cent of iron will not contain more than 0·5 per cent of iron. If the amount of iron in the residues rises above this percentage, the extraction of the nickel is very much delayed, on account of the low temperature which must be maintained in the reducer. It is necessary, in such a case, to re-smelt the residues before proceeding with the extraction of the nickel and copper. The following are analyses of the deposited nickel:—

——	I.	II.
	p.c.	p.c.
Nickel	99·82	99·43
Iron and (Al_2O_3)	0·10	0·43
Sulphur	0·0068	0·0099
Carbon	0·07	0·087
Insoluble residue	....	0·026

The experimental plant at Smethwick has been working for some time, and about 80 tons of nickel have already been extracted in it from different kinds of matte. The results obtained were quite satisfactory, and they point to the conclusion that the process is fully able to compete with any other process at present in use for the production of metallic nickel.

By the kindness of Dr. Mond, the author is able to exhibit plans for a large manufacturing plant, and Figs. 12 and 13 show a front elevation, plan, and cross section of it. This plant will, it is estimated, produce 1,000 tons of nickel per year. The plant is so arranged that the matte is continuously charged into the first reducer and traverses the whole set of appliances.

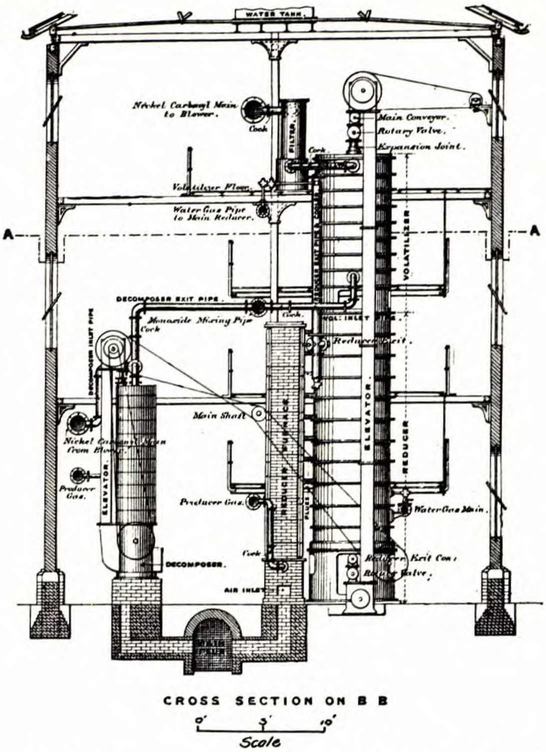


FIG. 13. Cross-section of reducers and volatilizers: Mond process: after Roberts-Austen.

When the matte issues from the last volatilizer the first nickel extraction is finished. The matte is re-roasted and submitted to the second copper and nickel extraction. There are ten appliances, consisting of one large reducer, eight combined reducers and volatilizers, and one large volatilizer. They are so arranged that the matte has first to pass through the large reducer, and is then lifted by means of an elevator and conveyer, into a volatilizer (erected on the top of the next reducer). The relative positions of the reducers and volatilizers are best shown in the cross section, Fig. 5. It passes through the volatilizer into the upper portion of the reducer and in traversing this it is further reduced. It is then lifted again to the next volatilizer, and so on till it finally reaches the larger volatilizer at the end of the whole series, and, after passing through this, it is discharged into the roasting furnace. The conveyer on the top of the volatilizers into which the elevators discharge, is common to the whole set of volatilizers and reducers, so that, in case any portion of the plant has to be disconnected, the rotary valve through which the material is discharged from the conveyer into the volatilizer is stopped. The material then passes on through the conveyer into the next volatilizer. The two gases, carbon-monoxide in the volatilizers and water gas in the reducers, are kept separate by rotary valves of the same construction as in the small plant. The water gas connexions are so arranged that each reducer receives fresh gas from the main, with the exception of the first large reducer, through which the waste gas of all the other reducers is passed, so as to burn completely all the hydrogen in the water gas. The carbon-monoxide passes through the volatiilizers from a common main, and is collected, after it has passed through the filters, in a main leading to the blower. From the blower the carbon-monoxide charged with nickel passes through a set of decomposers, and again into the main which feeds the volatilizers."

The works at Clydach are equipped in the way described by Roberts-Austen but with many more units, so as to produce 1,700 tons of nickel, 7,000 tons of copper sulphate, and 800 tons of nickel sulphate including a little nickel ammonium sulphate. Dr. Langer states that the nickel now produced is 99·98 per cent pure and is sold in the shot form to the Armstrong Co. for armour plate and to smaller firms of steel workers and producers of German silver and nickel plate. Some is sold also to Arthur Krupp, and to a pure nickel goods company at Berndorf near Vienna.

The works show none of the roughness and disorder of the usual metallurgical plant, but are as clean and scientifically managed as a laboratory, everything being accurately adjusted, and the temperatures of the different parts being frequently taken and recorded.

The gases employed in the process are very poisonous but so much care is taken as to joints and fittings that for eight years there have been no cases of poisoning.

The plant is run continuously except for a stop of three weeks in the year to clean flues and repair machinery; and the demand for nickel has increased so much that plans are made to double the present works.

Clydach, being in the midst of the Welsh anthracite and steam coal fields, supplies at a minimum of expense the varieties of coal needed for the production of carbon-monoxide and for other purposes in the running of the plant, as explained by Dr. Langer, and also gives a convenient distributing point for the sulphate of copper and other products resulting from the process.

I am under great obligations to the Mond Company for permission to visit the Clydach works, and to Dr. Langer for his courtesy in taking me through them.

Methods of Treatment at Evje and Kristiansand.

Although no Canadian ore or matte is used in the works at Evje and Kristiansand, in Southern Norway, their ores so closely resemble those of Sudbury that their methods might, no doubt, be used also in Ontario. The Flaad mine, three miles north of Evje in the Saetersdal valley, sends its ore by a cable tramway somewhat like that of Victoria Mines to the smelter beside Otra river. The ore is not subjected to heap roasting, partly, no doubt, because it is comparatively rocky in character, but goes directly into small water-jacketed furnaces. It averages 2·3 per cent of nickel and 1·2 per cent of copper, according to Mr. Henricksen, who was in charge of the smelter. The ore requires no flux but is mixed with from 7 to 10 per cent of coke from Westphalia, and a low grade matte is produced which

PLATE LIX.

Evje smelter, Saetersdal, Norway.

PLATE LX.

Evje smelter, Saetersdal, Norway.

PLATE LXI.

Reduction works, Kristiansand, Norway.

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PLATE LXII.

Water jacket furnaces: Evje, Norway.

PLATE LXIII.

Furnaces for high grade matte: Evje, Norway.

may contain from 8 to 15 per cent of nickel and copper, but usually not more than 8 to 10 per cent.

An example of ordinary matte contained 5·3 per cent of nickel and 3·15 of copper, while the slag ran 0·21 of nickel, 0·10 of copper, 26·2 of iron, and 38·6 of silica. Another example of matte from the larger of their two furnaces contained 5·25 of nickel and 3·30 of copper, with a slag running 0·30 per cent of nickel, 0·12 of copper, 23·4 of iron, and 39·4 of silica. A special grade of matte is sometimes produced containing 8·9 of nickel and 5·35 of copper; but apparently the standard of 30 per cent of the two metals usual at Sudbury is not aimed at, since the lower grade matte implies a smaller loss of nickel and copper in the slags.

Connected with the building containing the two water-jacket furnaces are sheds open on one side in which a number of small furnaces are used in making high grade matte with 70 or 80 per cent of the two metals, corresponding to our bessemer matte. These furnaces are open, almost like a blacksmith's forge, beneath a hood to carry off fumes, and are worked in what seems a most primitive way by two men who get the required result by a kind of instinct.

In this second smelting most of the sulphur is got rid of and 1½ tons of silica to 1 ton of the resulting high grade matte are required to flux off the iron, while to produce the necessary heat a ton of coke is needed. Mr. Borthen, one of the engineers of the works, informed me that high grade matte contained:

Nickel	50—60	per cent
Copper	30—20	"
Iron	1—2	"
Sulphur	20	"

and that the slag from the process contained one or two per cent of nickel and was sent to the water-jacket furnace with the ore. An estimate of the composition of the high grade matte supplied by Mr. Henriksen runs, however, somewhat lower.

Nickel	40—53	per cent
Copper	27—22	"
Iron	8—1	"

An assay of a particular sample ran as follows:—

Nickel	55·44	per cent
Copper	22·88	"
Iron	2·04	"

Apparently the somewhat crude and rough method employed gives rise to considerable variations in the composition of the high grade matte. Mr. Hybinette states that the cost of mining the Evje ore is $1.25 per ton, and that the smelting to low grade matte amounts to about as much; but that the second smelting costs about $20 per ton of high grade matte. One hundred men are employed at the mine and as many at the smelter.

The little establishment at Evje is interesting as a contrast with the great smelting plants at Copper Cliff and Coniston; and it is rather surprising to find so modest a plant with such simple methods able to compete successfully with these large, costly, and highly organized enterprises.

The high grade matte is shipped by narrow gauge railway to Kristiansand, the seaport at the end of the valley, to the refining plant which is under the charge of Mr. V. Hybinette. The works, which are a little west of the city, have been in operation for over a year and have been so successful that plans are under way for a large increase in the plant. I am under obligations to Mr. Hybinette for taking me through the works and explaining the process, which is in accordance with U.S. patents No. 805,550 and No. 805,969, taken out in 1895, and first used in the plant in the Southern States now owned by the Dominion Nickel Copper Company. As this electrolytic process is described in the patents, it will be unnecessary to refer to its features in detail at this point.

At the time of my visit—June, 1911, about one ton of nickel was produced a day having a composition as follows:

Nickel	98·70	per cent
Copper	0·07	"
Iron	0·63	"
Sulphur	0·02	"
Arsenic	0·005	"
Cobalt	0·90	"

In a general way it may be said that the matte is roasted to convert the metals into oxides, then leached with weak sulphuric acid, which extracts principally the copper. The residue is heated with sulphuric acid to a temperature at which hydrous sulphates do not exist, and is again leached with weak sulphuric acid to extract copper. The residue is then heated with hydrochloric acid to a temperature sufficiently high for partial decomposition of the anhydrous chlorides and again leached with weak acid, the heatings being repeated if necessary, in order to obtain a residue of nickel oxide suitable for further treatment.

Treatment of New Caledonian Ores.

Garnierite, the chief nickel ore of New Caledonia, is free from sulphur and copper and theoretically might be looked upon as a source of iron as well as of nickel; so that Garnier suggested that it be smelted direct to ferro-nickel. For this purpose two blast furnaces were built at Noumea in New Caledonia, and a refinery near Marseilles, in France. It was found, however, that there was sulphur enough in the fuel to rob this process of its value, since nickel has a high affinity for sulphur.

The method adopted therefore was to produce matte by adding fluxes and sulphur or some compound containing sulphur, in the smelting operations. The resulting matte, as described by M. Levat, contained 60-55 per cent of nickel, 25-30 per cent of iron, and 16-18 per cent of sulphur, which was treated with quartz sand in a reverberatory furnace to flux off the iron, or in a bessemer converter.[1]

The usual source of sulphur is gypsum, though pyrite, Norwegian pyrrhotite, and native sulphur have been used, gypsum apparently being used most frequently.[2]

It is stated that a similar method is still employed, but the policy of the Société Anonyme Le Nickel of refusing information or access to its smelters makes it difficult to get exact information. Mr. G. A. Boeddiker,

[1]Bur. Mines, Vol. II, 1892, pp. 151-3.
[2]Prof. J. W. Bain, Ibid., Vol. IX, 1900, p. 215.

of Henry Wiggin and Co., Birmingham, has kindly supplied the information that their refineries are in Scotland, France, Belgium, and Germany, and that formerly nickel ore from New Caledonia was treated also at Birmingham. He states that the method used in Birmingham was to smelt to a nickel-iron-sulphide or matte by mixing the ore with gypsum and coal or coke dust. The matte was crushed, calcined, melted in a cupola and tapped into a small bessemer converter and blown till free from iron. This matte was treated in the usual way by calcining to remove the sulphur, producing a pure oxide which was used for reduction into nickel.

