Nickel Deposits of the World

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Preface

This description of the Nickel Deposits of the World has been reprinted from the Report of the Royal Ontario Nickel Commission, Chapter IV, in the hope that as a separate it will be in handier form for those readers who are especially interested in geology and ore deposits. The Report itself, with appendix, consists of over 800 pages.

A much fuller description is given of the geology and ore deposits of Sudbury than of those of any other country, owing to the fact that this district contains the greatest nickel mines of the world, a few at least being among the most valuable ore bodies of any kind known. Moreover, the Sudbury district is in the Province of Ontario and, therefore, would naturally receive more attention from the Commissioners.

During the last year one of us visited nickeliferous iron-ore deposits in Cuba and the famous nickel deposits of New Caledonia, together with the small occurrences in Tasmania. Another member of the Commission visited Norway. Descriptions are given of the deposits of a few countries concerning which little has yet been published; the information has been furnished by individuals or companies that have had private reports made. Fuller descriptions are given of deposits that have been worked, or that have attracted attention, during recent years than of those which are of little more than historic interest and of little importance as competitors with those of Ontario. Owing to the desire to conserve space the geological descriptions are in some cases brief. Instead of trying to summarize the views of various authors quotations are given wherever possible.

A paper entitled "Lateritic Ore Deposits" was presented by W. G. Miller at the meeting of the Royal Society of Canada, May, 1917, in which attention is drawn to certain features of the New Caledonia deposits that are not specifically discussed in following pages. As usually described, laterites are materials that contain a low percentage of combined silica, in distinction from clays which are the normal products of weathering of many rocks in temperate climates. The New Caledonia ores, compared with those of Cuba and elsewhere, contain a high percentage of silica, combined with magnesia and other substances, and a comparatively low percentage of alumina. They thus differ radically in composition from both clays and laterites as usually defined. Their character leads to the suggestion that the definition of laterite should be modified. In the paper the importance of ores of lateritic origin as a class, including certain of those of nickel, cobalt, iron, aluminum, manganese and others, is emphasized.

Although so much has been published on the Sudbury deposits, judging from the following quotation from a recent standard work on ore deposits, information is still required: "It is indeed striking that nickel, in spite of its more or less considerable distribution in the basic rocks, never, or very seldom, forms important deposits." As shown on following pages the Sudbury deposits are measured in tonnages of millions. A fuller description of the size and character of these deposits than has yet appeared is given in the following pages.

The world's production of nickel, in metric tons, from 1896 to 1913, was approximately as follows:—

Year....	*1896*	*1897*	*1898*	*1899*	*1900*	*1901*	*1902*	*1903*	*1904*
Tons....	4,407	4,758	6,898	7,855	7,526	8,900	8,700	9,900	12,000
Year....	*1905*	*1906*	*1907*	*1908*	*1909*	*1910*	*1911*	*1912*	*1913*
Tons....	12,500	14,300	14,100	14,600	17,300	20,100	24,500	28,500	30,000

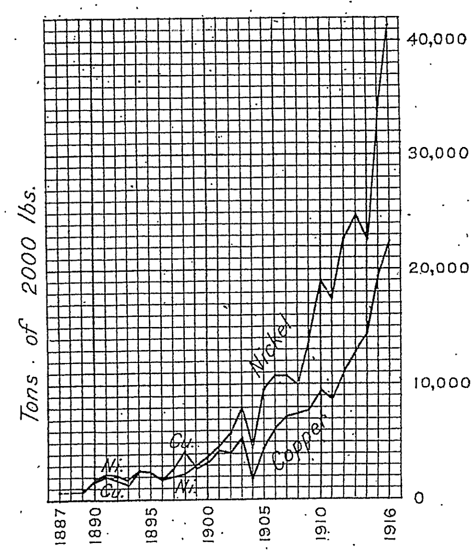


Diagram showing growth in production of nickel and copper from 1887 to the end of 1916, Sudbury, Ontario.

The accompanying diagram shows the growth that has taken place in the production of nickel and copper from the Sudbury ores. These ores are also an important source of platinum, palladium and other metals whose value has recently so rapidly increased.

WILLET G. MILLER,
CYRIL W. KNIGHT.

Provincial Geologist's Office,
Toronto, May, 1917.

Nickel Deposits of the World

INTRODUCTION

While nickel is widely distributed in nature, occurring as an essential or as an accessory constituent of numerous minerals, and having been found even in the ashes of certain marine plants, known workable deposits of the metal are confined to fewer localities than are those of the more common metals. The deposits of two countries, the Province of Ontario and the French island colony of New Caledonia, as has been shown on preceding pages, control the market for the metal.

Nickel is found native, alloyed with iron, in meteorites and in a few terrestrial minerals, but this form of the element, while of scientific interest, is of no economic importance. It has been detected in numerous igneous rocks, especially magnesian varieties, where it probably occurs most frequently as a constituent of the silicate, olivine. According to F. W. Clarke, in 262 analyses of igneous rocks made in the laboratory of the United States Geological Survey an average of 0.0274 per cent. of nickel oxide was found. Had it been sought for in all cases, this figure might have been slightly reduced, but perhaps not materially.[1]

As a constituent of the solid crust of the earth nickel occurs in greater quantity than copper, a fact that would scarcely be credited from a consideration of the much wider distribution of workable deposits of the latter and the production of the two metals. In a discussion of the relative abundance of the elements, Clarke shows that the igneous rocks contain iron and nickel in the porportions, approximately, of 4.56 of the former to 0.020 of the latter;[2] the proportion of copper is probably about 0.010, while the proportions of two other common metals, zinc and lead, are still less. It can thus be said that nickel is less amenable to concentration by the agencies that tend to produce workable deposits than are the other metals mentioned.

A small percentage of nickel usually, if not always, occurs in certain iron ores, especially in the titaniferous variety and in those of a residual nature derived from the weathering of basic igneous rocks. Ores of the former class that occur in Ontario universally contain small percentages of the metal, varying from 0.08 to 0.80.[3] Nickeliferous iron ores of residual origin will be described on later pages.

Basic igneous rocks in various parts of the world contain nickel in quantities sufficient to show that, while it occurs in few countries in deposits that are of economic importance, still the metal is often present in one-tenth or more of the

[1] The Data of Geochemistry, p. 691, 3rd Edition, Bull. 616, U.S.G.S. [2] *Ibid*, p. 27.

[3] W. G. Miller, Rept. British Ass. Ad. Sci., 1897, p. 660, and Ont. Bureau Mines, Vol. VII, p. 230, and F. J. Pope, A.I.M.E., Vol. XXIX, 1899, pp. 397 *et al.*

quantity that is of commercial value. For instance, a trap dike that outcrops at the edge of the Rideau canal in southeastern Ontario, was found to contain as much as 0.612 per cent. of nickel.[1]

Few analysts have taken the trouble to determine the percentage of nickel in rocks. In analyses available of Canadian rocks the presence or absence of nickel is rarely mentioned. It will be seen that this statement applies even to most of the analyses of the Sudbury norite that are quoted from various authors in this volume. Analyses of Canadian rocks have not been collected and published in readily available form, as have those of the United States, but the content of NiO in a few may be given. "The serpentines of the altered Silurian rocks in Eastern Canada [Quebec] often form vast masses, almost without admixture. . . . The almost constant presence of small portions of oxides of chrome and nickel is to be remarked in the analyses, not only of these serpentines but of the other magnesian rocks of the region."[2] In two specimens of serpentine from Orford, Que., the percentages of NiO are given as 0.26 and 0.15 respectively.

A peridotite (dunose) from the junction of Eagle creek and Tulameen river, British Columbia, was found to contain 0.10 per cent. of NiO.[3]

Doubtless if it is looked for, NiO will be found in similar percentages in numerous other Canadian rocks. Analyses showing a lower percentage are available from a number of localities.

In the chemical laboratory of the United States Geological Survey many detailed analyses of rocks have been made. The following list giving the percentage of NiO in rocks from widely separated localities serves to illustrate the statement that nickel is widely distributed.[4] In the analyses selected the percentage of NiO is in all cases 0.05 or more. Numerous analyses showing a lower percentage might be given. Similar nickeliferous rocks are found in various parts of the world, but in many analyses the percentages of the metal have not been determined.

Nickeliferous Rocks

(A) Massachusetts, serpentine from seven localities, 0.17, 0.21, 0.45, 0.53, 0.40, 0.47, 0.33. (B) Connecticut, hornblende norite 0.9. (C) New York, peridotite 0.9. (D) Pennsylvania, pyroxenite 0.5. (E) North Carolina, pyroxenite 0.11. (F) Kentucky, peridotite 0.10. (G) Missouri, granite 0.20, porphyry 0.15. (H) Texas, nepheline basalt 0.06. (I) Michigan, peridotite 0.21, diabase 0.10. (J) Minnesota, hypersthene gabbro 0.06, olivine gabbro 0.16. (K) Yellowstone National Park, Electric Peak, pyroxene-mica diorite 0.09, quartz-pyroxene-mica diorite 0.05, augite-andesite porphyry 0.06, Absaroka range, monzonite 0.10, quartz diorite porphyry 0.19, quartz-mica diorite porphyry 0.17, banakite dike 0.14. (L) Montana, hornblende picrite 0.09, pyroxenite 0.11, peridotite 0.16, shonkinite 0.07. (M) Idaho, diorite 0.12. (N) Colorado, perofskite-magnetite rock 0.05. (O) Arizona, mica basalt 0.08. (P) Nevada, andesitic perlite 0.07. (Q) California, quartz diorite 0.05, altered peridotite 0.09, diorite 0.05, pseudo-diabase (ornose) 0.10, andesite 0.20, basalt 0.41, black serpentine 0.33, pyroxenite 0.07, gabbro 0.06, serpentine (pyroxenite) 0.11. (R) Oregon, peridotite (saxonite), the matrix of the silicate nickel ores, 0.10, olivine separated from the same 0.26, hypersthene-augite andesite 0.05, serpentine 0.13. (S) Hawaiian Islands, picritic basalt 0.09, plagioclase basalt 0.05, porphyritic gabbro 0.12, olivine basalt 0.08, olivine separated from latter 0.34.

[1] Ont. Bureau Mines, Vol. VII, p. 231.

[2] Geology of Canada, 1863, p. 472.

[3] Geol. Sur. Can., Memoir 26, p. 53, and U.S.G.S. Bull. 591, p. 210.

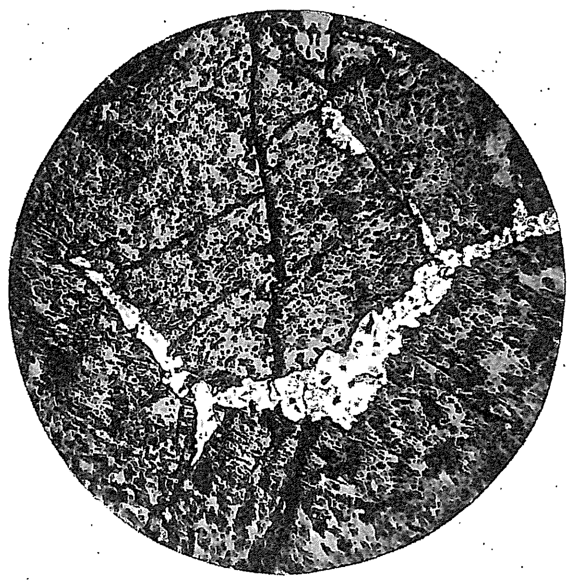
[4] Bull. 591, U.S.G.S

Nickel Minerals

Among the numerous compounds, in which nickel occurs in nature, the following, from the economic point of view, may be said to be the most important:—

Pentlandite..........(Fe, Ni) S.	Gersdorffite..........Ni As S
Millerite.............Ni S	Breithauptite.........Ni Sb
Niccolite............Ni As.	Annabergite.........$Ni_3 As_2O_8+8 H_2O$
Chloanthite..........$Ni As_2$	Garnierite.

Pentlandite, which contains varying percentages of nickel and iron, is believed to be the source of nearly all the nickel produced from the pyrrhotite-chalcopyrite ores of the Sudbury area. In the ores of certain mines, such as the Worthington, the mineral can be readily distinguished in hand specimens. Usually, however, it is identified only on polished or etched surfaces. Details concerning the

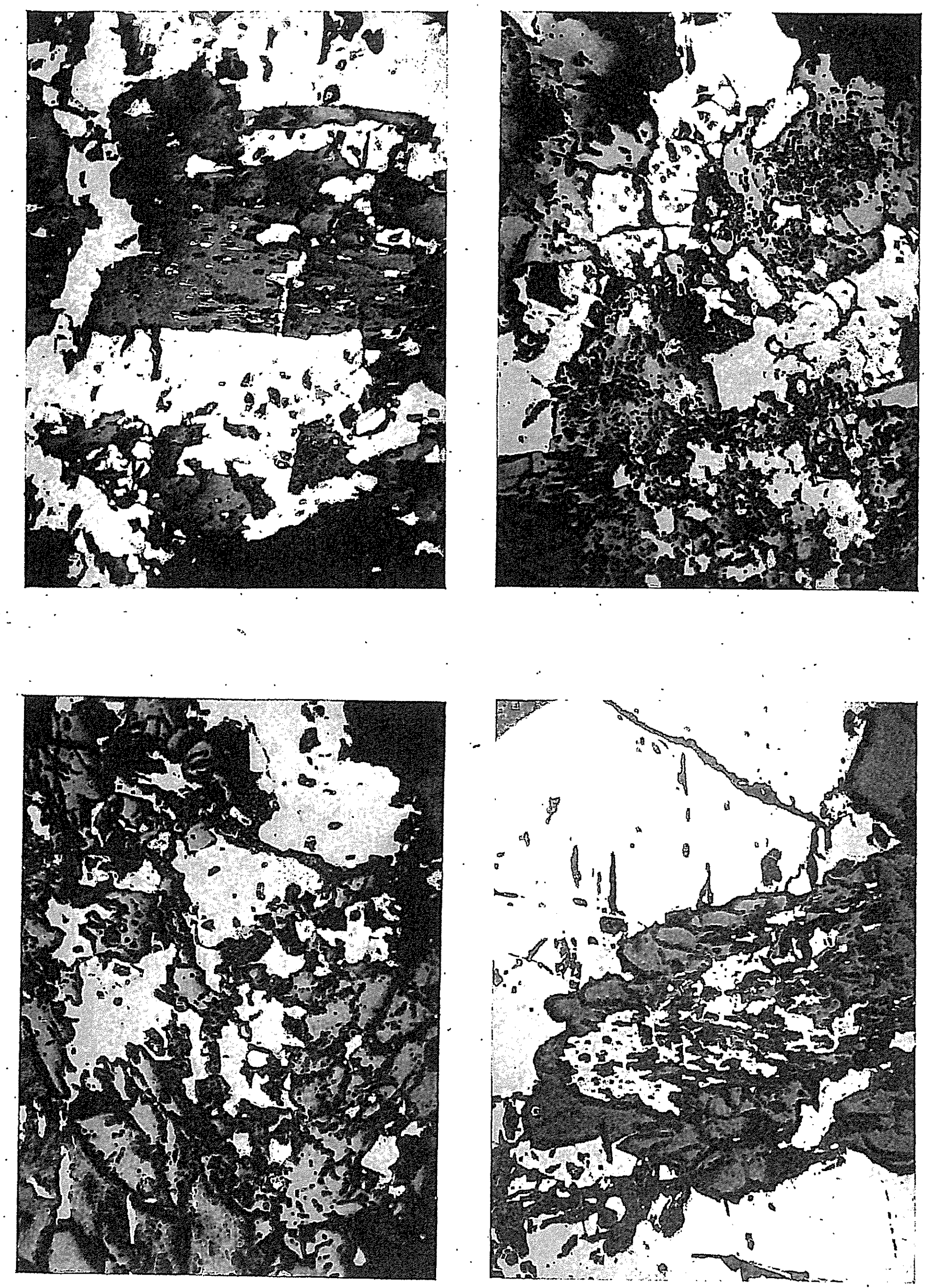


Polished and etched surface of ore, showing pentlandite in veins cutting pyrrhotite; magnified 50 diameters; Copper Cliff mine, Sudbury area, Ontario.
Photomicrograph by Wm. Campbell.

occurrences of the mineral with the ores of Sudbury are given in the reports of Barlow, Coleman and other writers and need not be repeated here. Illustrations of the modes of occurrence of the mineral will be found in following pages.

Gersdorffite and millerite have been observed only occasionally in the Sudbury ores. It may be added that polydymite, Ni_4S_5 or Ni_3FeS_5, occurs at the Vermilion mine and doubtless in other Sudbury deposits.

Niccolite, chloanthite, breithauptite and annabergite are of common occurrence in the veins of the Cobalt area. The first mentioned mineral has been found in small quantities in two or three of the Sudbury deposits.



Polished surfaces of sulphides and norite, Creighton mine, Sudbury area, Ontario. The white areas are the sulphides—pyrrhotite, chalcopyrite and pentlandite; the dark areas are norite. Magnified 70 diameters.

Photomicrographs by Wm. Campbell.

Linnæite, a sulphide of cobalt, $Co_3 S_4$, in which the cobalt is replaced by nickel, and to some extent by iron and copper in varying proportions, occurs at Mine La Motte, Missouri, which has been a small producer of nickel and cobalt.

Garnierite is second only to pentlandite as a source of nickel. It is essentially a hydrated silicate of nickel and magnesium, but is of somewhat indefinite chemical composition. Dana says its formula is "perhaps H_2 (Ni,Mg) Si O_4 + aq., but very variable in composition, particularly as regards the mutual replacement of nickel and magnesium, and not always a homogeneous mineral. Liversidge has attempted to distinguish two varieties, one of which is dark green and unctuous, *noumeite;* the other rarer, pale green and adhesive to the tongue, *garnierite.*"[1] There are other hydrous nickel-magnesium silicates, more or less related to garnierite, such as genthite, pimelite and schuchardite. Garnierite is an alteration product of serpentine, derived from peridotite, and is the essential source of the nickel in the ores of New Caledonia and elsewhere, although other compounds of the metal, the products of weathering, occur in association with it.

Classes of Ores

The ores that are worked primarily as sources of nickel fall naturally into three classes—(a) Sulphides, represented especially by the pyrrhotite-chalcopyrite ores of Sudbury and Norway. Ores of this class have been mined to a much smaller extent in Pennsylvania, Tasmania, Sweden, Italy, South Africa and elsewhere. The sulphides of iron and copper that are associated with the lead ores of southeast Missouri should also be mentioned as they have been worked for cobalt and nickel. (b) Silicates or oxidized ores, of which the chief occurrences are those of New Caledonia. Similar ores occur in Greece, Madagascar, North Carolina, Oregon and in other countries. (c) Arsenical ores, usually containing both nickel and cobalt, the principal working mines being those of Cobalt, Ont. Ores of this nature have been worked in Saxony, Bohemia, France and elsewhere.

Other sources of nickel are (d) blister copper, which contains nickel and other metals, (e) manganese ores of the earthy class known as wad, sometimes rich in cobalt and to a lesser extent in nickel, (f) nickeliferous iron ores, such as those of Cuba, the nickel forming a valuable ingredient in the iron or steel produced from such ores, but not being separable, commercially, from the iron.

By-Products of Nickel Ores

Nickel in commercial quantities in pyrrhotite-chalcopyrite ores may be said to be an accessory constituent, since many deposits of this class do not contain the metal in workable quantities. In addition to nickel and copper these ores that are worked contain gold, silver, platinum, palladium and other metals as by-products. These are discussed in the section devoted to precious metals. At Sudbury, as is shown on other pages, no use has yet been made of the sulphur or the iron in the ores. The platinum in the Sudbury ores is known to occur essentially as the arsenide, sperrylite, but the form in which palladium occurs has not been determined. Discovery of compounds of the latter metal would be of great interest, both from the scientific and the economic point of view.

[1] Descriptive Mineralogy, 6th Ed., p. 677.

The silicate ores of nickel have been treated essentially for the one metal, although attempts have been made to utilize the iron by smelting to a nickeliferous pig. Excepting these two metals the silicate ores contain no constituents of value.

The cobalt-nickel ores of Cobalt contain several constituents in commercial quantities. The chief of these is silver. Then there are cobalt, nickel and arsenic. Certain of these ores also contain an important quantity of mercury.

Historical Notes on Nickel Mining

The history of nickel mining may be conveniently divided into two periods, namely, that preceding the working of the New Caledonia deposits and that which has followed. During the last 30 or 40 years the production has increased enormously and New Caledonia and Sudbury have dominated the market.

Although the metal nickel was discovered by Cronstedt in 1751, in niccolite from a cobalt mine in Sweden, an alloy, containing copper, zinc and nickel, had been in use in China for thousands of years. Coins, found in Persia, dating from prior to 200 B.C., contain percentages of copper and nickel similar to those in coins made at the present time. It is interesting to note that use was also made, in early ages, of the closely related metal cobalt, glass coloured with this metal having been found in the ruins of Troy and in the graves of the ancient Egyptians.

Owing to the hardness of nickel and the temperature required to melt it, there is little likelihood that any use was made of the metal except in alloys until modern times. In considering the use by the ancients of nickel alloys, it may be pointed out that tin had a similar history. Bronze, an alloy of copper and tin, was used for ages before the latter metal was employed in the unalloyed state.

It was some time after Cronstedt's discovery that pure nickel was prepared, Bergman extracting it in 1775. The first refining of the metal for commercial purposes appears to have been done at Schneeberg, which had long been the site of the cobalt industry. For some years the ores of nickel treated were those that occur in the cobalt deposits, especially of Saxony and Bohemia. In 1838 it was found that the pyrrhotite ores of Sweden contained nickel, and a refining plant was erected. Nickel ores were also discovered in Norway and several plants were erected in that country which became the largest producer of the metal. Norway continued her lead until 1877, when she was eclipsed by New Caledonia, export of ores from this country beginning in 1875. Immediately prior to the advent of New Caledonia as a producer, the world's output of nickel appears to have been about 500 metric tons a year. Norway's greatest annual output is said to have been 360 tons in 1876.

In the period preceding the beginning of mining in New Caledonia several countries, in addition to Scandinavia, Germany and Austria, were producers of nickel ore. Mines in Piedmont, Italy, were operated between 1860 and 1870, the ore produced being similar to the Norwegian, but the deposits were of smaller size. The United States had one important mine, that at Lancaster Gap, Penn. Although its total production is given as only about 2,000 tons, its annual output at one time represented about one-sixth that of the world. This mine is said to

Blezard Mine.

Blezard Mine.

Blezard Mine.

Creighton Mine.

The three specimens from the Blezard mine, Sudbury area, Ontario, are polished sulphides (white), and norite (dark). Magnified 70 diameters. The polished specimen from the Creighton mine shows a veinlet of pentlandite, with good cleavage, in pyrrhotite (white). Magnified 70 diameters.

Photomicrographs by Wm. Campbell.

have been worked for copper prior to 1774, and subsequently at various periods without much success. It was not until 1853 that the ore was found to contain nickel. Ten years later the mine became a nickel producer. Owing to competition from New Caledonia and Sudbury, the mine was finally closed in 1891. It may be added that the ores from Lancaster Gap contain pyrrhotite and chalcopyrite and in this respect resemble those of Sudbury, Scandinavia and Italy. In this earlier period of nickel production the copper and iron sulphides that occur in certain of the lead deposits of southeast Missouri received some attention. Small shipments were made to England with the object of extracting the nickel which the ores contain.

Reference should also be made to the fact that nickel was produced from Canadian ores before the discovery of the Sudbury deposits. These ores came from the Silver Islet mine, Lake Superior, discovered in 1868, and contained nickel and cobalt, in addition to being very rich in silver. Prior to 1873 and later nickel was extracted from the matte produced from these ores at the Wyandotte, Mich., smelting works.

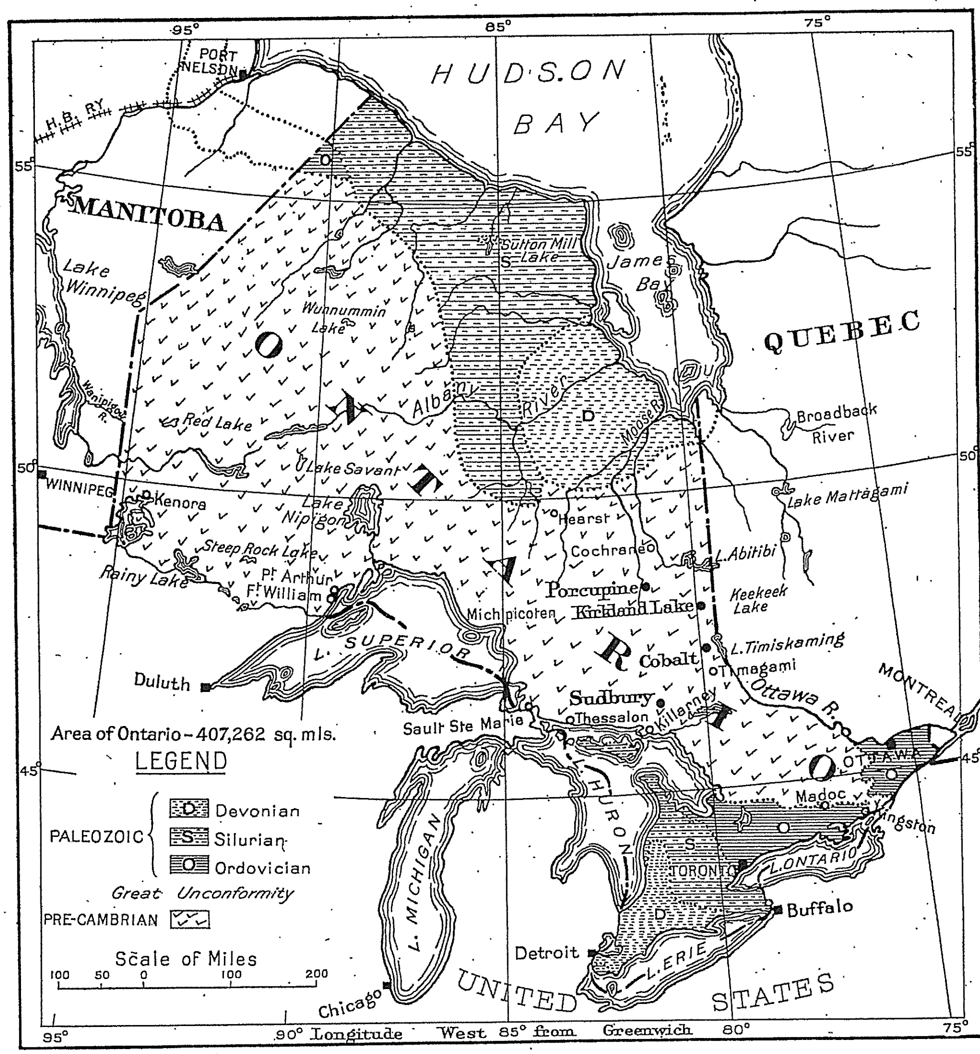
Nickel ores were refined at an early date in England. Johnson of Hatton Garden introduced nickel refining about 1830. The plant of Henry Wiggin & Co., Ltd., near Birmingham, was established, under the name of Evans & Askin, in 1832, for the treatment of cobalt-nickel ores.[1] A process for the separation of nickel from cobalt on a commercial scale was developed at this plant about the year 1836. These were the first works to refine nickel, by a wet process, in England. Arsenical nickel ores were treated almost exclusively until mining began in New Caledonia in 1875. The arsenical ores came partly from Hungary and partly from South America and elsewhere. After the New Caledonia ores came on the market another company erected a plant to treat them at Erdington, near Birmingham. Both plants are still in operation, as is also the Vivian plant, now known as the Anglo-French, in Swansea. This Vivian plant was also a pioneer in the treatment of cobalt and nickel ores.

Since the coming of the New Caledonia ores on the market, 1875, and later those of Sudbury, 1886, other sources of supply have played only an insignificant part. The difference between the price of refined nickel and the cost of production has enabled the Norwegian mines to operate, and small quantities of ore from other countries, valuable for its nickel content, have been sold from time to time. Moreover, there will always be a small production of nickel as a by-product in the refining of copper, cobalt and other ores.

Nickel Deposits of Various Countries

The geology, ore deposits and mining methods of Sudbury are described on pages 103 to 227, and Alexo mine, 228 to 232. Then follow descriptions of the nickel resources of New Caledonia, pages 234 to 263, Norway, 264 to 265, and other countries in alphabetical order, 266 to 286.

[1] Birmingham Handbook, Brit. Ass. Ad. Science, 1913.



Geological Map of Province of Ontario, Canada, showing location of the Sudbury Area.

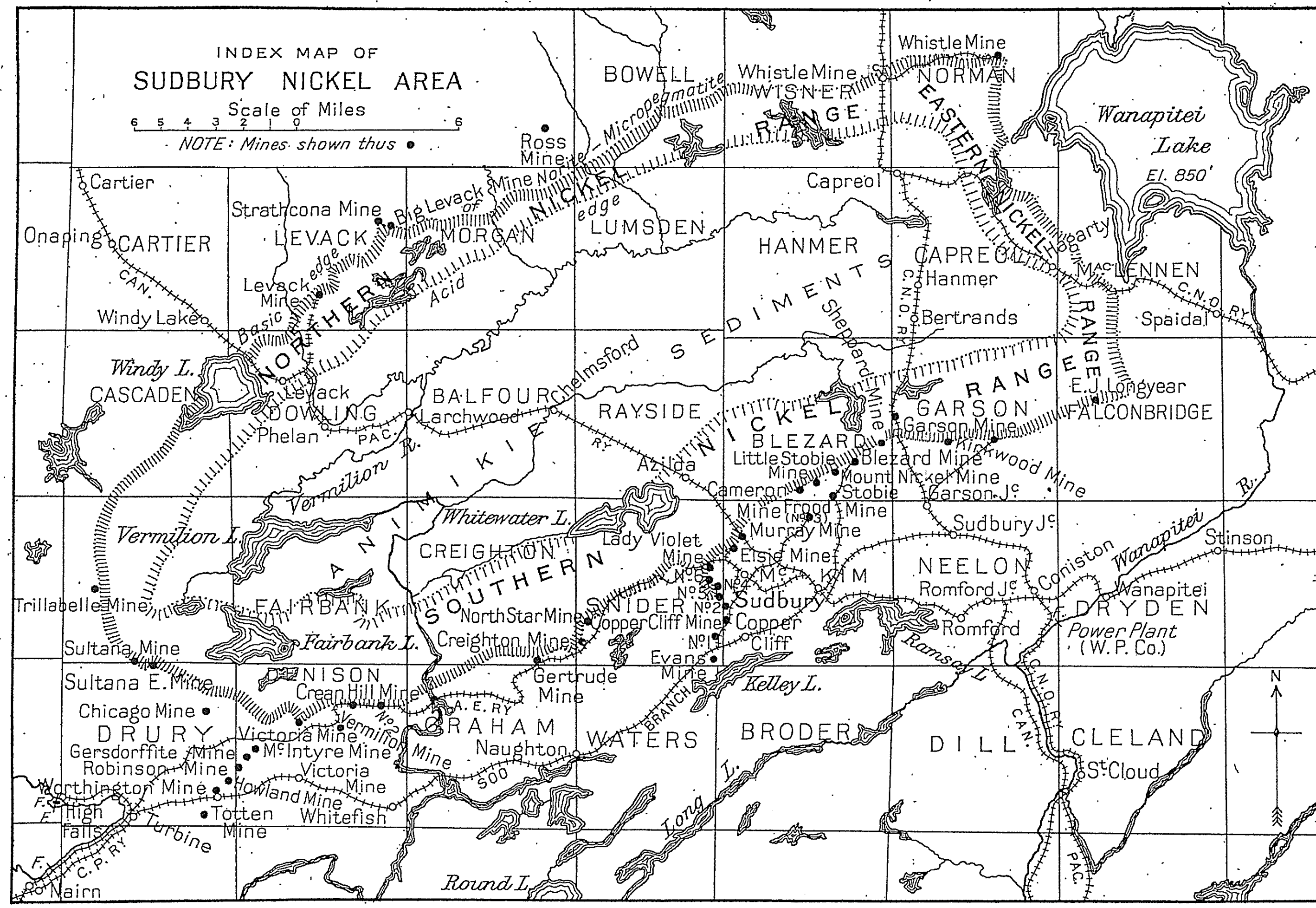


Fig. 1. Map of the Sudbury Nickel-Copper area, Ontario, Canada, showing the location of the mines. The outlines of the norite-micropegmatite are also indicated.

GEOLOGY OF SUDBURY AREA*

The surface geology of the Sudbury nickel-copper area has been described in considerable detail by various authors. The present report deals especially with the size, structure and character of the ore bodies and their relations to adjacent rocks.

While this report will be confined mainly to a study of the ore bodies, it may be helpful to give a brief outline of the geological history of the area. The reader who desires to obtain more details regarding the general geology may do so by consulting the reports referred to in the bibliography on following pages of this Report.

The rocks have been divided into the groups indicated in the following table, the oldest formations being shown at the bottom of the column. This classification differs somewhat from those employed by other authors.

TABLE SHOWING THE ROCK GROUPS IN THE SUDBURY NICKEL-COPPER AREA.

PRE-CAMBRIAN

Keweenawan Series[1]	Olivine Diabase Dikes Trap Dikes Granites Norite-micropegmatite Gabbros
	Intrusive Contact.
Animikie Series	Chelmsford Sandstone Onwatin Slate Onaping Tuff Trout Lake Conglomerate, Ramsay Lake Conglomerate
	Unconformity.
	Greenstones, including Sudburite[2]
	Intrusive Contact.
Timiskaming Series[3]	Wanapitei Quartzite McKim Greywacké Copper Cliff Arkose
	Unconformity[4]
Grenville Series	Crystalline Limestone, Quartzite, Various Schists and Gneisses.

* Mr. Cyril W. Knight, Assistant Provincial Geologist of Ontario, who has spent some months, during each of the years 1915 and 1916, in a study of the Sudbury nickel-copper deposits, has kindly furnished the Commissioners with the following descriptions of the geology and of the ore bodies, together with his views on the origin of the latter.

[1] Some of the intrusives here grouped with the Keweenawan are possibly of later age.

[2] These rocks have not been observed in contact with the Animikie series, but they are believed by some observers to be older than the Animikie. They may be Keweenawan in age.

[3] In this area these rocks are given the name of Sudbury series by some authors.

[4] The unconformity has not been seen in the Sudbury area, but is known elsewhere in Ontario.

Grenville Series

The oldest rocks in the area are named the Grenville series. They consisted originally of sediments which have now been changed to various schists and gneisses. In addition to the schists and gneisses there are also quartzites and, very rarely, crystalline limestone. The Grenville series has not yet been found in actual contact with the Timiskaming series, but it is thought to be older than this series because it is more highly altered, or metamorphosed. The formations on which the Grenville series rested originally are unknown. In southeastern Ontario, however, about 200 miles to the southeast, the series rests on pillow lavas and green schists called the Keewatin series[1]. Certain green schists associated with iron formation, in the township of Hutton, a few miles north of the Sudbury area, may be of Keewatin age. In the Sudbury area Coleman has mapped an extent of the Grenville rocks to the south of the Mond Nickel Company's smelter at Coniston, about eight miles from the mines.[2] It may be added that Robert Bell originally described the Grenville rocks in the Sudbury area.[3]

Timiskaming Series

The next youngest group of rocks is the Timiskaming series, the Sudbury series of certain authors. It consists of quartzites, greywackés, arkoses, slates and conglomerates. The series is supposed to have a total thickness of 29,000 feet[4]. The rocks were no doubt laid down under the ocean in horizontal beds. They have since been subjected to mountain-building forces which have often tilted the beds into steeply inclined positions, Fig. 2, the greywackés and slates sometimes being changed to schists and gneisses. The Timiskaming series, between Worthington mine and Victoria mine station on the Canadian Pacific railway, contains coarse boulder conglomerates. There are boulders of granite and granite gneiss two or three feet in diameter. The presence of the granite fragments shows that there was a granite formation older than the conglomerate. This old granite floor has not been discovered in the Sudbury area, although it has been found elsewhere in the Canadian shield. It may be added that every granite yet found in contact with the Timiskaming series in the Sudbury nickel-copper area is younger than these sediments.

Greenstones, Including Sudburite

Associated with the Timiskaming series there are some greenstones whose age is not definitely ascertained. They are evidently younger than the Timiskaming series, but whether they are pre-Animikie in age or Keweenawan is not certainly known. The greenstones are basic rocks, sometimes having pillow structures and amygdaloidal textures when they are called sudburite, Fig 59, or "older" norite.[5] They are often altered to schists. They occur mainly on the

[1] Miller & Knight, Ont. Bur. Mines, Vol. 22, Part II, pp. 3, 9, 11, 34, 35, 45, 50, 88.
[2] Ont. Bur. Mines, Vol. 23, Part I, p. 204.
[3] Geol. Sur. Can., Vol. 9, 1896, pp. 9-11, I.
[4] Ont. Bur. Mines, Vol. 23, Part I, p. 214.
[5] Ibid., p. 215.

Fig. 2—Greywacké and slate, Timiskaming series, on the outskirts of the town of Sudbury. The bedding planes of the rocks have been tilted into vertical position. The cliff is about ten feet high.

southern nickel range immediately adjacent to or near the norite. Sudburite is found at the Murray and Gertrude mines, and elsewhere.