Uses of Nickel.

An alloy of copper, nickel and zinc, called packfong, has been known to the Chinese since time immemorial, and it is stated that an alloy containing 77·58 per cent of copper, 20·04 per cent of nickel and 1·72 per cent of impurities was used for coinage by Ethydemos, who reigned over Bactria about 235 B.C.; so that alloys of nickel were used long before the pure metal had been separated from its ores. It is interesting to note that the Bactrian alloy is closely like that now used for subsidiary coins in the United States.

Pure nickel is employed in small amounts for a number of purposes because of its strength and durability and its white colour, which resists tarnishing. For these reasons several nations have introduced it for coinage, e.g. France, Switzerland and Turkey, and its cleanness and hardness contrast very favourably with copper or bronze on the one hand and silver on the other. It is rather surprising that Canada, which produces two-thirds of the nickel of the world, should still retain its ugly bronze cents and troublesomely small silver five cent pieces. These and the ten cent piece should certainly be replaced by pure nickel coins.

One might expect also that iron kitchen utensils, which constantly grow black and rusty, might well be made of the clean and white, and untarnishable metal nickel. For many purposes steel is now plated with nickel to preserve it from rusting.

Though the importance of pure nickel is likely to grow, the chief use of the metal is in the production of alloys, particularly nickel steel, in which the greater part of the nickel now refined is employed.[1]

The alloy of nickel with iron is no novelty, since all native iron of terrestrial as well as meteoric origin contains nickel. The telluric iron from Ovifak and elsewhere in Greenland contains, according to Dana, from 0·34 to 6·50 per cent of nickel, with an average of 2·11 per cent; and meteoric iron from various sources runs much higher, containing, according to the same authority, from 3·81 to 59·69 per cent. In Greenland such iron was long ago utilized by the Esquimo, who used to hammer off flakes of it from the large masses left on the surface by the weathering of the parent basalt, making from them knives and spear points. Peary with his supplies of modern steel tools and weapons put an end to this industry, at least for the present, and removed the largest masses of telluric iron to the United States.

Steel containing from $2\frac{1}{2}$ to $3\frac{1}{2}$ per cent of nickel has certain of its properties greatly improved, so that for many purposes it is replacing ordinary structural steel. Its value for armour plate has long been known, and the rivalry of the great maritime nations in the building of Dreadnoughts is

[1]See Bur. Mines, Vol. XIV, Part III, pp. 165-6.

one of the causes for the recent increased demand for nickel. It is stated by Mr. Monell, President of the International Nickel Company, that the growth of the motor vehicle business is important in this respect also; and its value for bridge building is shown by the selection of nickel steel for the rebuilding of the Quebec bridge, which fell so disasterously some years ago.

By the kindness of Dean Galbraith of the Applied Science Department of the University of Toronto, and of Mr. C. R. Young, the following data bearing on this use of the alloy may be given:

COMPARISON OF CARBON AND NICKEL STRUCTURAL STEELS.

Based upon Average Present Practice (1912).

——	Medium Carbon Steel	Medium Nickel Steel
Percentage of Carbon	0·20	0·38
Percentage of Ni	0	3·50
Elastic limit (lbs. per sq. in)	30,000 (Min.)	60,000 (Min.)
Ultimate tensile strength (lbs. per sq. in.)	60,000 (Min.)	105,000 (Min.)
Modulus of elasticity	29,000,000	30,000,000
Safe working stress in tension (lbs. per sq. in)	16,000	28,000

APPROXIMATE SAVING IN WEIGHT AND COST OF BRIDGES EFFECTED BY USE OF NICKEL STEEL.

Mixed Nickel and Carbon Steel—
- Saving in weight up to 25 per cent.
- Saving in cost up to 17 per cent.

Nickel Steel throughout—
- Saving in weight 10 to 30 per cent.
- Saving in cost up to 12 per cent.

Alloys much higher in nickel are employed for special purposes, such as *Invar*, steel with 36 per cent of nickel, which has the property of varying very little in length with change of temperature, making it of great value for tapes to be used in the accurate chaining necessary in geodetic surveys.

MONEL METAL.

Next to nickel steel the most important alloy is monel metal, so named for Mr. Ambrose Monell of the International Nickel Company, consisting of 68 to 72 per cent of nickel with the balance copper, except for trifling impurities (0·5 to 1·5 per cent of iron, 0·073 to 0·15 per cent of carbon, and 0·014 per cent of sulphur). The proportions of nickel to copper are those of the ores now worked by the Canadian Copper Company, so that the alloy may be produced directly from the matte, at a cost not much greater than that of copper. The alloy is silver white and takes a brilliant polish, which slowly turns greyish on exposure. It melts at 1350° C., has the same specific gravity as copper and can be cast or rolled and treated in various ways like copper or steel, but is distinctly stronger than ordinary steel or than manganese bronze. The Orford Copper Company in a circular to the trade makes the following statements as to strength, etc.:

	Castings.		1 inch rods.	½ inch plates.
	Grade C.	Grade D.	Rolled, annealed and cold drawn.	
Tensile strength (lbs. per sq. in.)......	70,000	85,000	110,000	90,000
Elastic limit (lbs. per sq. in.).........	27,000	40,000	80,000	45,000
Elongation in 2 in. (per cent)..........	30	25	25	30
Reduction in area (per cent)...........	35	25	50	60

They are prepared to furnish ingots, sheets, rods, bars, castings, tubes, and wire of this alloy; and it is stated that the sheets are as flexible and malleable as copper, and that wire may be drawn of all sizes down to 0·004 in., the finest being as soft and pliable as silk thread.

It is not alone strong but resists corrosion, and so may be used for many purposes for which steel is unfitted, such as propellers, boilers, and roofs exposed to acid fumes. During 1908 about 300,000 square feet of monel metal sheets were used to roof the Pennsylvania tunnel station in New York city.[1]

Because of its great colouring power nickel has long been alloyed with copper, zinc, etc. to produce a white metal imitating silver, and called by various names such as German silver, Brittania metal, or argentan. These alloys are familiar from their use in household articles, such as spoons, forks, etc., which are generally plated with silver.

[1]Mineral Industry, Vol. XVII, p. 671.

APPENDICES.

Patents relating to the

SEPARATION OF NICKEL AND COPPER

and the

REFINING OF NICKEL.

APPENDIX I.

METHOD OF SEPARATING NICKEL AND COPPER SULFIDS.

UNITED STATES PATENT OFFICE.

AMBROSE MONELL, OF NEW YORK, N. Y.

No. 802,012. Specification of Letters Patent. Patented Oct. 17, 1905.

Application filed January 19, 1903. Serial No. 139,630.

To all whom it may concern:

Be it known that I, AMBROSE MONELL, of New York, in the county and State of New York, have invented a new and useful Method of Separating Nickel and Copper Sulfids, of which the following is a full, clear, and exact description.

In the reduction of ores containing nickel and copper where a matte is produced containing sulfids of nickel, copper, and iron, a process has been devised in which a separation of the nickel sulfid is effected by the use of sodium sulfid, advantage being taken of its power of dissolving the sulfid of copper and iron freely and forming a solution of less specific gravity than the nickel sulfid. The matte mixed with coke and sulfate of sodium has been charged into a cupola-furnace. When this charge is smelted, the sodium sulfate is reduced by the coke to sodium sulfid and, forming a solution with part of the copper sulfid and iron sulfid, flows with the undissolved and melted sulfids of nickel, copper, &c., through the tap-hole, which is kept constantly open, into molds, where the molten constituents separate in accordance with their specific gravity, the sodium sulfid containing the dissolved copper and iron sulfids floating on the surface and the undissolved sulfids settling to the bottom. When the contents of the mold have solidified, the parts are separated by fracture and the tops containing the copper and iron are recharged into a smelting-furnace, where the sodium sulfid is fluxed off in an iron slag, being then lost. The bottoms contain most of the nickel sulfid of the original matte; but owing to the imperfection of the separation they also contain so much copper sulfid and iron sulfid that it is necessary to resmelt them with fresh additions of coke and sodium sulfate, and thus to repeat the smelting and separation to the fourth or fifth time before the bottoms are brought to sufficient degree of freedom from iron and copper to enable the resultant nickel sulfid to be economically subjected to the succeeding steps of the refining process. The process as thus carried on is slow and wasteful and because of the cost of materials and the amount of labor and handling required adds greatly to the expense of the nickel or nickel oxid, which is the final product. I have discovered that these difficulties can be overcome and the separation rendered quick and inexpensive by the following process.

Instead of smelting the compound matte, as heretofore, in a cupola-furnace and running the product continuously into molds I so smelt the matte that when melted it will remain in a molten state subject to the high temperature of a furnace for a considerable period of time, during which I find that the copper and iron sulfids will be thoroughly dissolved by the sodium sulfid, and in one melting a good separation can be effected, and by two such treatments results are obtained equal or superior to the results of the four or five meltings which have been employed heretofore. For this purpose I employ as the smelting-furnace an open-hearth reverberatory furnace lined with magnesite brick, as I find that silica-lined furnaces are quickly destroyed by fluxing with the sodium sulfid. Into such furnaces I introduce a charge of nickel-copper-iron matte, either solid or molten, together with coke and sodium sulfate, the latter being preferably present in the proportion of sixty per cent of the weight of the matte and the coke in the proportion of fifteen per cent of the matte. The sulfate is preferably added in the form of commercial niter-cake. Where, for example, a fifty-ton charge of matte is treated containing, say forty-five per cent of nickel sulfid and thirty-five per cent of copper sulfid, it is, melted in the furnace and retained subject to the heat for some time—say four to five hours after fusion has occurred—during which time it is preferably "poled"—that is to say, treated by immersing beneath its surface poles of green wood, which evolve hydrocarbon gases and vapors, and thus aid in the reduction of the sulfate and produce an agitation of the material, which facilitates and renders more thorough the solution of the sulfids to be removed. Nearly complete solution of the copper and iron sulfids in the sodium sulfid reduced from the niter-cake is thus effected, and the molten charge may be tapped from the furnace and allowed to separate in molds; but to get the best results I tap the different strata from the furnace separately, tapping first the solution of copper and iron sulfids floating on the surface of the bath and finally tapping the undissolved nickel sulfid, or the order of tapping may be reversed, the lower stratum of nickel sulfid being removed first. The great proportion of the iron and copper is thus separated the nickel sulfid obtained being nearly pure. Where greater purity is desired, the nickel sulfid may be recharged into the furnace and treated again in like manner.

The skilled metallurgist will be able to modify the apparatus and also to use other solvent materials. For example, sodium sulfid may be charged into the furnace instead of sodium sulfate, in which case, as no reduction is required, the coke may be omitted or a less quantity of it employed, and even when sodium sulfate is used deoxidation may be performed by the operation of poling without the use of coke or with only a little coke.

Instead of sodium sulfid I may employ the sulfids of other alkaline metals or sulfid of maganese.

I claim—

1. The method herein described of separating metallic sulfids, which consists in adding to a matte containing such sulfids, a material which is solvent for some of the sulfids therein, heating the mixture to the point of fusion of said solvent, maintaining the mass in fusion until substantially all of the soluble sulfids have been dissolved, and allowing the undissolved sulfid to settle and separating it from the dissolved sulfid or sulfids.

2. The method herein described of separating metallic sulfids, which consists in adding to a matte containing such sulfids, a material which is a solvent for some of the sulfids therein, heating the mixture to the point of

fusion of said solvent, agitating the mass and maintaining it in fusion until substantially all of the soluble sulfids have been dissolved and allowing the undissolved sulfid to settle and separating it from the dissolved sulfid or sulfids.

3. The method herein described of separating metallic sulfids, which consists in adding to a matte containing such sulfids, a material which is a solvent for some of the sulfids therein, heating the mixture to the point of fusion of said solvent, maintaining the mass in fusion until substantially all of the soluble sulfids have been dissolved, and allowing the undissolved sulfid to settle and withdrawing the molten strata separately.