The Animikie Series

The Animikie series consists of sandstones, slates, tuffs and conglomerates, having an estimated thickness of about 9,500 feet[1]. At Ramsay lake the conglomerate rests unconformably on the Timiskaming series. The Animikie rocks are found for the most part in a remarkable depression known as the Sudbury basin. The latter is surrounded by prominent hills of the Animikie conglomerate and the acid part of the norite-micropegmatite. The conglomerate contains pebbles and boulders of quartzite, granite, and other rocks, and is regarded as an ordinary basal conglomerate.

These Animikie rocks at Sudbury are believed to be of the same age as the Cobalt series at Cobalt, Gowganda and elsewhere.

The Keweenawan Series

The Keweenawan series is the most important group of rocks from an economic point of view. During this period the nickel-copper ores were formed. In other parts of the pre-Cambrian region, notably at Cobalt and on Keweenaw point on the south shore of Lake Superior, the Keweenawan period was also a time during which valuable minerals were deposited, e.g, the silver, cobalt, nickel and arsenic ores at Cobalt, and the native copper deposits at Keweenaw point.

At Cobalt and Sudbury the Keweenawan series consists entirely of igneous rocks, but at Keweenaw point the series is made up of a stupendous pile of interbedded lavas and sediments.

In the Sudbury area there appear to be igneous rocks, of the Keweenawan series, of several ages, as shown on the table on page 105. The oldest group consists of gabbros which are medium to coarse-grained rocks resembling somewhat the norite of the area. A prominent intrusion of the gabbro stretches from the town of Sudbury southwest to Kelley lake. Gabbros are also met with at Murray, Mount Nickel and Frood mines, and elsewhere. The age of the gabbros has not been definitely ascertained. It is known that they are younger than the rocks of the Timiskaming series, since they have been intruded into this series. On the other hand, they have not been observed in contact with the Animikie rocks in the Sudbury basin, and therefore it is not possible to state definitely whether they are older or younger than the Animikie. It may be, of course, that the gabbros are not all of the same age.

The next youngest rock of this series is the norite-micropegmatite which occurs in such large volume. It is younger than the gabbro at Murray and Mount Nickel mines, at both of which places it has caught up fragments of the gabbro. The form and composition of the norite-micropegmatite are described on pages 115-121.

The granites appear to be the next youngest rocks. There is, however, some difference of opinion regarding the age of these rocks, but this matter is discussed more fully elsewhere in the report, pages 122-125. It is certain that some of the

[1] The Nickel Industry, Dept. of Mines, Canada, 1913, p. 9.

granites are younger than the norite-micropegmatite since they are enclosed wholly by it and have evidently been erupted through it. These granites have come to be spoken of as "later," or "younger," granites.

The formation of the nickel-copper ore bodies probably closely followed the intrusion and consolidation of the granites.

After the formation of the ore bodies there followed intrusions of fine-grained trap dikes, now having the composition of uralitic diabase. These traps are met with at Creighton, Crean Hill and Worthington mines. Their age relationships were determined by C. H. Hitchcock.

The last important event in the geological history of the area was ushered in by the formation of great cracks or fissures and by the eruption into them of olivine diabase dikes. Certain of these dikes are several miles long and two or three hundred feet wide, and they intersect every rock in the area, including the Animikie sandstone in the Sudbury basin and the nickel-copper ore bodies. They are widespread throughout pre-Cambrian areas not only at Sudbury but at Cobalt, Gowganda, Porcupine and elsewhere.

While the eruption of the olivine diabase dikes constituted the last important event in pre-Cambrian times, of which there is record in the Sudbury area, it may be added that these dikes are cut by small veinlets of granitic material[1].

Granite and Granite-Gneiss

In addition to the rocks briefly described in preceding pages there is a great belt of granite and granite-gneiss immediately north of the norite-micropegmatite, on the northern nickel range. This granite and granite-gneiss are older, in so far as known, than the norite-micropegmatite, but their age relations to the Timiskaming and Animikie rocks have not been ascertained. Another belt of granite and granite-gneiss is found from 6 to 10 miles southeast of the southern nickel range; these granites are intrusive into the Tismiskaming series.

Topography, Sudbury Area*

A word may be said regarding the character of the topography. The country has an average elevation of about 1,000 feet above sea level, the highest hills not being much more than 1,400 feet above the sea. The main line of the Canadian Pacific railway crosses the area, so that a cross-section, Fig. 3, along the railway track gives a fair idea of the topography. It will be understood, of course, that there are some hills which rise 200 or 300 feet above the railway track. It is hardly necessary to point out that the well-known, characteristic feature of the area consists of a distinct, oval-shaped basin, often as level as a plain, while, in striking contrast, hills as high as 600 feet encircle the basin. The latter, where crossed by the Canadian Pacific railway, has an average elevation of 900 feet above the sea. The nature of the rocks which underlie the basin partly accounts for its shape, since the central part consists of soft sedimentary formations, while the encircling hills consist of

[1] Ont. Bur. Mines, Vol. 14, Part III, p. 125.

*The entire surface of the rocks in the Province of Ontario has been glaciated during the Glacial period. Much of the surface, including that at Sudbury, is covered with superficial deposits of sand, gravel, clay and boulders.

harder, igneous or sedimentary rocks. Beyond the basin the country consists of rugged hills, 100 or 200 feet high. The drift-covered valleys between these hills sometimes have farm lands of tolerable fertility.

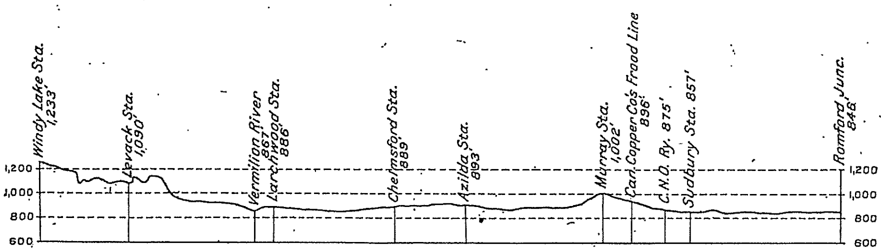


Fig. 3—Section from Romford Junction, near Sudbury, Ontario, to Windy lake, along the main line of the Canadian Pacific Railway. This section crosses the Sudbury basin and shows the elevations above sea level along the railway track. Horizontal scale 8 miles equals 1 inch; vertical scale 1,600 feet equals 1 inch.

Crush-Conglomerates and Crush-Breccias

Crush-conglomerates and crush-breccias, Figs. 4 and 5, are rocks which have been formed by disturbances resulting in crushing and brecciation. The rocks may occur in all the formations of the Sudbury area, they having been met with in quartzites, greywackés, slates, greenstones, granites, norite, and other rocks. The fragments composing the rocks are generally rounded, this variety being known as crush-conglomerate. When, on the other hand, the fragments are angular, the rock is known as a crush-breccia. The matrix which cements the fragments together consists of the more finely crushed material of the rock which has been disturbed. Sometimes the fragments in the crush-conglomerates and crush-breccias are 10 or 15 feet or more in diameter. An example of the rock in greywacké or quartzite may be seen on the hill immediately to the south of the Canadian Pacific railway station at Sudbury, Fig. 5. Here the crushed zone evidently formed a pathway for the circulation of sulphide-bearing waters, for the rock is "spotted" with blebs of sulphides.

The crush-conglomerates and crush-breccias referred to in the preceding paragraph differ only in one respect from the crush-conglomerates and crush-breccias which constitute the commercial ore bodies. In the case of the ore bodies it is the sulphides which largely form the cementing material for the rock fragments, Figs. 6, 14, while in the case of the non-mineralized crush-conglomerates and breccias it is the finely ground-up rock which forms the matrix.

Commercial Ore Bodies Made up of Crush-Conglomerates and Crush-Breccias

As already said crush-conglomerates and crush-breccias may occur in any of the rocks, but they are most commonly found along the rocks adjacent to the norite and along the so-called offsets. They furnished convenient zones for the circulation of hot mineral-bearing waters, and consequently where they occur near the edge of the norite or in offsets they have been heavily mineralized with sulphides, thus forming the commercial ore bodies. The fragments and blocks are cemented together by the sulphides. The sulphides also impregnate or replace the rock fragments, occurring in veinlets, in irregularly shaped masses, and in disseminated grains—"spots" or "blebs."

Fig. 4—Crush-conglomerate and crush-breccia, Copper Cliff, Sudbury area, Ontario. Width of face is 2 feet 6 inches. The rock has been formed by crushing and brecciation; the more finely crushed material constitutes the matrix for the larger fragments. The commercial ore bodies consist largely of these crushed rocks, but in the case of the ore bodies the matrix consists mainly of sulphides instead of the more finely crushed rock fragments, the more finely crushed rock having been partly or wholly replaced by ore.

The "conglomerate"—like character of the nickel-copper ores was noted by one of the earliest observers, Robert Bell, who described the ore more than a quarter of a century ago in the following words[1]:

[1] Geol. Sur. Can., 1890-91, Vol. V, Part F, p. 48.

In each case the ore-mass consists of a brecciated or agglomerated mixture of the pyrrhotite and chalcopyrite along with the country rock. The included fragments of the latter are both rounded and angular, and vary in size from that of pebbles to large boulders, but the average is a few inches in diameter. Immense blocks or 'horses' also occur in the midst of the ore.

The geologists who worked in the field after Bell have also noted the "conglomerate"-like nature of the ore, but little emphasis has been laid on it, except by C. W. Dickson.[1]

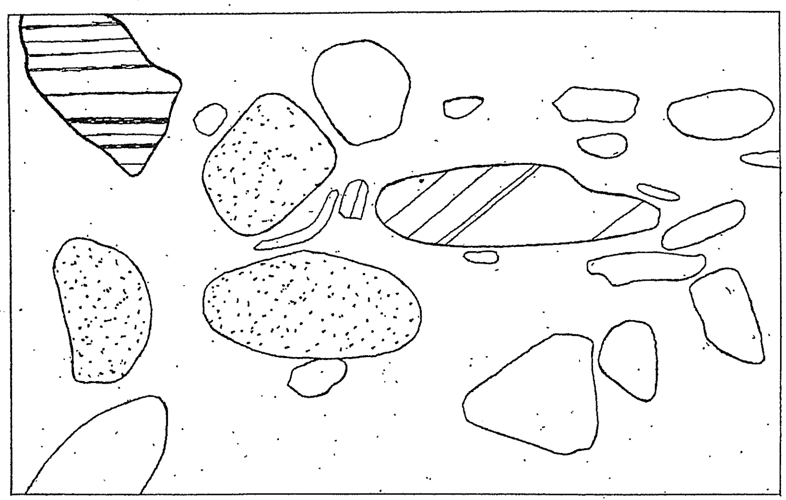


Fig. 5—Crush-conglomerate and crush-breccia on hill immediately south of Canadian Pacific Railway station, Sudbury, Ontario. The rock was formed by crushing and brecciation, and may occur in any rock such as quartzite, slate, greenstone, norite, etc. The length of the rock surface represented in the drawing is 12 feet.

Occurrences of the Ore Bodies*

1. Marginal Ore Bodies

The ore deposits occur for the most part along the outer, basic, contact of the norite-micropegmatite, but the commercial ore bodies are rarely found in the norite. On the contrary, they occur largely in the rocks adjacent to the norite, there being a comparatively small quantity of commercial ore met with in this rock. Examples of ore bodies which occur wholly or mainly in the rocks adjacent to the basic edge of the norite are the Crean Hill, Creighton, Levack, and Whistle. The Creighton is found about at the contact, Fig. 21, while the Levack ore body is wholly in the underlying granite gneiss at an average distance of about 175 feet from the contact of the norite measured at right angles to the dip of the contact, Fig. 40. While it is true that little commercial ore occurs in the norite, there is at times light, non-commercial mineralization in this rock, impregnating or replacing large masses, the sulphides often being found in the form of blebs about the size of peas, giving rise

[1] Trans. Am. Inst. Min. Eng., Vol. 34, pp. 1-67. The brecciated or conglomerate-like nature of the ore bodies is again and again referred to by Dickson; see pages 37, 43, 45, 46, 47, 48, 49, 50, 51, 54, 55, 59 of Dickson's report.

* The mine workings of the nickel-copper deposits at Sudbury have proved that the ore bodies, as they are found to-day, have neither been enriched nor impoverished by the action of surface waters. There has been formed on the surface of the ore bodies, however, a little gossan, caused by the weathering and decomposition of the ore, where the deposits are not protected by a covering of clay, gravel or other materials. Before glaciation took place, the upper part of the deposits no doubt contained a comparatively thick zone of weathering and impoverishment due to the action of surface waters. But the glaciers have long since scoured away this zone.

to what has been called "spotted" norite. The notable example of this non-commercial variety of mineralization is met with at the Creighton, where a zone three-quarters of a mile long and about 600 yards wide is thus mineralized. It may be repeated, however, that the commercial ore bodies are found almost wholly in the rocks adjacent to the norite—not in the norite.

The deposits described in the preceding paragraph are known as "marginal" deposits.

2. Offset Ore Bodies

The second class of deposits has been called "offset" deposits. The offsets are mineralized dikes. There are four main occurrences of the offsets, namely, Worthington, Copper Cliff, Frood and Foy. In the case of the first three it may be pointed out that they cannot be traced directly into the norite or so-called nickel eruptive, although they are believed by many to be of the same age as this eruptive. This relationship has not been proved nor disproved. The offsets have a maximum length of six miles and a width of from a few feet to 700 or 800 feet.

The marginal and offset deposits occur along extensive and well-defined lines that have either a northwest-southeast or northeast-southwest direction. These directions constitute lines of crushing, brecciation and shearing. It has so happened, in the case of the marginal deposits, that the lines of disturbance occur along the contact of the basic edge of the norite-micropegmatite and adjacent rocks, largely in the latter, thus accounting for the occurrences of the ore bodies in this position. The disturbances referred to have broken the rocks along their path into crush-conglomerates and crush-breccias. The ore occupies or fills the spaces between the rock fragments composing these disturbed zones. The ore also impregnates or replaces the rocks in the form of irregular veinlets, masses, and in disseminated grains.

The origin of the ores will probably remain a controversial subject for many years. All that can be said with certainty is that the sulphides were introduced after the norite-micropegmatite had solidified. This is proved beyond doubt, even if there were no other evidence, by the presence in the ore bodies, which occur exactly at the contact of the norite, of both round and angular fragments of the norite cemented together by pure sulphides.

It appears, indeed, to be a common experience to find that ore deposition is later than the igneous rock with which an ore body may be associated. The remarks of J. E. Spurr are of interest in this respect: "Where ore bodies occur in, near, or following the contact of igneous rocks," writes Spurr, "there is evidence in every case that I have seen (with the exception of certain pegmatite veins and pegmatitic quartz veins), that ore-deposition was distinctly subsequent to rock consolidation; and hence that the ore was derived from some deeper horizon."[1]

The origin of the Sudbury ores is more fully discussed in succeeding paragraphs.

A word may be added regarding the surface outcrops of the ore bodies. Some of the deposits outcrop in valleys, while others outcrop on hills. For instance, the Frood, Victoria, Crean Hill, and Garson occur on hills, while the Worthington, Creighton, and particularly the Levack, are examples of deposits which occupy pronounced valleys.

[1] Economic Geology, Vol. II, No. 8, December, 1907, p. 794.

The Shape of the Ore Bodies

The shape of the commercial ore bodies is for the most part rudely lenticular, the Creighton, Murray, Garson, Levack, and numerous other deposits having lenticular outlines. Other commercial ore bodies, like the Victoria and Copper Cliff, have the form of irregular cylinders or tubes. Some ore bodies are distinct veins.

Character of the Sudbury Nickel-Copper Ores

The character of the Sudbury nickel-copper ores may be described as being more or less "rocky." That is to say, the ore is always accompanied by rock, generally in the form of fragments, Figs. 6, 19. These fragments vary from microscopic specks to great blocks 5, 10, 15 feet or more in diameter, and they consist of granite, greenstone, norite, quartzite, greywacké, schist, or the individual minerals constituting these rocks. The rocky nature of the ore bodies makes it

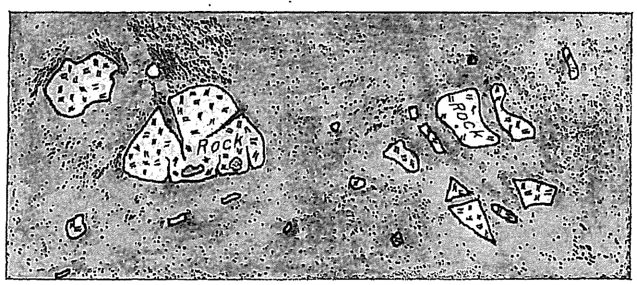


Fig. 6.—Character of ore at Creighton mine, Sudbury area, Ontario, ninth level, 15 feet from footwall. Greenstone boulders and fragments enclosed in sulphides (shaded area). Width of face 8 feet.

necessary to hand-pick from the ore from 10 to 60 per cent. of rock, and even this hand-picked product contains 14 to 35 per cent. or more of silica. The cleanest ore in the whole field is that which is mined from the Creighton deposit, but even from this ore there is hand-picked from 10 to 16 per cent. of rock. This hand-picked product still contains 18 to 21 per cent. of silica. The character of the ores from important mines is shown in the following table:

Name of Mine.	Per Cent. of Rock Hand-Picked from Ore.	Per Cent. of Silica Remaining in Hand-Picked Ore.
Crean Hill	50	28-35
Creighton	10-16	18-21
Garson	25	24*
Victoria	25	14
Levack	33	14
Worthington	60	26†

* Including Kirkwood mine. † Including Worthington No. 2.

The ore consists almost wholly of three minerals; namely, pyrrhotite, chalcopyrite and pentlandite. Several other minerals occur but these are found in comparatively insignificant quantities. Coleman[1] and Barlow[2] have described the minerals in great detail. Pentlandite is the nickel bearing mineral, and it contains 22 per cent. of this metal. Chalcopyrite is the copper bearing mineral, containing as it does 34.5 per cent. of copper.

The Norite-Micropegmatite, its Form and Composition, and its Relation to the Nipissing Diabase

The norite-micropegmatite has been mapped by Coleman as an oval area surrounding a basin composed of conglomerates, sandstones, tuffs and slates, Fig. 1. The average width of the intrusive on the southern nickel range is 3.1 miles and on the northern range 1.9 miles. The length of the area is about 36 miles and its width, including the sedimentary basin, 16 miles.

This great mass of igneous rock has been shown by the workings of the various mines and by diamond drilling to have sometimes a gigantic dike-like form, Fig. 7, and sometimes a sheet-like form, Fig. 8. On the southern nickel range, where most of the mines occur, more is known about the dip of the basic edge of the

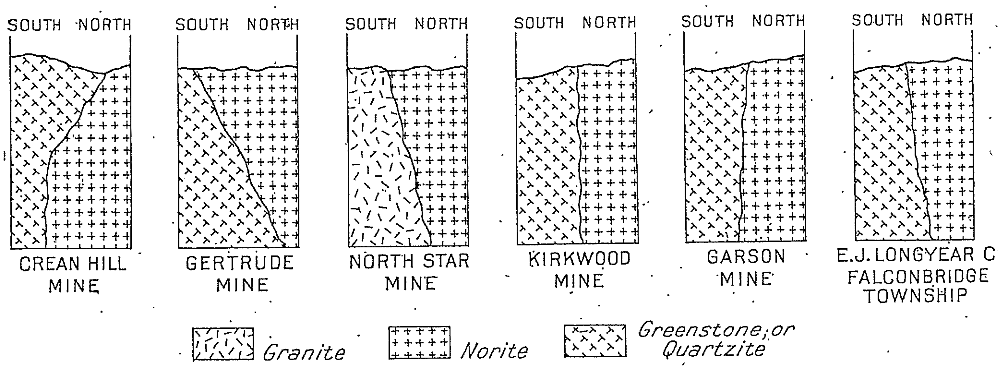


Fig. 7—Cross-sections illustrating dike-like character of the contact of the basic edge of the norite-micropegmatite (the so-called nickel eruptive) on the southern nickel range, Sudbury, Ontario. These diagrams show that the norite-micropegmatite has partly a dike-like form.

intrusive than is known elsewhere. It has been found that the basic edge of the intrusive has a dike-like contact at Crean Hill, Gertrude, North Star, Garson, on the E. J. Longyear Company's property, Falconbridge township, and on part of the eastern nickel range. At Crean Hill the intrusive in the shaft section dips at an angle of 50° to 60° to the southwest, under the greenstones, to about the sixth level, below which it is more or less vertical, Fig. 18. Generally speaking, the contact of the intrusive at Crean Hill may be said to be more or less vertical; *i.e.,* dike-like. The intrusive at the Gertrude dips at 55° to 67° to the north. At the North Star mine the dip of the intrusive is 75° to 80° to the northwest—also a dike-like occurrence. The dip of the intrusive at the "northwest" ore body of Garson mine is 80° to 90° to the southwest. The main ore body at the Garson dips at angles of 53 to 60 degrees to the southeast; if the ore body here follows the dip of the intrusive, then the latter is plunging to the southeast below the adjacent rocks for at least 1,800 feet, not to the northwest, as it should do if it had a sill-like form. Three miles east of the Garson, on the E. J. Longyear Company's property, the

[1] The Nickel Industry, 1913, Dept. of Mines, Canada.
[2] Geol. Sur. Can., Report on the Nickel and Copper Deposits of Sudbury, 1907.

dip of the intrusive is from 70° to 90° to the north, in one instance 85° to the south. On the eastern nickel range there is little definitely known about the contact of the intrusive, but I am informed by C. H. Hitchcock that there are places, proved by diamond drilling, at which the intrusive dips towards the east—under the greenstones. In addition to the above localities, where it has been proved that the intrusive has a dike-like contact with adjacent rocks, the Victoria ore body may be mentioned. The ore body has a vertical dip, with a pitch of 70° to the southeast. If the intrusive has the same dip as the ore body, then here also it has a dike-like form. The Kirkwood ore body, a mile and a half west of the Garson mine, has also a vertical dip; if the intrusive has a similar dip it will likewise have a dike-like contact.

Some of the various dips of the outer edge of the intrusive on the southern nickel range referred to in the preceding paragraph, are illustrated in Fig. 7, which shows the dike-like nature of the norite-micropegmatite.

The sill-like nature of the norite-micropegmatite, on the southern range, has been proved at the following localities: Lot 2 in the fifth concession of Denison township, Creighton mine, Elsie mine, Murray mine, Mount Nickel mine and Blezard mine. The contacts at these localities dip at angles of 45°, 45°, 29°, 36°, 30° and 50° respectively to the northwestward. Some of these inclinations are illustrated in Fig. 8.

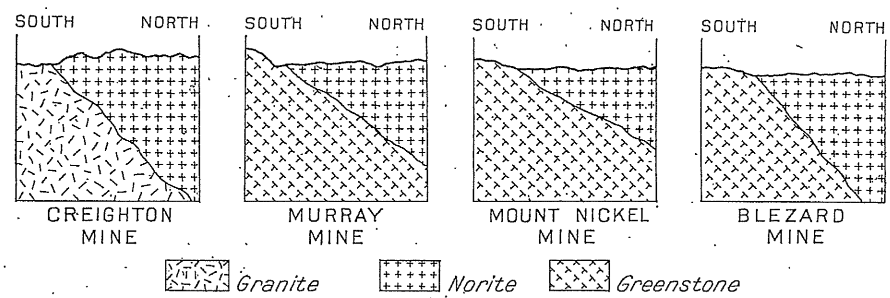


Fig. 8—Cross-sections illustrating sill-like character of the basic edge of the norite-micropegmatite (the so-called nickel eruptive) on the southern nickel range, Sudbury, Ontario. These diagrams show that the norite-micropegmatite has partly a sill-like form.

On the northern nickel range the dip of the intrusive, so far as known, is inwards, towards the basin. The dip at Levack mine has been proved to be 45° to the southeast; and on lot 4 in the fourth concession of Levack township the dip is 45° to 50° to the southeast.

All of the dips so far mentioned refer wholly to the basic (outer) edge of the intrusive. Nothing is definitely known concerning the dip of the acid (inner) edge, since no work or diamond drilling has been done on the inner edge. However, some of the sediments in the basin near the inner part of the intrusive dip inwards, and it has been inferred by certain writers that the dip of the contact of the intrusive follows the inward dip of these sediments. It is prudent, however, to consider that the inward dip of the sediments may have been caused by the faulting down of the basin in one great block. If this happened it would naturally result in tipping the beds so that they dipped inwards. The intrusion of the norite from below around the faulted block, would intensify this inward dip of the beds. The character and origin of the Sudbury basin is more fully discussed elsewhere in the Report.

The mineralogical and chemical composition of the norite-micropegmatite may now be briefly discussed. It has been shown by Walker, Coleman, and others that the rock has been subjected to magmatic differentiation as it cooled and solidified. The more basic minerals are said to have segregated towards the outer edge, while the more acid minerals segregated towards the inner edge. The basic portion consists of norite, gabbro, diorite and diabase. These rocks appear to grade, through syenite, into granitic rocks, known as micropegmatite, at the inner edge.[1] The micropegmatite contains abundant graphic intergrowths of quartz and feldspar. According to Barlow: "There is no sharp line of demarcation between the acidic and basic portions of the nickel bearing eruptive, but the change, though gradual, is usually sharp enough to enable a boundary to be placed between these two types, with tolerable accuracy."[2]

Analyses of the rock are given in the following table:

Table Showing Chemical Composition of the Norite-Micropegmatite in the Sudbury Area.

—	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
SiO_2	49.90	51.52	56.89	60.15	68.48	64.85	61.93	68.95	69.27	67.76
Al_2O_3	16.32	19.77	19.39	18.23	12.70	11.44	13.03	12.74	12.56	14.00
Fe_2O_3	......	.47	.38	1.51	2.41	2.94	.50	.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	6.22	6.49	2.11	3.22	.74	1.60	1.76	1.57	.91	1.00
CaO	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	......	......	......	.17	......	......	......	......	......	......
Cu	......	......	......	.16	......	......	......	......	......	......
S	......	......	......	.54	......	......	.19	......	......	......
Totals	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

Nos. 1 and 2—Basic edge on the southern range near Blezard mine. Analyst, T. L. Walker.
No. 3—Near the basic edge on the northern range at Onaping. Analyst, E. G. R. Ardagh.
No. 4—Basic edge near Creighton mine. Analyst, M. T. Culbert.
No. 5—Middle of Onaping section. Analyst, T. L. Walker.
No. 6—Middle of the Blezard-Whitson lake section. Analyst, T. L. Walker.
No. 7—Acid edge on the Onaping section. Analyst, E. G. R. Ardagh.
No. 8—Near acid edge on the north shore of Fairbank lake. Analyst, E. G. R. Ardagh.
Nos. 9 and 10—Near the acid edge of the Blezard-Whitson lake section. C. B. Fox, analyst of No. 9; T. L. Walker, of No. 10.

[1] Regarding magmatic differentiation in the norite-micropegmatite Alfred Harker says: "I found no indication of a regular 'composition gradient' in either norite or granophyre, considered separately, while the transitional zone between them has all the characters of a hybrid rock" (Jour. Geol., Vol. 24, 1916, p. 555). This view is at variance with the views of Coleman, Barlow and Walker.

[2] Geol. Sur. Can., Report of the Nickel and Copper Deposits of Sudbury, 1907, p. 85.

Four of the analyses are from the basic edge, two are from the middle of the intrusive, and four are at or near the acid edge of the intrusive. The analyses, in so far as they go, appear to demonstrate that the rock is more basic at the outer edge than at the inner edge, but they also demonstrate, at the same time, that the middle portion of the intrusive is even more acid than part of the inner edge itself. Judging wholly, then, from the analyses, one is not able to say that there is a gradual transition from basic to acid rock as one goes from the outer to the inner edge.

It is desirable, indeed, that more chemical analyses be made to ascertain the precise character of the magmatic differentiation which has taken place in the intrusive. Its general nature is already known. To obtain more information at least six complete sections could be made across the intrusive at strategic points on the northern and southern ranges, specimens being collected at desirable intervals and rock analyses made. Perhaps it might be found, as a result of this work, that the character of the magmatic differentiation is not as regular as it has been considered to be.

This investigation has already been begun in a small way for the Ontario Nickel Commission, the Creighton and Murray mines having been selected for the purpose. At the Creighton mine seven samples of the intrusive were collected at the following distances respectively to the northwest of the Creighton open pit:—140, 200, 300, 750, 1,200, 2,000 and 3,250 feet. The analyses of these samples, shown in the table below, demonstrate that practically no differentiation has taken place in the intrusive for about two-thirds of a mile from its outer edge.

Table, Showing Chemical Composition of Norite at Creighton Mine.

——	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
SiO_2	55.58	51.34	51.80	55.24	54.12	53.26	54.84
Al_2O_3	....	....	....	....	20.18	17.40	....
Fe_2O_3	2.32	2.51	2.80	1.42	2.65	3.35	1.42
FeO	8.03	8.19	7.92	7.07	5.80	5.72	5.67
CaO	7.20	7.40	6.72	6.72	6.72	8.00	7.25
MgO	0.69	3.95	3.36	1.13	3.81	6.62	1.56
Na_2O	2.56	2.18	1.84	2.74	3.17	2.64	2.88
K_2O	0.98	0.80	0.62	1.04	1.52	1.27	1.38
CO_2	0.21	0.32	0.39	0.22	0.40	0.31	0.33
H_2O	2.54	0.78	3.59	1.04	1.74	1.71	1.72
Totals	....	....	....	....	100.11	100.28	....

No. 1—Norite, Creighton mine, 140 feet northwest of open pit.
No. 2— " " " 200 " " " "
No. 3— " " " 300 " " " "
No. 4— " " " 750 " " " "
No. 5— " " " 1,200 " " " "
No. 6— " " " 2,000 " " " "
No. 7— " " " 3,250 " " " "

The result of the chemical analyses at Murray mine also proves that no magmatic differentiation took place in the intrusive for at least 1,900 feet to the northwest of the basic edge. Seven samples of the rock were selected at this mine at the following distances respectively from the edge of the intrusive: 30, 150, 300, 600, 900, 1,400, 1,900 feet. The analyses are shown in the following table.

Table, Showing Chemical Composition of Norite at the Murray Mine.

——	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
SiO_2	54.84	54.81	55.96	56.10	51.78	54.08	53.08
Al_2O_3	15.82	16.98	21.84	18.72	20.90	16.72	18.54
Fe_2O_3	3.36	1.82	2.84	2.42	1.82	4.90	2.26
FeO	7.02	6.67	5.55	5.78	6.54	5.88	5.28
CaO	5.71	6.96	6.52	6.67	7.52	7.53	7.51
MgO	6.02	6.07	1.48	5.08	5.77	5.23	6.18
Na_2O	3.87	2.99	2.58	2.25	2.82	2.79	3.35
K_2O	2.31	2.18	1.79	1.96	1.84	1.55	2.41
CO_2	trace	0.17	trace	0.22	trace	0.42	trace
H_2O	1.27	1.87	1.19	1.29	1.31	1.08	1.41
Totals	100.22	100.52	99.75	100.49	100.30	100.18	100.02

No. 1—Norite, Murray mine, 30 feet northwest of basic edge.
No. 2— " " " 150 " " "
No. 3— " " " 300 " " "
No. 4— " " " 600 " " "
No. 5— " " " 900 " " "
No. 6— " " " 1,400 " " "
No. 7— " " " 1,900 " " "

In addition to the analyses given above several others were made in order to ascertain the chemical composition of the intrusive at other points. These analyses are shown in the following table.

Table Showing Chemical Composition of Norite or Diorite at Cameron, Evans, Gertrude and Whistle Mines.

——	No. 1	No. 2	No. 3	No. 4
SiO_2	56.86	51.20	59.32	58.86
Al_2O_3	21.62	17.32	16.46	19.54
Fe_2O_3	2.82	5.04	2.52	0.28
FeO	5.29	9.06	5.04	5.76
CaO	6.28	6.76	6.24	6.54
MgO	1.33	4.14	4.12	1.01
Na_2O	2.81	2.32	3.11	2.91
K_2O	1.95	2.14	1.99	2.48
H_2O	0.85	2.15	1.04	2.10
CO_2	0.29	0.25	0.12	0.22
Totals	100.10	100.38	99.96	99.70

No. 1—Norite at Cameron mine.
No. 2—Evans mine.
No. 3—Norite at Gertrude mine.
No. 4—Norite at Whistle mine.

It is of interest to compare the norite-micropegmatite with a similar rock, known as the Nipissing diabase, which occupies comparatively large areas at Cobalt, South Lorrain, Timagami, Gowganda, and elsewhere. These localities are from a few miles to 50 miles or more beyond the norite-micropegmatite. The rocks prob-

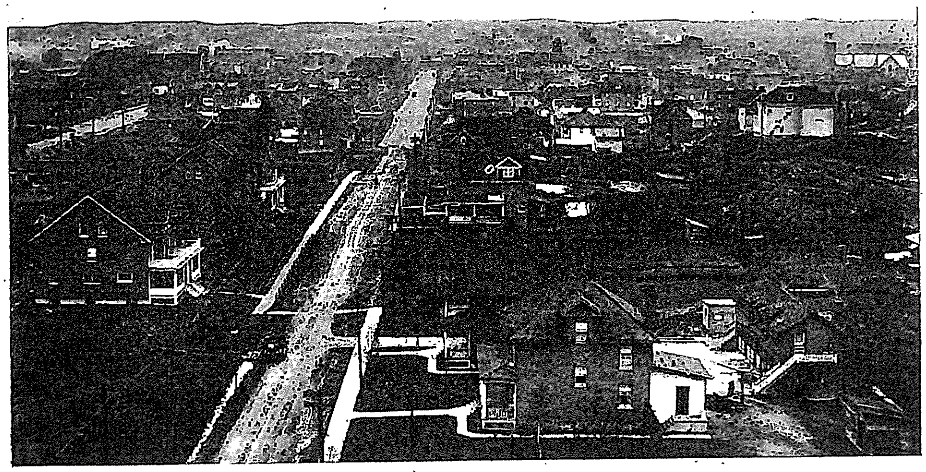


Fig. 9—A residential part of the town of Sudbury, Ontario, October 26th, 1916.

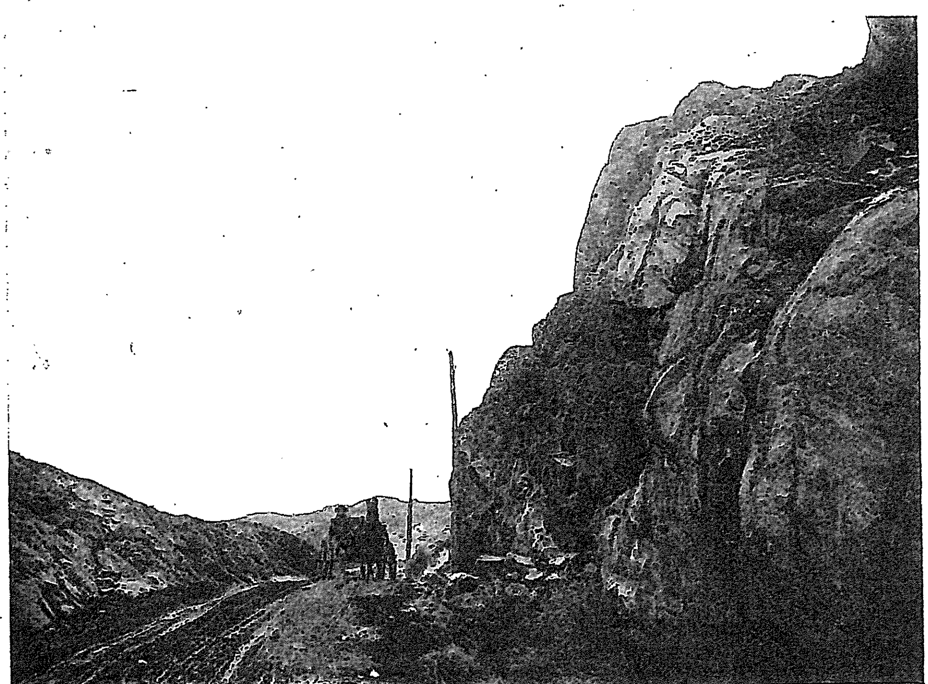


Fig. 10—Showing rugged nature of country near Murray mine, Sudbury area, Ontario.

ably both belong to the Keweenawan series and resemble each other in many striking respects. It is not unlikely that they were intruded at the same time and will be proved some day to be one and the same rock. At Cobalt the Nipissing diabase has the form of a sill, while at Sudbury the norite-micropegmatite has a dike-like and sill-like form. Some years ago Miller and Knight compared the two rocks, the following quotation being extracted from their paper.[1]

> These eruptives both show differentiation, or insensible gradations, from such basic rocks as diabase, gabbro and norite to acid rocks with the composition of granite. The differentiation appears to have taken place on a larger scale at Sudbury than at Cobalt and the surrounding region. Although the basic portion (norite) of the nickel eruptive is coarser in grain than the Nipissing diabase, it nevertheless resembles petrographically the latter rock. For instance, in the descriptions by A. P. Coleman and A. E. Barlow, it is brought out that the nickel eruptive sometimes shows "distinct traces and, at times, well marked diabasic or ophitic texture." Furthermore, the basic facies of each contain quartz, usually intergrown in micrographic fashion with an acid plagioclase. When this micrographic intergrowth increases in quantity until it finally becomes the predominant constituent, a rock with the chemical composition of granite results, which is commonly called micropegmatite, granophyre or aplite.