4. The method herein described of separating metallic sulfids, which consists in adding to a matte containing such sulfids, in an open-hearth furnace, a material which is a solvent for some of the sulfids therein, heating the mixture to the point of fusion of said solvent, agitating the mass and maintaining it in fusion until substantially all of the soluble sulfids have been dissolved, and allowing the undissolved sulfid to settle and separating it from the dissolved sulfid or sulfids.

5. The method herein described of separating metallic sulfids, which consists in adding to a matte containing such sulfids, in an open-hearth furnace, a material which is a solvent for some of the sulfids therein, heating the mixture to the point of fusion of said solvent, agitating the mass and maintaining it in fusion until substantially all of the soluble sulfids have been dissolved, and allowing the undissolved sulfid to settle and withdrawing the molten strata separately.

6. The method herein described of separating metallic sulfids, which consists in adding to a matte containing such sulfids sodium sulfate and a reducing agent for the sulfate, heating the mixture to the point of fusion of the resultant solvent, maintaining the mass in fusion until substantially all of the soluble sulfids have been dissolved, and allowing the undissolved sulfid to settle and separating it from the dissolved sulfid or sulfids.

7. The method herein described of separating metallic sulfids, which consists in adding to a matte containing such sulfids, a material which is a solvent for some of the sulfids therein, heating the mixture to the point of fusion of said solvent, poling the mass and maintaining it in fusion until substantially all of the soluble sulfids have been dissolved, and allowing the undissolved sulfid to settle and separating it from the dissolved sulfid or sulfids.

8. The method of separating metallic sulfids, which consists in adding to a matte containing such sulfids, in an open-hearth furnace, a material which is a solvent for some of the sulfids therein, poling the mass, and maintaining it in fusion until substantially all of the soluble sulfids have been dissolved and allowing the undissolved sulfid to settle and separating it from the dissolved sulfid or sulfids.

9. The method of separating metallic sulfids, which consists in adding to a matte containing such sulfids, in an open-hearth furnace, a material which is a solvent for some of the sulfids therein, poling the mass, and maintaining it in fusion until substantially all of the soluble sulfids have been dissolved, and allowing the undissolved sulfid to settle and withdrawing the molten strata separately.

In testimony whereof I have hereunto set my hand.

AMBROSE MONELL.

Witnesses:
ERVU F. WOOD,
BENO B. GATTELL.

APPENDIX II.

PROCESS FOR REFINING COPPER-NICKEL MATTE.

UNITED STATES PATENT OFFICE

NOAK VICTOR HYBINETTE, OF WESTFIELD, NEW JERSEY.

No. 805,555. Specification of Letters Patent. Patented Nov. 28, 1905.

Application filed November 25, 1904. Serial No. 234,160.

To all whom it may concern:

Be it known that I, NOAK VICTOR HYBINETTE, a citizen of the United States of America, and a resident of Westfield, county of Union, and State of New Jersey, have invented certain new and useful Improvements in Processes for Refining Copper-Nickel Matte, of which the following is a specification.

The raw material for my process is a copper-nickel sulfid produced by roasting and smelting of ordinary copper-nickel ores. This raw material generally called "concentrated matte", contains about twenty-five per cent sulfur and one-half per cent to five per cent iron, the remainder being copper and nickel in differing proportions, generally about thirty-five to forty per cent of each metal.

The first step in my process is now to grind and roast the matte. The roasted material is leached with sulfuric acid until the material will no longer neutralize the acid. This step in my process is not new in itself and is well known to those conversant with the metallurgy of nickel. I prefer to grind the matte to a size passing through a screen with thirty meshes to the inch. The roasting is starting at a low temperature and gradually increased until the sulfur contents are brought down to about one per cent. More or less copper and nickel will be changed into sulfates; but such sulfur as is present as sulfates is not detrimental; but after the material is leached with water there may still be allowed to remain about one per cent sulfur. When the material is being leached with sulfuric acid, I take the precaution to use only dilute acid, so that the amount of free acid in my solution will at no time be more than five to ten per cent. In this way it is possible to remove the bulk of the copper without at the same time dissolving much nickel. My solution will contain one part nickel to about ten parts of copper. If I do the leaching with stronger acid, the proportion of nickel will be greater. The solution so prepared is crystallized and boiled down and again crystallized, and at each repeated crystallization I receive crystals of commercially pure copper sulfate. The mother-liquor from such crystallization contains copper and nickel in about equal parts. I concentrate it and boil it down to a solid mass of copper-nickel sulfates. The material that has been leached contains about fifty-five to sixty per cent nickel and twelve to eighteen per cent copper and is subjected to the second operation in my process. I mix the material with sulfuric acid of about sixty per cent free acid in such quantity that there will be sufficient acid to form sulfate of copper with all the copper that is present. The mass is then slowly brought up to a low red heat and roasted at that temperature for a short time. The reaction that takes place is that the free acid becomes combined with copper and nickel to sulfates of these metals; but sulfate of copper is preferably formed. When the material reaches a temperature of about 800° centigrade, the sulfates begin to decompose; but the sulfate of copper is not affected in the same way as the sulfate of nickel, and the consequence is that when the sulfates are completely decomposed, or nearly so, and the material drawn from the furnace and leached with weak sulfuric acid I again obtain a solution with about ten parts of copper to one part of nickel and which upon crystallization will yield commercially pure sulfate of copper. The mother-liquor from this second leaching is of the same nature as that above referred to and is boiled down, giving more salts of about equal parts of copper and nickel. This heating with sulfuric acid may be repeated, and after one or more such treatments I have a residue after leaching which contains about seventy per cent nickel and three to five per cent copper. The next step in my process is to mix this residue with hydrochloric acid or a mixture of common salt or chlorid of sodium and sulfuric acid. The material is again heated to a low red heat, and chlorids of nickel and copper are formed. As, however, chlorid of nickel is far more readily decomposed by heat than chlorid of copper, I can continue my roasting operation to a point where a maximum of copper and a maximum of nickel are present as chlorids. I then draw the material from the furnace and leach it with water and weak acid, whereby I obtain a residue of practically pure nickel oxid with about one-half per cent copper still present. The treatment with hydrochloric acid may be repeated, in which case a still more pure nickel oxid is obtained, assaying about seventy-seven per cent nickel and one-tenth per cent copper. This chloridizing roasting of nickel oxid for the sake of removing small percentages of copper is not unlike the ordinary Henderson process for the extraction of copper from ores and is well known to those conversant with metallurgy of nickel. The reactions that take place in my sulfuric acid process are probably not corresponding to or congruent with those of the chloridizing roasting. In the latter case chlorid of nickel is first formed and is decomposed as the roasting goes on, and more and more chlorid of copper is formed at the same time. By careful roasting copper can be extracted in this way down to mere traces. In the sulfuric acid treatment there is no decomposition of nickel sulfate with simultaneous formation of copper sulfate. In the leaching of the mixed oxid of nickel with weak sulfuric acid the copper is dissolved as long as the oxid of nickel in the mixed oxids is not in such excess as to protects the oxid of copper from the action of the acid. This point is reached when the copper percentage is down to twelve to fifteen per cent. It is lower the more copper was contained in the original material and the lower the temperature of roasting. After this point no separation of copper by leaching is possible, and such material has heretofore been handled in the very expensive way of completely dissolving the whole mass in hydrochloric acid and precipitating the metals separately from such solution. I have now found that if the material is heated in a furnace with concentrated sulfuric acid large quantities of both copper and nickel form sulfates, but always so that a greater proportion of copper than nickel is made soluble. This proportion is more favorable the higher the copper contents are in the material. If, therefore, the percentage of copper is as high as, say, eighteen per cent, I can draw the material from the furnace at a point below red heat, where only the free acid is driven off, and the solution with water will then contain copper and nickel in about equal quantities. When however, the copper is down to twelve per cent or below, I find that an undue proportion of nickel is made soluble, and I do therefore raise the heat to a point where all or nearly all nickel sulfate is decomposed. At this point the copper is also made insoluble in water, but not in the same way as the nickel, because it is again made soluble by very weak acid, and the solution so obtained contains very little nickel. I have no theoretical explanation to offer for this process; but it is a fact that each time the material is heated with sulfuric acid I can afterward extract a portion of the copper with acid so weak that it would have no influence on the material before said heating. This nickel oxid is refined to metallic nickel in one of the several ways now in use and well known to those conversant with the art. Preferably I may smelt the oxid to metallic nickel anodes containing about ninety-five per cent nickel. Such anodes are suitable for refining by ordinary electrolytic processes. This last leaching of chlorids leaves a solution from which no pure salts can be separated. It contains nickel and copper in about equal parts.

Each one of the three steps in my process has left a solution of mixed copper and nickel salts. I prefer to heat these salts to a strong red heat, whereby all the nickel sulfate and chlorid are changed in oxid. This residue is leached with water and weak sulfuric acid, whereby copper sulfate is again obtained, and the residue from the leaching is nickel oxid of about the same purity as that produced by the regular process.

It is evident that instead of heating with acid I may use its chemical equivalent, such as sodium bisulfate, which upon heating will give off sulfuric acid, and instead of using hydrochloric acid I may use sodium bisulfate and sodium chlorid, which upon heating will produce hydrochloric acid.

The treatment which I have called the "second step" is naturally more expensive than the first, and there is no call for its use until the copper contents are reduced to about twelve per cent, at which point the operation called the "first step" refuses to work satisfactorily. This second step give less favorable results the lower the copper contents are and has to be substituted by the treatment with hydrochloric acid when the percentage of copper is brought down to five to three per cent. This third step is not practical when the copper contents are above three to five per cent.; but by combining the three steps I can successfully treat all grades of material.

I do not intend to make any claim to the first and third steps in themselves. They have long been known to be well suitable for the separation of copper; but as the first step becomes impractical when the copper contents have been brought down to twelve per cent and the third step cannot very well be used until the copper is as low as three to five per cent it has been impossible fo combine the two in a practical process. I have now invented the process of separating copper from nickel by heating with sulfuric acid and leaching with weak acid, a process which is well suited to handle the material after the first step is no longer useful and leave a product which can be conveniently treated by chloridizing roasting.

There are many electrolytic copper refineries which treat nickel-bearing copper. These factories made as a by-product a mixed sulfate of about equal portions of nickel and copper. With former processes this salt has to go through a long and expensive separating process; but according to my invention these salts may be handled as the mother-liquor from crystallization of sulfate of copper, as herein described.

What I claim as my invention is—

1. The process of separating copper from nickel in copper-nickel matte, consisting in first roasting the matte to oxids, then leaching with weak sulfuric acid, thereby extracting principally sulfate of copper, then heating with sulfuric acid at least to a temperature where hydrous sulfates

do not exist, leaching with weak sulfuric acid, thereby extracting principally sulfate of copper, then heating with hydrochloric acid to a temperature enough for partial decomposition of the anhydrous chlorids, leaching with weak acid and repeating the said heatings when necessary thereby obtaining a nickel oxid, suitable for refining by ordinary means.

2. The process of separating oxids of copper and nickel by heating with sulfuric acid at least to a temperature where hydrous sulfates do not exist, leaching with weak sulfuric acid, thereby extracting principally sulfate of copper, then heating with hydrochloric acid to a temperature high enough for partial decomposition of the anhydrous chlorids, leaching with weak acid and repeating the said heatings when necessary thereby obtaining a nickel oxide, suitable for refining by ordinary means.

3. In the process of separating oxids by heating with sulfuric acid and leaching with weak acid, the method of heating the material to at least partial decomposition of the anhydrous sulfates and leaching with weak acid, thereby extracting copper oxid formed in said decomposition without extracting the nickel oxid formed at the same time.

Signed at New York this 22nd day of November, 1904.

NOAK VICTOR HYBINETTE.

Witnesses:
C. Sedgwick,
J. M. Howard.

APPENDIX III.

HYBINETTE PROCESS FOR THE ECONOMIC SEPARATION OF ALLOYS INTO THEIR CONSTITUENTS, BY ELECTROLYSIS.

UNITED STATES PATENT OFFICE.

NOAK VICTOR HYBINETTE, OF WESTFIELD, NEW JERSEY.

No. 805,969. Specification of Letters Patent. Patented Nov. 28, 1905

Application filed November 25, 1904. Serial No. 234,159.

To all whom it may concern:

Be it known that I, NOAK VICTOR HYBINETTE, a citizen of the United States of America, and a resident of Westfield, in the county of Union and State of New Jersey, have invented certain new and useful Improvements in the Separation of Metals, of which the following is a specification.

I have discovered a process for the economical separation of alloys into their constituents by electrolysis. It has been designed specially for the separation of nickel and copper from alloys of these metals, which are generally also associated with iron; but it may be employed for the treatment of other alloys.

The fundamental principles on which the process is built are as follows:

First. If copper-nickel alloy is electrolyzed, the nickel will dissolve more rapidly from the anode and the result will be that the anode-slimes falling to the bottom of the tank will consist mainly of copper compounds. If at the same time sulfur is present in the anode, sulfid of copper is separated as anode-slime. This reaction is one of the means used in my process for separating copper from nickel. I find in practice that about one-half of the copper which I take into the process is recovered as such slimes.

Second. There are at present in use several well-known processes for removing large proportions of copper from copper-nickel mattes. For instance, if a copper-nickel matte is roasted and leached with sulfuric acid, practically only copper is removed until the residue contains nickel and copper in the proportion of three to one. I have therefore in my power to produce an anode containing three parts of nickel and one part copper, and by the selective action of the electric current I have only to handle one part of copper to every six parts of nickel through my electrolytic solution.

Third. By this combination of processes I therefore come down to such proportions between copper and nickel that it becomes commercially possible to eliminate the copper by allowing it to pass off as an impurity through a solution of nickel, which is regenerated or purified as soon as the copper has accumulated in the solution to such an extent as to make the nickel deposit contain more copper than is allowed in the market.

Fourth. To be able to circulate a nickel solution in the way now mentioned, it has been necessary to invent a ready way to purify the same without in the least disturbing its plating qualities and return it in its original condition. Several electrolytic nickel processes have been proposed in the past; but all of them have had to make up new solution from time to time by an outside and independent process. Not all nickel-plating solutions would be suitable for such a process of constant regeneration; but

I have now found a solution which will lend itself to my purpose in a weak neutral solution of nickel sulfate to which a weak acid—such as phosphoric, boric, acetic, or lactic acid is added. That nickel can be plated in such solution is not new; but it has never been used for this purpose before.

Fifth. Means by which such solution can be purified from copper will readily suggest themselves to the trained metallurgist; but for the best results commercially I want to make use of one particular way—namely, cementation—and in this connection I have discovered certain conditions under which the cementation of copper on nickel and even on copper-nickel alloy will take place as readily as to make the reaction available for commercial purposes, as will be further described below. With this system of circulation and purification the quality of the nickel produced to a certain extent will only be a question of how fast the solution is circulated; but the process would not be so economical had I not introduced means by which a pure nickel could be produced at the same time, as the solution passing from the plating-tanks contains a considerable quantity of copper.

Sixth. I accomplish this end by separating anode from cathode in a novel way. It is done by inserting between the two poles a filtering-diaphragm directing the current of solution perpendicularly from the surface of the cathode to that of the anode. Such diaphragms have been used before, but never for the purpose of separating metals from an alloy constituting the anode. I believe also that I am the first one to use such diaphragm in a case where the least decomposition of the solution would prevent the plating of the metal on the cathode. Furthermore, I do not know that anybody has succeeded in giving to such diaphragm a mechanical construction which will allow of its being used in an ordinary electrolytic plating-tank where the anode and cathode are hung vertically.

After now having given an outline of the different means which I employ for obtaining my results I will give a more detailed account of the different steps which constitute the process.

Referring to the drawings, Figure 1 is a vertical section of the apparatus which I use, and Fig. 2 is a plan view.

A is the tank in which the electrolysis is carried out. It is preferably a wooden tank with or without lead lining. It has the overflow G, which always keeps the level of the solution at I and contains a filtering-bag D. The filtering-bag is made up of the wooden frame K and the two thicknesses of cotton cloth D, separated by the wooden frame K.

C is the cathode-plate with the wooden rib E, which is shown in the drawings to extend over the bottom edge of the cathode; but it may for still better protection extend all around the plate.

B represents the anodes.

F is the inflow, which is regulated in such a way that the solution in the bag stands at the level H, which is about one inch above the level I.

The rib E prevents the cathode from warping and making contact with the bag.

In separating copper and nickel I preferably employ as electrolyte a dilute solution of sulfate of nickel with a small proportion of weak acid—such as phosphoric acid, boric acid, lactic acid or other organic acid well known to those conversant with the trade—and I particularly prefer a solution of nickel sulfate and weak acid so diluted that it will not crystallize at ordinary temperature. Other solutions—such as a very concentrated solution of sulfate or chlorid of nickel with or without inactive salts, such as sulfate or chlorid of aluminium or magnesium, used at comparatively high temperature and with high current density as means of making a coherent nickel deposit—are not well adapted to my process, and I therefore intend to make a specific claim to the employment in this process of a solution

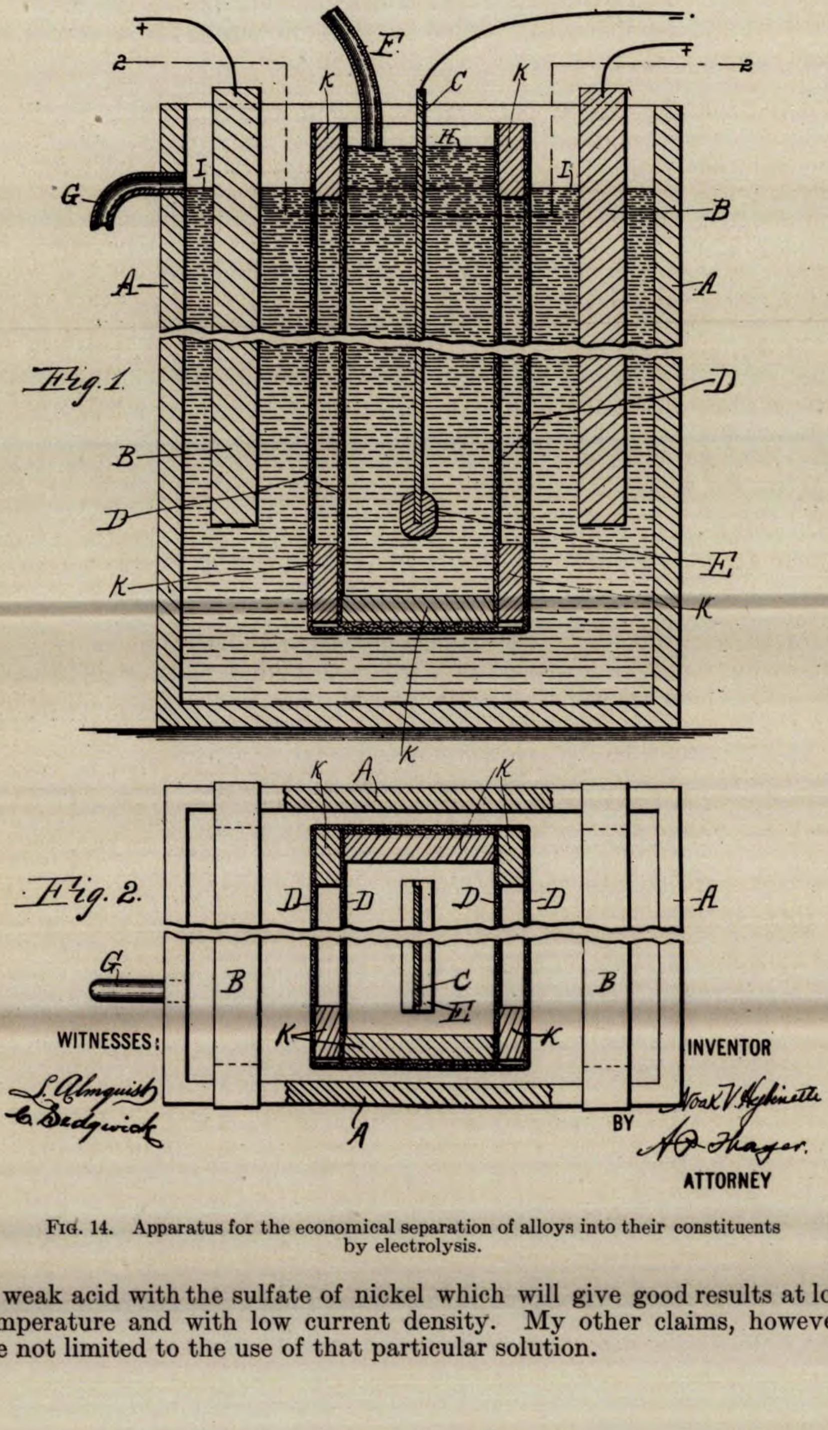

Fig. 14. Apparatus for the economical separation of alloys into their constituents by electrolysis.

of weak acid with the sulfate of nickel which will give good results at low temperature and with low current density. My other claims, however, are not limited to the use of that particular solution.

The first step of my invention consists in placing in the electrolytic solution an anode composed of the alloy to be separated and a cathode-plate upon which the metal is to be deposited and separating the electrodes by a pervious diaphragm, such as filter-cloth or filter-paper. This is done, preferably, by inclosing one of the electrodes, preferably the cathode, in a bag of such cloth or paper. In that it has a decided filtering capacity my diaphragm is of a different nature from those porous diaphragms ordinarily employed in electrolytic processes, which diaphragms allow one reaction to take place on one side and a different reaction on the other side. My diaphragm is so porous that if it were alone relied upon to separate the anode side from the cathode side the solutions would mix and become homogeneous in a short time. Its action is therefore supplemented by keeping the solution in motion, causing it to flow from the cathode to the anode through the porous material, and thus preventing the metal which has been dissolved at the anode from coming into contact with the cathode. The diaphragm-bag is, in other words, only a convenient mechanical device for directing the circulation of the liquid in a direction from cathode to anode.

The anode may consist either of a pure alloy of copper and nickel, containing, say, equal parts of these metals or containing them in other proportions, or it may contain considerable proportions of sulfur, iron, carbon, silicon, oxygen, etc., its composition in this regard being determined by the conditions prevailing at the works where the process is employed. When the copper contents are high, I prefer to remove part of it by some well-known process before making my anode. I have also found that an anode containing less than one per cent of sulfur is preferable on account of the smaller percentage of scrap which remains after the solution of the anode. On the other hand, a higher percentage of sulfur will leave more copper in the anode-slimes. I have also found that it is best to have not more than three or four per cent of iron in the anode, as it is cheaper to remove iron by furnace treatment when it is in excess of that amount.

The cathodes preferably consist of copper plates, which should be greased or otherwise treated, so as to prevent the deposited nickel from adhering thereto, and each cathode made of heavy metal—say ·10 to ·15 inch thick—is held by a non-conducting, preferably wooden, frame. These thick metal plates when held in the frame will not warp and come into contact with the bags, which would interfere with the process. To make the bags more reliable, I prefer to employ two thicknesses of cloth at a distance from each other of about one-half inch, and this improvement I consider most important. The anodes described above are placed in the bath with the cloth-incased cathodes in vertical position. A solution of the metal desired to be plated on the cathode is caused to flow into the bag and through the filter-cloth at right angles to the surfaces of the electrodes to the anode side of the tank.