The Sudbury Basin—Its Origin

The Sudbury basin, originally referred to by Robert Bell[2], forms the central part of the Sudbury nickel-copper field. It consists of a very distinct basin about

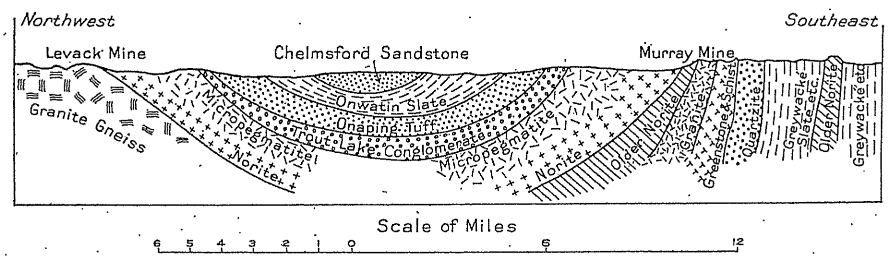


Fig. 11.—Theoretical cross-section through the Sudbury area, illustrating A. P. Coleman's conception of the shape of the norite-micropegmatite, the so-called "nickel eruptive." It is seen that the intrusive is supposed to have the form of a sill. In other parts of the Sudbury area, however, the norite-micropegmatite has a dike-like form; this is true at Crean Hill, Garson, Longyear, and other properties. See Fig. 7, page 115.

36 miles in length and some 16 miles wide. Most of it is covered with clay, sand and gravel. Where the rocks are exposed they consist of sandstones, slates, tuff, and conglomerates of the Animikie series. The basin is often perfectly flat for miles, although it is relieved here and there by gentle undulations in the strata. Its edges are surrounded by rugged hills of conglomerates of the Animikie series, while immediately beyond are somewhat lower hills consisting of the acid edge of the norite-micropegmatite. The latter entirely surrounds the basin. Fig 1.

[1] Eng. and Min. Jour., June 7th, 1913, pp. 1129-1132.
[2] Geol. Sur. Can., Vol. V, Part I, 1890-91, p. 11F.

There is one remarkable feature concerning the basin which requires explanation. Its inner edge is surrounded by the continuous belt of coarse conglomerate already mentioned. Beyond this is the encircling mass of the norite-micropegmatite which completely cuts off the conglomerate. Why this conglomerate does not occur immediately along and beyond the basic edge of the norite-micropegmatite is a question which has occupied the minds of those who have studied the physiography of the basin.

It has been suggested by A. P. Coleman that the norite-micropegmatite was intruded in the form of a sill or sheet which forced its way along the contact between the Animikie series and the underlying older rocks, lifting the former bodily upwards. "The collapse of the foundations of the older rocks," writes Coleman, "caused the cooling sheet of magma to settle into a basin shape, and the nearly flat sediments above it took the same form."[1] Fig. 11. If this solution of the origin of the basin is the true one, then it is an extraordinary thing that not a trace of the conglomerate, not a fragment, not even a pebble has been found below the intrusive. This means that every vestige of the Animikie series was broken off and raised from the uneven surface of the rocks on which the series rested, and that the intrusive was injected precisely along this contact.

As an alternative explanation to Coleman's the following origin of the basin is suggested. This explanation is given because mining operations have shown that the norite-micropegmatite has a gigantic dike-like form as well as a sill-like form, Figs. 7 and 8.

The alternative explanation suggests that the preliminary stage in the formation of the basin may have begun by a great block of the earth's crust gradually faulting down for several thousand feet, carrying with it Animikie sediments. It may be further supposed that the norite-micropegmatite then forced its way upwards and around the faulted block. After the consolidation of the intrusive there followed a prolonged period of erosion, and the rocks were denuded to their present level. The conglomerates, tuffs, slates and sandstones of the Animikie, which extended beyond the outer edge of the intrusive, were thus everywhere carried away by erosive agencies, except the Ramsay lake conglomerate and similar rocks in Falconbridge township. The immense block of these sediments in the basin, however, was preserved from annihilation by the depth to which it had been carried down by faulting.

"Later" Granites

There are several areas of granites which have come to be spoken of as "later," or "younger," granites, meaning that they are later in age than the norite-micropegmatite. The later granites were originally referred to by Adams[2], and afterwards by Walker[3]. Some of these intrusive masses occur within the norite-micropegmatite itself, as, for example, those about two miles northwest of the Murray mine and those near Whitson lake. There are other granites which are met with

[1] The Nickel Industry, Canada Dept. of Mines, 1913, p. 10.

[2] Jour. Gen. Mining Association of Quebec, 1894-95, p. 49.

[3] Quart. Jour. Geol. Soc., London, Vol. 53, 1897, pp. 40-66.

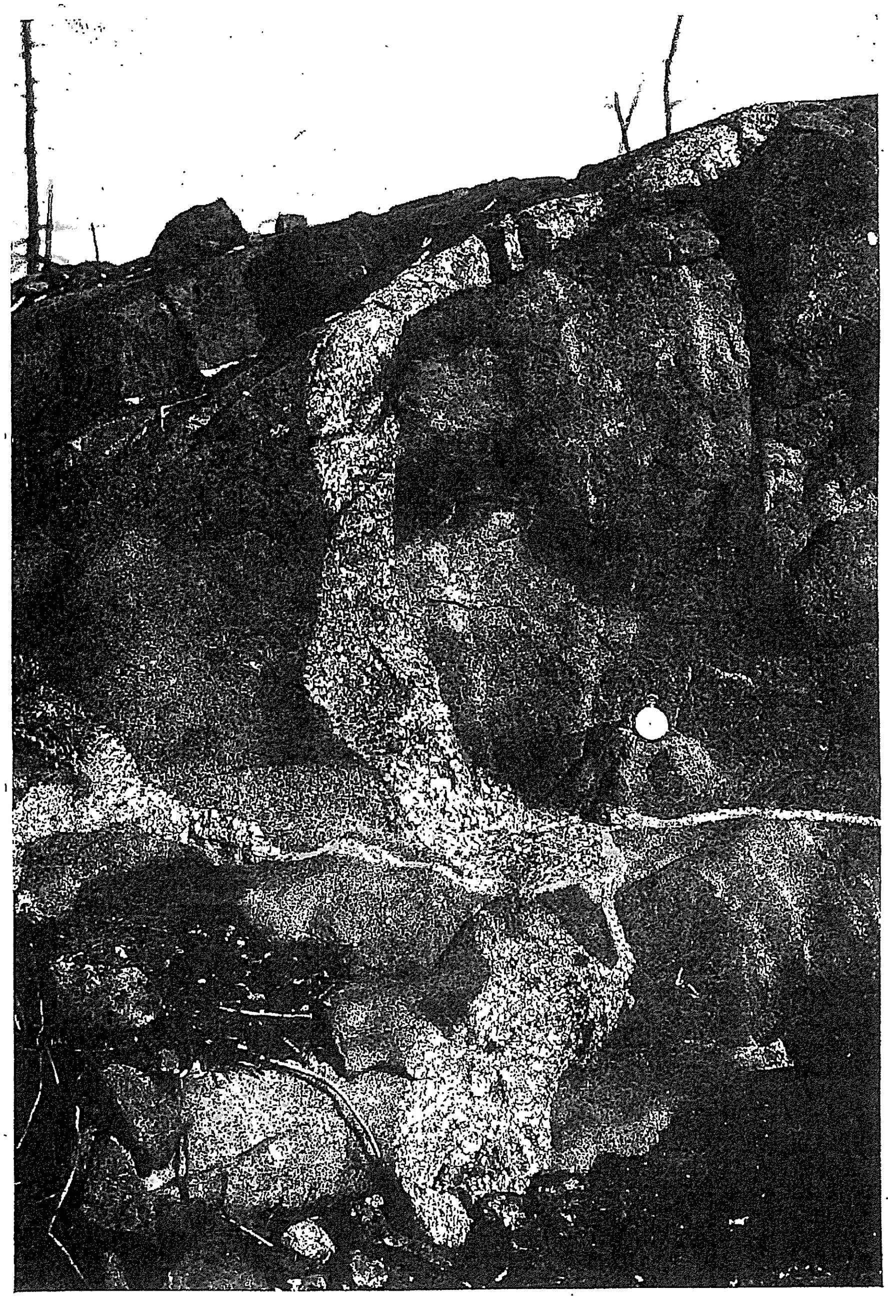


Fig. 12—Coarse-grained granite dikes cutting norite, lot 2, concession IV, Snider township; north of the town of Copper Cliff, Ontario. Many of these granite dikes intersect the norite between Crean Hill mine and Copper Cliff, apparently showing that the main mass of the granite is younger than the main mass of the norite.

at the contact of the norite. One of these occurs to the east of the Murray mine. It has a length of three miles and a width of about a mile, and is believed by Coleman to be "distinctly younger" than the norite-micropegmatite.[1] The evidence for believing that this granite is younger is that the granite sends dikes into the norite.

The age relations of the granite masses referred to in the preceding paragraph are probably as outlined above. There is a larger mass of granite, however, whose age relations to the norite are not agreed upon. This mass is 13 miles long and from one to two and a half miles wide. It occurs as a continuous belt between Copper Cliff and Crean Hill No. 2 and forms the footwall of the Creighton mine. To the writer this granite appears to be younger than the norite because it sends coarse and fine-grained dikes into that rock, Fig. 12. It is only fair to add that Barlow and Coleman have not arrived at a definite decision regarding its age. The importance of knowing its age relation to the norite is great because of the bearing it has on the origin of the ores, pages 131, 151. If, for example, the granite footwall at Creighton mine is younger than the norite, then it was manifestly impossible for the sulphides to have settled from the norite by gravity on this granite.

The views of Barlow and Coleman on the subject of the later granites may be quoted. Barlow's opinions are summed up in the following paragraph:[2]

The nickel-bearing eruptive, which, in its fresh condition is now referred to as a quartz-hypersthene-gabbro or norite, is decidedly later than, and intrusive through, the green schists and associated diorites. The relations between the so-called 'younger' granite are much more complex and anomalous. For the most part, the nickel-bearing eruptive has cooled against the granite, as may be seen at the junction between these two rocks, on the west side of the large pit known as the No. 2 mine at Copper Cliff. Here the norite is distinctly finer in grain at the immediate point of contact, this rock growing visibly coarser farther away from the line of junction. This cooling of the norite against the granite, and the production of a finer-grained or chilled selvage, is especially well seen in the vicinity of the openings made by the Vivians on lot 9, concession VI, of McKim township. On the other hand, in some localities, certain dikes or apophyses of the granite seem to penetrate the norite, as may be noticed along the line of junction to the northwest of No. 2 mine, at Copper Cliff; while the intrusive nature of the granite, and its apparently later age in relation to the norite, is quite marked to the north of Clarabelle lake, where the line of junction between the two rocks is well exposed for a considerable distance. Besides, near the Creighton mine, the granite becomes decidedly more basic in the vicinity of the norite, and a certain zone or belt is formed by the commingling of the material of both rocks, as a result of actual fusion. It has been suggested that the granite and norite may have been differentiates of the same magma, but a more reasonable explanation would seem to be that their periods of intrusion were so closely synchronous, that they overlapped in their time of crystallization, and that the later secretions from the slower cooling granite magma, forced or ate their way into the norite in certain places.

Coleman's views on the subject of the later granites are given in the following quotations:[3]

As explained before, the nickel-bearing eruptive is younger than the series of sediments which rest upon it, but it is by no means the latest eruptive of the district. Penetrating its edge near Murray mine and Copper Cliff there are flesh coloured to grey, medium

[1] Ont. Bur. Mines, Vol. XIV, Part III, pp. 83, 14, 15, 82, 123, 124.
[2] Geol. Sur. Can., Vol. XIV, Part H, pp. 53, 54.
[3] Ont. Bur. Mines, Vol. XIV, Part III, p. 14.

grained granites, and within the eruptive north of Murray mine and near Whitson lake, as well as in other places, there are pale or flesh-coloured granitic rocks, probably later dikes or irregular bosses; so that the main laccolithic sheet was followed by more acid flows of a somewhat later age, but perhaps before the sheet had completely lost its heat.

. . . .

Besides the granite and granitoid gneiss of the Laurentian, which are much older than the sheet of nickel eruptive and underlie it, there are coarse and medium-grained granite and granitoid gneiss, probably not very different in age from the nickel eruptive, but sometimes a little older and sometimes younger. As they occur in bands parallel to the southern nickel range and at no great distance from it, they may be supposed to have some connection with the nickel rock in origin, perhaps having segregated from the same magma before or after the magma of the laccolithic sheet reached its present position. The coarse textured granitoid gneiss, often porphyritic, is, in my opinion, generally older than the nickel rock.[1]

. . . .

While the coarse granitic rocks are generally older than the norite, there is a medium grained flesh-red granite covering considerable areas from near Elsie to Little Stobie, which is undoubtedly later in age, since it penetrates the edge of the norite at Murray mine.[2]

. . . .

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 greywacké, and sending dikes 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.[3]

. . . .

The granite to the south [near the Vermilion river] 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.[4]

The preceding quotations show that the age relation of the granite, between Crean Hill and Copper Cliff, to the norite-micropegmatite is not positively proved according to Barlow and Coleman. If it can be demonstrated that the Copper Cliff offset (dike) is part of the norite-micropegmatite then a portion at least of the granite is older than the norite-micropegmatite, since the Copper Cliff offset is undoubtedly younger than the granite. This offset, however, is separated by a lake from the main mass of the norite.

It may be added that at many places between Copper Cliff and the Crean Hill No. 2 there are irregular, elongated masses of greenstone intervening between the granite and the norite-micropegmatite. These greenstones may have acted as a buffer, so that the norite was protected from the metamorphosing effect of the intrusive granite. It is otherwise difficult to explain why the norite has been so little altered by the granite, except for a zone several feet more or less in width along the contact.

On the northern nickel range, at the Levack and Strathcona mines, for example, there are granites and granite gneisses which are undoubtedly older than the norite-micropegmatite.

[1] Ont. Bur. Mines, Vol. XIV, Part III, p. 123.

[2] Ibid, p. 124.

[3] The Nickel Industry, Department of Mines, Canada, 1913, p. 8.

[4] Ibid, p. 53.

THE ORIGIN OF THE SUDBURY NICKEL-COPPER ORES

It has been remarked that in the case of many ore deposits throughout the world which have been closely studied no agreement has yet been reached regarding the source of the ores, or the manner in which they arrived at their present positions. Certain authorities, for example, consider that the Rio Tinto pyritic deposits in Spain, among the largest and oldest known of copper occurrences, are sediments, while others believe they are magmatic segregations—two widely differing theories. Then there are, even yet, different opinions as to the origin of the famous Rand gold deposits. The great Sudbury nickel-copper deposits have likewise proved, from the time they were first discovered, a source of controversy regarding their origin, and it is likely that many years will elapse before unanimity will be reached in respect of their manner of formation.

Two main theories have been proposed to account for the origin of the Sudbury deposits. One suggests that the nickel, copper and iron sulphides cooled and segregated from a molten condition like igneous rocks. This is known as the igneous or magmatic segregation theory; it is, indeed, what may be called the fashionable theory of the day, in so far as it concerns the Sudbury ores. The other theory accounts for the origin of the deposits by supposing that the ores have been formed by heated waters circulating through crushed, brecciated, fissured and sheared zones. The waters carried in solution the components of nickel, copper and iron sulphides. These two theories regarding the origin of mineral deposits in general were the cause of controversies throughout Europe long before the Sudbury deposits were worked.

The theory that certain ore deposits cooled and solidified from a molten condition like igneous rocks is a very old one indeed. It was proposed by Fournet and others sometime prior to 1838. The language used in explaining the theory was clear and unmistakable. Veins "were formed similarly to the igneous rocks, by means of an igneous fluid injection"; and, again, "the material has been introduced by an igneous fluid injection and has then solidified in the fissures."[1]

This is not only a very old theory, but it was at one time a very commonly accepted one. Von Cotta has remarked that when the igneous origin of many rocks which occur as dikes had once been recognized, many persons were inclined, during the first half of the nineteenth century, to consider all lodes as igneous fluid injections.[2]

The theory that ore deposits were formed by heated circulating waters is also a very old one—older than the theory of igneous origin. It appears to have first been clearly defined by Lasius in 1789. The waters were believed by Elie de Beaumont to have been derived from volcanic exhalations.[3] This remarkable statement was made in 1846.

[1] Von Cotta's Treatise on Ore Deposits, Prime's Translation, 1870, pp. 71, 75, 76.

[2] Ibid, p. 75.

[3] Bulletin de la Société Geolog. de France, 2nd Series, Vol. 4, p. 1349; Von Cotta's Treatise on Ore Deposits, p. 73.

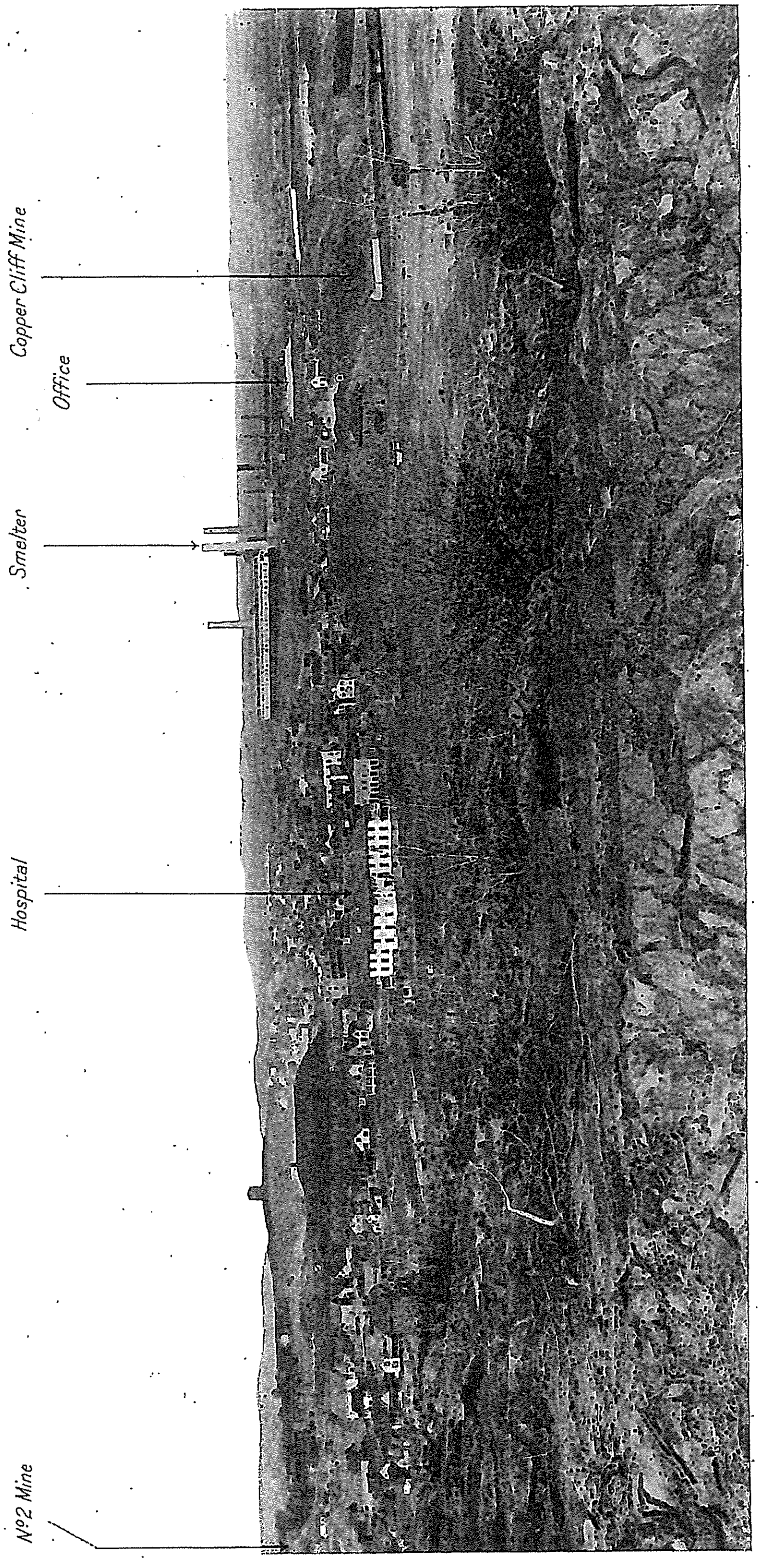


Fig. 13—Town of Copper Cliff, Sudbury area, Ontario, August 13, 1916. The nickel-copper ores from the mines of the Canadian Copper Company are smelted here.

Igneous or Magmatic Segregation Theory

The igneous origin of the Sudbury ores has been advocated by Bell, Walker, Barlow, Coleman, and many others. Coleman has published more information regarding the character and origin of the deposits than has any other worker, and his views may therefore be given rather fully, especially as his suggestions have met with much recognition. He believed that:

> . . . the ore bodies form part of the edge of a great eruptive sheet having a length of 36 miles, a breadth of 16 miles, and a thickness of a mile and a quarter. While cooling, this molten sheet underwent magmatic segregation in which gravitation played a large part, so that the heaviest ingredients, the ores, sank to the lowest points, merging upwards into norite, the next heaviest rock, which passes upwards into granite, the lightest rock of the sheet.[1] [Fig. 11.]

This conception of the formation of ore bodies of igneous origin was foreshadowed in a crude but remarkable manner by D. C. Davies prior to 1888. Speaking generally of ore bodies of this type, although not referring specifically to Sudbury, Davies wrote:

> The eruptive mass would also be itself charged with whatever metals prevailed in it as it lay quiescent in the furnace below. In the process of cooling, especially if this were slow, this heavy metallic matter would sink to the bottom of the overflowing mass and gravitate towards hollows in the underlying rock. This affords an illustration of the way in which a contact deposit lying underneath an eruptive rock may have been produced.[2]

The conception of the settling of sulphides by gravity was also advanced many years ago in connection with the Meinkjar nickel mine in Norway.[3] Bell likewise suggested this idea regarding the Sudbury ores.[4] "If the diorite," Bell wrote, "flowed out originally upon the nearly horizontal surface of the other rocks, the constituents of the ore which it contained may have sought the lower portion of the mass." The theory was later applied by Coleman, as shown in the above quotation, to explain the formation of the Sudbury ores.

While Coleman believed that the theory of magmatic segregation accorded best with the facts, he considered that there had been some subsequent rearrangement of the ores by solution and redeposition in all the deposits.[5] Indeed, he went so far as to say that a few deposits, such as the Worthington and Vermilion mines, may have been formed principally through the action of heated water circulating along fissures at distances, sometimes miles, away from the edge of what he called the great eruptive sheet or sill[6]

Coleman divided the deposits into the following types:

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[1] Jour. Geol., Vol. 15, 1907, pp. 759-782; Ont. Bur. Mines, Vol. 12, 1903, pp. 276-281.
[2] A treatise on Metalliferous Minerals and Mining, D. C. Davies, 4th ed., 1888, p. 30.
[3] Ore Deposits, by Beyschlag, Vogt and Krush, 1914, Truscott's translation, Vol. I, p. 292.
[4] Bull. Geol. Soc. Am., Vol 2, 1890, pp. 125-137.
[5] Ont. Bur. Mines, Vol. 14, 1904, Part III, p. 17.
[6] Ibid., p. 19.

Marginal—

a. "Dipping toward the axis of the basin—ores with comparatively little rock and more than twice as much nickel as copper." Examples: Creighton, Elsie, Murray.

b. "Faulted marginal—irregular in shape and character—usually mixed with much rock and carrying as much copper as nickel, or sometimes more." Examples: Crean Hill, Garson.

Offsets (dikes)—

a. "Columnar offsets, roughly cylindrical bodies nearly vertical and going to great depths. Ore usually rich in copper and the precious metals." Examples: Copper Cliff, No. 2.

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

He advanced the following arguments to prove that the ore bodies were formed by magmatic segregation:[1]

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

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

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

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

E. "The marginal ore bodies show hardly a trace of hydrothermal or pneumatolytic action. There are seldom any of the minerals usual in deposits formed by water except very small quantities of quartz and calcite, and these are often in seams cutting the ore and evidently of later formation. There is no banding such as one finds where cavities are filled with minerals deposited from solution; nor are there concentric structures about the rock fragments enclosed in the ore.

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

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

[1] Ibid, pp. 18, 19.

There are some objections to the theory of magmatic segregation. Before giving these objections, however, it may be pointed out that all observers agree there is some connection between the origin of the ores and the norite, just as there is, for instance, between the cobalt-silver ores and the diabase of Cobalt and the surrounding region.

In *argument B* it is stated that ore and norite are mixed in every degree from rock enclosing particles of ore, to pyrrhotite-norite, in which ore and rock are in equal amounts, and, finally, to almost pure ore with a few rock-forming minerals. While it is true that norite and ore are "mixed," as Coleman points out, it is also true that granite and ore, greenstone and ore, and quartzite and ore are also "mixed" in the same manner. Nevertheless in marginal deposits it has been found that the commercial ore bodies occur almost wholly in the rocks adjacent to the norite, not in the norite. The contact between commercial ore and norite is generally a comparatively abrupt one. This is particularly true at the Creighton mine where the massive sulphides occur more or less sharply defined against the lean "spotted" norite.[1] Indeed, at this mine it may be said that as soon as the norite hanging-wall is encountered the commercial ore body ends.

In the case of *argument C* it may be said it has since been found that granite, gneiss, greenstone, greywacké, schist, quartzite, and other rocks are "spotted" with ore. The "spotted" granite at Creighton mine is quite fresh. It has, further, been pointed out in the preceding paragraph that the commercial ore bodies do occur almost wholly in the adjoining rock, the conspicuous example being the Levack occurrence. The Levack ore body occurs entirely in the granite gneiss, and is separated from the norite by 40 to 220 feet of granite gneiss, Fig. 40.

It is urged in *argument D* that the norite is too fresh to have allowed the sulphides to have been introduced by solutions. The norite is very fresh at most deposits, but at such occurrences as the Garson and Victoria mine it is often so badly decomposed and altered to a schist that it is difficult to distinguish it from other altered rocks. At deposits where it has remained fresh, the explanation seems to be that the rocks generally were but slightly affected by the introduction of sulphides, as the granite at the Creighton, for instance, is as fresh as the norite.

Probably at the time when *argument E* was brought forward it was not known that, at such deposits as the Garson, Victoria and Crean Hill, quartz and calcite, particularly the former, are present in such quantities as to suggest that the ores were deposited from solutions. At the Garson mine, for example, some 35,000 tons of quartz have been mined and shipped, and there still remain in the ore body many thousands of tons of this mineral.

In the case of *argument F* it is agreed by those who support the theory of deposition from heated waters that the norite, or the reservoir from which it was intruded, was the source of the ores and of the heated waters.

Finally, it may be pointed out, in the case of *argument G*, that there are too many notable exceptions to the statement that the largest ore bodies are found "where bays of the norite project into the country rock." One of the largest ore bodies in the entire area, the Levack deposit, does not occur in a "bay" in the norite. This is also true of the Crean Hill mine, the second largest producer in 1916, belonging to the Canadian Copper Company.

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[1] See pages 146, 147.

In addition to the objections above outlined, there are other reasons which make it difficult to accept the theory of magmatic segregation—particularly that variety of segregation in which gravity is thought to have played an important part. It has, for example, been found that in many deposits fragments and blocks of norite are found cemented together by sulphides, Figs 24, 25. It is, therefore, evident that the norite had solidified before the sulphides were introduced. Microscopic studies also bear out the fact that the sulphides had crystallized later than the rock-forming minerals of the norite. This being true, it is not easy to accept the statement that the sulphides settled through a molten norite magma.

In another part of this report, pages 122-125, it is shown that the granite footwall at the Creighton mine is younger than the norite hanging-wall. This age relationship between the granite and norite also presents an obstacle to a belief in gravity segregation.

Little or no magmatic differentiation has taken place in the norite at Creighton or Murray mines. Chemical analyses of the norite at these two mines show that the rock is remarkably uniform along the basic edge. At the Creighton, for example, for a distance of 3,250 feet from the contact there is scarcely any change in its composition.

Even the most ardent believers in magmatic segregation declare that heated waters may have played the principal role in the formation of some deposits—the Worthington, Vermilion, and perhaps the Crean Hill.[1] There appears to be, however, no essential difference between such ore bodies as the Worthington and Crean Hill, on the one hand, and deposits like the Creighton and Garson on the other. It would seem that an explanation of the formation of one class would also account for the origin of the other. All of the commercial ore bodies are of the same monotonous character; that is to say, they consist largely of rock fragments cemented together by sulphides. "Spotted" rocks, i.e., those with "spots" and "blebs" of sulphides about the size of peas, occur at all the deposits.

Theory of Deposition of Ores from Heated Waters

The difficulties confronting a belief in magmatic segregation seem to make it necessary to turn to an alternative explanation as to the formation of the ores. That explanation is the one which suggests that the ore bodies were formed by the circulation of heated, mineral-bearing waters through openings and lines of disturbances—crushed, brecciated, fissured and sheared zones. The heated waters contained in solution the components of nickel, copper and iron sulphides, and probably to a minor extent lime, magnesia, silica, and other materials. The nickel, copper and iron were precipitated mainly as pentlandite, chalcopyrite and pyrrhotite. Regarding this explanation of the origin of the ores Kemp,[2] although a believer in magmatic segregation, has remarked: this theory is a time-honoured one; it involves nothing unreasonable, and has the support of some of the ablest investigators.

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[1] Ont. Bur. Mines, Vol. 14, Part III, p. 19, and The Nickel Industry, Mines Branch, Ottawa, 1913, p. 52, A. P. Coleman. Economic Geology, Sept.-Oct., 1915, pp. 536-542, T. L. Walker.

[2] Ore Deposits of the United States and Canada, J. F. Kemp, 1903, pp. 61, 62.

It suggests that the rocks have been crushed, brecciated, fissured and sheared or otherwise disturbed. In marginal deposits, these disturbances took place mainly in the rocks adjacent to the norite and only to a minor extent in the norite itself. In offset deposits (dikes) the crushing did take place largely in the dikes. There is ample proof of these disturbances, since the ore bodies consist mainly of fragments and blocks of rocks of all sizes, cemented together by sulphides, Figs 14, 20. These fragments possess great variety in shape, and they consist of granite, greenstone, norite, gabbro, quartzite, greywacké, and other rocks. They may be almost wholly replaced or impregnated by sulphides; the process of replacement is particularly well seen at the Creighton mine, where all gradations are found between coarse-grained granite fragments that are slightly replaced by pyrrhotite, chalcopyrite or pentlandite, to ore in which only a few specks of granite remain. Replacement or impregnation has also taken place in fragments of norite at Creighton.

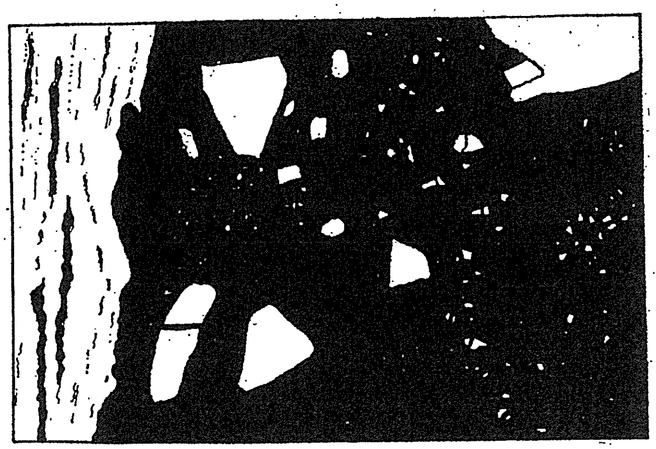

Fig. 14.—Character of ore at Levack mine, third level, Sudbury area, Ontario. Black represents sulphides; white represents granite-gneiss. Width of face 4 feet.

The walls of the marginal and offset ore bodies are also universally replaced or impregnated by ore whether they consist of norite, granite, greenstone, or any other rock. Usually this process of replacement or impregnation is accompanied by little or no alteration of the rocks, this being particularly noticeable in the case of norite and granite at Creighton. The walls of ore bodies such as the Garson and Victoria, however, have usually suffered great alteration. Norite and greenstone at these two deposits are often entirely altered to schists and gneiss.

In the case of offset deposits (mineralized dikes) the process of crushing and brecciation has also taken place. The Worthington and Howland ore bodies are examples of this type of deposit. The sulphides have been introduced through the crushed offsets, the latter being partly replaced or impregnated by the ore.

There is not lacking direct evidence to show that the sulphides were introduced by heated waters. Such minerals as quartz and calcite are of common occurrence, as previously mentioned, at the Garson, Crean Hill, Victoria and Chicago mines.

Quartz is found in large quantities at the Garson. Quartz and calcite are commonly formed by deposition from circulating waters. In the majority of deposits, however, these two minerals constitute a very unimportant part of the ore bodies.

To the question: "Where did the heated, circulating waters, which formed the ore bodies, come from?" it must be replied that it is not possible to give a definite answer. It may be pointed out, however, that, prior to the formation of the ore bodies, igneous activity, i.e., the eruption of masses of igneous rocks, took place on a stupendous scale in the Sudbury area. One of the earliest eruptions appears to have been the greenstone (sudburite). This was followed by intrusions of gabbro, after which the norite-micropegmatite was injected into the crust of the earth. Then came the intrusions of "later" granites. Thus there were at least four distinct eruptions of igneous rocks prior to the formation of the ore bodies. Without doubt each one of these eruptions gave off heated waters during and after its injection. Inasmuch as the ore bodies are more closely associated with the norite than with any other rock, it would appear that the heated waters given off by that immense mass of igneous material, or from its deeper seated, molten reservoir of rock, may have played an important part in the formation of the ores.

Finally, in speculating as to the origin of the ore-bearing waters which formed the Sudbury deposits, there is the possibility that these solutions may have emanated directly from the same deep-seated reservoir of igneous material which gave off the successive intrusions of greenstone, gabbro, norite-micropegmatite, and "later" granites.

In the preceding paragraphs the discussion on the origin of the ores has been given in order to bring out both sides of the question, and to show that unanimity of opinion has not yet been reached.*

* The most recent publication on the Sudbury deposits, and similar occurrences in Norway, Sweden, South Africa, California and elsewhere, is by C. F. Tolman, Jr., and Austin F. Rogers. This publication was received while the Report of the Ontario Nickel Commission was going through the press. Tolman and Rogers do not appear to have visited the Sudbury area in order to study the deposits in the field. Their work was done in the laboratory. Nevertheless the writer is in entire agreement with their statement that the ore bodies were not formed by the sinking of the sulphides in the molten magma. Objections to the theory of gravity segregation were pointed out by the writer in the Engineering and Mining Journal for May 6th and September 23rd, 1916. Tolman and Rogers concluded that ores of this class throughout the world have been introduced at a late magmatic stage as a result of mineralizers, and that the ore-minerals replace the silicates. They regard sulphur as a mineralizer of importance. They believe that a sulphide melt, similar to that in the reverberatory furnace, does not exist after the final consolidation of the silicates of the magma. They believe that the "molten" condition of the sulphides must be due to mineralizers in such amounts that the characteristics of the mixtures are those of a high-temperature solution and not a melt. They find no support whatever for the idea that the sulphides separated as molten mixtures and solidified later. Regarding the Sudbury ores in particular these authors state that the ore bodies were not formed by the sinking of the ores in the molten magma. Summing up their conclusions in respect of the Sudbury ores Tolman and Rogers say: "Although the ores are believed to be magmatic they have been formed at the end of the magmatic period by the replacement of the silicates." (Leland Stanford Junior University Publications, University series, 1916, "A Study of the Magmatic Sulphide Ores." Eng. and Min. Jour., Feb. 3rd, 1917, pp. 226-29.)

DESCRIPTION OF SUDBURY ORE BODIES

During the latter part of the summer of 1916 eight mines were producing in the Sudbury area, namely, the Crean Hill, Creighton, No. 2 and Vermilion of the Canadian Copper Company, and the Garson, Levack, Victoria and Worthington of the Mond Nickel Company. Development work was being done on the Murray mine of the British America Nickel Corporation. The Mond Company pumped out the Blezard mine and were testing it by means of diamond drills. Important diamond-drilling operations were also being carried on by the Longyear syndicate in the township of Falconbridge. It may be added that, in addition to the ore obtained from the mines mentioned, the Mond Nickel Company was purchasing a comparatively small quantity of ore from the Alexo mine, which lies beyond the boundaries of the Sudbury area.

Descriptions of the deposits at the properties mentioned, where ore was being produced in the summer of 1916, will be given under the heading of Working Mines. Afterwards descriptions will be given of the deposits that were lying idle.

An estimate of the tonnage of ore developed in the Sudbury area is given on a preceding page.

WORKING MINES

The Crean Hill Ore Body

The Crean Hill mine is located on lots 4 and 5 in the fifth concession of Denison township. It is served by the Algoma Eastern railway, and is distant from the town of Sudbury about 18 miles. The ore reserves at the end of 1916 amounted to about 2,000,000 tons.