By causing the solution to flow in a regular stream into the cathode-bag it may be made to stand therein at a level of, say, about one inch above the level of the solution outside the bag, thus imparting to the entire body of the solution within the cathode-bag a uniform hydrostatic pressure of one inch of liquid, causing it to flow outwardly through the pores of the entire bag in a direction perpendicular to the surfaces of the electrodes and at a uniform rate. The rate of flow is easily regulated by maintaining a desired difference of level between inside and outside the bag—for example, by having an overflow at a proper level outside the bag and an inlet-pipe admitting the sulfate-of-nickel solution in a regulated stream inside the bag. I can thus maintain such a flow of the solution as will prevent any of the ions dissolved at the anode from penetrating the bag to the cathode side. After the bag has been in use some time the pores become filled up with slimes of basic salts. This feature, far from being harmful, is a very desirable one. The electrical resistance of the diaphragm or bag is insignificant and the plating process goes on apparently as if no diaphragm were employed. There is, however, this important difference—namely, that an equivalent of nickel is deposited on the cathode within the bag and an ion of sulfuric acid is left free. This ion decomposes the molecule nearest to it, and so on throughout the bath, so that the final exchange will cause an ion of sulfuric acid to be liberated at the anode and at the same moment an ion of nickel to be deposited at the cathode. The ion of sulfuric at the anode immediately causes an ion of copper or nickel to be dissolved in the solution. As the exchange of ions goes on the newly-dissolved atoms of copper and nickel are traveling in a direction toward the cathode; but this movement is counteracted by the current through the porous bag, and the dissolved ions cannot pass to the cathode. Thus if I introduce into the cathode bag a solution of nickel sulfate containing forty grams of nickel per liter the reaction will leave in the solution outside of the bag on the anode side of the tank, say, thirty-nine grams of nickel and one gram of copper per liter, the atomic weight of copper and nickel being approximately the same. A constant flow of the nickel sulfate is supplied to the cathode-bag and although plating is going on the solution standing in the bag does not become deprived of its nickel, and thereby acidulated, but it contains at all times the same forty grams of nickel per liter. This process does therefore illustrate the theory for the wandering of the ions in a way that to my knowledge has never been done before. The operation thus goes on continually, nickel being deposited at the cathode until a sufficiently thick plating has been made, when the cathode-plates are removed and the nickel stripped therefrom, and there is a corresponding simultaneous solution of the copper nickel, and iron at the anode until the anode is dissolved, when it is replaced by a fresh anode of impure alloy. The insoluble constituents of the anode—such as platinum, palladium, gold, etc., together with considerable copper—are deposited as a slime on the bottom of the tank. Copper, and specially sulfid of copper, is thus deposited as a slime, because the nickel of the anode, being more electropositive, is dissolved at a more rapid rate.

If desired, the anodes may be set in the porous bags and the solution drawn off from inside the bags. I prefer, however, to employ the arrangement above described.

It is evident from what I have said above that the process can be worked under the claims without the porous diaphragm and that still by far the greater part of the copper can be separated, partly as slime and partly through the regeneration of the solution; but nickel produced in such a way will always be very impure and can either be sold as such for special purposes or else will have to be refined.

The second step of the operation is to remove the dissolved iron and copper from the liquid which flows from the electrolytic tank. I may do this in various ways—for instance, by electrodeposition; but I derive great advantages by cementing the copper on nickel or an alloy of nickel and copper. Copper has been cemented heretofore on metallic nickel, but the reaction has always been slow, and complete cemetation has only been obtained by applying the nickel in the form of a fine powder, fresh portions of which are added to the solution from time to time. Ordinary nickel in the form of grains, shots, or sheets, such as are obtainable in the market, has been so slow in its cementing action that it is practically impossible to use it when it is desired to free the solution substantially from copper. I have discovered that the slowness of the cementing action which has attended such use of nickel is due to the fact that it has contained a small percentage of carbon, silicon, or sulfur. If these impurities are removed, there is no trouble in cementing all the copper out of a solution, especially when it is kept at a boiling temperature, and it is a remarkable fact that complete separation takes place even when the nickel, which is conveniently cast in slabs, becomes covered by a hard layer of cemented copper as much as an inch in thickness. I have also discovered that I can not only use pure-nickel slabs in this process of cementation, but I may employ efficiently slabs of copper and nickel alloy containing as much as thirty per cent of copper, the alloy being free from sulfur, silicon, and carbon, as above explained. This novel use for such alloy is a very important step in my process, inasmuch as the metal can be produced cheaply by roasting and smelting of copper-nickel matte. Therefore after drawing the solution from the electrolytic tank I first heat it and then regenerate it with nickel by passing it into a vessel in which it is maintained at a boiling temperature and is brought into contact with suspended slabs of nickel and copper alloy containing, say, thirty per cent of copper. In this tank copper is very largely cemented out of the solution upon the slabs, its place in the solution being taken by an equivalent of nickel dissolved from the slabs, so that if on entering it contains thirty-nine grams nickel and one gram copper per liter it will contain after cementation, say, 39·9 grams nickel and 0·1 gram of copper, together with some iron dissolved from the anodes. I then prefer to complete the cementation by transferring the solution into a second tank, where it is also maintained at a boiling temperature in contact with pure nickel slabs, which, being more efficient in cementing action than the copper-nickel alloy, will more rapidly remove every trace of copper, leaving the solution containing forty grams nickel per liter, as it originally did, minus the iron dissolved from the anodes, as well as from the slabs of nickel and copper alloy. The nickel slabs should be free from the impurities above stated.

The next step of the process is to remove the iron. This I do, preferably, by passing the solution through an electrolytic tank containing insoluble anodes of platinum, lead, or carbon, by which the iron compound is converted by oxidation from $FeOSO_3$ to $Fe_2O_33SO_3$. The solution is then passed into a tank where nickel carbonate is added to it in excess. This precipitates the iron as iron carbonate, and it is then removed from the solution by filtering. The solution which then contains the original forty grams per liter of nickel as sulfate is delivered into a tank or reservoir from which it is supplied to the porous cathode-bags, as explained above. The process is therefore a continuous one, the nickel electrolyte being supplied to the porous bags in a continuous stream, so as to maintain an outward current from the cathode, the equivalent of copper, nickel, and iron being dissolved in the liquid on the anode side. The liquid thus treated is regenerated by cementation on slabs or plates of nickel or nickel-copper free from carbon, silicon, and sulfur. The iron is then extracted from the solution, preferably by oxidation and precipitation, and the liquid thus regenerated and purified is again supplied to the electrolytic tank.

I have found that a current density at the cathode of ten amperes per square foot is suitable; but my invention is not limited in this respect.

My invention may be employed for the separation of other metals. For example, in separating an alloy of copper, zinc, and lead I introduce a pure solution of zinc-salt into the cathode-bags and regenerate the solution when drawn from the anode side of the bags by cementing it on zinc or zinc alloy. My invention lessens very greatly the cost of separating the constituents of alloys of this nature and it enables me to effect great economy in the treatment of complex ores which hitherto have been separated by furnace treatment at very much greater expense. In some cases the expense has been so great as to be prohibitive, and as a consequence large bodies of such ores remain undeveloped.

The various steps of the process may be modified and the individual steps covered in the claims may be employed separately or in other combinations.

The process of circulation by means of the porous bag, particularly in combination with cementation, is applicable to the separation of alloys in general. The particular cementation of copper on nickel and copper-nickel alloy is of great value in all processes of electrolytic refining of nickel and also in those cases where electrolysis is not used.

What I claim as my invention is—

1. The process of separating nickel from copper consisting in electrolyzing an anode containing substantially an alloy of copper and nickel in a solution consisting of nickel sulfate and a weak acid, regenerating the solution and returning the same.

2. The process of separating nickel from copper consisting in electrolyzing an anode containing substantially an alloy of copper and nickel in a solution consisting of nickel sulfate and a weak acid, removing the copper partly at least from such solution by cementation on a metal containing nickel and returning the regenerated solution.

3. The process of separating nickel from copper consisting in electrolyzing an anode containing substantially an alloy of copper and nickel in a solution consisting of nickel sulfate and a weak acid, removing the copper partly at least from such solution by cementation on a metal containing copper-nickel alloy and returning the regenerated solution.

4. The process of separating nickel from copper consisting in electrolyzing an anode containing substantially an alloy of copper and nickel in a solution consisting of nickel sulfate and a weak acid, circulating such solution in a direction from cathode to anode, regenerating the solution and returning the same to the cathode.

5. The process of separating metals consisting in electrolyzing an alloy, circulating the solution from cathode to anode, causing the solution surrounding the cathode to contain only one of the metals constituting the anode, regenerating the solution partly at least by cementation on the metal produced in the electrolytic bath.

6. The process of separating metals consisting in electrolyzing an alloy, circulating the solution from cathode to anode, causing the solution surrounding the cathode to contain only one of the metals constituting the anode, regenerating the solution partly at least by cementation on an alloy consisting mainly of the metal produced in the electrolytic bath.

7. The process of separating nickel from copper consisting in electrolyzing an alloy and removing the copper from the solution partly at least by cementation on slabs of metal consisting mainly of nickel and refined at least to a point at which carbon, silicon, and sulfur are practically eliminated.

8. The process of separating nickel from copper consisting in electrolyzing an alloy and removing the copper from the solution partly at least by cementation on slabs of metal consisting mainly of copper-nickel alloy

refined at least to a point at which carbon, silicon, and sulfur are practically eliminated.

9. The process of separating nickel from copper consisting in electrolyzing an alloy circulating the solution from cathode to anode, causing the solution surrounding the cathode to contain nickel only, and removing the copper from the solution partly at least by cementation on slabs of metal consisting mainly of nickel and refined at least to a point at which carbon, silicon, and sulfur are practically eliminated.

10. The process of separating nickel from copper consisting in electrolyzing an alloy, circulating the solution from cathode to anode, causing the solution surrounding the cathode to contain nickel only, and removing the copper from the solution partly at least by cementation on slabs of copper-nickel alloy refined at least to a point at which carbon, silicon, and sulfur are practically eliminated.

11. The process of separating nickel from copper consisting in electrolyzing an alloy, circulating the solution from cathode to anode through a porous diaphragm, causing the solution surrounding the cathode to contain nickel only, the solution on the other side of the diaphragm and surrounding the anode containing copper and nickel, preventing the passing of the copper through the diaphragm by maintaining a pressure on the cathode side of said diaphragm and by circulating the solution from cathode to anode, regenerating the anode solution by substituting nickel for copper and returning said regenerated solution to the cathode-compartment.

12. The process of separating metals, consisting in electrolyzing an alloy, circulating the solution from cathode to anode through a porous diaphragm, causing the solution surrounding the cathode to contain only one of the metals constituting the alloy, and the solution surrounding the anode containing all the metals dissolved from the anode, preventing the passage of the metals contained in the anode solution into the cathode-compartment by maintaining a pressure on the cathode side, and circulating the solution through said diaphragm.

13. The process of separating nickel from copper by electrolysis of an alloy in an electrolyte of nickel sulfate and a weak acid, circulating the solution from cathode to anode through a porous diaphragm and maintaining a pressure on the cathode side and regenerating the solution partly at least by cementation on nickel.

14. The process of separating nickel from copper by electrolysis of an alloy in a solution of nickel sulfate and a weak acid, circulating the solution from cathode to anode through a porous diaphragm, maintaining a pressure on the cathode side and regenerating the solution partly at least by cementation on copper-nickel alloy.

Signed at New York, this 22nd day of November, 1904.

NOAK VICTOR HYBINETTE.

Witnesses:

C. Sedgwick,

J. M. Howard.

APPENDIX IV.

PROCESS FOR TREATING NICKEL AND COPPER CONTAINING MAGNETIC PYRITES, AND THE SEPARATION OF THE NICKEL AND COPPER CONTAINED IN SUCH ORES.

UNITED STATES PATENT OFFICE.

EMIL GÜNTHER AND RUDOLF FRANKE, OF EISLEBEN, GERMANY.

No. 879,633. Specification of Letters Patent. Patented Feb. 18, 1908.
Application filed June 18, 1907. Serial No. 379,535.

To all whom it may concern:

Be it known that we, EMIL GÜNTHER and RUDOLF FRANKE, citizens of the German Empire, and residents of Eisleben, Germany, have invented an Improved Process of Treating Metallic Ores or Mattes, of which the following is a full, clear, and complete specification.

The invention is directed more particularly to the treatment of nickel and copper-containing magnetic pyrites and the separating of nickel and of copper contained in such ores. It is known that the metals contained in the said ores can be concentrated by converting the ores into matte or copper-nickel-regulus which may be done by treating the ores in suitable furnaces. However till now there exists no satisfactory process for obtaining the metals themselves from said copper-nickel-regulus.

The object of this invention now consists in a process of treating the said copper-nickel-regulus and of separating the metals from same in an economical manner.