The oldest rocks in the vicinity of the deposit are quartzites and greywackés belonging to the Timiskaming or Sudbury series. They constitute a relatively small part of the formations and appear to be mainly inclusions in the greenstone. The greenstone, which is younger than the quartzites and greywackés, is a fine or medium-grained rock of about the composition of diorite or other closely related type. It is the most important rock in connection with the Crean Hill mine because the ore occurs largely in it. After the greenstone there followed the intrusion of the norite, and, when it solidified, brecciation, crushing and shearing took place along the contact, but mainly in the adjacent greenstone. Then followed the introduction of the sulphides along this crushed and disturbed zone, forming the ore body. When the formation of the deposit was complete, it was fissured, and a dike of trap rock was injected through it and the adjacent greenstone and norite. Finally, as is often the case in the deposits throughout the area, fissures were again formed and dikes of olivine diabase were injected, intersecting the trap dike, ore body, norite, greenstone, and quartzite.

In addition to the rocks above mentioned there are dikes and irregular intrusions of granite intersecting the greenstone and norite.

The shape and size of the main ore body are shown in the composite plan, facing page 134, which gives the outlines on the surface and on various levels down to the ninth. The main ore body has been worked to a vertical depth of about 750

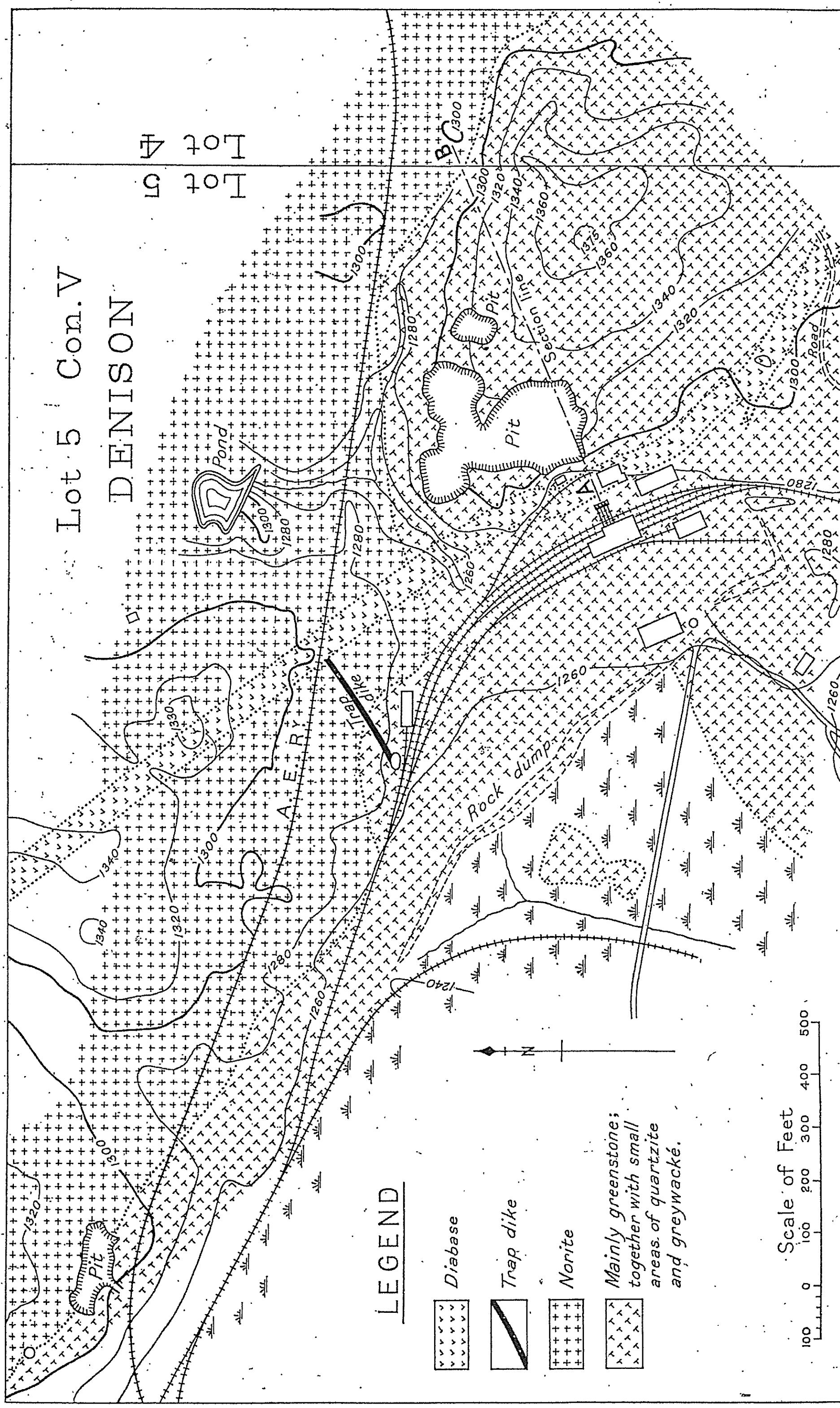

Fig. 15—Geological map of Crean Hill mine, Sudbury area, Ontario. After A. P. Coleman. The plan shows the location of cross-section A. B.

feet (the ninth level) below the collar of the shaft. On the surface it has a maximum dimension in a north and south direction of more than 300 feet, but with depth it appears to become smaller, the width being about 100 feet on the ninth level. On the fifth level, which is about 300 feet vertically below the collar of the shaft, another ore body is being worked at a distance of about 500 feet westward from the main deposit. This ore body is smaller than the main deposit. There is a third deposit about 1,600 feet westward from the main ore body. It has been worked by an open pit, the latter having a length of 150 feet, a width of 45 feet, and a depth of 25 feet. No work was being done here in the summer of 1916.

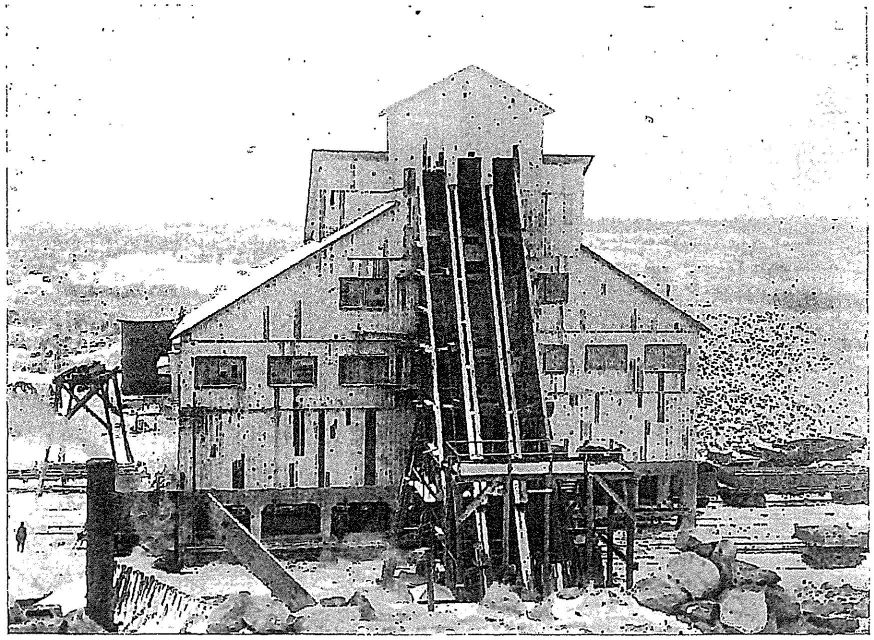

Fig. 16—Crean Hill rock house and shaft, November 24th, 1916, Sudbury area, Ontario.

The main ore body occurs largely in the greenstone. Down to about the fourth level the ore occurs wholly in greenstone, but at this level norite forms the north wall of the deposit, and at lower levels some ore does occur in the norite. The second ore body, which is being developed on the fifth level some 500 feet west of the main ore body, occurs about at the contact of greenstone and norite, some commercial ore being found in the norite, but mostly in the greenstone and to a certain extent in quartzite. The third ore body occurs at the contact of norite and greenstone, mainly in the latter.

The mineralized zone in which the ore bodies described above occur has a length of about two-thirds of a mile or more and a maximum width of 500 or 600 feet. It occurs at the contact of norite and greenstone, but mainly in the greenstone. The ore bodies consist largely of crush-conglomerates and crush-breccias of greenstone. The fragments and blocks of these crush-conglomerates and crush-breccias are cemented together by sulphides. The sulphides also occur in veinlets and in disseminated grains.

The contact between the norite and greenstone has been encountered at various places in the workings, and its angle of dip has been determined. In the

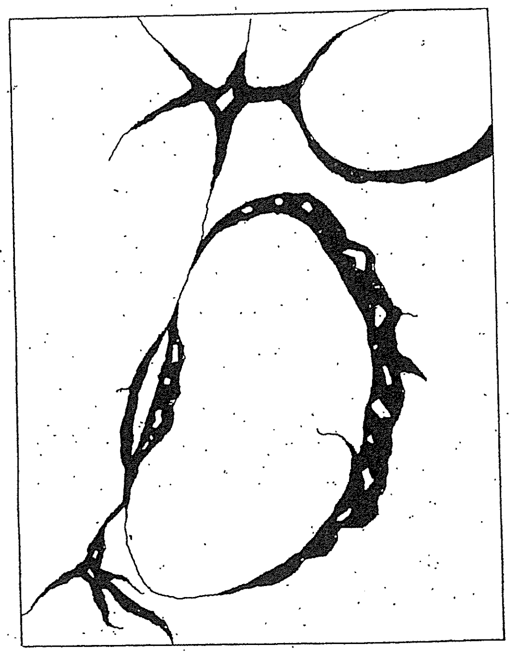

Fig. 17—Showing character of ore at Crean Hill mine, second level, Sudbury area, Ontario. White represents greenstone; black represents ore. The width of the face indicated in drawing is 15 feet.

shaft section, for example, Fig 18, the norite dips to the southward under the greenstone at an angle of 50 or 60 degrees to about the sixth level, below which it becomes about vertical. Some 500 feet westward from the main ore body the angle of dip is 80 degrees, more or less, to the northward. In the pit 1,600 feet westward from the main ore body the contact appears to be vertical.

In several parts of the mine well defined faults have been encountered. They consist of crushed zones averaging 2 or 3 feet in thickness, the fragments being made up of brecciated rock and ore and much soft, clay-like material. Two of these faults, Fig. 18, intersect the shaft between the third and fourth levels.

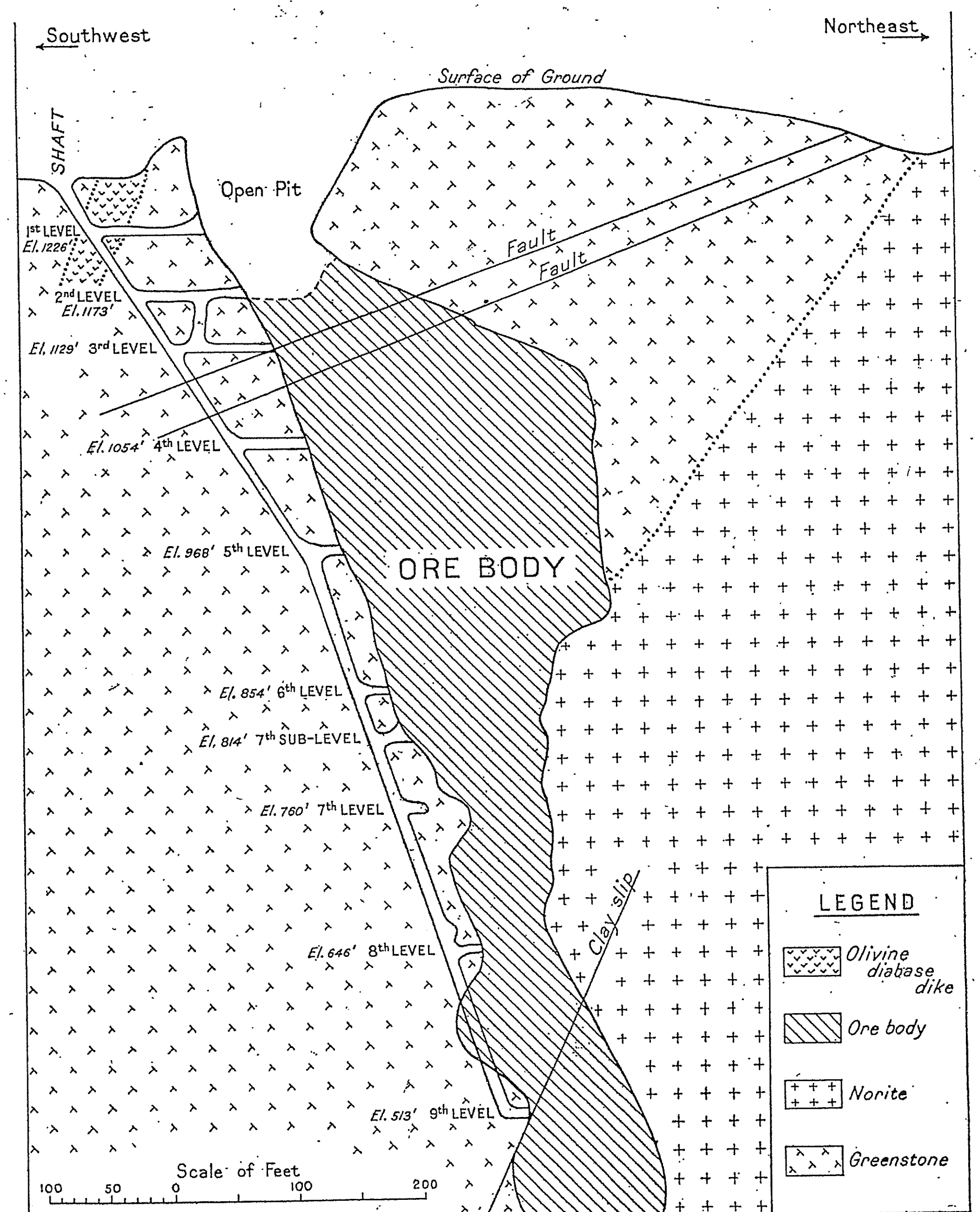

Fig. 18—Cross-section A B, see Fig. 15, through Crean Hill ore body along the shaft section, Sudbury area, Ontario. The upper portion of the deposit occurs entirely in the greenstone, while the lower portion occurs at the contact of greenstone and norite, partly in the greenstone, partly in the norite. There appears to have been little or no displacement of the ore body along the faults in the upper part of the deposit. From cross-section by the Canadian Copper Company.

They rise towards the northeast at an angle of about 20 or 25 degrees, and appear on the second level in the great open pit. It is evident that these two faults were formed long after the deposition of the ore body. No trouble has been experienced in following the ore on opposite sides of both faults. The throw, if appreciable, has not been determined. At no place in the mine have these two faults, or any others, been found in contact with the olivine diabase dike at the west side of the open pit. It would appear, however, that the faults were formed after the dike had solidified. The reason for believing this is that the material in the faults is recent-looking, soft, and loosely cemented together, and it would seem that, if the faults were older than the dike, molten material from the latter would almost certainly have found its way through this loosely cemented material. It may be

Fig. 19—Showing character of ore at Crean Hill mine, fifth level, Sudbury area, Ontario. White represents greenstone; black represents ore. The width of the face represented in the drawing is 2 feet.

added that similar dikes and faults occur at the Victoria mine less than two miles distant. Here the faults are younger than the dikes.

The sulphides which form the ore bodies at Crean Hill appear to have had an origin similar to those in other deposits in the Sudbury area. They have probably been deposited from heated, mineral-bearing waters which circulated through the crushed and disturbed zone along or near the norite-greenstone contact. The presence of noticeable quantities of quartz and calcite in the ore gives confirmation to this opinion; and the fact that the greenstone is completely altered at times to a schist is additional evidence.

The Crean Hill ore is very rocky, and it is necessary to hand-pick from it 50 per cent. of rock. The hand-picked product still contains 28 to 35 per cent. of silica; it carries 2.14 per cent. of nickel and 2.91 per cent. of copper.

The Creighton Ore Body

The Creighton ore body is the largest nickel mine which is being worked in the world, and, at the same time, one of the greatest metalliferous mines of any kind. Although the Frood mine is a larger deposit, and probably has four times the quantity of ore blocked out, it is of lower grade and more rocky, and for these reasons is not being worked at the present time. Probably the great importance of the Creighton mine justifies a more detailed description than is given to other properties.

There are said to be 10,000,000 tons of ore in the mine, estimated by actual workings and diamond drill.

The mine is located at the southwest corner of Snider township, on lot 10 in the first concession, about 11 miles by wagon road west of Sudbury. A colored geological map on a scale of 200 feet to the inch accompanies the Report. The Algoma Eastern railway passes within a stone's-throw of the shafts.

Geological History

The history of the rocks and their relation to the ore body are outlined in the legend below, the older rocks being shown at the bottom of the table and the younger at the top. It may be repeated that these rocks are all of pre-Cambrian age.

Olivine diabase dikes
Trap dikes
Ore body
Granite
Norite
Greenstone

The oldest rock in the vicinity of the Creighton is what has been called greenstone. It is generally coarse-grained and looks like a gabbro or diorite; there are also fine-grained facies of the rock. The coarse-grained greenstone resembles somewhat the norite, but it appears to be more decomposed than the norite and has a greener shade, the norite having a grey tint.

The eruption of the greenstone was followed by the great norite intrusion. That the norite is younger than the greenstone is shown by the fact that it has chilled against the latter. It also holds inclusions of the greenstone, one of these larger masses being shown on the map about 1,000 feet to the north of the open pit. The character of the norite has been described elsewhere in the Report, but it may be repeated that, mineralogically and chemically, the composition of the rock is very uniform for a distance of at least 3,250 feet northwestward from the Creighton pit.

After the norite had solidified, the granite mass, which occupies parts of Graham, Waters and Snider townships, was intruded. It broke its way through the crust of the earth along the norite-greenstone contact. The age relationship of the granite is shown in an outcrop about 800 feet north of the Creighton open pit, where the contacts are well exposed. Here the somewhat schistose norite is brecciated for about 10 feet from the contact into angular blocks from a few inches to 2 or 3 feet in diameter. These fragments of norite are cemented together by the coarse-grained granite; or, put in other words, dikes of the granite penetrate the norite through this brecciated zone. It is clear from this and other evidence that the granite is younger than the norite. The age relation is well shown at the east side of a small lake on lot 2 in the fourth concession of Snider township, where dikes of the coarse-grained granite may be traced into the norite. Hundreds of granite dikes penetrate the norite along the contact between Copper Cliff and Crean Hill mine.

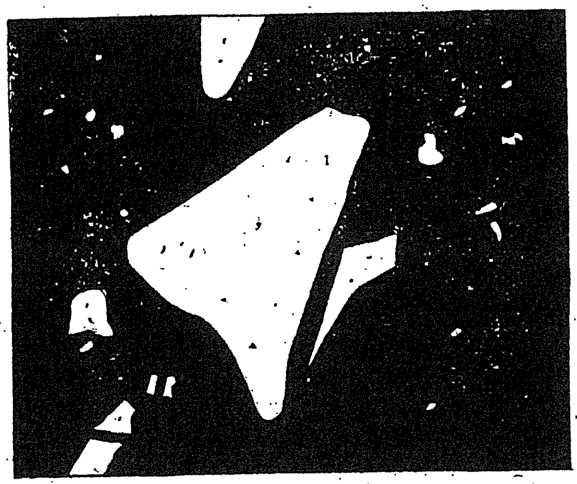

Fig. 20—Character of ore at Creighton mine, Sudbury area, Ontario, eighth level, 10 feet from hanging wall. White represents rock; black represents sulphides. Width of face 5 feet.

The next event, and the one which immediately preceded the formation of the Creighton ore body, was that which was represented by a period of tremendous crushing and brecciation along the norite-granite contact. A great crush-breccia and crush-conglomerate, of granite, greenstone and norite fragments, were formed.

A period of ore deposition closely followed the crushing and brecciation; and magmatic solutions, carrying sulphides, circulated upwards through the crushed rocks and deposited nickel, copper and iron sulphides in the spaces between the rock fragments, replacing the latter to some extent. Thus was the Creighton ore body formed.

After the formation of the ore body fissures were formed in all of the rocks in the vicinity of the deposit, including the deposit itself, and dikes of trap were intruded into greenstone, norite, granite, and the ore body. Ore deposition had practically ceased before this took place, for the trap dikes are free from ore except for small veinlets along the edges. The dikes do not cut entirely across the ore body, but appear to have penetrated it only a relatively short distance.

The final chapter in the history of this marvellous ore body was closed by the formation of another series of fissures through which were erupted coarse-grained olivine diabase dikes. These dikes cut the ore body and the trap dikes described in the previous paragraph. Their relationship to the trap dikes is beautifully shown about 1,100 feet northwest of the open pit. Here a coarse, olivine diabase dike cuts across the trap. Actual contacts are exposed which show the olivine diabase to have cooled and chilled against the trap dike. The same relationship may be seen about 3,000 feet north of the pit. The width of the trap and diabase dikes varies from about 20 to 75 feet or more. It may be added that C. H. Hitchcock, of the Canadian Copper Company, first recognized these trap dikes as distinct in age from the later olivine diabase dikes. On the map of the Creighton mine in the office of the company the diabase dikes are shown intersecting the trap dikes.

Shape and Size of Ore Body

The shape of the Creighton ore body is shown by a model, facing page 142, constructed by officials of the Canadian Copper Company. The white, horizontal lines represent the various levels, and the altitude of these levels above or below sea level are noted. Fig. B is a photograph of the model looking at the west side of the ore body; Fig. C is a photograph looking at the south end, and Fig. A looking at the north end of the ore body.

The upper part of the model was constructed from information obtained mainly from actual workings, while the lower part was outlined by means of information derived from diamond-drill cores. In July, 1916, there were but two crosscuts and no stopes in the ore body on the twelfth level. Three months later there were five crosscuts on this level and stoping had already begun. On the tenth and higher levels, however, the shape and extent of the deposit had been ascertained mostly from workings which consisted of crosscuts, drifts, and stopes.

From the model it is seen that the central part of the deposit is lenticular; that is to say, its length is much greater than its width, so that the ends "pinch" or taper out gradually. The upper and lower parts, on the other hand, are roughly oval in outline. It may be stated that its known depth is about twice its maximum length. Of course it is not possible to say how much of the deposit has been eroded during past geological ages. And it may also be noted that the depth to which the deposit goes has not yet been ascertained.

The ore body has a known depth of about 2,000 feet measured along its average dip of 45°, but the model only shows the ore body to a depth of about 1,600 feet measured along its dip. Diamond drilling ceased at about 2,000 feet, but the last drill cores still showed the presence of ore. The maximum length is about 1,000 feet. The width on the surface is about 180 feet. Between the fifth and sixth levels its width becomes abruptly less, so that on the sixth and eighth levels it has only a width of about 50 feet. Below the eighth level, however, it again becomes wider, and on the tenth it has increased to about 130 feet. Below this the diamond-drill cores show it to be even wider, in fact wider than in the great open pit on the surface.

There is a small isolated ore body, near the surface, southward from the main one. Its relative size and position are shown by the model.

More precise information than is given in the preceding paragraphs regarding the length and width of the deposit may be obtained by consulting the composite plan facing page 144. The plan shows the horizontal outlines of the ore body on the third, fourth, fifth, sixth, eighth and tenth levels. The outlines have been obtained largely from actual workings. Since the plans are horizontal sections, it is necessary to allow for the average dip of the ore body in ascertaining the actual

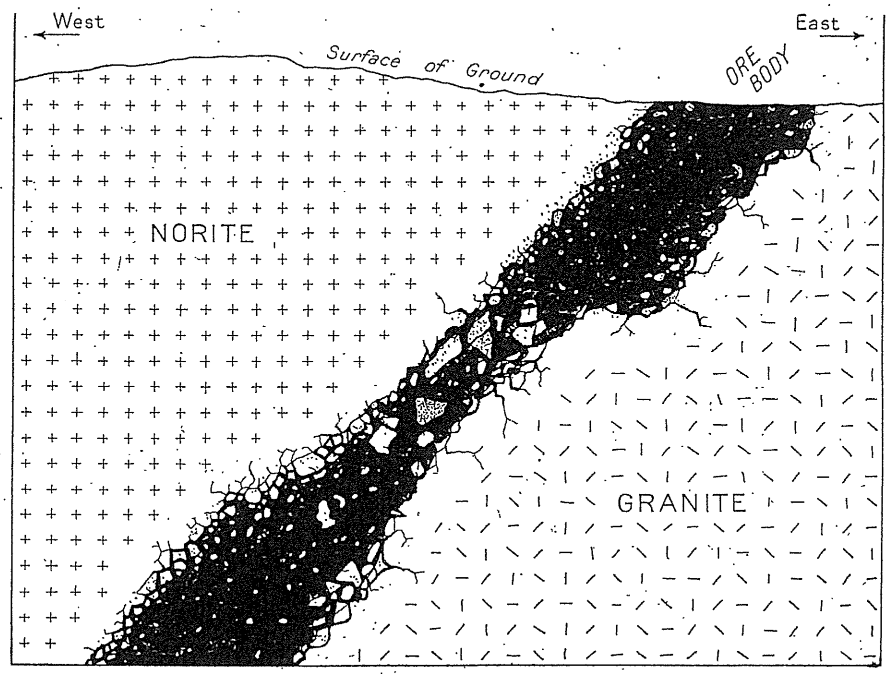

Fig. 21—Ideal cross-section through Creighton ore body, from the surface to the proposed eighteenth level, showing the nature of the deposit. Black represents ore. The norite is "spotted" with "blebs" of ore, about the size of peas, for 2,000 feet beyond the ore body. This "spotted" norite is not indicated in the drawing except along the edges. The granite is also "spotted" with ore, but to a much less extent than the norite. While the commercial ore body occurs about at the contact of the norite and granite, nevertheless the commercial ore body is found largely in the granite footwall —not in the norite.

width at any point. For instance, if the plan shows the deposit to have a horizontal width of 100 feet, then the actual width, allowing for the dip, is about 70 feet.

Nature of the Ore Body

The ore body occurs about at the contact between granite and norite, the latter forming the hanging-wall, the granite the footwall. It has been named a marginal deposit. The ore body, however, is found largely in the granite footwall, and it may be said that the limit of the commercial ore is met with when the norite hanging-wall is encountered. Sometimes, indeed, the commercial ore ends before the norite is met with, in which case massive granite forms not only the footwall but the hanging-wall. The strike of the ore body is about north and south—really a few degrees east of north. The exact strike on the third, fourth, fifth, sixth, eighth and tenth levels may be seen by consulting the composite plan facing page 144. The dip of the ore body is about 45° to the westward, and there appears to be no change on the lowest parts of the deposit.

An examination of the stopes, crosscuts, drifts and other workings has shown that the ore body consists of a mass of rock fragments cemented together by sulphides. Diamond-drill cores from the lower part of the deposit have also demonstrated this feature. Therefore, when the model of the ore body is looked at, it must not be thought of as consisting of pure sulphides. The "rocky" nature of the ore is demonstrated by the fact that from 10 to 16 per cent. of rock is hand-picked from the ore, and there still remains from 18 to 21 per cent. of silica in this

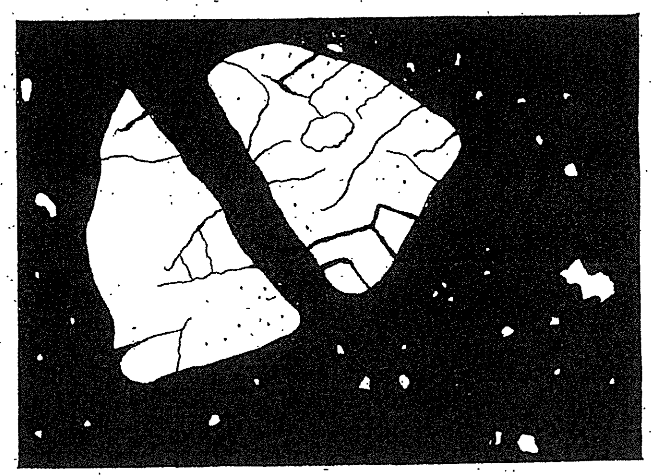

Fig. 22—Character of ore at Creighton mine, Sudbury area, Ontario, ninth level, near hanging wall. White represents greenstone boulders; black represents sulphides. Width of face 4½ feet.

hand-picked product. Of course the number of rock fragments in the deposit varies greatly in different parts of the mine. At and near the footwall and hanging-wall, and at the north and south ends the rock fragments are most numerous and, on the whole, largest. Here they may occur in such numbers as to make the ore too rocky to be of commercial value at present. Sometimes, on the eighth level, for instance, many blocks of rock of large size—5, 10, or 15 feet in diameter—occur in the centre and all parts of the ore body. However, it may be said that, generally speaking, the ore body is less rocky in the central portions than on the sides or ends.

The size of these rock fragments varies from great blocks 100 feet long down to specks which are visible only under the microscope.

The hand-picked ore contains 4.44 per cent. of nickel and 1.56 per cent. of copper.

Probably the average size of the fragments on the hanging-wall and footwall and the ends of the deposit varies from 5 or 6 inches, and less, to 2 or 3 feet. This rocky variety of ore on the hanging-wall and footwall may at times extend into the central parts of the deposit for as many as 30 feet before the fragments become smaller and less numerous, thus forming the purer or massive ore. But even in this massive type of ore it is rare to find sulphides in which tiny specks of rock do not occur.

The shape of the fragments is infinite in variety, varying from round or oval to sharply angular. Sketches showing their outlines are illustrated in Figs. 6, 20, 22 and 25.

The rock fragments consist of granite, greenstone and norite, or, where they are very small, of the various minerals which constitute these rocks, *i.e.*, feldspar,

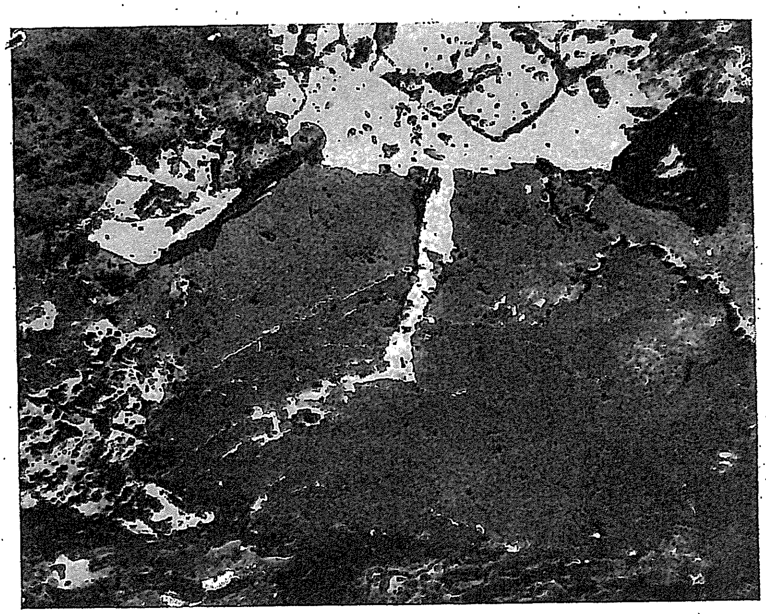

Fig. 23—Polished surface of ore, showing veinlets of sulphides (white) replacing or impregnating rock; magnified 88 diameters; Creighton mine, Sudbury area, Ontario. The sulphides replace or impregnate all the rocks at Creighton mine, whether they consist of norite, granite or greenstone. *Photomicrograph by Wm. Campbell.*

quartz, hornblende, pyroxene, and other minerals. The presence of the greenstone fragments is to be accounted for by the fact that frequently the granite footwall holds immense inclusions of greenstone. The diamond-drill cores, indeed, show that in the deeper part of the deposit the greenstone forms the footwall. The granite and greenstone fragments are most numerous, and are found in all parts of the ore body. They extend across the deposit to the norite hanging-wall. The norite fragments, on the other hand, appear to be confined largely to the proximity of the hanging-wall. Of course some of the norite fragments may have been so much altered that it may be difficult to distinguish them from the greenstone.

The contacts of many of the fragments with the sulphides are sharp and knife-like. As contrasted with this, there is frequently a transition between the fragments and sulphides, as if the outer parts had been replaced and replacement had ceased before it had extended into the central parts. Sometimes, however, the replacement has continued until a particular fragment has been almost wholly replaced. Often veinlets of sulphides ramify irregularly through the fragments, and if the latter are schistose, as is frequently the case with the greenstone, the veinlets of sulphides follow along the schistose planes. Sometimes it is found, too, that "blebs" of sulphides about the size of peas occur in the fragments, whether they consist of granite, greenstone or norite. When the "blebs" occur in the norite, the latter has been called "spotted" norite.

It is common to find veins of sulphides extending from the ore body and penetrating the granite footwall and norite hanging-wall for 25 or 50 feet.

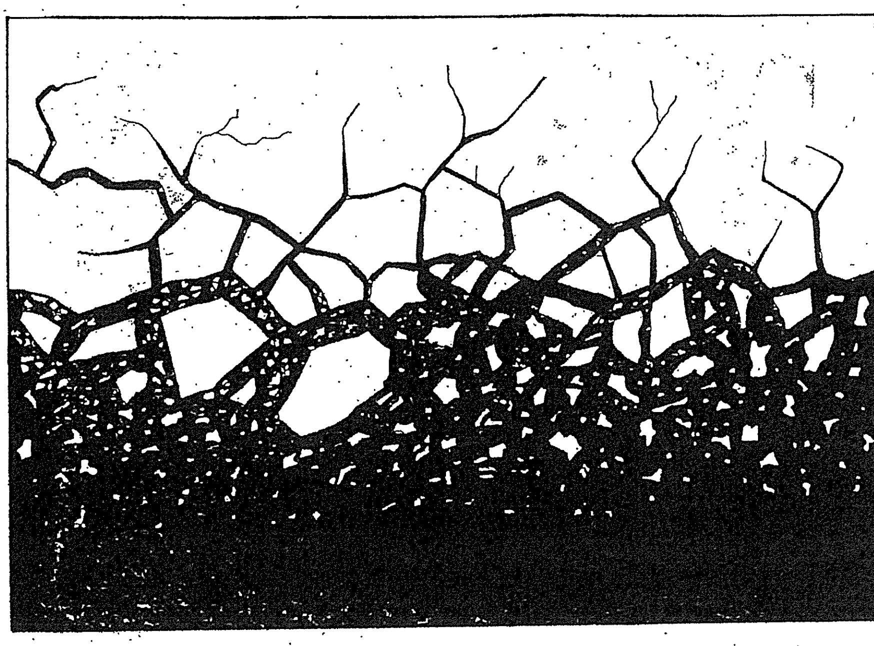

Fig. 24—"Diagrammatic drawing illustrating the character of the contact between massive sulphides (black) and norite (white)," Creighton mine, Sudbury area, Ontario. Drawing by E. Howe. The face represented in the drawing has a length of 20 feet. The drawing illustrates the fact that the ore was introduced after the norite had solidified.

Contact Between Ore Body and Norite Hanging-Wall

The character of the contact between the ore body and the norite hanging-wall has given rise to discussion. It has been stated that there is a gradual transition between the pure sulphides and the norite, but this statement does not agree with more recent observations, including those of E. Howe. The contact between the ore body and hanging-wall of norite is, comparatively speaking, abrupt. It may be three or four feet, sometimes more, sometimes less. In places it is a few inches, the commercial ore body ending abruptly against norite which is slightly impregnated with sulphides. Probably the relationships have been described best by Howe in the two following paragraphs:[1]

> Aside from the impressive size of the Creighton ore body, its most striking feature is the character of its contact with the norite of the hanging-wall. At a number of places in the open pit and in stopes at lower levels the change from ore to rock with no sharp line of separation is well shown. The transition may take place within a space of three or four feet, or may extend over as many yards. The character of this gradation of rock into ore calls for special consideration, as it constitutes one of the criteria upon which is based the theory of gravity segregation of the sulphides from the magma. According to most of the descriptions one expects to find the nearly pure sulphides pass by imperceptible increase in the quantity of associated silicates into a rock in which sulphides are sparingly present as accessories or altogether absent. While there is undoubtedly a gradual change from ore to rock, it would appear to be due to a mechanical mixture of sulphides and norite in the transition zone and not to a graduation in a mineralogical sense.
>
> In all places where transition from ore to rock is supposed to exist, the norite has been extensively shattered in the neighbourhood of the ore, and the sulphides appear to have penetrated the norite along the cracks and fissures so formed, while angular fragments of

Fig. 25—Shows relation of sulphides to norite hanging wall. White represents norite; black represents sulphides. Eighth level, Creighton mine, Sudbury area, Ontario. Width of face 15 inches. The drawing illustrates the fact that the sulphides were introduced after the norite had solidified.

> norite are included in the sulphides close to the rock, Fig. 24. The veinlets of sulphides die out gradually in the norite away from the massive ore, while the rock fragments included in the sulphides become less numerous and smaller in size as their distance from the hanging-wall increases. There is thus a transition from ore to rock in a mechanical sense, and, from a mining standpoint, the expression is justifiable. Neither megascopically nor with the aid of the microscope could the writer recognize a petrographical graduation.

Generally the norite for several feet from the contact of ore body or granite becomes finer in grain. The explanation of this appears to be that it originally chilled against the greenstone. At a later time the granite was intruded at the contact between the greenstone and norite.

Contact Between Ore Body and Granite Footwall

The contact between the granite footwall and the ore body is much the same as that between the ore body and the norite. There is, however, a slight preponderance of chalcopyrite in the ore body at its contact with the granite. The contact is more irregular along the granite footwall than along the norite

[1] Economic Geology, Vol. IX, September, 1914, p. 514.

hanging-wall. To illustrate this, crosscuts Nos. 9 and 10 on the twelfth level may be cited. The contact of the ore body and massive, barren granite in No. 9 crosscut is sharp, comparatively speaking, the transitional material having a width of only two feet. On the other hand, in No. 10, the adjacent crosscut to the north, the transitional material has a width of about 50 feet or more. Here veins of sulphides 6 to 15 inches in width are found intersecting the granite. They increase in size until blocks of granite several feet in diameter are enclosed in sulphides. The granite blocks become smaller and smaller as the ore body is approached, until, finally, more massive ore is found.

Mineralization of Hanging-Wall and Footwall

The hanging-wall is mineralized for a distance of about 2,000 feet to the west of the ore body. This mineralized area extends in a northeastward and southwestward direction for about three-quarters of a mile. The general outlines of this "gossan," as it is called, are shown on the large scale map of the Creighton mine which accompanies this Report. Considerable drift covers the gossan, and it is difficult to obtain the outlines accurately, so that the boundaries as shown are to be considered approximate.

The mineralization is most intense near the ore body, and its intensity decreases irregularly as the distance from the ore body increases. Some of the mineralized norite near the deposit contains from 1½ to 2½ per cent. of nickel and copper combined, but it does not at the present time constitute commercial ore.

Part of the mineralized norite is fresh-looking, and it has been stated by Coleman and Barlow that undecomposed hypersthene is found closely associated with the sulphides. However, it is equally true that much, it is difficult to say what per cent., of the mineralized norite is slightly sheared or brecciated and altered. It often contains great numbers of angular and round inclusions of other rocks, including greenstones. It would seem that there has been enough shearing and brecciation to have allowed sulphide-bearing solutions to circulate through and penetrate the rock, thus accounting for its mineralization.

The trap and olivine diabase dikes, described elsewhere, cut sharply across the mineralized norite and ore body, showing that the period of ore deposition took place before the dikes were intruded. They are practically barren of sulphides. In places the trap dikes have chilled against certain well-defined shear zones in the norite, proving, further, that some of the shearing of the norite took place before the dikes were intruded.

The mineralization of the granite footwall is much less intense than that of the hanging-wall. It extends into the granite a maximum distance of about 100 feet, but for the most part it is much less, probably 25 or 50 feet. During the process of impregnation the sulphides sometimes formed "blebs" about the size of peas in the granite, resulting in what may be called "spotted" granite, Fig. 26, which is analogous to the "spotted" norite of certain writers. The remarkable point about the granite, which has been partly replaced or impregnated by sulphides, is the freshness of the minerals which constitute it. The feldspar retains its pink colour and bright, shining, cleavage faces. Evidently the solutions did not decompose the granite to any appreciable degree.

Faults

In many parts of the mine, particularly between the sixth and tenth levels, a fault or slip has been encountered. It has not been proved to be continuous, and occurs about at the contact of the ore body and the norite hanging-wall. Frequently mining operations are carried to the fault, but rarely beyond, so that the fault often constitutes the limit to which the commercial ore body may be mined. It has not been ascertained if any great movement has taken place along this fault, which is two or three inches wide, or more, and often has clay-like material in it. The rocks on each side have sometimes been rendered schistose. The fault was evidently formed after the ore body, but a little deposition of ore has taken place after the fault was formed, for some sulphides occur in it, and fragments of the schistose rock from the sides of the fault have been found cemented together by sulphides.

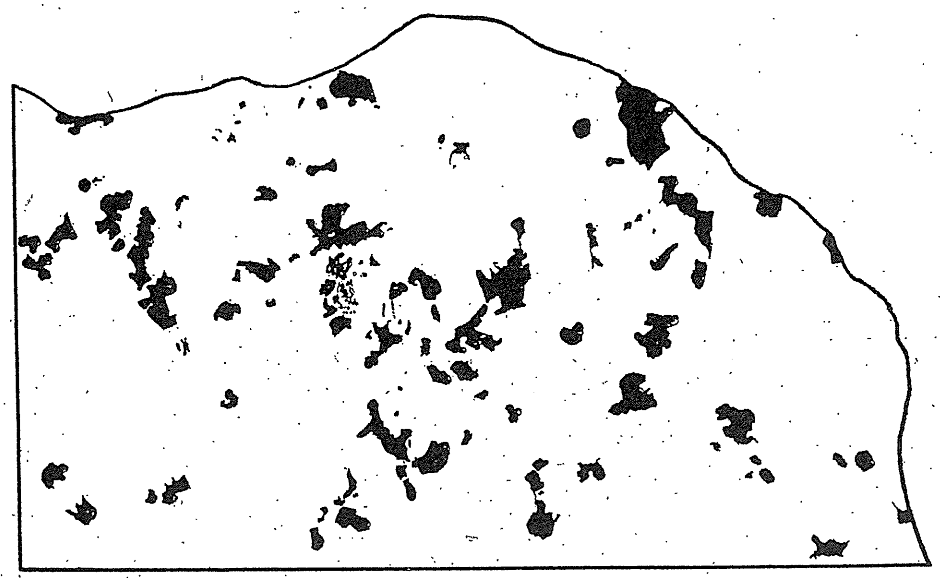

Fig. 26—"Spotted" granite, actual size. Black represents sulphides; white represents granite. The sulphides replace or impregnate the rock. Creighton mine, Sudbury area, Ontario.

Less frequently a somewhat similar fault is found in the footwall, between the granite and ore body. Other faults occur elsewhere in the mine.

Dikes Intersecting Ore Body

There are two series of basic dikes which intersect the ore body. The older set is the trap dikes referred to elsewhere. The map of the Creighton mine shows one of these dikes at the northwest side of the open pit. On the third level of the open pit what is probably this same trap is found on the hanging-wall at the northwest end of the pit. The workings show that it extends down to about the sixth level. A similar trap has been observed on the tenth level and at other parts of the mine. These dikes are barren of ore, though sometimes they have been slightly brecciated, thus allowing stringers of sulphides a few inches in width to ramify through them, particularly along their edges. The deposition of these sulphides along the edges of the dikes must have taken place long after the formation of the ore body. The traps are intersected by numerous jointing planes which are often slickensided. The presence of the joints sometimes causes trouble in mining operations when the dikes are met with, the rock having a tendency to fall. The dikes consist essentially of plagioclase and hornblende, with an ophitic texture. They are properly named uralitic diabase, but have been called trap in this Report in order to avoid confusing them with the olivine diabase dikes.

The younger series of dikes is the olivine diabase. One of these occurs on the surface at the northwest end of the open pit, and it may be traced to the southeast across the ore body. It is well exposed on the first level of the open pit, where its fine-grained, chilled edges are seen in actual contact with the sulphides. Before reaching the granite footwall it breaks up into four or more smaller dikes. Even in the case of these diabase intrusions there has been a small amount of mineralization after they solidified, for small veinlets of sulphides cut them at and near the edges. The formation of the ore body and the mineralization of the hanging-wall and footwall were practically completed before the intrusion of the trap and diabase dikes.

An analysis of the trap dike is given in the table below.

Table showing Chemical Composition of Trap Dike in the Open Pit, at Creighton Mine, on the Hanging-Wall of the Third Level at the North End.

SiO_2	52.54
Al_2O_3	16.10
Fe_2O_3	5.88
FeO	9.94
CaO	7.35
MgO	1.66
Na_2O	3.02
K_2O	1.58
H_2O	1.84
CO_2	Trace
Total	99.91

Origin of the Ore Body

From what has been said in preceding paragraphs it is evident that the formation of the Creighton ore body was preceded by a period of tremendous brecciation and crushing along the contact of granite and norite. That this crushing took place largely in the footwall is shown by the fact that most of the rock fragments in the ore consist of granite and greenstone, while the norite fragments are confined mostly to the vicinity of the hanging-wall. In other words, the commercial ore body occurs in the granite footwall—not in the norite. Sometimes indeed the granite actually forms the hanging-wall as well as the footwall. Generally speaking, it may be stated that, when the norite hanging-wall is met with, the commercial ore comes more or less abruptly to an end.

In searching for an explanation of the origin of the Creighton ore body an observer is soon confronted with the fact that the gravity segregation theory does not appear to be a suitable one. That theory supposes that while the norite was still molten the sulphides settled to the bottom of the norite, largely by means of gravity, and rested on the granite footwall. Now it has been shown elsewhere that the granite footwall is younger than the norite hanging-wall. Thus it is clear that the sulphides could not have settled on the granite, since the latter rock was not intruded until the norite solidified. While the Creighton ore body is not referred to, nevertheless this objection to magmatic segregation was pointed out many years ago by Frank D. Adams,[1] and later by L. P. Silver.[2]

A second point which presents an obstacle to a belief in gravity segregation is found in the character of the norite hanging-wall. The norite at its contact with the ore body is brecciated into fragments for a distance of from 3 to 12 feet or more, Figs. 21, 24. The sulphides cement these blocks and fragments together. It is evident, therefore, that the sulphides were introduced after the norite had solidified. This being so, it is apparent that gravity segregation cannot be accepted as an explanation of the origin of the ore.

It would seem that it is necessary to fall back on the time-honoured theory of deposition from heated solutions. This theory requires little explanation. The crushed nature of the granite footwall and of part of the norite hanging-wall presented an ideal zone for the circulation of heated aqueous solutions. These solutions possibly carried little else than sulphides. It is supposed that they came from great depths, and nearer the surface the sulphides were precipitated, filling the spaces between the fragments in the crush-breccia and crush-conglomerate. As might be expected, the hanging-wall and footwall and the fragments composing the crush-breccias and crush-conglomerates are more or less replaced or impregnated by sulphides. Since the ore body dips at an angle of 45°, it is obvious that the solutions in rising along the contact would also tend to rise vertically and penetrate into all the cracks and crevices of the norite hanging-wall. This appears to be exactly what took place, for the norite is impregnated or replaced by sulphides for as much as 2,000 feet or more from the granite. The impregnation is naturally greatest near the contact, and it becomes gradually less as the distance from the contact increases. It may be added that, under present economic conditions, there appears to be little commercial ore in the norite. The granite footwall is mineralized only for a maximum distance of about 100 feet beyond the ore body.

An examination of the mineralized portion of the norite for 1,000 feet from the ore body shows that a minor amount of crushing, shearing and brecciation has taken place. This was accompanied by some alteration of the rock. At the same time it is true that much of the norite in this mineralized zone is perfectly fresh, even when heavily impregnated with sulphides. It is also true that the granite where it has been replaced by sulphides remains fresh, the feldspars retaining their colour and lustre. The immense stopes of the Creighton mine demonstrate that there are all gradations between granite slightly replaced or impregnated with

[1] Jour. Gen. Min. Ass. Province Quebec, 1894-95, p. 49.

[2] Jour. Can. Min. Inst., Vol. 5, 1902, pp. 536-542.

sulphides and granite which is almost wholly replaced. In the latter case the remaining specks of feldspar still retain their fresh appearance.

It is evident, even to those who favor magmatic segregation as an explanation of the origin of the deposit, that some of the sulphides were deposited from hot waters. The sulphides, for instance, which occur along the brecciated edges of the trap and diabase dikes were unquestionably deposited from hot waters long after the norite solidified. There appear to be no special characteristics which distinguish these sulphides in the trap or diabase dikes from the sulphides in the ore body.

It may be added, in connection with the origin of the ore body, that the suggestion has been made by E. Howe[1] that the sulphides were injected in a molten state as a later intrusive after the norite had solidified. The writer is in entire agreement with Howe's statement that the sulphides came in after the norite had solidified, but whether they were introduced in a molten condition or by means of hot magmatic waters may be a debatable question.

No. 2 Ore Body, Canadian Copper Company

The mine belonging to the Canadian Copper Company, known as No. 2, is on the northern outskirts of the town of Copper Cliff.

The deposit occurs in a dike of diorite or gabbro, which is considered by some writers to be connected with the norite about a mile to the north. The dike, which is from 100 to 180 feet in width, intersects coarse-grained granite and greenstone. The youngest rocks in the vicinity of the mine are diabase dikes which cut all the rocks mentioned.

The shape and size of the ore body on the various levels are shown on the composite plan, Fig. 29.

The character of the ore body does not differ from that of other deposits in the area. The ore consists of fragments of the diorite dike cemented together by sulphides; and of stringers and irregular masses of sulphides which replace or impregnate the dike. Much of the diorite is "spotted" with blebs of ore. The mineralization appears to be confined wholly to the dike. The fact that fragments of the diorite dike are enclosed in the sulphides shows that the sulphides were introduced after the dike had solidified.

A fault intersects the dike of diorite in which the ore body occurs. The plane of this fault dips about 48° to the northwest, Fig. 27. The horizontal displacement, or throw, has been proved by workings to be about 350 feet, but the vertical movement has not been ascertained. The fault completely cut off the ore body, and although the dike itself, spotted with ore, has been found 350 feet to the southwest, Fig 28, the commercial ore body has not yet been located, in spite of a vigorous campaign of diamond drilling. It has not been determined whether the fault is normal or reversed. If it is normal in character and the throw is great, thousands of feet, it may be that No. 2 mine is simply the faulted-down portion of Copper Cliff mine, which is about half a mile to the south. If the throw is

[1] Economic Geology, September, 1914.

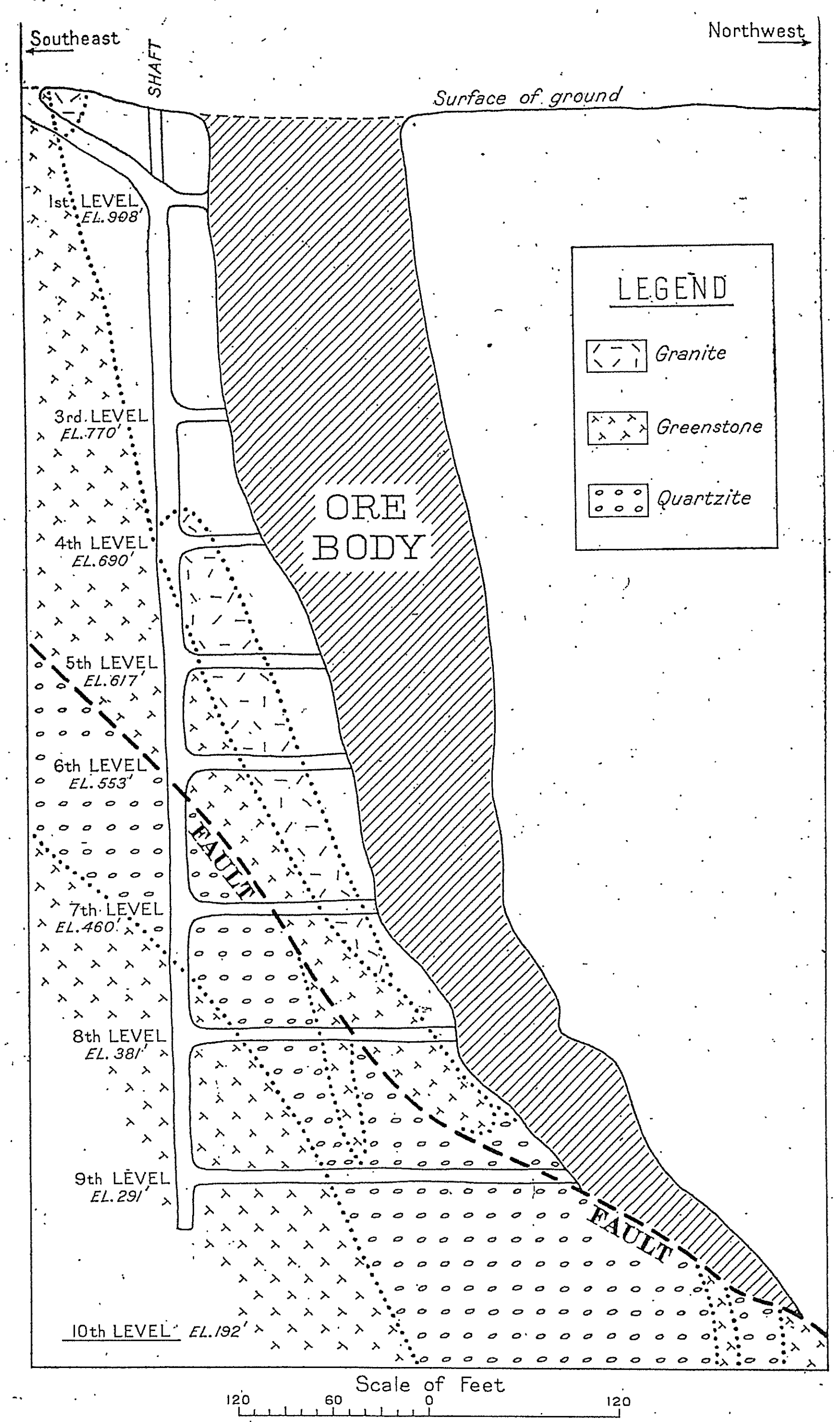

Fig. 27—Cross-section through No. 2 ore body, Canadian Copper Company, Copper Cliff, Ontario. The section shows the position of the fault which has cut off the ore body. Cross-section by Canadian Copper Company.

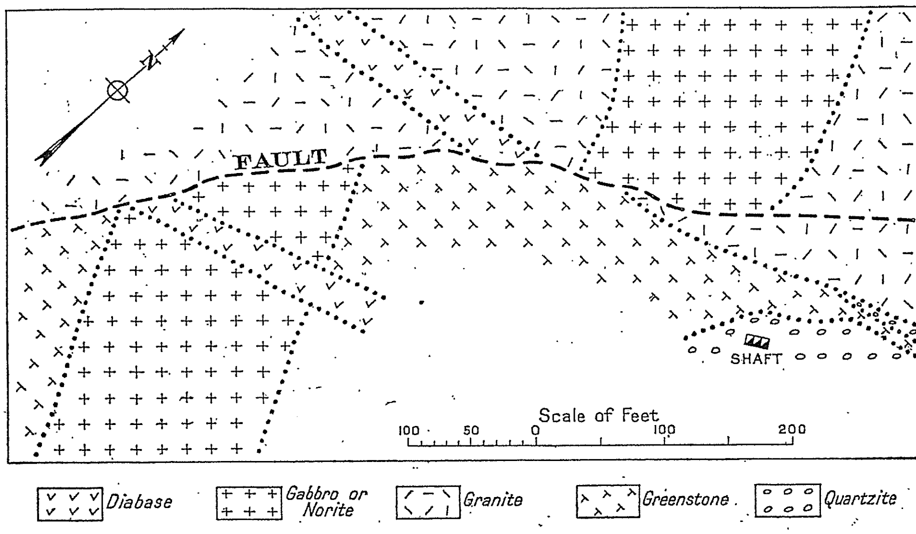

Fig. 28—Plan of ninth level, No. 2 mine, Canadian Copper Company, Copper Cliff, Ontario, showing fault. The dike has been faulted 350 feet to the southwest, but the vertical displacement is not known. From plans of the Canadian Copper Company.

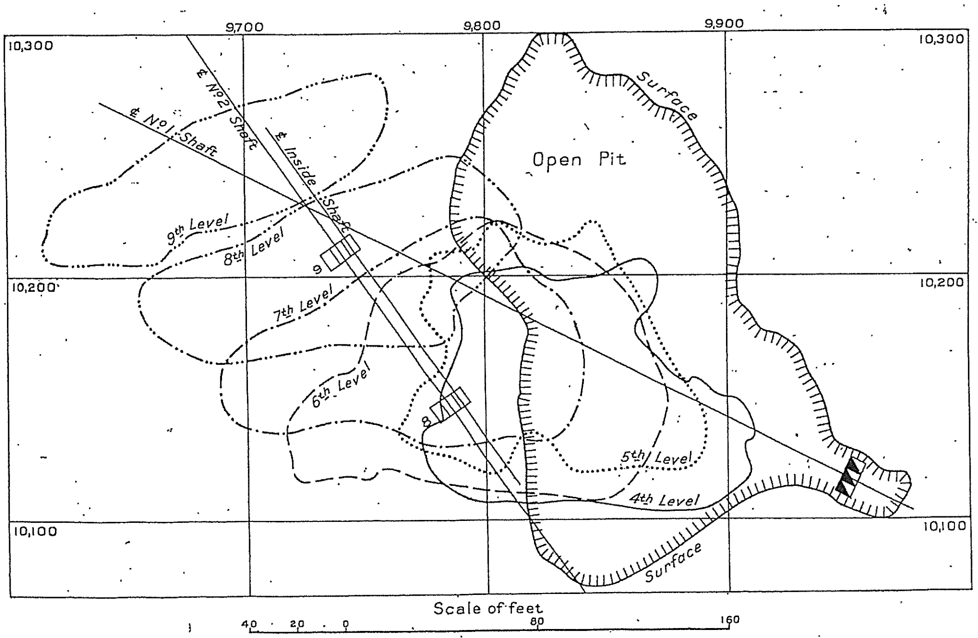

Fig. 29—Composite plan showing outlines of ore body on the surface, and the fourth, fifth, sixth, seventh, eighth and ninth levels, No. 2 mine, Canadian Copper Company, Copper Cliff, Ontario. The left side of the drawing is west, the right side is east. From plans of the Canadian Copper Company.

less than this and also normal, it may be that the lost ore body occurs below the drift at some point between Copper Cliff mine and No. 2 mine, in which case it might be advisable to run an exploration drift, following the dike, from the underground workings of Copper Cliff mine to No. 2 mine.

Very little ore was being broken in the fall of 1916, but ore was still being raised from the stopes. Unless the continuation of the ore body on the other side of the fault can be located, the main ore body of the mine is worked out. It has been one of the important mines of the area.

There is ore along the dike to the northward of No. 2 mine as far as Lady Macdonald Lake, a few pits having been opened here and there.

The Vermilion Ore Body

The Vermilion was the smallest deposit in the area which was being worked in the year 1916. It is of value on account of the presence of the precious metals, gold, silver, platinum and palladium. Were it not for these metals it would not pay to operate the property for the nickel and copper contents alone. The mine is situated on lot 6 in the fourth concession of Denison township, about a mile south of Crean Hill.

The deposit consists of a number of small veins or irregular bodies of ore from a few inches to about 15 feet in diameter. The largest ore shoot yet encountered is only 38 feet long by about 15 feet wide. These ore bodies occur in an irregular fashion in the rocks, making it difficult to discover new ones. The ore is found in greenstone, quartzite and norite. It is evident that the rocks were fractured and that the ore was introduced into the irregular fissures and cracks so produced. Ore shoots have been found to a depth of 115 feet, but exploration work has been carried to about 150 feet in depth.

The deposit contains an unusual number of minerals, including pyrrhotite, chalcopyrite, bornite, chalcocite, native copper, cassiterite, native gold, sperrylite, millerite, polydymite, and quartz.

It is generally agreed by all observers that the ore was introduced by hot water, circulating through the cracks and irregular fissures in the rocks.

Aside from its interest as a producer of precious and rare metals, the Vermilion is noteworthy on account of the fact that the mineral sperrylite, $PtAs_2$, was discovered at the property. Sperrylite was afterwards shown by G. R. Mickle[1] to occur mostly in chalcopyrite. It was found by F. L. Sperry, after whom it was named. Sperry forwarded the material to Messrs. Wells and Penfield, who made the determination.

The Garson Ore Body

The Garson ore body is located about 10 miles northeast of Sudbury, on lots 4 and 5 in the third concession of the township of Garson. It is connected with the main line of the Canadian Northern railway between Toronto and Winnipeg by a branch line.

[1] A. P. Coleman, Ont. Bur. Mines, 1905, Vol. XIV, Part III, p. 161.
The Nickel Industry, 1913, p. 29, A. P. Coleman.

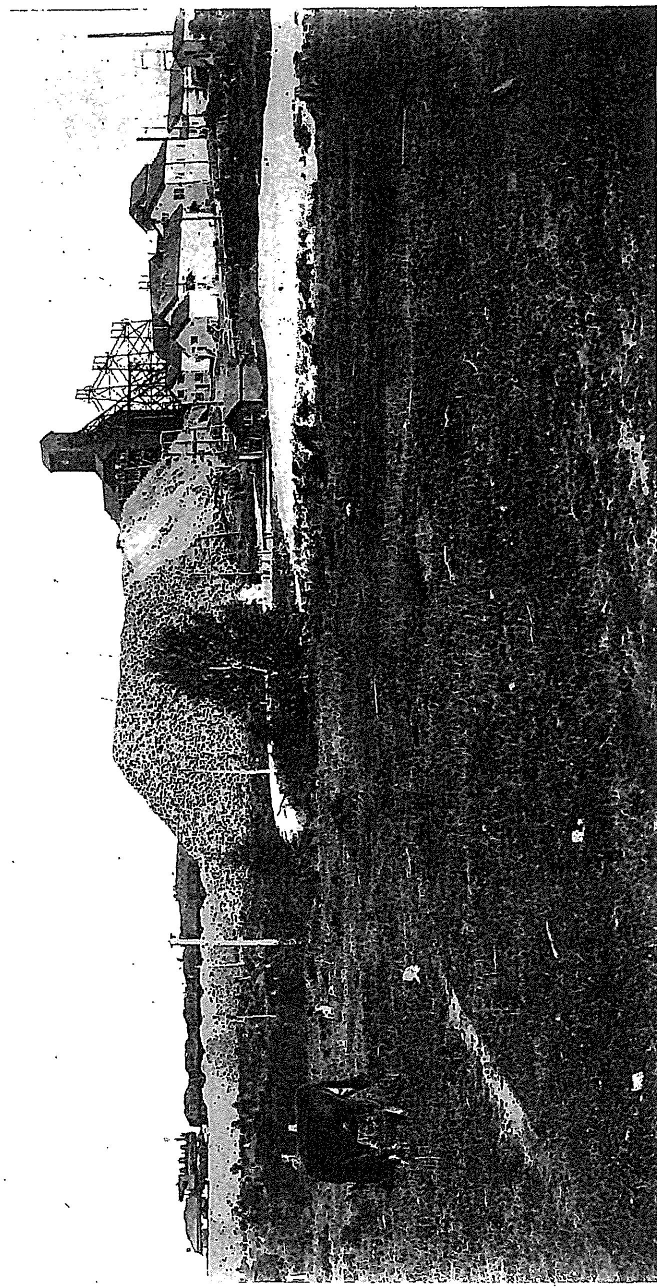

Fig. 30—Garson mine, Sudbury area, Ontario, September 9th, 1916.

The mine occurs on a hill at the north edge of a great sand and gravel plain; these deposits of sand and gravel have covered much of the contact between the norite and adjacent rocks and also much of the ore bodies, Fig. 31. The drift and the schistose and mineralized character of the rocks have obscured the age relationships of the formations. Judging, however, from general geological conditions elsewhere in the Sudbury area, the oldest rocks at the Garson mine appear to be schistose quartzites and greywackés of the Timiskaming series. Probably the rock next in age is greenstone. The latter is generally fine-grained, somewhat schistose at times, consisting almost altogether of dark green minerals,

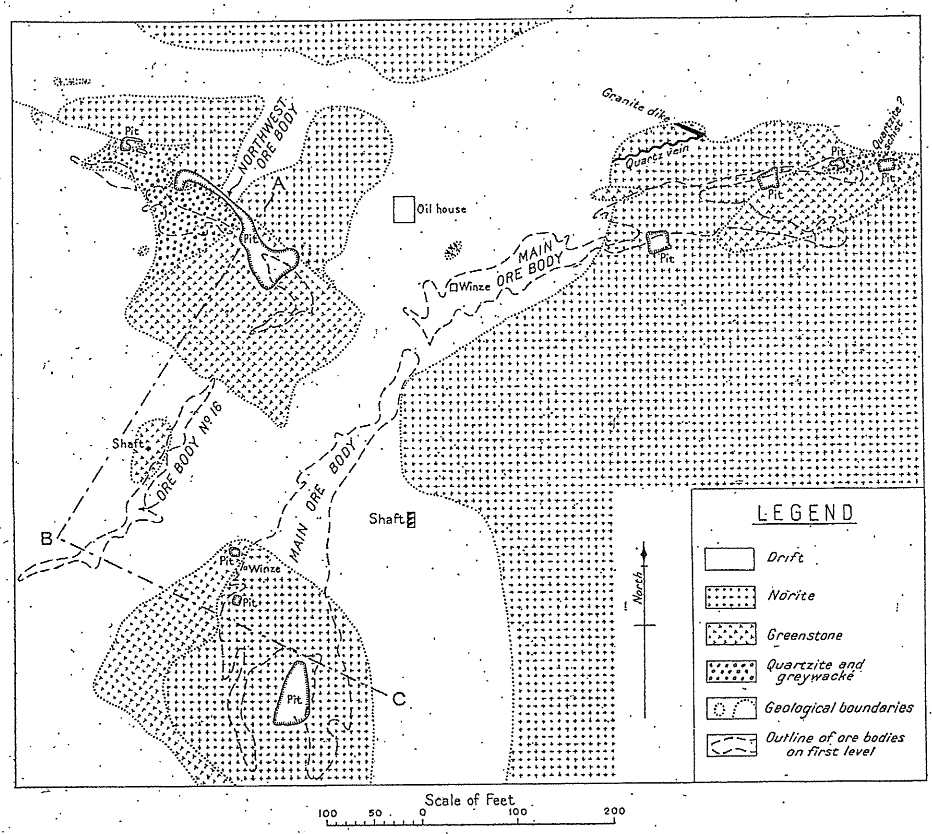

Fig. 31—Geological map of Garson mine, showing outline of ore bodies on first level, and location of cross-section A B C, Sudbury area, Ontario.

hornblende, etc. Pillow structure and amygdaloidal textures were noted in the greenstone in one instance about a mile to the east of the mine, but these appear to be rare. Following the greenstone the great norite intrusion then broke into the crust of the earth. This rock in the vicinity of the mine for 200 or 300 feet from the contact has been partly altered by shearing and other stresses to a schist or gneiss, and is much decomposed, resembling in these respects the norite at Victoria mine. It is intersected by dikes of medium-grained granite as wide as 30 feet, which contain only small amounts of coloured minerals, *i.e.*, mica or hornblende. The relation of these dikes, which are probably aplites, to the ore body has not been observed. After the shearing of the norite and adjacent rocks took place the ore body was formed. This is evident from the fact that fragments of the schistose norite are found embedded in the sulphides, and stringers of sulphides often cut across the schistose planes of the norite. Finally, all the rocks previously mentioned, and the ore body as well, are cut by fresh diabase dikes which resemble in texture and freshness the olivine diabase dikes which are of common occurrence elsewhere in the area. One of these dikes, having a width of 17 feet, cuts the ore body on the sixth level, and another is found on the surface about a quarter of a mile northeast of the shaft. A stringer from the latter dike intersects one of the granite dikes referred to above.

The Garson ore body is probably the most complex, in respect of its form, of any of the deposits which were being worked in the summer of 1916. It has been referred to by other writers as a faulted marginal deposit. Mining has been carried on to a depth of 600 feet vertically, but exploration by diamond drill has demonstrated that the deposit continues to at least a depth of 1,800 feet measured along the dip of the main ore body.

The occurrence really consists of three ore bodies; *i.e.,* (1) the main ore body, (2) the northwest ore body, and (3), No. 16. The outlines of these ore bodies on the first, second, third, fourth and sixth levels are shown by the composite plan, facing page 158.

The main ore body has a general northeast-southwest strike and a dip of 53 to 60 degrees to the southeast. It will be seen from the composite plan that it is lenticular in shape, and forms, roughly speaking, an arc of a circle, the northeast part bending easterly, and the southwest part bending southerly. Of the marginal deposits, *i.e.,* those which occur at or near the contact of norite and adjacent rocks, the main ore body at the Garson is unusual in respect of its dip to the southeastward, most of the other marginal deposits along the southern range dipping vertically or to the northwestward. The main ore body has a length of about 1,000 feet, or more, and, in places, a width of 100 feet, or more. It has been mined to the sixth level, about 600 feet vertically, but diamond-drill cores show that it extends to at least 1,800 feet in depth measured along its dip.

The northwest ore body, as its name implies, strikes to the northwest. It has a steep dip of 80° or 90° to the southwest. The deposit consists of three lenses which pitch towards the southeast. Little mining has been done on the northwest ore body below the fourth level.

The ore body, known on the surface as No. 16, is a narrow vein-like deposit which strikes to the southwest and dips at about the same angle as the main ore body; *i.e.,* 53° to 60° to the southeast.

The three ore bodies have probably been formed along lines of fissuring, the fissuring having been accompanied by shearing and brecciation. The shearing has often been so intense that the wall rocks have been altered to schists, making it difficult to determine what kind of rocks these schists were originally, whether norite, greenstone or greywacké. The schistose character of the wall rocks is in strong contrast to the wall rocks of such ore bodies as Creighton, Murray, Worthington, etc., where the rocks usually retain their massive character.

The main ore body occurs near the contact of norite and adjacent rocks, the latter consisting of greenstone, greywacké or quartzite. The ore appears to occur for the most part in the adjacent rocks, although some is found in the norite. However, the schistose character of the wall rocks, including norite, makes it difficult to always ascertain whether the ore bodies do occur in the norite or the other mentioned rocks. The problem is sometimes complicated also by the occurrence in the norite of great numbers of quartzite or other inclusions, as may be seen on the surface at the southwest end of the main ore body. When the norite with these inclusions has been rendered schistose, the difficulty of ascertaining the character of the rock, particularly below the surface, is readily appreciated. On the sixth level, however, the ore body appears to occur mainly in schistose greywacké and quartzite.

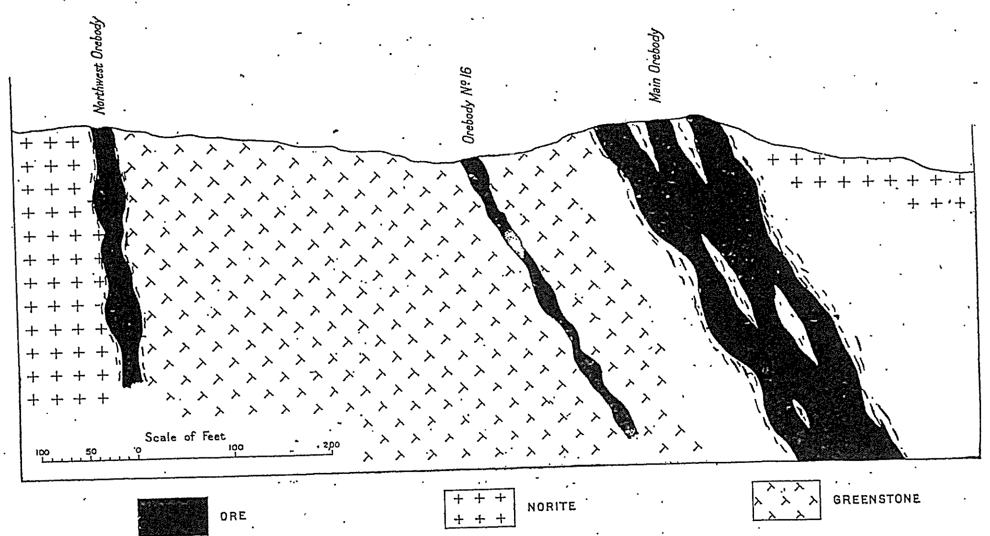

Fig. 32—Diagrammatic drawing along line A B C, see Fig 31, showing ore bodies at Garson mine and their relation to the norite and greenstone.

At the northeast end of the main ore body the rocks on the surface are massive and non-schistose, their character and relation to the ore being shown in a pit and winze near the northeast end. The sulphides here are found along the brecciated contact of greenstone and norite, angular fragments of both rocks being cemented together by the sulphides, while veinlets of ore penetrate into cracks in the norite and greenstone.

Although the relation of the main ore body to the wall rocks may not always be clear, for the reasons given above, the relation of the northwest ore body, on the other hand, to the wall rocks seems quite clear. The northwest ore body occurs at the contact of the norite and greenstone or greywacké, mainly the greenstone. The ore body, while following the contact, occurs nevertheless almost wholly in the greenstone, Figs. 31 and 32.

The relation of the third ore body, that one known as No. 16, is also simple. It occurs wholly in the greenstone, and is undoubtedly a fissure vein in which the wall rocks are impregnated or replaced with sulphides.

A diagrammatic cross-section through the three ore bodies is shown in Fig. 32, and it illustrates the relation of the ore bodies to the enclosing rocks.

The walls of the ore bodies are for the most part commercial, that is to say, mining ceases when the amount of sulphides in the rocks becomes too small to pay. Rarely are sharp contacts between the sulphides and wall rocks found. Mineralization has followed along the fissures and brecciated zones and has penetrated every crack and crevice. The ore bodies, like the other deposits in the Sudbury area, contain great numbers of fragments of the adjacent rocks: norite, greenstone,

Fig. 33—Diagrammatic sketch showing ore body and schistose rock on hanging-wall, Garson mine, Sudbury area, Ontario, sixth level. Black represents sulphides. Width of face 12 feet.

greywacké and quartzite, or their schistose equivalents. The rocky nature of the ore is shown by the fact that 25 per cent. of rock is hand-picked from the ore, and this hand-picked product still contains about 24 per cent. of silica. Like other ore bodies the large stopes often contain great masses of rock, too low-grade to work, surrounded by richer material. The ore contains 2.4 per cent. of nickel and 1.7 per cent. of copper.