Our new invention consists broadly in bringing the copper-nickel-regulus to reaction with chlorin either in the form of gas or in *statu nascendi* with the effect that chlorids of copper and nickel are formed and in processes of separating the pure metals from said combinations with chlorin.

The steps for carrying our invention into practical operation are different depending from the form in which the chlorin is brought to reaction with the copper-nickel-regulus. If the chlorin is used in the form of gas we prefer to proceed as follows: The ground regulus is introduced into a closed drum together with the solution of a chlorid, such as sodium chlorid, calcium chlorid, magnesium chlorid, subchlorid of copper and so on and treated with chlorin gas. The reaction which takes place if the temperature is not too much raised may be represented by the following equation:

$$a\mathrm{NiS}+b\mathrm{Cu_2S}+c\mathrm{FeS}+d\mathrm{Cl_2}+e\mathrm{NaCl}=$$
$$a_1\mathrm{NiCl_2}+b_1\mathrm{CuCl_2(Cu_2Cl_2)}+c_1\mathrm{FeCl_3(FeCl_2)}+(a_2+b_2+c_2)\mathrm{S}+e\mathrm{NaCl}.$$

From this equation it can be seen that the sulfids of the metals are converted into the corresponding chlorids or subchlorids, while at the same time sulfur is set free. Under practical conditions a more or less part of the sulfur contained in the copper-nickel-regulus is not obtained in chemical pure condition, but in the form of sulfuric acid. In order to reduce the quantity of sulfuric acid it is necessary to take care that the temperature is permanently kept at an invariable point.

The metals contained in the copper-nickel-regulus being converted into the form of chlorids, the solid particles are separated from the solution and the solution is freed from sulfuric acid and other impurities so that, technically speaking, a pure nickel-copper-solution is obtained. This nickel-copper-solution is electrolyzed with insoluble anodes. Copper is deposited at the cathode while at the anode chlorin is developed. The chlorin may be used for treating new portions of copper-nickel-regulus. The electrolyte becoming poorer in copper during the electrolyzing process, fresh copper-nickel-solution is added continuously or intermittently till the contents of the bath in nickel is raised to certain desired concentration. Now the bath is freed from copper preferably by electrolysis and by precipitating the last traces of the copper by chemical reagents, for instance by metallic nickel. The bath solution purified from copper and forming then a solution of subchlorid of nickel is likewise electrolyzed after purification with insoluble anodes. In this electrolyzing process chlorin is again set free and may be used for treating fresh portions of the copper-nickel-regulus. The nickel is deposited at the cathode in the same way as in the former electrolyzing process the copper.

The solid mass separated from the solution at the end of the chlorin treatment substantially consists of sulfur and small portions of sulfids. The sulfur may be extracted by suitable solvents whereas the sulfids are added to fresh portions of copper-nickel-regulus and again treated with chlorin.

In a modified method of carrying the invention into practical operation we make additions containing gold, silver or other precious metals to the copper-and-nickel-containing ores or to the copper-nickel-regulus. If copper-nickel-regulus into which precious metals have been incorporated in the said way is treated with chlorin gas, as above stated, the precious metals remain in the solid residue if excess of chlorin is avoided and may easily be obtained therefrom if chlorin in excess is admitted gold may go into solution forming chlorid of gold which is precipitated on later cleaning of the solution.

The process may also be used for producing nickel free from copper from the so-called concentration nickel-regulus with about 75% nickel and about 0·2% copper. In this instance the regulus is digested in the above manner with chlorin, whereupon the nickel-solution is chemically purified and electrolyzed with insoluble solutions.

If it is intended to use the chlorin *in statu nascendi* for treating the copper-nickel-regulus we proceed as follows: The copper-nickel-regulus is used as anode in an electrolyzing process in which the electrolyte is formed of a hydrochloric solution of copper-chlorid in mixture with an alkali—or earthy alkali-chlorid, whereas the cathode is formed of a sheet of copper. In such electrolyzing process at the anode chlorin is produced which converts the sulfids of the metals into the corresponding chlorids liberating at the same time sulfur. The effect of the chlorin *in statu nascendi* therefore is quite analogous to the effect in the previously described process of treating the copper-nickel-regulus with chlorin in the form of gas. The chlorin which is developed by the electrolytic decomposition of the bath solution is entirely used for bringing metal into solution. At the cathode copper is deposited. In view of the fact that at the cathode more copper is deposited than is dissolved at the anode, it is necessary to introduce continuously or intermittently copper salt into the bath which may be produced in the manner hereafter described. In the bath solution nickel accumulates, whereas the contents in copper is kept at an invariable suitable concentration. If after a certain time the concentration of the bath solution in nickel, iron, and other salts is raised to a point that it interferes with the depositing of the copper, the bath solution is drawn off and electrolyzed in other vats with insoluble anodes in order to free it as far as possible from copper and finally the last portions of copper are chemically deposited. In this way a chemical pure nickel-subchlorid-solution is obtained and electrolyzed with insoluble anodes. In this way pure nickel is deposited at the cathode, whereas at the anode chlorin is developed which is just sufficient for treating copper ores containing oxygen or sulfur combinations of copper with the effect of producing the copper salt which is necessary in order to carry out the electrolyzing process of the copper-nickel-regulus after treating with chlorin *in statu nascendi.*

The above process may also be used for treating concentrated nickel-regulus and for producing nickel free from copper from such regulus.

We are aware that it has already been proposed to treat ores and matte with chlorin. However in this instance the products of reaction were afterwards treated with hydrochloric acid or with other reagents or the metal chlorids were converted into sulfates, whereas in our process the products of conversion which are obtained after treating the copper-nickel-regulus with chlorin are directly used for depositing the metals contained therein. Also the Browne process in which copper-nickel-matte is at first roasted offers disadvantages which are avoided in our process, such disadvantages consisting especially in the difficulty of completely absorbing the roasting gases.

We wish to be understood that in the following claims the term copper-nickel-regulus is intended to cover all kinds of matte containing copper and nickel even if one of these two metals is only present in very small proportions. Furthermore the term alkali is used in a broad sense so as to cover not only the alkalies properly spoken but also the so-called earthy alkalies.

Having now described our invention, what we claim and desire to secure by Letters Patent is:

1. In extracting metallic ores and matte the method of producing nickel salt solution for electrolytic deposition of nickel consisting in subjecting copper and nickel containing concentrated regulus to electrolytic action as anode in a bath of chlorid of copper with addition of chlorid of alkali in presence of free hydrochloric acid, introducing copper salt into the bath during the electrolytic process separating the solution when rich in nickel from the solid residue of the anode and eliminating the contents in copper from the solution.

2. The method of obtaining pure metallic copper and nickel from copper and nickel containing regulus consisting in subjecting the copper-nickel-regulus to electrolytic action as anode in a bath containing chlorid of copper with addition of chlorid of alkali in the presence of free hydrochloric acid with the effect of electro depositing metallic copper at the cathode, introducing chlorid of copper into the bath during the electrolytic process, separating the solution when rich in nickel from the solid residue of the anode, electrolyzing the drawn off solution with insoluble anodes for electrolytically depositing the main portion of copper contained therein, chemically precipitating the rest of the copper out of the bath, electrolyzing the nickel salt solution obtained in this way with insoluble anodes with the effect of electrodepositing pure metallic nickel, using the chlorin formed at the anode for producing chlorid of copper from suitable copper ores, and using such chlorid of copper as electrolyte when subjecting fresh charges of copper-nickel-regulus, as anode, to electrolytic action.

In witness whereof we have hereunto set our hands in the presence of two witnesses.

EMIL GÜNTHER.
RUDOLF FRANKE.

Witnesses:
VILMA FRANKE,
RUDOLPH FRICKE.

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T—*Continued.*

CANADA
DEPARTMENT OF MINES
MINES BRANCH

HON. ROBERT ROGERS, MINISTER; A. P. LOW, LL.D., DEPUTY MINISTER;
EUGENE HAANEL, PH.D., DIRECTOR.

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        Coal Washing Tests and Diagrams, by J. B. Porter.

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        Boiler Tests and Diagrams, by R. J. Durley.

84. Gypsum Deposits of the Maritime Provinces of Canada—including the Magdalen islands. Report on—by W. F. Jennison, M.E. (Out of print).

85. Production of Cement, Lime, Clay Products, Stone, and other Structural Materials during the calendar year, 1909. Bulletin on—by John McLeish.

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89. Reprint of Presidential address delivered before the American Peat Society at Ottawa, July 25, 1910. By Dr. Haanel.

90. Proceedings of Conference on Explosives.

92. Investigation of the Explosives Industry in the Dominion of Canada, 1910. Report on—by Capt. Arthur Desborough. (Second Edition).

93. Molybdenum Ores of Canada. Report on—by Dr. T. L. Walker.

100. The Building and Ornamental Stones of Canada. Report on—by Prof. W. A. Parks.

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104. Catalogue of Publications of Mines Branch, from 1902 to 1911; containing Tables of Contents and List of Maps, etc.

110. Western Portion of Torbrook Iron Ore Deposits, Annapolis county, N.S. Bulletin No. 7—by Howells Fréchette, M.Sc.

111. Diamond Drilling at Point Mamainse, Ont. Bulletin No. 6—by A. C. Lane, Ph.D., with Introductory by A. W. G. Wilson, Ph.D.

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Producer Tests and Diagrams, by R. J. Durley.
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Chemical Tests, by Edgar Stansfield.

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203 Building Stones ofCanada—Vol. II: Building and Ornamental Stones of the Maritime Provinces. Report on—bW. A. Park

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†6. Magnetometric Survey, Vertical Intensity: Calabogie Mine, Bagot township, Renfrew county, Ontario—by E. Nyström, 1904.

†14. Magnetometric Survey of the Wilbur mine, Lavant township, Lanark county, Ontario—by B. F. Haanel, 1905.

†33. Magnetometric Survey, Vertical Intensity: Lot 1, Concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909.

†34. Magnetometric Survey, Vertical Intensity: Lots 2 and 3, Concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909.

†35. Magnetometric Survey, Vertical Intensity: Lots 10, 11, and 12, Concession IX, and Lots 11 and 12, Concession VIII, Mayo township, Hastings county, Ontario—by Howells Frechette, 1909.

*36. Survey of Mer Bleue Peat Bog, Gloucester township, Carleton county, and Cumberland township, Russell county, Ontario—by Erik Nyström, and A. Anrep.

*37. Survey of Alfred Peat Bog, Alfred and Caledonia townships, Prescott county, Ontario—by Erik Nyström, and A. Anrep.

*38. Survey of Welland Peat Bog, Wainfleet and Humberstone townships, Welland county, Ontario—by Erik Nyström, and A. Anrep.

*39. Survey of Newington Peat Bog, Osnabrook, Roxborough, and Cornwall townships, Stormont county, Ontario—by Erik Nyström, and A. Anrep.

*40. Survey of Perth Peat Bog, Drummond township, Lanark county, Ontario—by Erik Nyström, and A. Anrep.

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†57. The Productive Chrome Iron Ore District of Quebec—by Fritz Cirkel.

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Note.—1. Maps marked thus * are out of print.
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†76. Alfred Peat Bog, Ontario—by A. Anrep.

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†146. Distribution of Iron Ore Sands of the Iron Ore Deposits on the North Shore of the River and Gulf of St. Lawrence, Canada—by Geo. C. Mackenzie.

†147. Magnetic Iron Sand Deposits in Relation to Natashkwan harbour and Great Natashkwan river, Que. (Index Map)—by Geo. C. Mackenzie.

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†164. Julius Peat Litter Bog, Manitoba—by A. Anrep.

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166. Magnetometric Map of No. 3 mine, Lot 7, Concessions V and VI, McKim township, Sudbury district, Ont.—by E. Lindeman. (Accompanying summary report, 1911.)

†168. Map showing Pyrites Mines and Prospects in Eastern Canada, and their relation to the United States' Market—by A. W. G. Wilson.

†171. Geological Map of Sudbury Nickel region, Ont.—by Prof. A. P. Coleman.

†172. " " Victoria mine—by Prof. A. P. Coleman.

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†175. " " showing Contact of Norite and Laurentian in vicinity of Creighton mine—by Prof. A. P. Coleman.