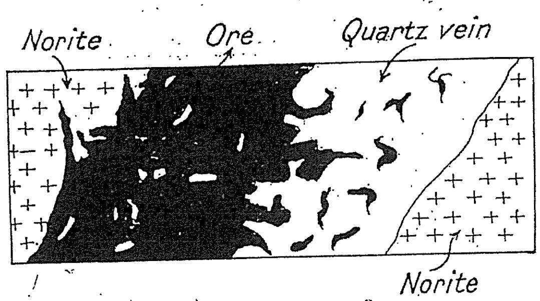

Fig. 34—Diagrammatic sketch showing quartz vein on foot-wall of main ore body, Garson mine, Sudbury area, Ontario. The width of the cross-section represented in the sketch is 20 feet.

The Garson ore bodies are replacement or impregnation deposits formed along fissured, brecciated and sheared zones. The sulphides are found impregnating or replacing the rocks, whether they consist of norite, greenstone, greywacké or quartzite. They occur in almost pure masses, or in irregular veinlets, or in disseminated grains. That they were introduced after the norite had solidified and even after it was rendered schistose, is proven by the fact that blocks of the massive and schistose norite are cemented together by the sulphides. Where the norite is schistose, veinlets often cut across the schistose planes.

A marked feature in the main ore body is the unusual amount of quartz associated with the sulphides. Between the surface and the fourth level the quartz occurs in the form of a vein cutting the norite; the vein constitutes the footwall of the ore body for a few hundred feet in length and down to the fourth level. This quartz vein averages about 6 feet in width, but the width is variable, being from a few feet to 12 or 14 feet. The contact between it and the sulphides is not a sharp one, Fig. 34, the sulphides ramifying into the quartz in veinlets as if they had been deposited a little later than the quartz. This assumption is strengthened by the presence of well rounded fragments of quartz embedded in the sulphides. About 35,000 tons of the quartz have been mined, demonstrating the large amount of the material which is present. There still remain in the mine many thousand tons. Apart from this quartz vein on the footwall of the main ore body, the ore bodies contain an unusual amount of quartz, so closely intermingled with the sulphides that it is impossible to escape the conclusion that the two were deposited during the same period of mineralization. In addition to the quartz there is a lesser amount of calcite, also closely intermingled with the ore, Fig. 35.

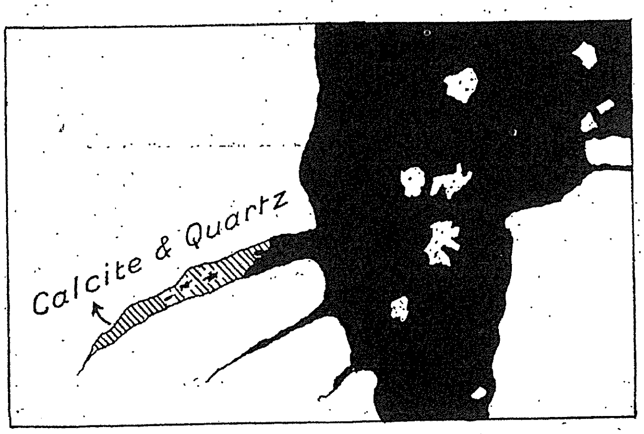

Fig. 35—Veinlet of calcite and quartz containing also sulphides, Garson mine, sixth level, Sudbury area, Ontario. Cross-hatched area represents calcite and quartz, with some sulphides; black represents sulphides; white represents rock. Width of face 12 inches. The calcite, quartz and sulphides appear to have been deposited during the same period of mineralization.

Veinlets, an inch or so wide, of calcite and galena, occasionally intersect the ore bodies.

A well-defined fault occurs on the sixth level 190 feet southeast of the shaft. It strikes north and south and dips at an angle of about 30° to the east. The extent of the movement along the fault has not been ascertained, but it does not appear to have disturbed the ore body to any appreciable degree. Along the fault the rocks and ore body have been crushed and the rocks altered in part to clay-like material. Slickensided surfaces are common. This fault appears to have formed long after the deposition of the ore bodies. It is similar in character to the well-defined faults at Crean Hill and elsewhere.

Fig. 36—Sixth level, Garson mine, Sudbury area, Ontario, showing manner in which the sulphides replace the schistose rocks. Width of face 3 feet. Black represents sulphides; white, rock.

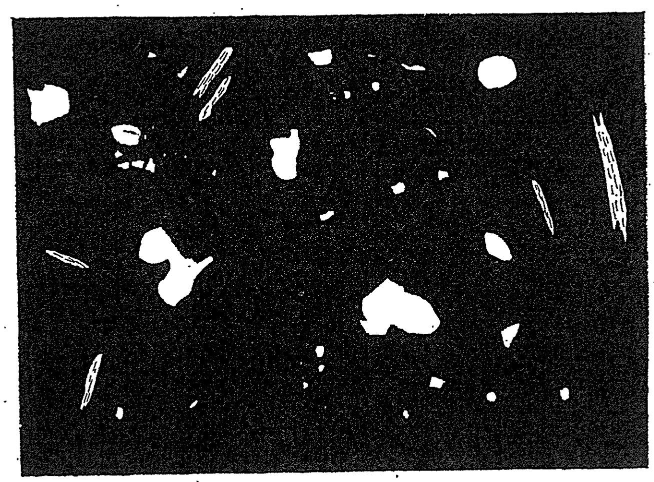

Fig. 37—Character of ore at Garson mine, Sudbury area, Ontario, sixth level. White represents rock fragments, some of which are schists; black represents sulphides. Width of face 5 feet.

The origin of the Garson ore bodies seems reasonably clear. The schistose and altered character of the wall rocks, their replaced and impregnated condition, the presence of large amounts of quartz, and to a less degree of calcite, and the vein-like nature of some of the ore bodies appear to indicate that the deposit was formed by deposition of the sulphides, the quartz and the calcite from hot circulating waters.

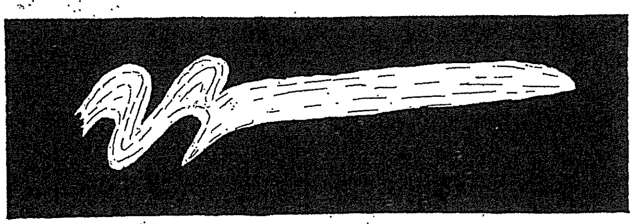

Fig. 38—Fragment of schist in sulphides, sixth level, Garson mine, Sudbury area, Ontario. The majority of rock fragments in the ore at Garson mine are schists or schistose rocks. Width of face 15 inches.

The Levack Ore Body

The Levack mine is situated on lots 6 and 7 in the second concession of Levack township. It is about four miles to the northeast of Levack station, which is on the main line of the Canadian Pacific railway. A branch line of the railway has been built to the mine.

The geology of the deposit appears to be comparatively simple, the rocks in the vicinity consisting chiefly of granite-gneiss and the norite-micropegmatite.

The granite-gneiss contains many fine to medium-grained greenstone inclusions. Sometimes these are drawn out into long schistose or gneissoid lenses, in which veinlets of granite have been injected parallel to the schistose or gneissoid planes. This has produced a banded gneiss. At other times the greenstone inclusions are brecciated into round or angular fragments, and the granitic magma has been injected into the spaces between the fragments. These basic greenstones, which now constitute a part of the granite-gneiss complex, appear to have been described as sudburite by C. Brackenbury.[1] Cutting this complex there are several fine-grained basic dikes near the mine. These have not been seen in contact with the ore body or the norite, so that their age relation to the deposit and to the norite was not ascertained. The norite at its contact with the gneiss strikes to the northeastward; and the workings and the diamond-drill cores show that the contact dips to the southeast at an average angle of 45°. The contact between granite-gneiss and norite is not exposed in the vicinity of the mine. About 4 miles to the northeast, however, at the Big Levack, a good contact is met with, and it is seen that the norite is younger than the granite-gneiss. The norite comes sharply against the granite-gneiss, there being no transition zone between the two rocks.

[1] Ont. Bur. Mines, Vol. 23, Part I, pp. 194-201. An excellent petrographic description of the rocks at Levack mine is given by Mr. Brackenbury.

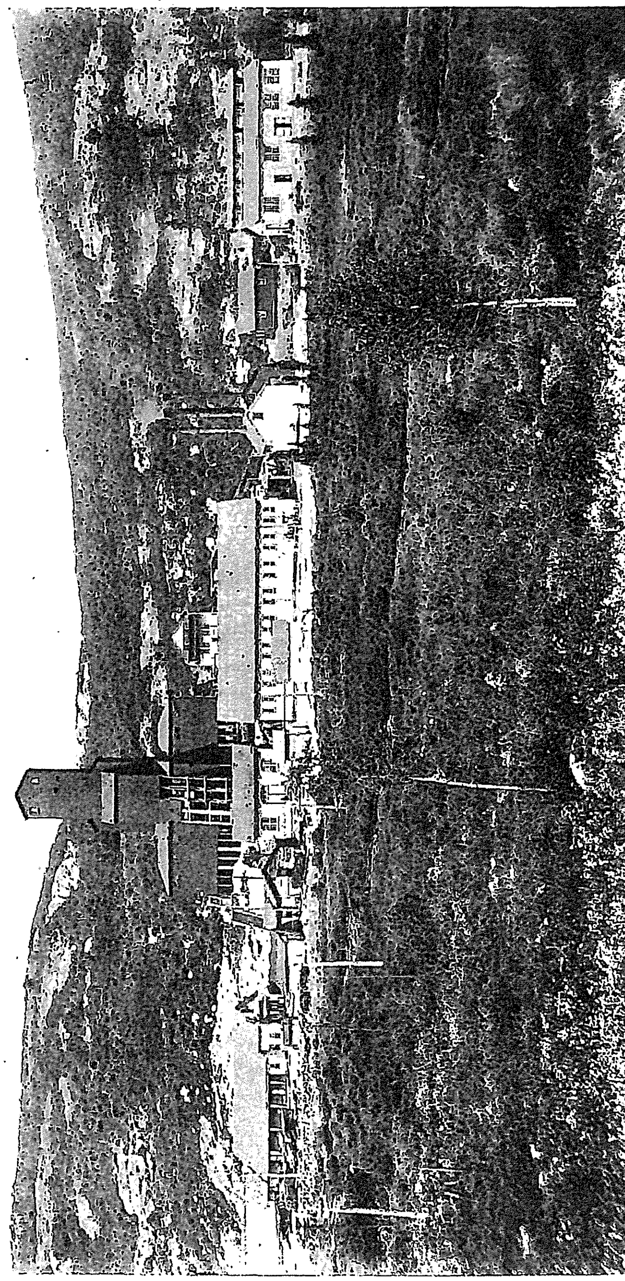

Fig. 39—Levack mine, Sudbury area, Ontario, August 28th, 1916.

Although the Levack ore body occurs near the norite, it nevertheless is found wholly in the granite-gneiss, this rock forming both footwall and hanging-wall, Fig. 40. The norite occurs from 40 to 220 feet, or an average of about 175 feet from the ore body, measured at right angles to the strike and dip of the norite.

No commercial ore occurs in the norite, but this rock is lightly "spotted" with sulphides near the contact.

In August 1916 mining was being done on the first, second and third levels, the depths of which were 150, 250 and 350 feet respectively. An irregularly shaped ore body occurs on the first and second levels, about 300 feet southwest of

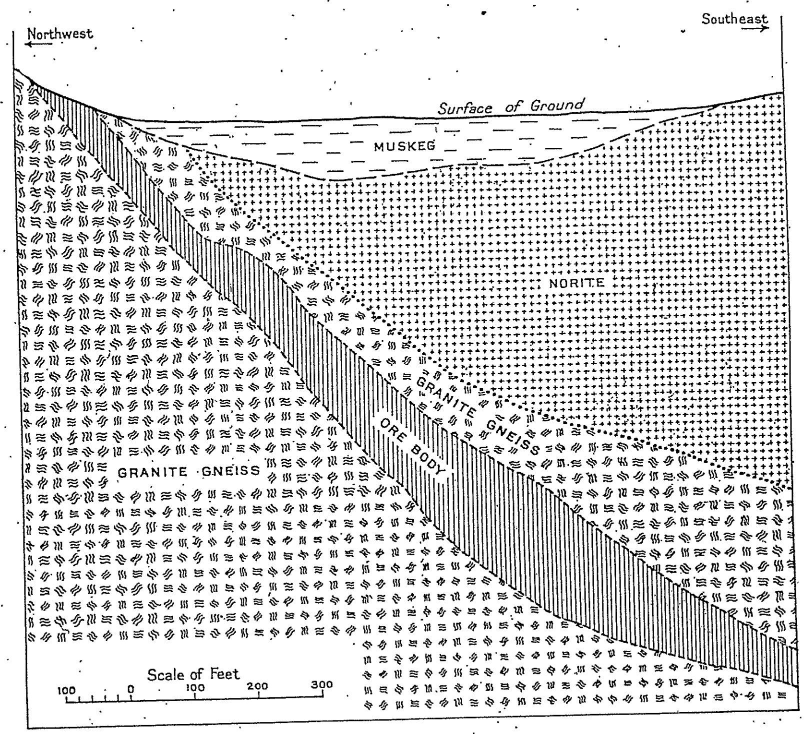

Fig. 40—Levack ore body, Sudbury area, Ontario, showing how the deposit occurs in the granite-gneiss.

the shaft. On the third level this ore body becomes larger and assumes a somewhat lenticular form, having a length of 500 feet or more, and a maximum width, measured horizontally, of 150 feet. On this level, about 160 feet northeast of the shaft, there is a triangular-shaped ore body which projects into the granite-gneiss footwall about 340 feet. These two ore bodies do not seem to be connected on this level. Below the third level no development work had been accomplished at the time referred to, but diamond-drill cores showed that the ore body extends to a depth of nearly 1,300 feet measured along the dip.

The Levack ore body is a replacement or impregnation deposit in granite-gneiss. It is evident that the granite-gneiss was fractured and brecciated, so that the introduction of the sulphides was readily accomplished. The sulphides occur in irregular masses, in veinlets, and in disseminated grains. The larger, irregular masses of sulphides may be several feet in diameter and be made up of almost pure ore, with only specks of rock fragments enclosed. Sometimes these large masses of sulphides enclose boulders of rock of various shapes and sizes, Fig. 41. These boulders in the ore body are not, however, as common and characteristic as they are at Creighton, Worthington and elsewhere. The sulphides occur for the most part disseminated through the gneiss in a very irregular fashion, Fig. 42. All gradations are found between gneiss which is but slightly replaced or impregnated with ore, and gneiss which has been almost wholly replaced. Granite-gneiss "spotted" with sulphides often occurs.

There are no sharp walls on either the hanging-wall or footwall. Mineralization gradually becomes less intense as the walls are approached. Mining ceases

Fig. 41—Character of ore at Levack mine, Sudbury area, Ontario, first level. Black represents sulphides; white represents granite-gneiss. Width of face 3 feet.

when the grade of ore becomes too low to pay. As is to be expected the commercial ore body contains many masses of almost barren rock.

Above the commercial ore body the hanging-wall is impregnated with ore for 50 to 350 feet measured at right angles to the dip and strike of the deposit. The mineralization becomes less and less intense as the distance from the ore body increases. The norite itself is "spotted" with ore for 25 to 250 feet from the contact with the granite-gneiss, measured at right angles to the dip and strike of the contact. The footwall below the ore body, on the other hand, appears to be mineralized only for 50 or 60 feet beyond the limits of the commercial ore body.

About 33 per cent. of rock is hand-picked from the ores, but the hand-picked ore still contains 14 per cent. of silica.

The sulphides were probably introduced by means of hot aqueous solutions which circulated through the brecciated granite-gneiss and deposited the sulphides in every crack and crevice, replacing and impregnating the granite gneiss. The feldspar of the granite-gneiss retains its fresh appearance; in other words, the introduction of the sulphides appears to have produced little or no alteration in the granite-gneiss or, indeed, in the norite.

Fig. 42—Character of ore at Levack mine, third level, Sudbury area, Ontario. Black represents sulphides; white represents granite-gneiss. Width of face 1 foot. The sulphides replace or impregnate the granite-gneiss.

The Victoria Ore Bodies

The Victoria mine is notable on account of the fact that it has been worked to a greater depth than has any other nickel-copper deposit in the Sudbury field, and, in fact, to a greater depth than any other mine in the Province of Ontario. Although the deposit is not, relatively speaking, a large one, it is nevertheless a persistent and important one. The main shaft is located on the north part of lot 8 in the fourth concession of Denison township, and the mine is served by the Algoma Eastern railway.

The oldest rocks in the vicinity of the mine are schistose quartzites, greywackés and slates of the Timiskaming series. These have been intruded by greenstones, fine to medium in grain. In rare cases the greenstones have amygdaloidal textures and pillow structures showing that some were formed at or near the surface of the earth. The norite intrusion then followed. It was invaded by granite dikes a few feet in width. The formation of the ore bodies then took place. Finally, the geological history of the area, in so far as it treats of pre-Cambrian rocks, was closed by the intrusion of olivine diabase dikes which have not yet been found on the surface, but which intersect the ore bodies in the lower levels of the mine.

The norite, like that at the Garson, is somewhat metamorphosed, with the result that it has often been altered to a gneiss or schist. On the whole it has a more ancient and altered appearance than the norite at the Creighton or Murray mines. There are no workings which show the nature and dip of the contact between the main mass of the norite and the adjacent rocks. However, along the contact of the norite between Victoria and Crean Hill mines, a distance

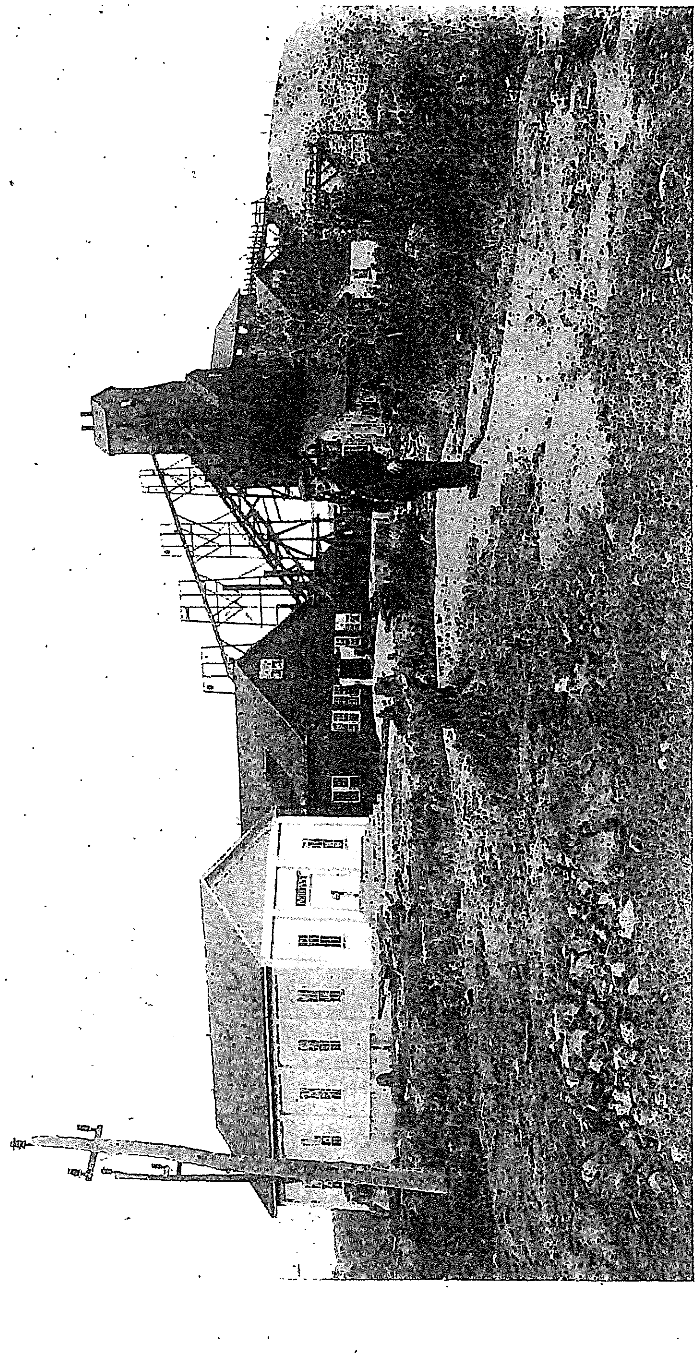

Fig. 43—Victoria mine, Sudbury area, Ontario, October 10th, 1916.

of about two miles, the rock adjacent to the norite is sometimes quartzite or greywacké. The bedding of these sediments at the contact is more or less vertical, so that, if the norite follows the bedding planes in its downward extension, it will possess a more or less vertical dip. The workings at Crean Hill prove that the contact is more or less vertical.

The ore bodies occur about at the intersection of a northwest-southeast and a northeast-southwest zone of shearing, crushing and mineralization. The main ore bodies of the Victoria mine are found on the northwest-southeast zone of disturbance; in addition to the main deposits which are being worked there are several smaller deposits on this zone to the northwest and southeast of the shaft which have been prospected to a minor extent by shafts and other workings.

The northwest-southeast zone of shearing, crushing and mineralization is the more important one in connection with the Victoria mine. Crush-conglomerates and crush-breccias are found along it at various points, and the mineralized zone has a length of more than three-quarters of a mile. It follows the contact of the norite and adjacent greenstone for half a mile to the northwest of the shaft, along which part both of these rocks, norite and greenstone, are often altered to schist or gneiss at the contact, so that it may be difficult at times to decide where one rock begins and the other ends. In this part northwest of the shaft the mineralized and sheared zone has a width of as much as 300 feet in places. To the southeast of the shaft the mineralized zone leaves the norite contact and passes into the greenstones, extending for about one-third of a mile or more to the southeast. In this part of the mineralized zone there are two or more small, irregular intrusions of a rock which looks like norite but which appears to have no surface connection with the main mass of the norite to the north.

Along the entire length of this mineralized zone the rocks, whether they are norite or greenstone, have been impregnated or replaced by sulphides and to a less degree by calcite and quartz. The sulphides in the non-economic portion are present in disseminated grains, in ramifying veinlets, or irregularly shaped masses. The extensive workings, to a depth of 2,312 feet, have shown that this zone has a vertical dip. The shaft has a depth of 2,618 feet.

The economic part of the zone consists of two distinct ore bodies which have been named the west ore body and the east ore body. They are found about the centre of the mineralized zone. The west ore body has been mined to a depth of about 2,312 feet, the sixteenth level, the east ore body to a depth of about 1,200 feet. The workings at these depths are still in ore. These ore bodies are from 80 to 185 feet apart, Fig. 44. The length of the west ore body varies from 60 to 150 feet. The east ore body is smaller, its length being from 65 to 100 feet. The two ore bodies do not appear to have any regular strike, but they pitch to the southeast at an angle of about 70°, Fig. 44. Both ore bodies occur in fine-grained greenstone and quartzite, or schistose rocks which have resulted from the shearing of the greenstone and quartzite. The west ore body is about 200 feet or more south of the main mass of the norite, while the east ore body is found still farther from the main mass. The crosscuts from the shaft to the ore bodies intersect an intrusion of a rock resembling the norite. This intrusion is on the footwall side of the ore bodies, sometimes removed from them a distance of 300 feet, Fig. 44.

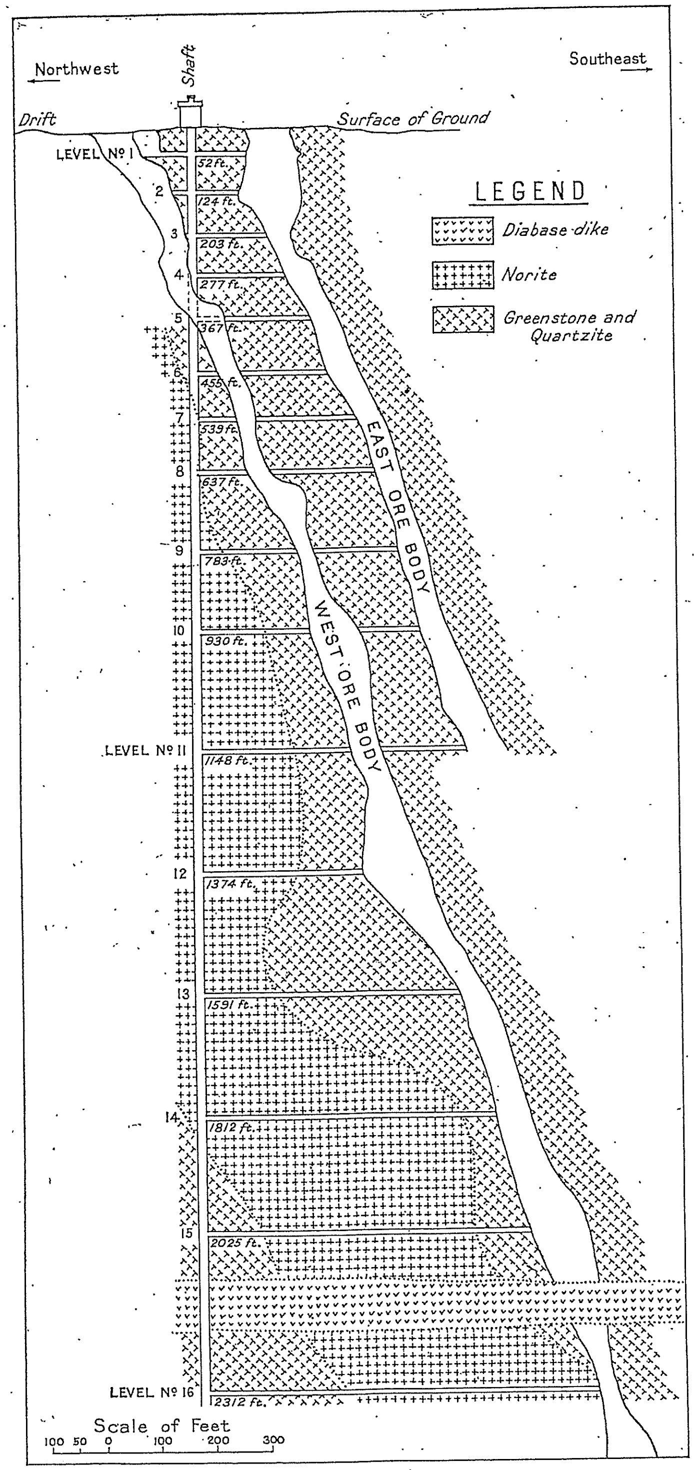

Fig. 44—Cross-section through Victoria ore bodies, Sudbury area, Ontario. At the time this Report was written the Victoria mine was the deepest in the Sudbury area, the west ore body having been worked to a vertical depth of 2,312 feet, and the shaft having been sunk to a depth of 2,618 feet.

In addition to the above economic ore bodies, there is another smaller economic deposit to the southeast. Several thousand tons of ore are blocked out here, but it is not being worked at present. Beyond this, to the southeast, there is a hill which contains economic ore, but which is also not being worked. The rock on this hill is greenstone, and the sulphides are found in disseminated grains and in vein-like occurrences along sheared zones.

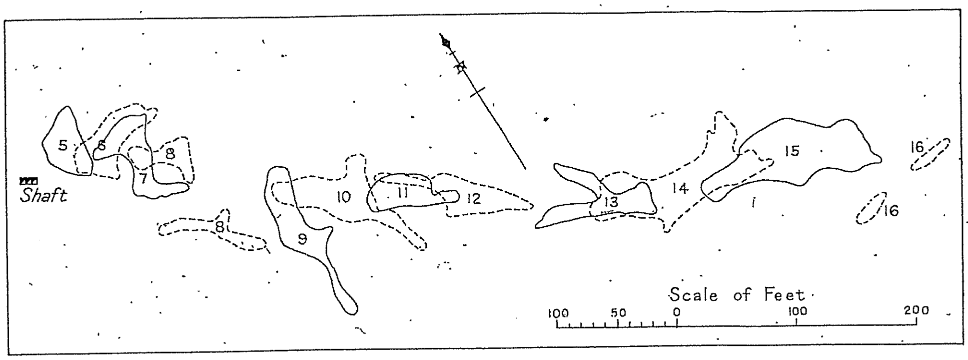

Fig. 45—Composite plan showing size of west ore body on the fifth to sixteenth levels, inclusive, Victoria mine, Sudbury area, Ontario.

The shapes of the west and east ore bodies in the various levels are shown in the composite plans, Figs. 45 and 46. It is to be remembered, however, that these outlines are of commercial ore, and that mineralization, like the mineralization at Creighton, Worthington and other deposits, occurs beyond the limits of the commercial ore bodies. The structure of the two ore bodies is often vein-like,

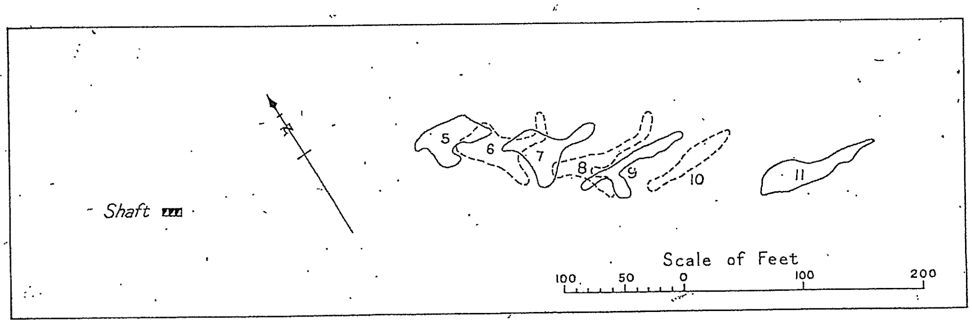

Fig. 46—Composite plan showing size of east ore body on the fifth to eleventh levels, inclusive, Victoria mine, Sudbury area, Ontario.

Fig. 47, the sulphide coming sharply against the wall rock. On the other hand, the wall rock is often replaced and impregnated with sulphides in the clearest manner. Where the wall rock is schistose the sulphides may follow the schistose planes in the process of replacement or impregnation. As a general rule the rocks adjacent to the ore bodies are schistose. Veinlets of ore from the main ore bodies often ramify in all directions into the wall rock. Like other commercial deposits in the Sudbury field, the west and east ore bodies of the Victoria mine contain great numbers of boulders and fragments of the country rock, the presence of which constitutes proof of the crushing and brecciation which took place before the introduction of the sulphides. These inclusions are of all shapes. Their size varies from microscopic dust to masses several feet in diameter. Sometimes, of course, the massive ore is practically free from these inclusions.

To the northeast of the two ore bodies described above there is a crushed, sheared and mineralized zone extending for a few hundred yards. It occurs in the main mass of the norite at the contact with adjacent rocks. Fine examples of crush-conglomerate and crush-breccia are found along this northeast-southwest zone. It may be added that commercial ore has not yet been discovered here.

On the 2,312-foot level the west ore body is intersected by a dike of fresh olivine diabase which has a width of about 30 feet measured at right angles to the walls of the dike, Fig. 44. It strikes northwestward and dips at an angle of about 65° to the northeast. In a raise some 80 feet above the level the fine-grained edge of the dike may be seen to have chilled against the ore body, proving that it was intruded after the formation of the deposit. While the edges of the dike are dense and fine-grained, the central parts are coarse-grained. On the north side of the dike a well-defined crushed zone, or fault, about two feet or more wide, containing much soft, clay-like material, follows the contact of dike and wall rock, but the crushed material is inside the dike about 3 feet from the edge. Evidently some movement took place along this crushed zone, but its extent and direction were not determined. Similar faults are met with at Crean Hill and elsewhere. The dike is readily distinguished from the wall rocks by its freshness and by the absence in it of seams of calcite or quartz. At the time of examination in August, 1916, the shaft was timbered down to the 2,312-foot level, so that it was not possible to search for the dike in the shaft. It is said, however, to have been met with in the shaft about 260 feet above this level and about 700 feet to the northwest of where it intersected the ore body. The dike has not been found on the surface, although its probable outcrop may be along a northwest-southeast valley which occurs three or four hundred yards south of the shaft house. This valley is drift-covered, and follows the course of a small creek. In addition to the main dike there are small dikes 1 or 2 feet wide intersecting the ore body on the 2,312-foot level and elsewhere in the mine. They are dense and fine-grained, and no doubt directly connected with the main dike. The latter appears to be of the same age and character as the olivine diabase dikes at the Murray, Creighton and other mines.

The Victoria ore bodies, and the northwest-southeast zone of crushing, shearing and mineralization on which they occur, furnish what appears to be a clear example of sulphides which have been deposited from solutions circulating along crushed and sheared zones. While the commercial parts of the west and east ore bodies are indeed sometimes pipe-like, sometimes vein-like, they are nevertheless simply a part of the mineralized zone which extends half a mile to the northwest and about one-third of a mile to the southeast of the main ore bodies The sulphides replace and impregnate the rocks along this zone whether they are norite, greenstone or quartzite, or their schistose equivalents. Some favourable combination of circumstances tended to produce workable deposits along this zone, resulting in the formation of the west and east ore bodies. The occurrence of quartz and calcite, or dolomite, in the main deposits and along the impregnated zone furnishes evidence for believing in the theory that the ores were deposited from solution, although it may be added that some of the quartz and calcite may have been deposited earlier than the sulphides. The drifts and other workings in the country rock, for instance, have shown that the rocks contain

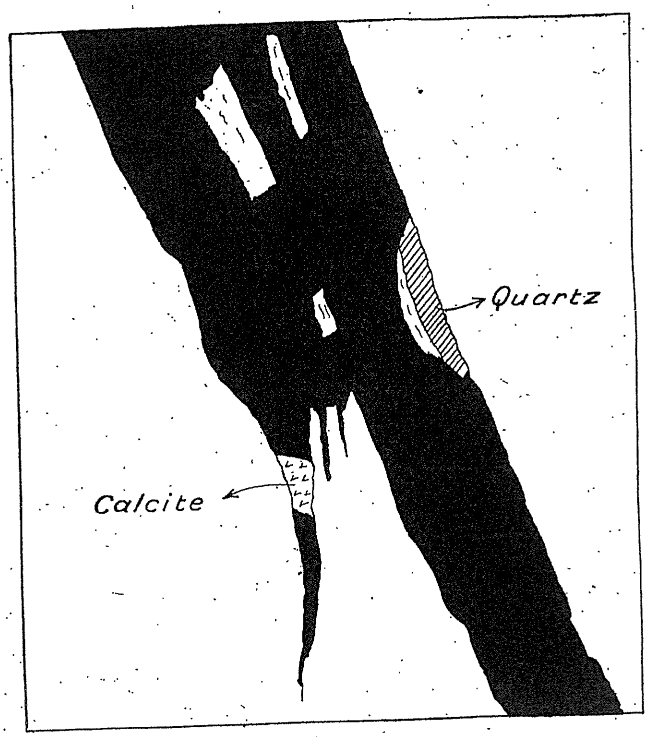

Fig. 47—Character of ore body at Victoria mine at narrow end of a lens, eleventh level. Black represents sulphides; white represents greenstone. Width of face 12 inches. The calcite, quartz and sulphides appear to have been deposited during the same period of mineralization.

many veinlets of quartz or calcite about a quarter or half an inch in width. On the other hand, quartz, calcite and sulphides are often so closely intermingled in the ore bodies and mineralized zone that it seems reasonable to suppose they were deposited during the same period of mineralization.

The ore in the upper levels of the west and east ore bodies contained 3 to 4 per cent. nickel and 2 per cent. copper. As depth was obtained the amount of nickel decreased and the copper increased, until on the lower levels the ore contained 1.5 to 2.5 per cent. nickel and 3 per cent. copper. There is handpicked from the ore about 25 per cent. of rock, and this handpicked product still contains about 14 per cent. of silica.

Between the Victoria mine and the Canadian Pacific railway, about two miles to the south, there are half a dozen or more fahlbands. They have a width of five to as many as 200 feet, and one of them has a length of about two miles. The fahlbands occur in fine-grained schistose rocks which were originally quartzites, greywackés or slates, but are now more or less altered to schists which, however, still retain their bedding planes. Sulphides are finely disseminated through these rocks, and the weathered surface assumes the characteristic brown colour due to the formation of iron oxides which result from the decomposition of the sulphides. Of the latter, pyrrhotite and chalcopyrite have been recognized in a small pit about 250 yards southeast of Mond station on the Algoma Eastern railway. The pit in question is about 50 feet south of the waggon road.

The fahlbands, however, probably contain on the average only traces of nickel and copper. The mineralization follows the strike of the bedding planes which are about northwestward. Their dip is more or less vertical. Crushing has often taken place along the fahlbands, as, for instance, that one which occurs at the intersection of the waggon road to Victoria and Crean Hill mines on lot 7 in the third concession of Denison. Crush-breccias and crush-conglomerates occur here and there along this fahlband.

The fahlbands were in all probability formed by hot solutions circulating along bedding planes, and depositing sulphides. The crushing no doubt aided in the circulation of the solutions. It seems evident that the fahlbands were formed during the same period of mineralization as that in which the Victoria ore bodies were deposited. Indeed, the northwest-southeast zone of mineralization, of which the west and east ore bodies of the Victoria are a part, is really of the nature of a fahlband.