†176. " " of Copper Cliff offset—by Prof. A. P. Coleman.

†177. " " No. 3 mine—by Prof. A. P. Coleman.

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†185. Magnetometric Survey, Vertical Intensity: Blairton iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911.

†185A. Geological Map, Blairton iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911.

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†188. Magnetometric Survey, Vertical Intensity, Baker mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911.

†188A. Geological Map, Baker mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911.

†189. Magnetometric Survey, Vertical Intensity, Ridge iron ore deposits, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911.

†190. Magnetometric Survey, Vertical Intensity, Coehill and Jenkins mines, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911.

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†191. Magnetometric Survey, Vertical Intensity, Bessemer iron ore deposits, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911.

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†193. Magnetometric Survey, Vertical Intensity, Kennedy property, Carlow township, Hastings county, Ontario—by E. Lindeman, 1911.

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†194. Magnetometric Survey, Vertical Intensity, Bow Lake iron ore occurrences, Faraday township, Hastings county, Ontario—by E. Lindeman, 1911.

†204. Index Map, Magnetite occurrences along the Central Ontario Railway—by E. Lindeman, 1911.

205. Magnetometric Map of Moose Mountain iron-bearing district—by E. Lindeman.

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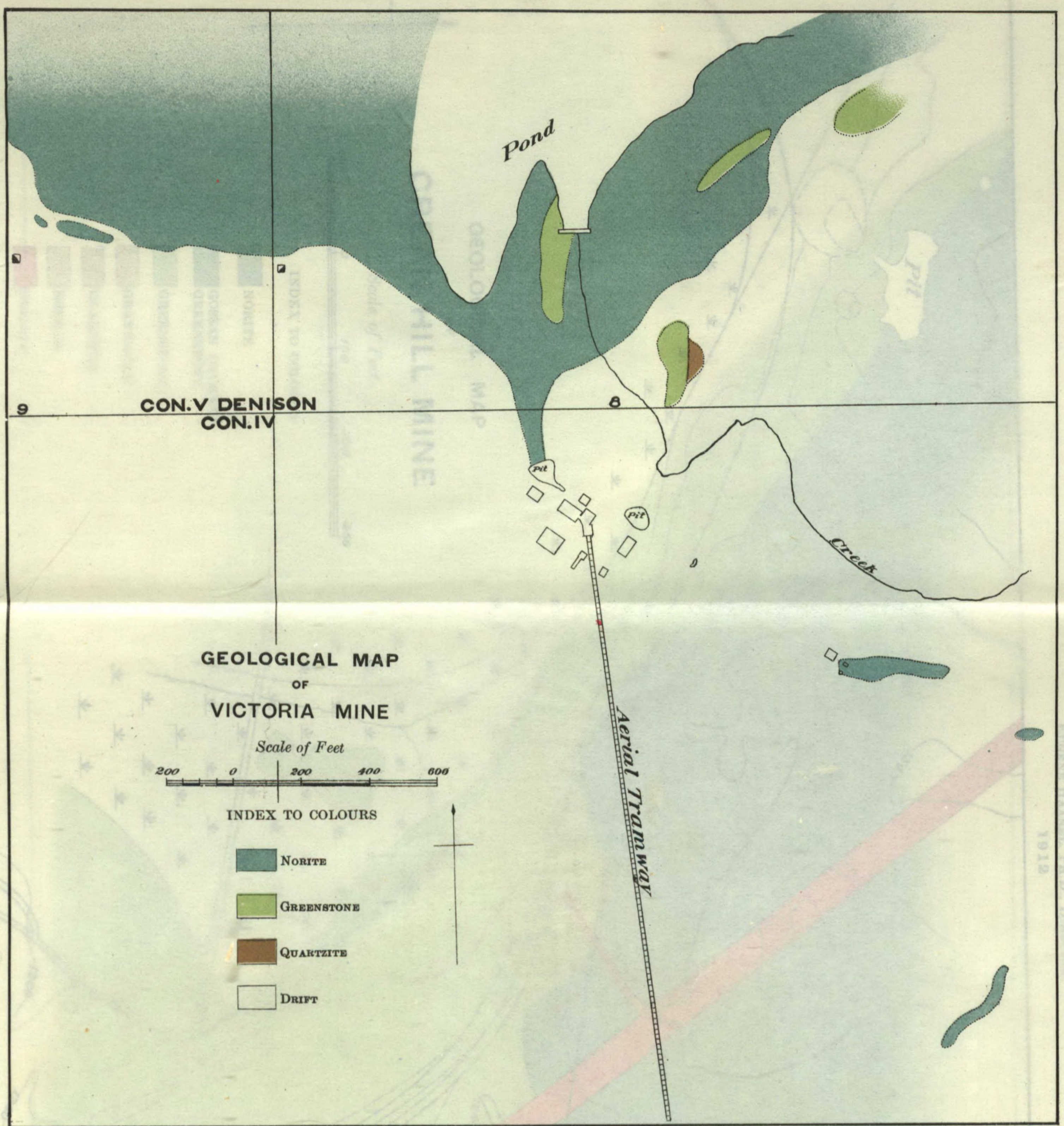

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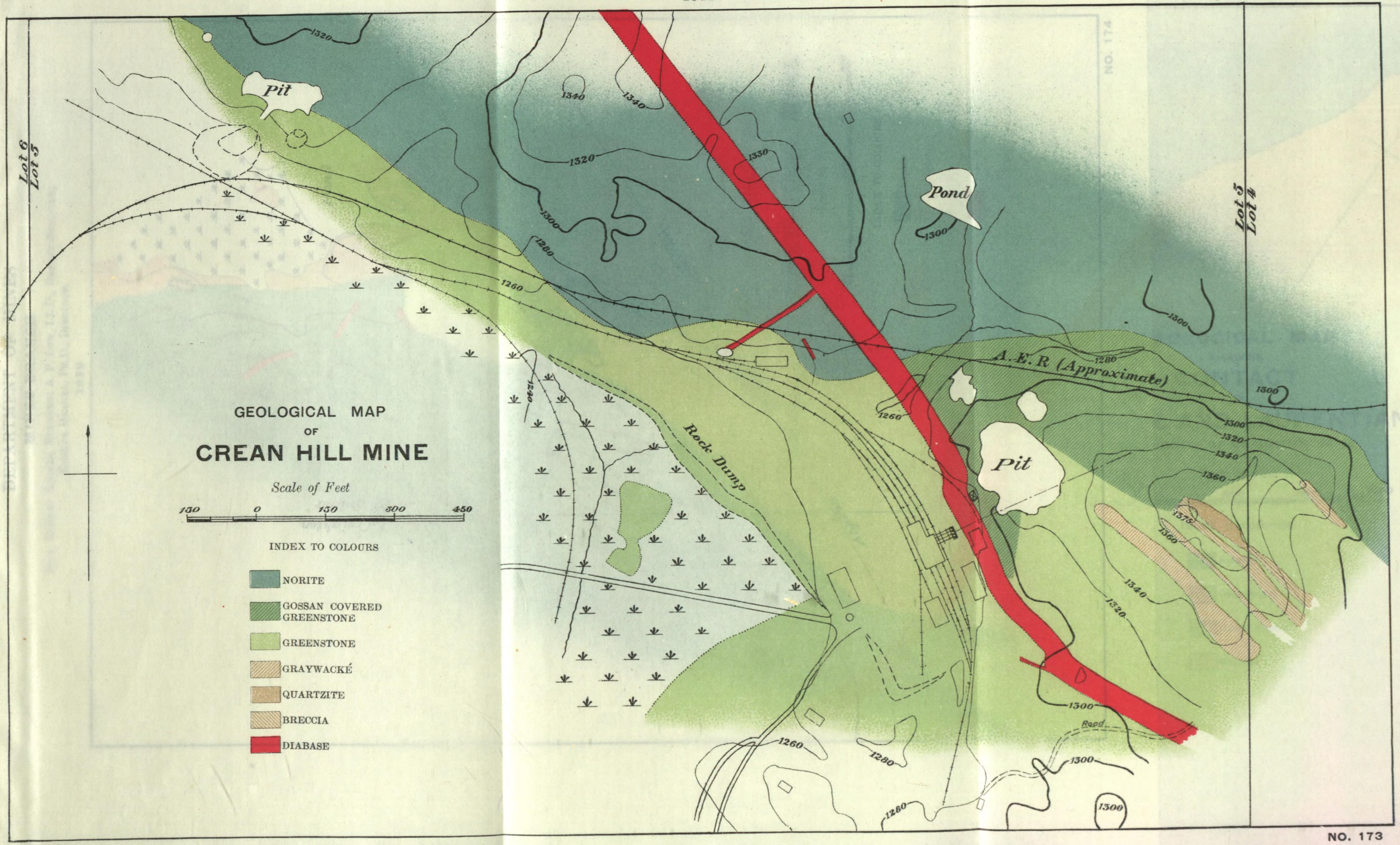

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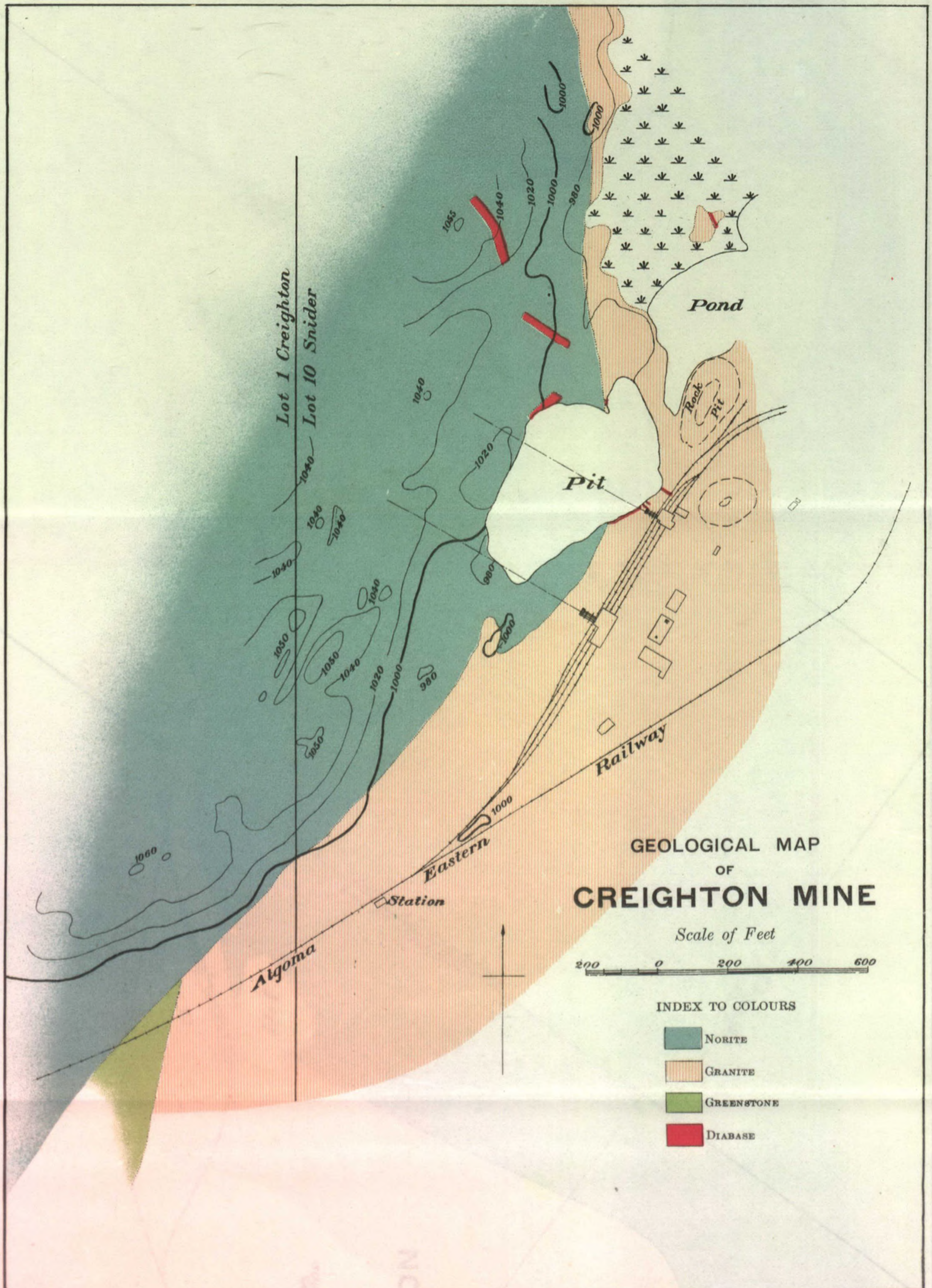