The Worthington Ore Body

The Worthington mine is situated about 25 miles west of the town of Sudbury, on the Sault Ste. Marie branch of the Canadian Pacific railway. Like the Murray mine, the railway cut was blasted into the ore body, and the track was thus laid on top of the deposit. The mine occupies part of lot 2 in the second concession of Drury township.

The deposit is one of the simplest in the Sudbury area, it being merely a mineralized dike, similar to No. 2 mine of the Canadian Copper Company. It has been called an offset deposit.

The geological story may first be related. The most ancient rocks in the environs of the mine consist of beds of slate, quartzite, conglomerate and greywacké of the Timiskaming series. These sediments have been tilted into nearly vertical positions, Fig. 49, until they now dip at an angle of about 72° to the southeast, their strike being about northeast and southwest. The beds, which were much altered and more or less schistose, were then intruded by greenstone, which is also sometimes considerably altered but still retains its massive structure. The greenstone, for instance, about half a mile northeast of the mine, has been changed to a rock consisting largely of actinolite. It appears to have been, before alteration, a diorite or other closely related rock. The intrusion of the greenstone was followed by the formation of a fissure which apparently followed in part the strike

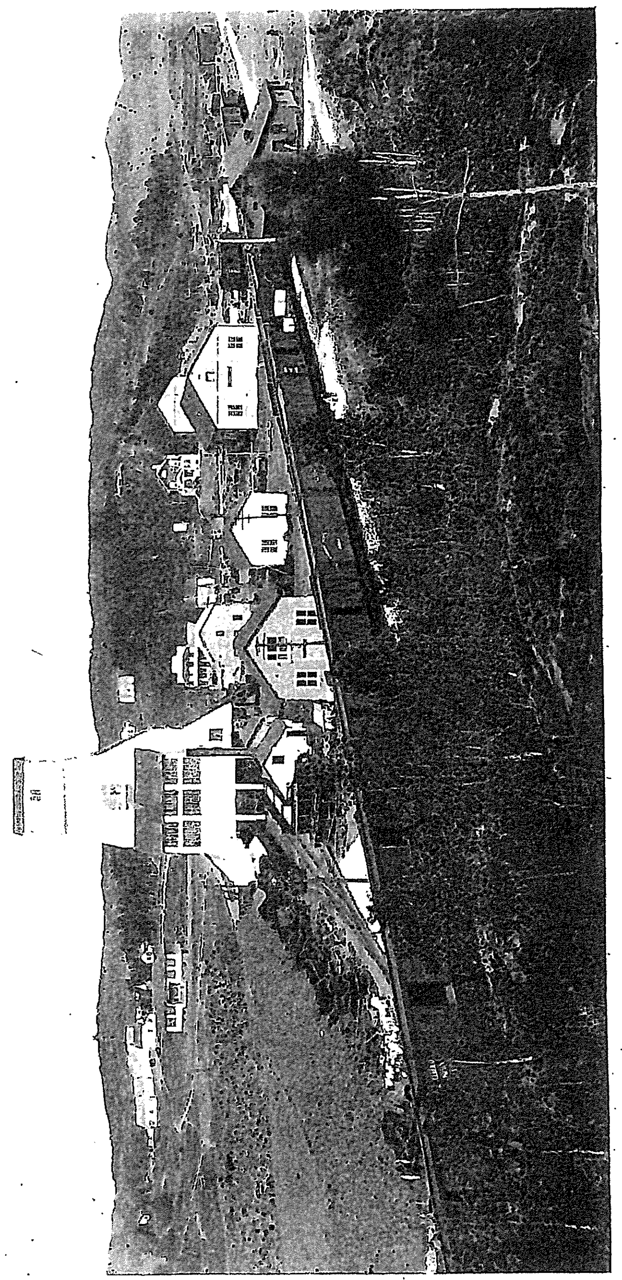

Fig. 48—Worthington mine, Sudbury area, Ontario, September 16th, 1916.

and dip of the sedimentary beds and, in part, intersected the bedding planes. It also cut through the greenstones. Along this great crack a dike, which has been named norite by Coleman, was erupted. The dike is a fine-grained rock from 125 to about 180 feet in width. It is characterized by the amazing number of rock fragments which it has caught up during its intrusion. These fragments consist of various kinds of greenstone, together with fragments of the sedimentary rocks. The most common inclusions are the actinolite rock, and, indeed, in that part of the dike which constitutes the ore body, these actinolite inclusions form 50 per cent., if not more, of the dike. The inclusions are round or angular, and vary from small specks to great blocks 25 feet or more in diameter.

Below are given three analyses of the norite. Nos. 1 and 2 are from various workings of the Worthington mine, while No. 3 is from the Totten mine, about half a mile southwest of Worthington.

Table showing Chemical Composition of "Norite" at Worthington and Totten Mines.

	No. 1.	No. 2.	No. 3.
SiO_2	57.40	54.90	57.98
Al_2O_3	15.61	19.02	18.94
Fe_2O_3	....	5.00	2.24
FeO	10.02	8.51	6.93
CaO	5.45	5.90	5.71
MgO	4.49	1.68	1.84
Na_2O	....	1.99	2.01
K_2O	....	1.72	2.45
H_2O	....	1.81	0.98
CO_2	....	Trace	0.52
		100.53	99.60

Analysis No. 1 in the above table is by the Mond Nickel Company; analyses Nos. 2 and 3 are by W. K. McNeill.

After the norite dike had solidified it was crushed and brecciated along its central portions, for a width of 50 or 60 feet, the width of the ore body, and crush-breccias and crush-conglomerates were formed. Norite and its greenstone inclusions were alike crushed and brecciated, but both rocks retained for the most part their non-schistose character. Then followed the introduction of the sulphides, the latter cementing the fragments together and filling the cracks and other openings in the rocks, Fig. 49. This mineralization was accompanied by some replacement and impregnation of the norite and its inclusions. Little or no mineralization occurs in the slates, quartzites and other rocks of the Timiskaming series.

When the period of mineralization ceased, or about ceased, the norite dike and sedimentary rocks were fissured in two places, and dikes of trap were intruded. The larger of these occurs to the southwest of the shaft and beyond the commercial ore body; it may be seen a few feet south of the railway track. It has a width of 17 feet or more at the widest point exposed, but gradually becomes smaller in about 150 yards to the west, where it finally narrows down to only a foot in width. It strikes about east and west and dips at an angle of 66° to the south, in so far as surface exposures indicate. If the dike continues in depth with this dip, it will not intersect the ore body since the latter has a still deeper dip of 72°. The second trap dike occurs about 125 feet south of the first. It is only 6 or 8 feet

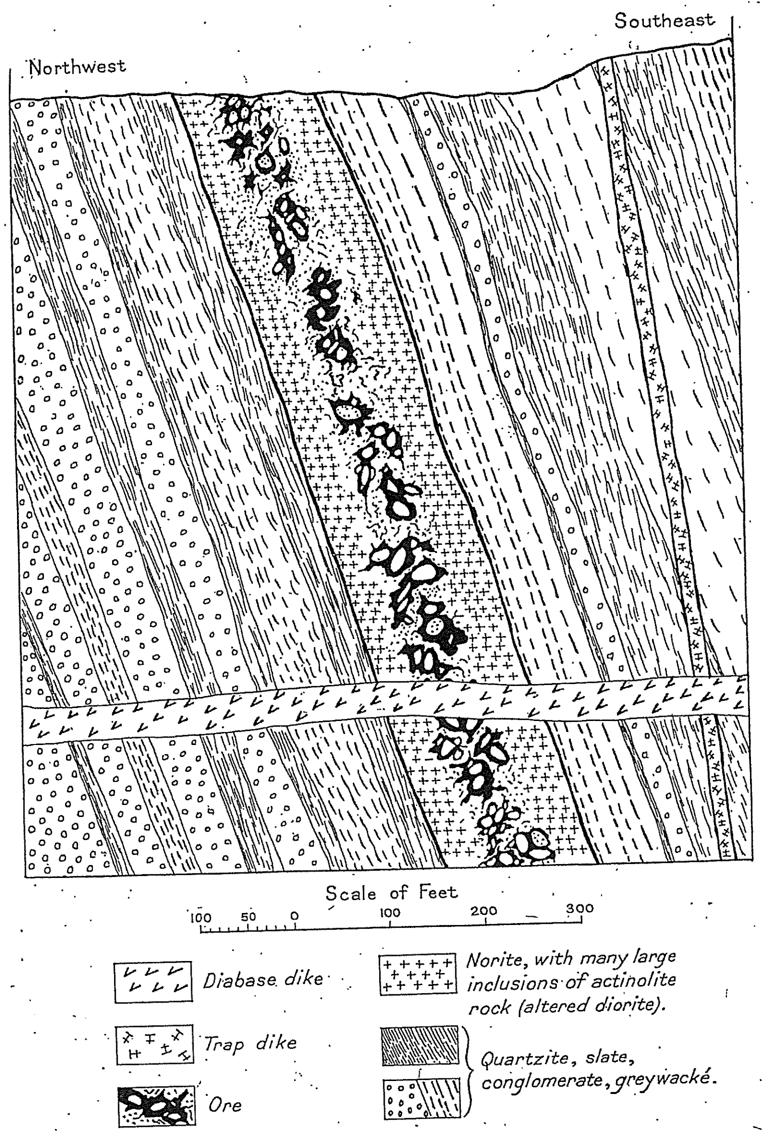

Fig. 49—Diagrammatic vertical cross-section, showing Worthington ore body, Sudbury area, Ontario. The deposit occurs in a dike which has been crushed into round fragments. After the crushing the ore was introduced into the spaces between the rock fragments.

wide and strikes about parallel to the first. Its dip, however, appears to be steeper, some 80° to the southward, judging from surface indications only. These two dikes have not yet been encountered in mining operations, showing that the larger of the two, at any rate, dips away from the ore body. The smaller of the dikes may be seen intersecting the slightly mineralized norite on the hill southwest of the shaft about 500 feet. It has chilled against the norite and against the sulphides, which would indicate that it is younger than the ore. The larger of the trap dikes is drift-covered where it crosses the norite dike, but it is inferred from its resemblance to the second dike that it also is younger than the norite and ore. These trap dikes are probably of the same age as those at the Creighton mine. C. H. Hitchcock was the first observer to note their presence at the two mines in question.

The traps at the Worthington are fine-grained basic rocks with a dark green colour. A diabase texture was noted in one instance. The following is a partial analysis by the Mond Nickel Company of the larger of the two dikes:

Composition of Trap Dike at Worthington Mine.

SiO_2	55.37
FeO	12.99
Al_2O_3	15.30
CaO	7.75
MgO	4.35

After the intrusion of the trap dikes the rocks in the vicinity of the mine were again fissured, and six or more dikes of diabase, resembling in texture and appearance the olivine diabase dikes at Murray, Creighton, Garson, and other places, were intruded. The diabase is a fresher rock than the trap dikes. A diabase dike intersects the Worthington ore body at its eastern end, having been encountered on the first, second and third levels. It is about 35 feet wide and dips steeply to the northeast, cutting the ore body about at right angles. Another diabase dike striking to the southeast occurs some 450 feet southwest of the shaft. It is dipping at about 45° to the northeast, and will, if it continues at that dip, intersect the ore body in the underground workings, though it had not been met with there in the autumn of 1916. A chemical analysis by the Mond Nickel Company of the first-mentioned diabase dike, which intersects the northeast end of the ore body, gave the following results:

Composition of Diabase Dike at Worthington Mine.

SiO_2	49.05
FeO	14.91
Al_2O_3	16.96
CaO	7.75
MgO	5.27

Small dikes, emanating from this diabase dike, intersect the second trap dike described above.

The final chapter in the geological history of the ore body appears to be closed by the formation of veins, containing calcite, galena, zinc blende and iron pyrites. The veins are 1 to 6 inches wide. That some of these veins were formed at a very much later period than the ore body is shown by the fact that one of them intersects the diabase dike on the first level at the east end of the ore body.

There are numerous slips and crushed zones intersecting the ore body in various parts of the mine. Many of them are at right angles to the strike of the ore body, and dip to the southwest.

The deposit has a length of about 700 feet and a width of 50 to 60 feet. It is being worked to a depth of 438 feet—the third level—but diamond-drill cores have demonstrated that the deposit extends to greater depth. Although the commercial part of the deposit is about 700 feet long, non-commercial mineralization has extended far to the northeast and southwest of the workable ore. The latter is confined chiefly to a central zone in the norite dike.

From what has been said, it is probable that the reader already has grasped an idea of the nature of the deposit. The walls of the ore body are commercial, no sharp lines being found between workable ore and wall rock. The ore consists of: (1) rock fragments cemented by sulphides, Fig. 49; (2) small veinlets of ore ramifying through the rock; and (3) disseminated "blebs" or grains in the rock. The rock fragments consist of norite and its greenstone inclusions, and it is evident that both norite and greenstone were brecciated and crushed prior to the introduction of the sulphides. The disseminated "blebs" or grains are confined largely to the norite.

The ore body is one of the most rocky in the Sudbury field, and, as a result, it is necessary to hand-pick 60 per cent. of rock from the ore. Even this hand-picked material contains about 26 per cent. of silica. The hand-picked ore, however, carries a little less than 7 per cent. of copper and nickel in the proportion of 4 of copper to 3 of nickel, making it the richest ore produced from the mines which were working in the summer of 1916. The unusually high percentage of nickel is due to the large amount of pentlandite in the ore, pentlandite containing about 22 per cent. of nickel.

In addition to pentlandite, gersdorffite and niccolite also occur in the ore body.[1] The ore-bearing minerals are associated with small amounts of quartz which appear to have been deposited at the same time as the sulphides. The presence of quartz has a bearing on the origin of the ore, since quartz is often a water-deposited mineral.

The origin of the deposit appears to be due to hot waters circulating along the crushed and brecciated norite dike. These solutions carried sulphides, quartz and other minerals, and deposited their mineral contents in the cracks and spaces between the crushed rocks.

The Murray Ore Body

The Murray mine is on the main line of the Canadian Pacific railway, about three miles northwest of the town of Sudbury, on lot 11 in the fifth concession of McKim township. It is one of the important deposits of the area, there having been proved, by diamond-drill cores, some 9,000,000 tons of ore.

The oldest rocks in the area consist of greenstones. There are two main varieties, of which the most abundant is a fine-grained type containing numberless veinlets of hornblende ramifying through it; this rock at the nearby Elsie mine has well-defined pillow structures and amygdaloidal textures, and has been named sudburite.

[1] The Nickel Industry, 1913, p. 47.

A complete rock analysis[1] of sudburite is shown in the table below. The analysis is by J. H. Horton.

Table Showing Chemical Composition of Sudburite from the Murray Mine.

SiO_2	46.69
Al_2O_3	14.23
FeO	12.82
Fe_2O_3	2.00
CaO	13.32
MgO	8.15
P_2O_5	0.19
TiO_2	1.28
Na_2O	0.98
MnO	0.11
S	0.12
H_2O	0.08
	99.97

The second variety of greenstone may be called a gabbro or other closely related rock. It has a green colour, and occurs as a belt between the sudburite and the norite, having a maximum width of 350 feet. The rock resembles the gabbro at Frood and Mount Nickel mines. It is of importance because the ore body, in so far as may be judged from the excellent surface exposures, occurs almost wholly in it. The age relations between the gabbro and greenstone are obscure. There are some contacts between the two rocks showing a sharp junction; other contacts are vaguely defined. In addition to the fine-grained greenstone and the gabbro, there is a dike of green diabase, on the hill to the south of the mine, cutting the greenstone. This diabase appears to be older than the olivine diabase dikes later to be mentioned, although the two varieties of diabase were not seen in actual contact. Finally, there is a coarse-grained feldspar-porphyry which has been encountered in the shaft and on the surface. Its relation to the fine-grained greenstone and gabbro was not definitely determined, although it appears to have a dike-like form. It may be added that the greenstones contain inclusions of greywacké or quartzite of the Timiskaming series; these inclusions are, of course, older than the greenstone or gabbro.

The next youngest rock in the area is the norite. That it is younger than the gabbro referred to in the preceding paragraph is proved by the fact that it has caught up blocks of this rock. Good exposures showing the contact between the two rocks may be seen a few hundred yards east of the Canadian Pacific railway track. The gabbro, while resembling the norite, has a distinct, characteristic green colour.

After the norite had solidified there was erupted a mass of granite about 3 miles long and a mile wide. It literally cuts to pieces the fine-grained greenstone and the gabbro with a network of dikes, some of which extend up to the norite and penetrate that rock for 100 or 200 feet.

When the granite had solidified, the gabbro and in part the greenstone along the edge of the norite were crushed, brecciated and broken into a great crush-conglomerate and crush-breccia. The sulphides were introduced into the spaces between these blocks of rocks, and cemented the fragments together, forming the ore.

[1] Ont. Bur. Mines, Vol. 23, Part I, p. 216.

The final chapter in the geological history of the Murray ore body was closed by the formation of great fissures extending across the country for seven or eight miles. Dikes of olivine diabase were erupted through these great cracks, penetrating not only all the rocks mentioned but also the ore bodies. They are probably younger than the dike of green diabase mentioned before.

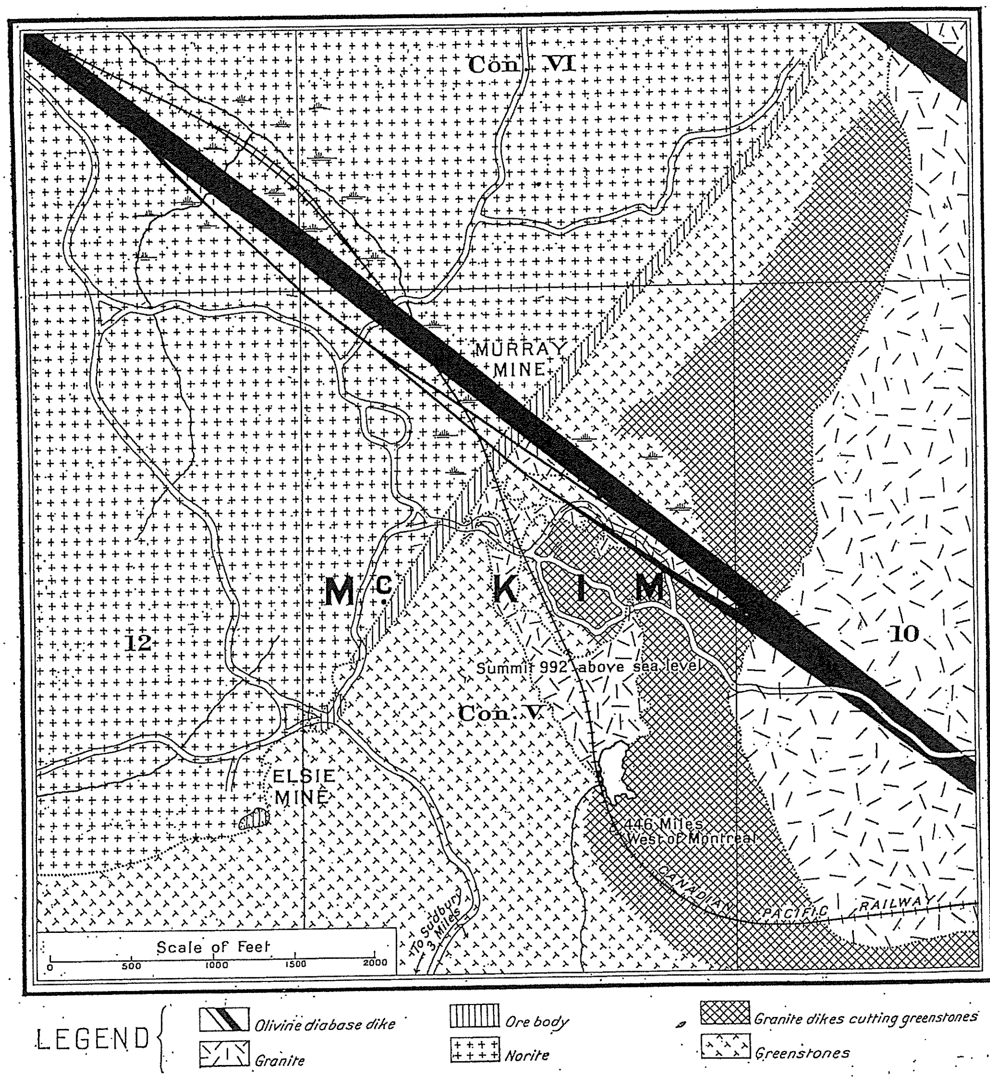

Fig. 50—Geological map after A. E. Barlow, showing Murray and Elsie mines. The left side of the cut is west, the right side is east.

The Murray mine has not been worked for many years, so that an examination of the underground workings was not possible. The character of the ore body, however, is excellently shown in the railway cut of the Canadian Pacific railway, which penetrates across the deposit about at right angles to its strike. It is seen to consist of a mass of gabbro fragments, round or angular, cemented by sulphides.

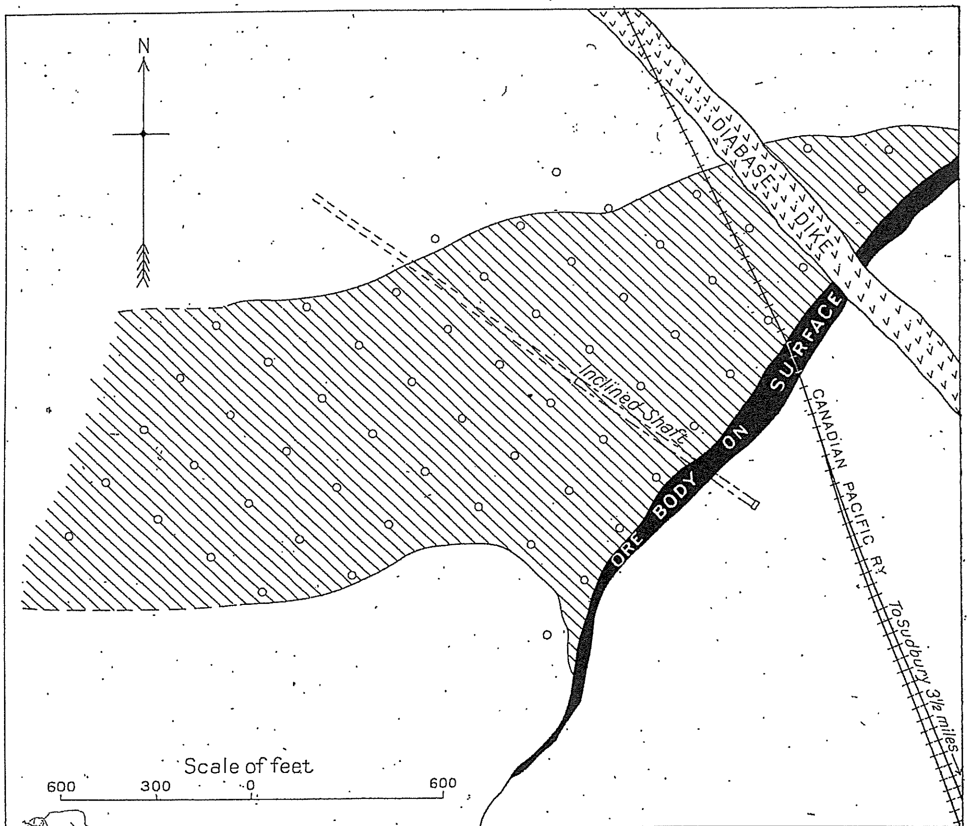

Fig. 51—Map showing Murray ore body, Sudbury area, Ontario. The shaded area denotes the known extent of the deposit below the surface; the ore body dips to the northwest at an angle of 36° as shown in Fig. 52. The small circles indicate diamond drill holes. From drawing by the British America Nickel Corporation.

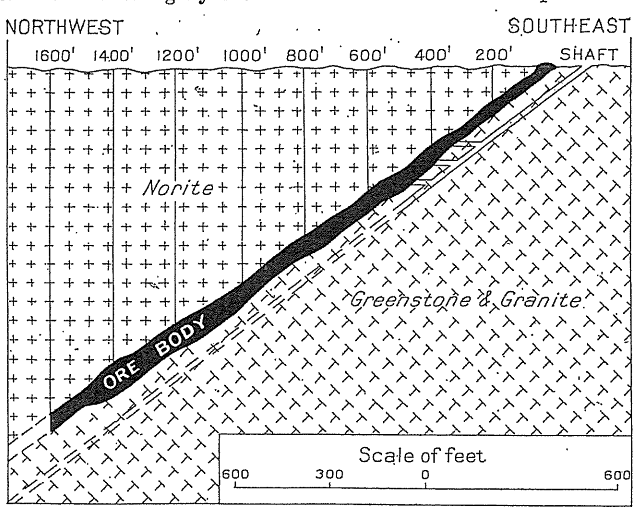

Fig. 52—Vertical cross-section through Murray ore body, Sudbury area, Ontario, showing depth of diamond drill holes. While the ore body occurs about at the contact of the norite and footwall rocks (greenstone, granite and gabbro), nevertheless the Murray ore body is found in the footwall rocks—not in the norite. From drawing by the British America Nickel Corporation.

The ore body occurs almost wholly in the gabbro, but the norite is slightly impregnated with sulphides. Although gabbro and greenstone form the footwall of the upper part of the ore body, drill cores show that granite forms, in part, the footwall in its deeper portions.

The ore body strikes about northeast and southwest and dips at an angle of 36 degrees to the northwest. The deposit extends to a depth of at least 2,000 feet measured along the dip of the ore body. The mineralized zone has a length of 5,000 feet, not all of this being of commercial grade. The average thickness is 50 or 60 feet, measured at right angles to the strike and dip of the ore body. It is estimated that about 33 per cent. of rock will be hand-picked from the ore, and that the hand-picked product will contain about 3 per cent. nickel and copper combined.

Fig. 53—Murray mine, Sudbury area, Ontario, September 2nd, 1916. A modern plant and smelter are being erected at the Murray mine by the British America Nickel Corporation.

A shaft has been sunk to a depth of 700 feet in the footwall, and is being sunk to greater depth. The old workings, made many years ago, were still full of water in the fall of 1916.

The Blezard Ore Body

After being closed for about twenty-three years the Blezard mine was pumped out during July and August, 1916, and diamond drilling begun on the surface. During the time that the property was idle, the smelter, mine and other buildings were burned. The property is on lot 4 in the second concession of Blezard township.

The oldest rocks in the vicinity of the mine are quartzites and greywackés of the Timiskaming series. In greater volume, and possibly younger than the quartzites or greywackés there are fine-grained greenstones which have been called sudburite. The greenstones are sometimes amygdoloidal. That they have undergone a certain amount of metamorphism is shown by the development of red garnets here and there. The very numerous veinlets, fractions of an inch wide, which intersect the rocks, may be of a secondary nature.

In the table below there is given a complete analysis[1] of sudburite from the Blezard by W. K. McNeill.

Table Showing Chemical Composition of Sudburite from Blezard Mine.

SiO_2	46.86
Al_2O_3	16.94
FeO	15.49
Fe_2O_3	4.18
CaO	9.65
MgO	2.94
P_2O_5	0.28
TiO_2	1.54
K_2O	0.23
Na_2O	1.51
S	0.09
H_2O	0.47
	100.18

In addition to the quartzites, greywackés and greenstones, there are irregular areas of a very basic intrusive 50 to 300 feet in length consisting almost wholly of hornblende or pyroxene. Their age relation to the greenstones appears to be obscure.

The norite is younger than any of the rocks above mentioned. It was found, however, that a sharp line of division does not occur between it and the greenstones or basic intrusives. There exists between the norite and the rocks mentioned what may be called a contact zone having a width of 10 to 130 feet. This contact zone consists of a curious intermingling of the norite and greenstones. There appears to have been crushing along the contact zone after the norite had solidified, since blocks of coarse-grained and fine-grained norite are found in it. It may be added that, while an indefinite zone exists between the norite and greenstones, the contact, however, between the norite and quartzite or greywacké is sharp.

The ore body, which is of the marginal type, occurs at the contact of the norite and adjacent rocks, partly in the contact zone referred to above, partly in the fine-grained greenstone and basic intrusive and partly in the norite. Little commercial ore, however, occurs in the norite, the sulphides being sparsely disseminated in grains through this rock, resulting in "spotted" norite. The dip of the norite contact with adjacent rocks is about 50 degrees to the northwest, this representing also the dip of the ore body.

[1] Ont. Bur. Mines, Vol. 23, Part I, p. 216.

The commercial part of the ore body consists of the usual fragments and blocks of rocks cemented together by sulphides. In this respect it in no way differs from other marginal deposits. Veinlets and disseminated grains of sulphides also occur.

The ore body was worked by an open pit and two shafts. The open pit has a length of 200 feet by a maximum width of 120 feet, and a depth of about 35 feet. The main shaft is near the southwest end of the bottom of the pit. It is about 100 feet deep, measured from the bottom of the pit. A small amount of stoping was done from this shaft, a stope about 75 feet in length having been begun by the old miners. The second shaft is on the surface near the north end of the pit. It has a depth of 120 feet, and was not connected with the pit by drifts or any other workings. Two drifts about 30 feet in length occur at the bottom of the second shaft.

In the neighbourhood of 100,000 tons of ore are reported to have been mined, containing 4 per cent. nickel and 2 per cent. copper.

Although an exploration campaign by diamond drill was in progress during the summer and fall of 1916, no attempt was made to work the deposit.

Results of Drilling by the E. J. Longyear Company in the Townships of Falconbridge and Garson, Sudbury Nickel-Copper Area, Ontario*

Introduction

The E. J. Longyear Company, of Minneapolis, Minnesota, has conducted explorations in the Sudbury area with five diamond drills during the year 1916. Holes were drilled in the townships of Levack, Trill, Denison, Blezard, Garson, Falconbridge and MacLennan.

A body of nickel and copper ore was found in lots 10, 11 and 12, in the fourth concession of Falconbridge township. This property lies in the southeastern part of the area, about three miles east of the Garson mine.

Local Geology in Falconbridge Township

Since a discussion of the geological features developed by the exploration is now being prepared by H. M. Roberts and Robert D. Longyear, no attempt will be made in this summary to discuss the mode of occurrence and genesis of the ores. The ore body under consideration occurs along the outer edge of the norite at its contact with older rocks, in this instance, composed of greenstone, greywacké and quartzite. The contact is steep, the dip varying from vertical to 70 degrees northward. In one cross-section the dip has been found to be 85 degrees to the south. The ores are composed of the sulphides, pyrrhotite, chalcopyrite and pentlandite, with varying admixtures of norite and footwall rocks.

The lands are covered with deep kettles and morainic hills, consisting of gravel and boulders, which were left behind upon the retreat of the ice sheet. The surface

*Mr. Hugh M. Roberts, of the E. J. Longyear Company, has kindly furnished the Commissioners with the following description of the diamond drill operations in Falconbridge and Garson townships.

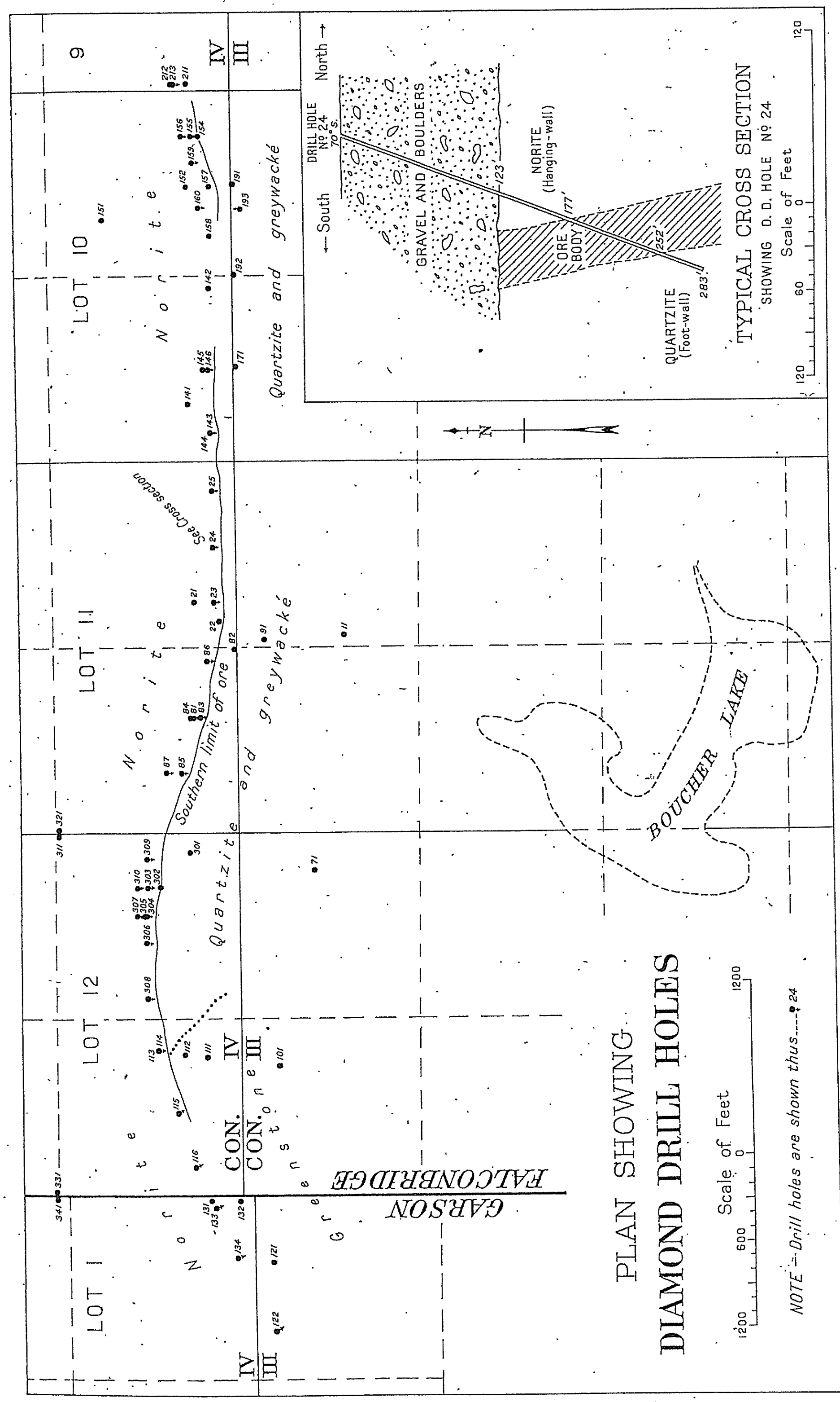

Fig. 54—Plan showing location of ore body which was discovered in the year 1916 by the E. J. Longyear Company in Falconbridge and Garson townships, Sudbury area, Ontario.

covering had heretofore retarded developmnt in this vicinity and presented a serious obstruction to exploration, since all rock exposures were concealed. This increased the hazard of the undertaking and added to the cost of the drilling.

Ore Body

The drills were still at work in January, 1917, in this vicinity, and the limits of the ore body were not yet determined. Thus any description at the present time is necessarily fragmentary.

An accompanying map, Fig. 54, shows the drill holes which were completed before January 1, 1917. The position of the ore body, as thus far indicated, is also shown on this map. The map also shows a typical cross-section of the ore body. The ore is believed to extend from the east line of lot 10 to the west line of lot 12, a distance of one and one-half miles, and has been crossed at intervals of 200 or 400 feet, excepting in the vicinity of the centre of lot 10, where holes have not yet been drilled. The horizontal width of the ore body varies from a minimum of 10 feet to a maximum of 150 feet.

During the conduct of the exploration, it was planned first to outline the norite contact by means of vertical holes, which would merely penetrate rock. After this preliminary "scouting," angle holes were planned to cross the contact for the purpose of finding ore and to determine its extent and quality.

The appended tables, in the appendix, summarize the information obtained from the drill holes which penetrated ore.

Sampling

The method of sampling may be briefly described: During the course of the drilling, 90 to 95 per cent. of the core was recovered. This core was split longitudinally by means of a "core-splitter" devised for the work; one-half was kept on file as a record of the physical characteristics of the ore and the other half was ground for analysis. In pure ore, intervals of five feet were analyzed. In mixed ore and rock the division points were chosen according to the character of the material; but in no case was a smaller interval than six inches analyzed, or a greater interval than five feet.

Summary

Owing to the incomplete state of the exploration, it is obviously impossible to give any statement of tonnages or of average metallic content. General ideas along these lines may be best obtained from inspection of the tables, the map and the typical cross-section.

The ore body, as thus far disclosed, varies in width from 10 feet to 150 feet; the metallic content varies from 1 to 5 per cent. in combined copper and nickel. Subsequent drilling may alter these figures. No deep drilling has been projected as yet. The present work merely indicates the remarkable extent and continuity of the deposit. The greatest depth at which ore has been cut is 580 feet. There is no geological reason why ore may not be expected to extend to far greater depth.

OTHER NICKEL-COPPER DEPOSITS, SUDBURY*

On preceding pages descriptions are given of deposits that were being worked in the year 1916. In following pages deposits that were not being worked in that year will be discussed.

THE SOUTHERN NICKEL RANGE

Of the ore bodies on the southern nickel range, ten have already been described, under the heading of working mines; namely, Worthington, Victoria, Crean Hill, Vermilion, Creighton, No. 2, Murray, Blezard, Garson and Longyear. Reference will now be made to the other ore bodies. They are of the marginal and offset types, and were not being worked in the autumn of 1916. The deposits will be described, following Coleman's procedure, by beginning with those that occur at the west end of the norite-micropegmatite and following the basic edge of that rock north-easterly to the eastern nickel range.