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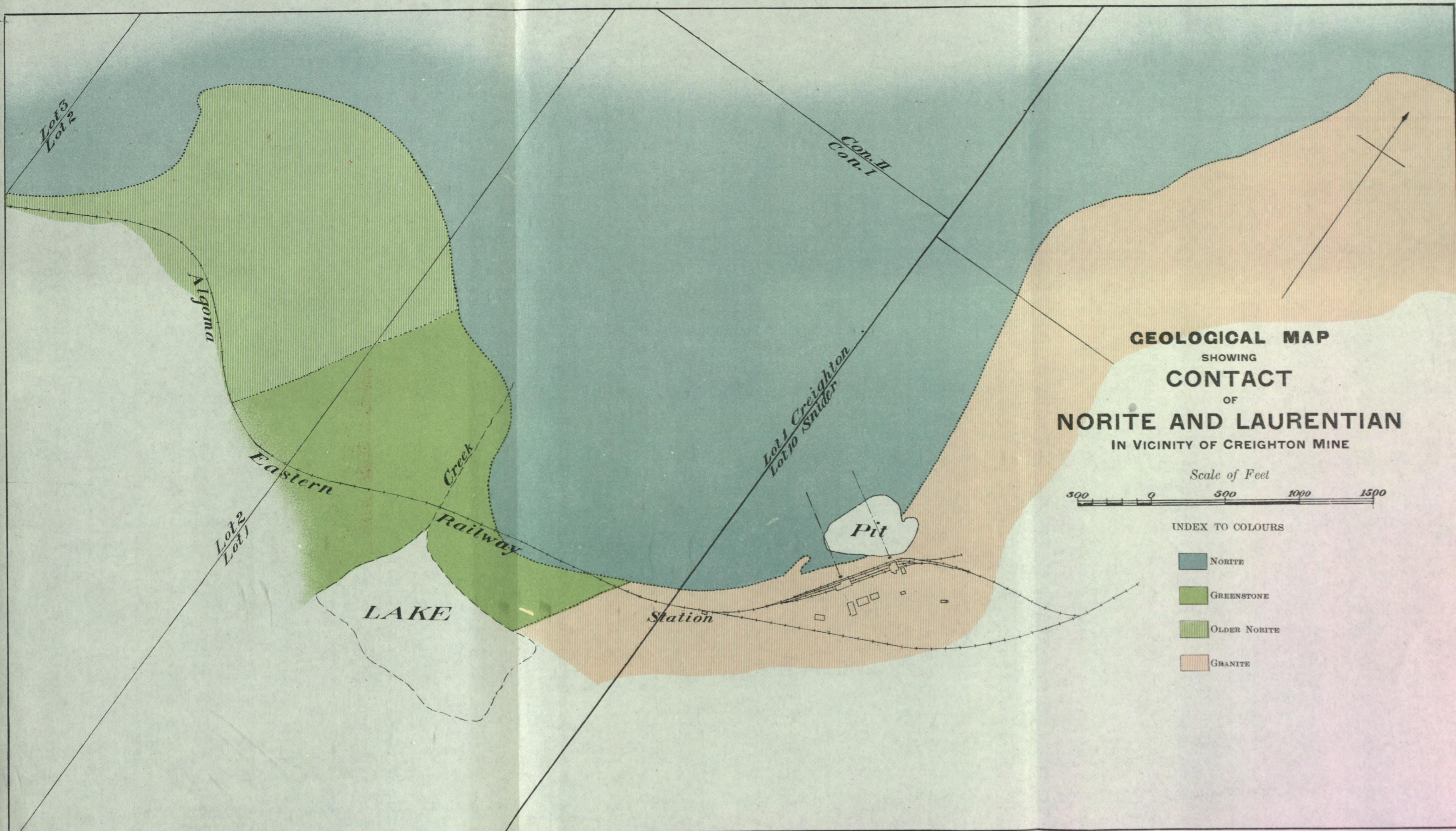

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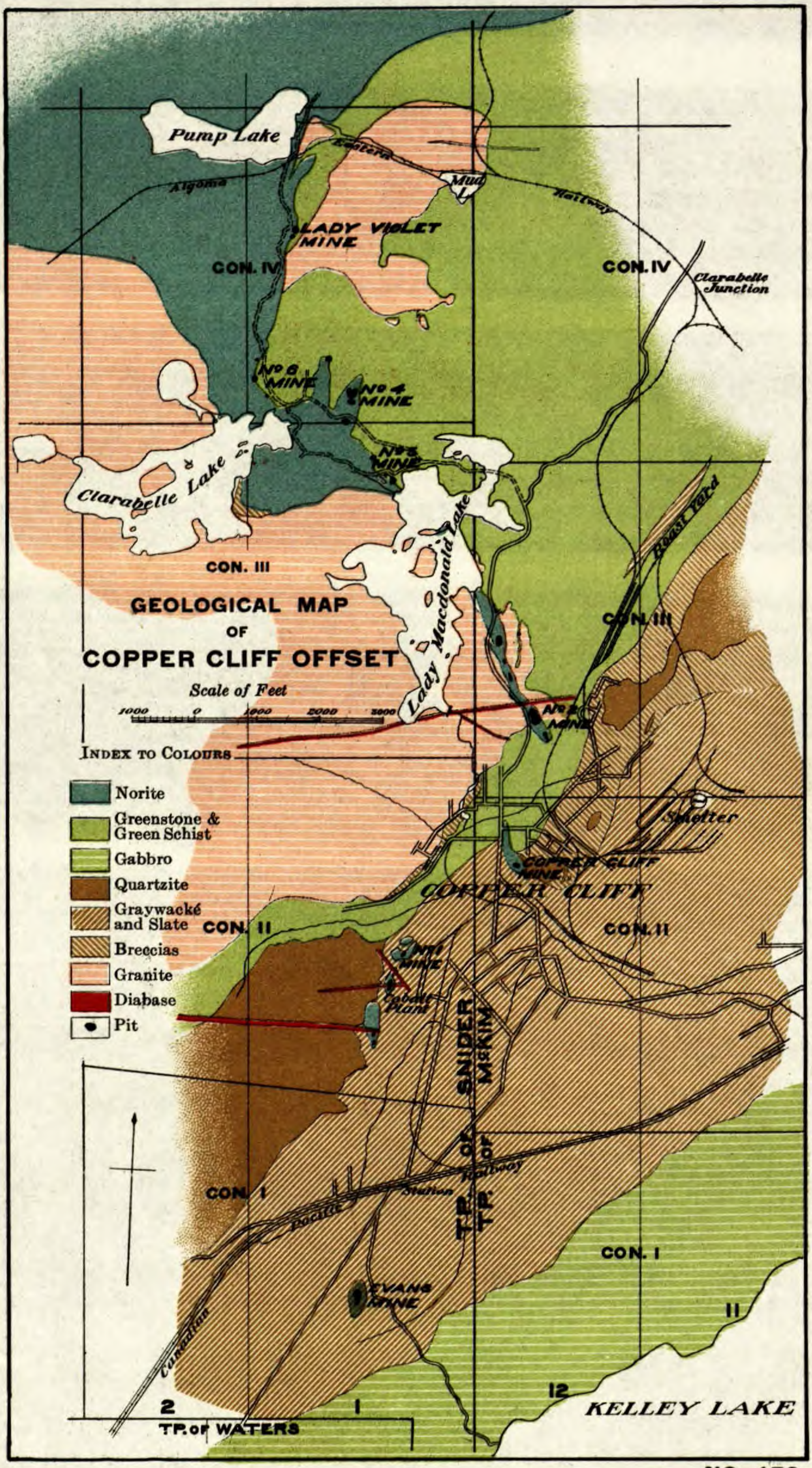

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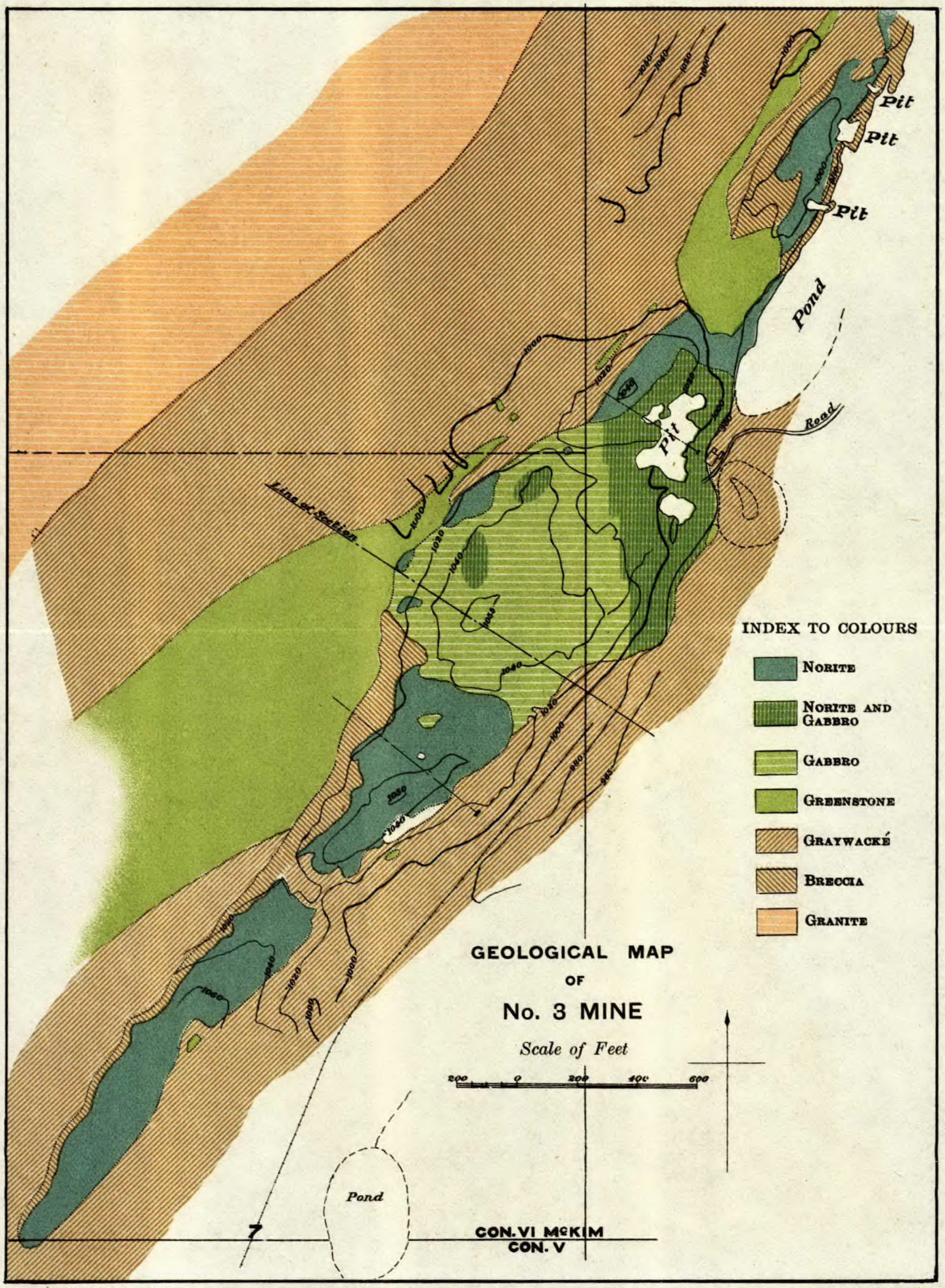

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