Sultana and Sultana East Ore Bodies

The series of pits and small shafts which have been designated as the Sultana mine, occur mostly on lots 7 and 8, in the first concession of the township of Trill. The deepest shaft is said to have been sunk to a depth of 110 or 120 feet. The series of pits and exposures of ore show that the zone of mineralization has a length of about three-eighths of a mile. These ore bodies occur largely in the greenstone. The character of the ore is shown in one of the pits, where it may be seen that it consists of fragments of greenstone cemented together by sulphides.

The Sultana east property is about half a mile east of the Sultana, on lots 6 and 7, in the first concession of Trill township. There are some small pits on the claim. The ore occurs in greenstone.

The Chicago Ore Body

The Chicago also known as the Travers or Inez mine, is on lot 3, in the fifth concession of Drury township, about 4 miles north of the Worthington mine.

The ore body occurs in greenstone and a coarse-grained anorthosite, the deposit being about a third of a mile south of the norite-micropegmatite. The ore body was worked by an open cut about 200 feet long and 5 to 25 feet in width; a shaft is said to have been sunk to a depth of 160 feet. At least 3,500 tons of ore were mined from the deposit. The ore body, which strikes northeasterly and dips steeply to the northwest, is veinlike in part. It was evidently formed along a fissured and sheared zone, the rocks being schistose near the deposit. There is an unusual amount of quartz and calcite or dolomite associated with the ore, and this, together with the veinlike character of the deposit and the altered and schistose condition of the wall rocks, show that the minerals, including the sulphides, were deposited from hot circulating waters.

* By Cyril W. Knight.

Ore Bodies between Chicago and Victoria Mines

About a mile southeast of the Chicago mine there is some mineralization near the southeast corner of lot 2 in the fifth concession of Drury township, and near the line between concessions 4 and 5. Stripping and small pits extend for 200 or 300 yards. Farther east, at the north end of lot 12 in the fourth concession of Denison township, ore has been found in several pits.

At the north end of lot 11 in the fourth concession of Denison township, half a dozen pits and strippings have disclosed a considerable body of ore in greenstones and green schist.

The Totten, Worthington No. 2, Howland, Robinson, Gersdorffite and McIntyre Ore Bodies

These ore bodies occur in what is known as the Worthington offset—a dike about four miles long and 100 to 200 feet wide. The dike has the composition of a diorite or other closely related rock, and is thought by certain writers to be connected with the norite-micropegmatite, although there is no direct surface connection with this rock. The ore bodies associated with the dike are much alike; the largest, and the only one which was being operated in the fall of 1916, is known as the Worthington, and is described elsewhere in this report. The commercial ore in all the deposits is of the usual character, and consists largely of fragments of the dike cemented together by sulphides.

At the northeast end of the dike on lot 10 in the third concession of Denison township two pits have been sunk. About a quarter of a mile to the southwest on lot 11 in the same concession there is a pit known as the McIntyre mine. At the Gersdorffite mine, about three-quarters of a mile southwest, there are three small pits; the dike here appears to cut across the bedding planes in the sedimentary rocks, and it pinches out into irregular stringers a short distance to the northeast. The property is at the south end of lot 12 in the third concession of Denison township. Beyond the Gersdorffite, on the north part of lot 12 in the second concession of Denison township, is the Robinson mine, at which a tunnel about 70 feet long has been driven into the hill. The offset here consists of many irregular intrusions ramifying through greenstone, the latter consisting largely of actinolite. Both offset and greenstone are spotted with blebs of sulphides, but the blebs are most common in the offset. Between the Robinson mine and the Howland, the next property to the southwest, the offset contains an enormous number of greenstone inclusions.

The Howland mine is at the north end of lot 1 in the second concession of Drury township. It consists of an open pit about 75 feet long, some 30 feet wide and about 30 feet deep. A dike, 12 inches wide, of a fine-grained, dark-coloured rock cuts across the northeast end of the deposit, while at the southwest end a very large olivine diabase dike appears to cut off the ore body. The deposit consists of angular and round fragments of rock cemented together by sulphides.

Worthington No. 2 is about half a mile southwest of the Howland, on lot 2 in the second concession of Drury township. There is a pit about 200 feet deep at the southeast side of the offset. The offset here is smaller than at the Worthington mine; it pinches out about 200 yards northeast of Worthington No. 2, and there is a break in its continuity for 300 or 400 yards, before it appears again near the Howland mine. The greenstone at Worthington No. 2, through which the offset cuts, is an actinolite rock; about a quarter of a mile to the east, this rock passes gradually into a diorite or gabbro, thus disclosing the origin of the actinolite rock.

Beyond the Worthington mine, to the southwest, there are several workings along the offset, including the Totten ore body, which is on lot 2 in the first concession of Drury township. Some mineralization is found for a mile to the southwest of the Totten mine.

The Crean Hill No. 2, and adjacent Ore Bodies

The deposit known as Crean Hill No. 2, is at the south end of lot 2 in the fifth concession of Denison township, about a mile and a half east of Crean Hill mine. It is of the marginal type and occurs partly in the norite and partly in the greenstone. Stripping and pits have disclosed a considerable body of rocky ore, and it may be seen that blocks of the norite are cemented together by sulphides, showing that the sulphides were introduced after the norite had solidified. The mineralized zone is about a quarter of a mile in length, and along this zone the norite is partly sheared and brecciated.

Between Crean Hill No. 2 and Crean Hill mine, on lot 4 in the fifth concession of Denison township, there are several test pits in the quartzite where ore has been disclosed near the norite.

To the northeast of Crean Hill No. 2, on lot 1 in the fifth concession of Denison township, and on lot 12 in the fifth concession of Graham township, light mineralization occurs for about 400 yards, some work having been done on the lot in Graham.

The Gertrude Ore Body

The Gertrude ore body, on lots 3, 4 and 5, in the first concession of Creighton township, is of the marginal type and occurs at the contact of the norite and what has been called an "older norite," or sudburite. The latter is finer in grain and more basic than the norite. The mineralized zone is about three-fifths of a mile long, and the ore occurs largely in the rocks adjacent to the norite. A drill hole 120 feet deep showed the ore body to have a dip of 55 degrees to 67 degrees to the northward. It is said that 15 feet of mixed ore and 20 feet of solid ore were found in the drill core. The property has been developed by three shafts and several pits, and in the latter it may be seen that the ore consists of rock fragments cemented together by sulphides. The largest pit has a length of 125 feet by a width of 25 to 50 feet. One shaft has a depth of 120 feet and another a depth of 80 feet. Some of the ore is said to have contained 6 per cent. of nickel and less than 1 per cent. of copper.

Diamond drilling at the Gertrude has disclosed the existence of about half a million tons of ore.

East of the line between lots 2 and 3 in the first concession of Creighton township, where the norite takes a bend to the north, there is said to be a small offset to the south on which some ore has been disclosed by stripping.

The North Star Ore Body

The North Star mine is on lot 9 in the third concession of Snider township, about a mile and a half north of the Creighton mine. The deposit, which has been called a marginal type, occurs at the contact of the norite and granite, there being some greenstone caught up in the granite. Dikes from the granite penetrate both greenstone and norite. The deposit dips at an angle of 75 or 80 degrees to the northwest. A shaft has been sunk to a depth of 375 feet. The ore, which is sharply defined against the footwall, appears to have the character of other ore bodies in the area, since the sulphides have been described as containing rounded boulders and angular masses of granite and greenstone.

To the northeast of the North Star mine light mineralization occurs on lots 7, 6, and 5 in the third concession of Snider township. Small test pits have been sunk on these lots.

Lady Violet, Clarabelle or No. 6, No. 4, and Lady Macdonald or No. 5 Ore Bodies

These four deposits, which have been classified as marginal, are a mile or two north of the town of Copper Cliff, and just to the north of Lady Macdonald lake. The first three are on lot 1 in the fourth concession of Snider township, while Lady Macdonald is on the north part of lot 1 in the third concession of the same township. At the Lady Violet there are two pits at the contact of the norite with greenstone. The deposit is said to contain workable quantities of the precious metals.

The Clarabelle, or No. 6 mine, as it is sometimes called, is about half a mile to the south of the Lady Violet. It occurs in the greenstones, and has been developed by two pits. The ore is associated with quartz, calcite, dolomite, and magnetite, a mass of the latter weighing five tons having been encountered. The deposit is said to have produced 4,000 tons of ore containing about 2 per cent. of nickel and 1.68 per cent. of copper.

No. 4 mine has two large open pits from which 43,700 tons of ore, containing 2.91 per cent. of nickel and 1.26 per cent. of copper have been mined. The deposit occurs largely in the greenstone.

Lady Macdonald, also called No. 5 mine, is at the north end of the lake of the same name. The property, which consists mainly of an open pit, has produced 8,000 tons of ore, containing 2.84 per cent. of nickel and 1.06 per cent. of copper. The ore body occurs largely in the greenstone at the contact of the norite.

The Canadian Copper Company has contributed the following information regarding the ore bodies referred to in the three preceding paragraphs:

The area around No. 4 mine, No. 5 mine and No. 6 mine is on the Copper Cliff offset. To the northeast is the older greenstone which underlies the ore-bearing norite, and to the southwest is a granite gneiss. The southeastern portion of the area is a layer of norite not over 400 feet in maximum thickness, which laps over the greenstone. In the northwestern portion the norite may be deeper.

There is a large gossan area which looks to a casual observer to have good possibilities. The area, upon close examination, shows it to consist of irregularly placed, disconnected patches of lean gossan. The ore is low grade.

The average grade from all holes was: copper, .9 per cent.; nickel, 1.3 per cent. There were 17 holes drilled in the area, but this did not accurately outline any regular commercial ore body.

Evans, No. 1, and Copper Cliff Ore Bodies

These deposits have been described as offset ore bodies since they are found in a dike. The latter may be called diorite, consisting as it does of plagioclase, hornblende, quartz and biotite.

The Evans mine occurs on a low hill surrounded by drift about a mile southward from the town of Copper Cliff. Only a few square yards of rusty diorite, together with the rock around the edge of the open pits, is to be seen. The dump shows diorite and greywacké, both spotted with sulphides. Whether the diorite is part of the gabbro mass a few hundred yards to the south or whether it is part of the norite-micropegmatite 2½ miles to the north is not positively known, but it is belived by Coleman to be connected with the norite-micropegmatite.

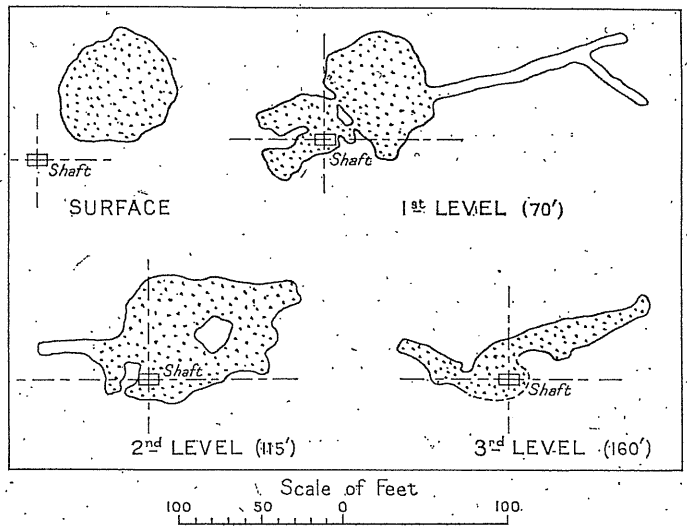

Fig. 55—Plan of old workings showing ore body on the surface to third level, Evans mine, Sudbury area, Ontario. The dotted portions represent "clean" ore.

The deposit has not been worked since 1899, but it was an important producer in the early days of the camp, 234,428 tons of ore having been mined, containing 3 per cent. of nickel and 2.66 per cent. of copper. The ore body was worked by two open pits to a depth of 160 feet, Fig. 55, and by a shaft and other workings to a depth of about 250 feet.

No. 1 mine, which is on the southwestern outskirts of the town of Copper Cliff, and about a mile north of the Evans, consists of five pits which are sunk partly in greywacké and partly in diorite, Fig. 56. The zone of mineralization has a length of a third of a mile and follows an irregular intrusion of diorite, 8 to 50 feet wide, which intersects greywacké and quarzite. The ore occurs mostly in the diorite, but also in greywacké and quartzite. The usual crushed mass of rocks, cemented by sulphides, was noted at a few places. There is also much rock spotted with blebs of ore. Diabase dikes intersect sedimentary rocks, diorite and ore bodies. The series of pits constituting No. 1 mine are said to have produced 23,000 tons of ore containing 3.56 per cent. of nickel and 3.42 per cent. of copper.

The old Copper Cliff mine is situated about the centre of the town of Copper Cliff on a prominent gossan-stained hill.

The deposit occurs in a dike of diorite, Fig. 58, the latter intersecting beds of greywacké and arkose. The diorite is described by A. P. Coleman as consisting of plagioclase, hornblende, quartz and biotite, with more or less titaniferous magnetite, sometimes surrounded with leucoxene and apatite. The width and length of the dike are not known, it being largely covered with drift, but where seen it is 800 feet long and 150 wide. Two small diabase dikes intersect the

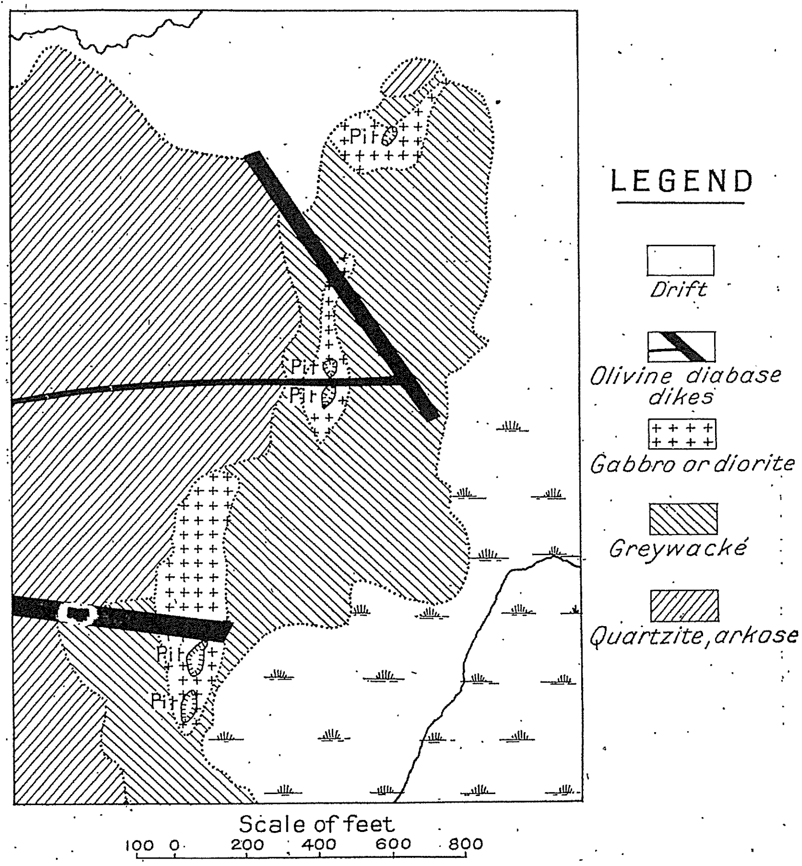

Fig. 56—Geological map of No. 1 mine, Canadian Copper Company, Copper Cliff, Ontario. After A. E. Barlow.

diorite; and two dikes of granite, 6 to 8 feet wide, cut the arkose. A dark-coloured diabase dike, fine-grained, having a width of 25 feet, is said to have been followed from the third to the thirteenth level during mining operations. Small veins of quartz, carbonates, and galena are said to have occurred at the contact of this dike and the mineralized diorite, proving that these veins are much younger than the ore body.

The diorite dike is more or less mineralized where exposed on the hill, but the commercial part of the ore body is much smaller. The following description of the commercial ore body is by A. P. Coleman:[1]

[1] The Nickel Industry, 1913, p. 66.

"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 cross section through the shaft, the somewhat flattened cylinder dips very uniformly at an angle of 77½ degrees 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 third level having the dip just mentioned."

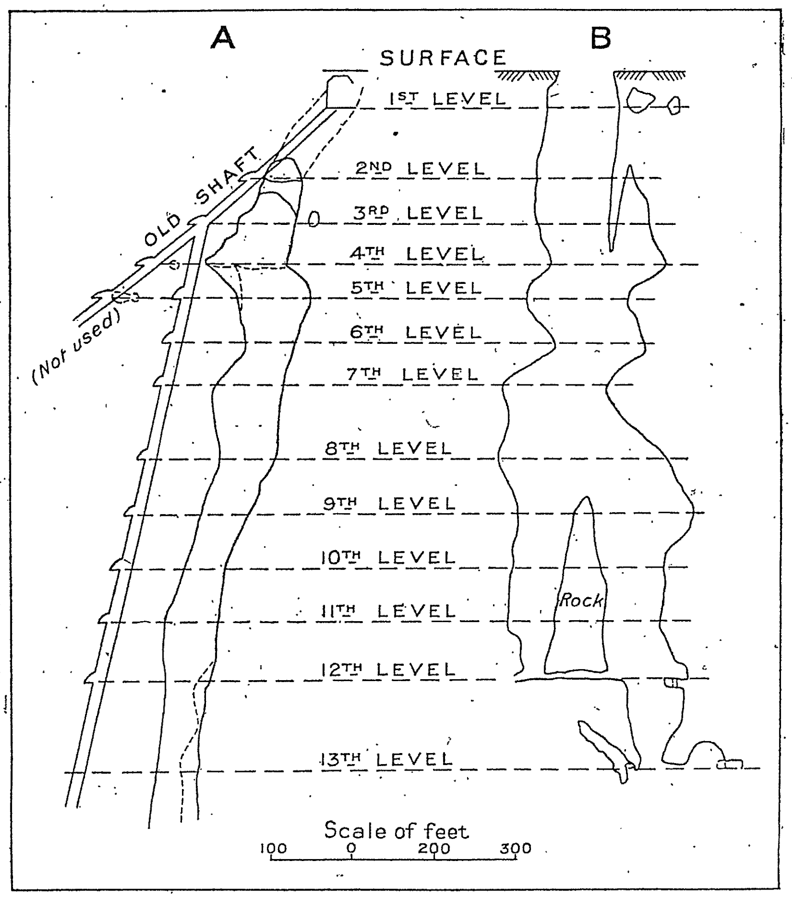

Fig. 57—Showing two sections through Copper Cliff mine, Copper Cliff, Ontario. A is a vertical section through shaft; B is a section at right angles to A. After A. P. Coleman.

The mine was one of the most important in the Sudbury area, having produced 376,739 tons of ore containing 5.13 per cent. of copper and 3.52 per cent. of nickel.

The isolated exposures of diorite in which the Evans, No. 1 and Copper Cliff mines occur are thought by A. P. Coleman to be connected underground by irregular channels with the norite-micropegmatite. The latter occurs about a mile and a quarter north of Copper Cliff mine, on the north shore of Lady MacDonald lake.

A word or two may be added regarding the origin of the sulphides at the Evans, No. 1 and Copper Cliff mines. It has been shown by Dickson, Campbell and others in their microscopic studies that the sulphides replace or impregnate the diorite. Apart, however, from microscopic studies, it is very plain that the ore has been introduced after the diorite had solidified. This is well seen in the old surface workings at Copper Cliff mine, where angular and round blocks of the diorite are cemented together by the sulphides. This condition evidently exists below ground, judging from the verbal descriptions of those who worked in the mine when it was in operation. Evidently the diorite dike, after it solidified, was broken or shattered into crush-breccias and crush-conglomerates and the sulphides were then introduced into the spaces between the fragments or blocks. The sulphides were also introduced in the form of disseminated grains so that the diorite is "spotted" with blebs of sulphides. It has been shown elsewhere, however, that these blebs occur in a variety of rocks, including sediments, and

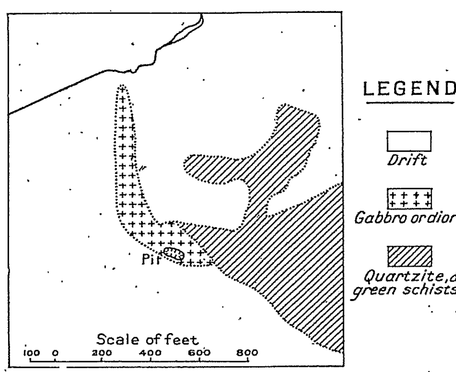

Fig. 58—Geological map of Copper Cliff mine, Copper Cliff, Sudbury area, Ontario. After A. E. Barlow.

that therefore their presence cannot be taken as proof that the sulphides cooled and solidified from the molten diorite. On the contrary, it is believed that the sulphides were introduced by hot circulating waters of magmatic origin.

The Elsie Ore Body

The Elsie mine is on lot 12 in the fifth concession of McKim township about one-third of a mile southwest of the Murray mine. There are two open pits on the property, one about 60 feet in diameter, the other about 130 feet in diameter. It is reported that 40,635 tons of low-grade ore were mined and shipped.

The deposit occurs at the contact of a fine-grained greenstone and the norite. The greenstone shows pillow structure and amygdules, and has been called sudburite, Fig. 59. The ore body appears to be immediately at the contact of the two rocks, the sulphides occurring in both. The ore consists in part of a mass of rock fragments cemented together by sulphides, and in part of veinlets and irregular masses of sulphides ramifying through the cracks in the rocks. The latter are also "spotted" with sulphides.

The Frood and Stobie Ore Bodies

The Frood, also called No. 3, and Stobie ore bodies are situated about two and a half and three and a half miles respectively north of the town of Sudbury. The former occurs on lots 6 and 7 in the sixth concession of McKim township, the latter on lot 5 in the first concession of Blezard township. Although the Frood mine was not being operated in 1916, it is, neverthless, the largest known deposit in the Sudbury area, there being about 45 million tons of ore in the mine, estimated mainly by diamond-drill cores. The ore is, however, lower in grade and more "rocky" than the Creighton deposit, the next largest ore body in the Sudbury area. The Frood ore contains about 3.5 per cent. of nickel and copper combined, in the proportion of 2.05 of nickel to 1.45 of copper. The Stobie mine is a much

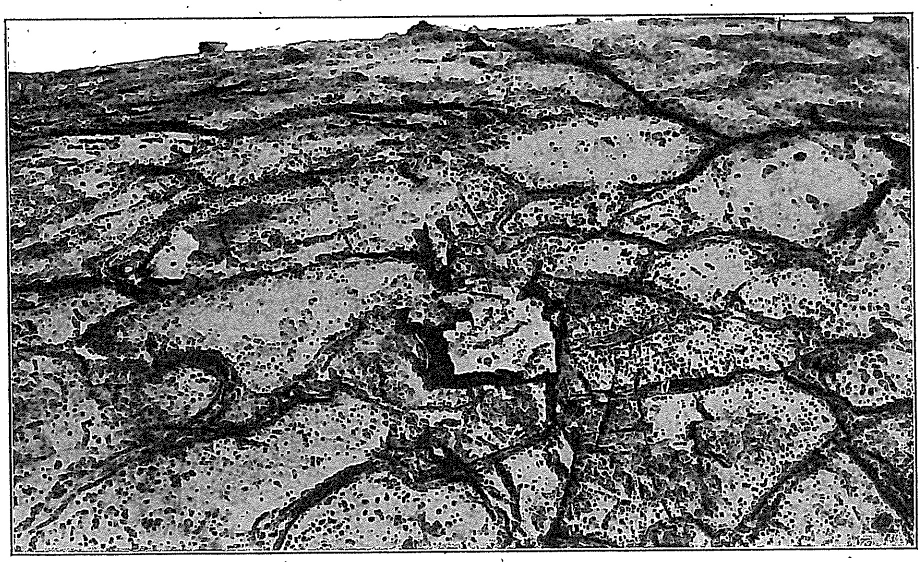

Fig. 59—Pillow lava, known as sudburite, Elsie mine, Sudbury area, Ontario. A. P. Coleman.

smaller deposit, and, although it was at one time a relatively important producer, 418,991 tons having been mined, it has not been worked since 1901. The Stobie ore contained 2.05 per cent. of nickel and 1.53 per cent. of copper.[1]

The rocks at the Frood-Stobie ore bodies may be grouped in the following manner, the oldest being shown at the bottom of the column and the youngest at the top.

Table Showing Rocks at Frood and Stobie Mines.

Granite.
Norite.
Gabbro.
Greenstone, including diorite.
Greywacké and quartzite.

[1] The Nickel Industry, 1913, p. 77.

The most ancient formation consists of schistose greywackés and quartzites belonging to the Timiskaming series. These sediments were intruded, more or less parallel to the bedding planes, by dikes, and other masses, of greenstones and diorite. The diorite is probably younger than the greenstone, the latter being more altered. In places the diorite is heavily mineralized, and it constitutes part of the ore body at the Frood. It was especially studied by Howe under the microscope who named the rock diorite.[1] Other writers have called it norite.[2] It consists of plagioclase, quartz, hornblende, biotite, magnetite, and apatite. It is a metamorphosed rock, the minerals of which have been re-crystallized. The greenstone and diorite have not been separated on the accompanying map, Fig. 60.

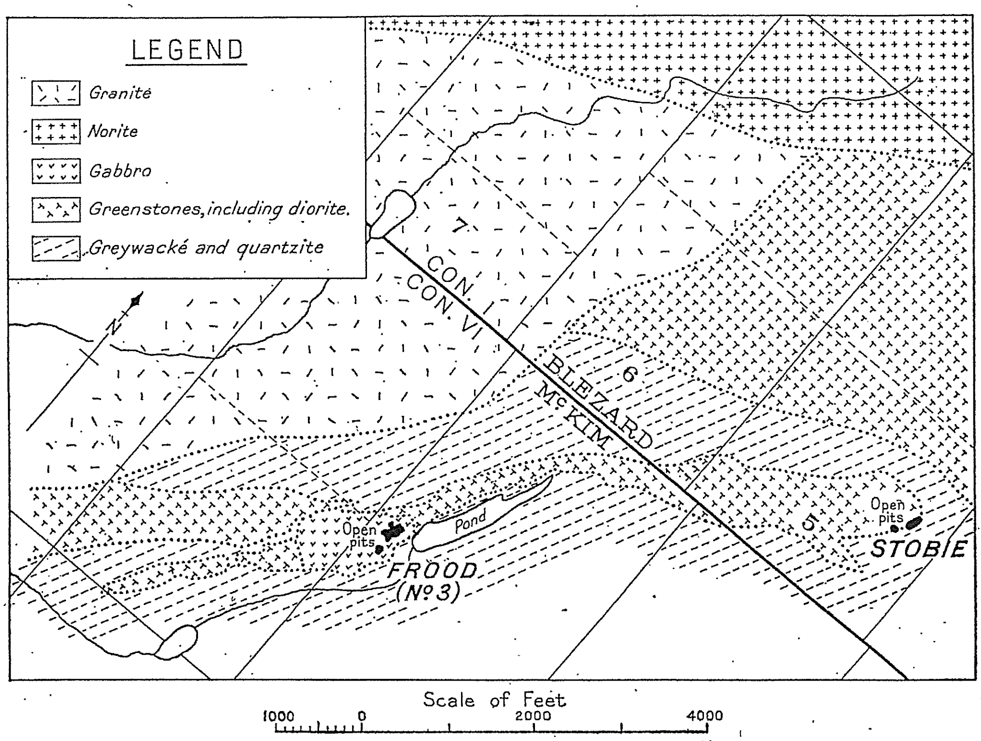

Fig. 60—Geological map of Frood and Stobie mines. After A. P. Coleman.

Following the diorite there were erupted masses of gabbro. An oval-shaped area, and the largest, of this rock occurs at the Frood mine. It has a width of about 800 feet and a length of about 1,200 feet, Fig. 60. In describing the rock Coleman refers to it as an "older" gabbro and considers that it may be an earlier effusion from the norite-micropegmatite magma. Near the Stobie there are also areas of a medium-grained gabbro, the outlines of which are difficult to determine on account of the gossan and drift, and the rock is therefore not shown on the map, Fig. 60. It outcrops 50 feet or more to the west of the Stobie ore body, and irregular masses extend for a few hundred feet to the west.

[1] Economic Geology, Vol. IX, September, 1914, p. 508.
[2] The Nickel Industry, Dept. of Mines, Canada.

The rocks mentioned above; *i.e.*, greywackés, quartzites, greenstones, diorite and gabbros, are the only ones with which the Frood and Stobie ore bodies are associated. Other rocks occur nearby. Norite, for instance, is found about a mile to the northwest. It is believed that it was erupted later than were any of the rocks at Frood and Stobie mines. The reason for this belief is that similar

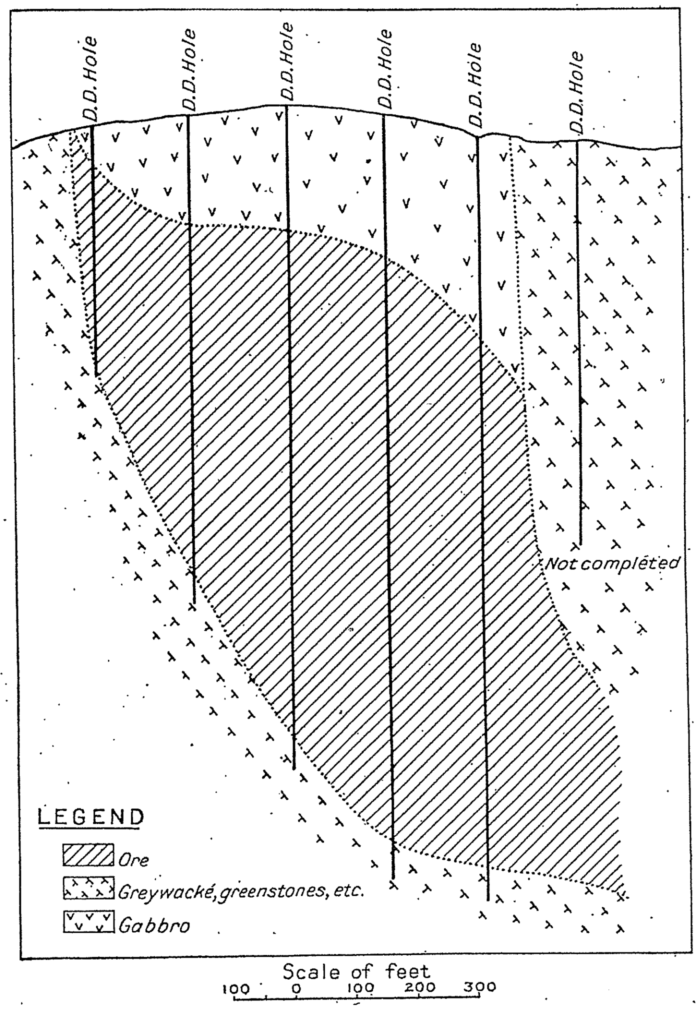

Fig. 61—Cross-section D.D. through Frood ore body, Sudbury area, Ontario.[1]

greenstones and gabbros occur along the edge of the norite at the Murray and Mount Nickel mines where they are seen to be older than the norite since the latter has caught up fragments of the greenstones and gabbros.

Between the Frood mine and the norite intrusive to the northwest a mass of what has been called "later" granite occurs. It sends dikes into the greenstones, gabbros and norite at Murray mine, and it is therefore younger than these rocks.

[1] The Nickel Industry, 1913.

The Frood and Stobie ore bodies may be described under one heading since they occur along a more or less continuous zone of mineralization, which has a length of about two miles and a maximum width of 900 feet. This zone of mineralization strikes northeast and southwest and dips steeply to the northwest, or roughly parallel to the strike and dip of the bedding planes of the greywacké and quartzite. It follows the path of dikes or irregular intrusions of the greenstones, diorite and gabbros referred to above, these rocks having been intruded more or less parallel to the bedding planes of the sediments. The Frood ore body occurs at the southwest end of the zone on a prominent ridge, and the Stobie at the northeast end. Between the two deposits there is more or less mineralization, but generally too low-grade to be of commercial value. Gabbros, greenstones, diorite, quartzites and greywackés are all mineralized, but most of the ore appears to occur in the diorite and gabbro at the Frood mine, while at the Stobie it occurs at the contact of greenstone and schistose greywackés or quartzites.

Fig. 62—"Spotted" diorite, actual size, Frood ore body, Sudbury area, Ontario. Black represents sulphides; white represents diorite. The sulphides replace or impregnate the rock.

The Frood, which has been called an offset deposit, dips in its upper part at an angle of about 65 degrees to the northwest. It is said to become flatter at depths of over 1,000 feet. The hill on which the deposit occurs is nearly all owned by the Canadian Copper Company. Part of the deposit, however, outcrops on the north half of lot 7 in the sixth concession of McKim township, and is owned by the Mond Nickel Company. Diamond drilling by this corporation has undoubtedly proved that the ore body continues into its property at depth. A shaft has been sunk to a depth of 1,005 feet to tap the deposit which is known as the Frood Extension. Operations, however, have been for the present (1916) suspended.

The character of the ore at Frood, in the old open pits, is in general like that of other ore bodies in the Sudbury area. These old pits were excavated in the gabbro. The latter has been fractured into blocks and fragments, round or angular in outline, and the sulphides fill the spaces between the gabbro fragments, cementing them together. "Spotted" gabbro also occurs. To the southwest and northeast of the oval-shaped gabbro mass the ore occurs largely in diorite, or what has been described as norite by other writers. The ore in the heavily mineralized diorite is mostly of a different character from that which occurs in the gabbro. That is to say, sulphides are present in the diorite in "blebs" about the size of peas, giving the rock a striking "spotted" appearance, Fig. 62. Ore of this character appears to constitute a large part of the deposit; it cannot be hand-picked, and therefore some form of grinding and mechanical separation will have to be undertaken if it is desired to remove the rocky material. It may be added that some brecciation has also taken place in this diorite, producing ore similar to that occurring in the gabbro; *i.e.,* rock fragments of various shapes and sizes cemented together by massive sulphides. In the deeper levels of the mine there is much massive ore.

The gossan-covered surface at Frood is the largest in the Sudbury area.

The Stobie ore body is said to dip at an angle of 65 degrees toward the west, and it has been worked to a depth of 250 feet partly by two open pits. The deposit occurs at the contact of greenstones on the one hand and greywackés and quartzites on the other. The latter form the footwall and have been altered for 100 feet from the ore body to dark greenish grey schists. The greenstones are basic, medium to coarse-grained rocks, consisting largely of dark-coloured minerals, mainly hornblende; they are much metamorphosed and have probably been entirely re-crystallized. The ore is the usual variety found in the Sudbury area. It consists of angular or round fragments of greenstone, greywacké, and quartzite cemented together by sulphides. It is evident that the rocks were broken or crushed into crush-breccias and crush-conglomerates, and that the sulphides were then introduced so that they cemented the rock fragments together. In addition to this commercial ore body, the rocks—greenstone, gabbro, greywacké, and quartzite—to the west are more or less impregnated with sulphides, the gossan, or stained surface, having a length of 1,000 feet and a width of some 500 feet.

The origin of the Frood and Stobie deposits, and the more or less continuous zone of mineralization between the two mines may now be briefly discussed. The rocks at and between the two ore bodies have been crushed, brecciated, sheared and otherwise greatly disturbed. Crush-breccias and crush-conglomerates have been formed more or less continuously along the entire zone. All the rocks, whether they are gabbros, greenstones, greywackés or quartzites, have been subjected to this crushing and brecciation. Such a zone formed an ideal channel for the circulation of mineral-bearing solutions, and it seems reasonable to suppose that the sulphides were carried into their present positions by means of hot circulating waters. It is a fact that not only the diorites, gabbros and greenstones are "spotted" with blebs of ore, but also the quartzites and greywackés. It has been thought by some writers that the blebs of sulphides in the igneous rocks constitute proof that the sulphides cooled and crystallized out of the molten rock. Since, however, it is now known that these isolated blebs of sulphides occur also in sedimentary rocks like greywackés and quartzite, it is evident that this reasoning loses its force.

E. Howe has described in greater detail than any other writer the microscopic characters of the rocks at the Frood mine. He concluded that, although the appearance of the Frood rock to the eye suggested that the sulphides and silicates formed contemporaneously, it nevertheless appeared to him that the magmatic origin of the sulphides could neither be proved nor disproved by a study of thin sections.[1]

Cameron and Little Stobie Ore Bodies

Between the Murray mine and Mount Nickel mine there are a number of small occurrences of ore, including the properties known as the Cameron and Little Stobie. There have been a dozen or more pits sunk at various places along this part of the area. Practically all of the ore exposed in these pits occurs in the greenstone, at a distance of a few feet to 150 feet from the norite. There is little mineralization in the latter rock. The test pits which constitute the Little Stobie mine occur on the north part of lot 6 in the first concession of Blezard township.

The Mount Nickel Ore Body

The Mount Nickel mine is situated on lot 5 in the second concession of Blezard township, about four miles north of the town of Sudbury. The deposit occurs at the contact of norite and greenstones or gabbro.

The oldest rocks in the vicinity of the mine are greenstones, all of them basic, but presenting at the same time a variety of textures from fine-grained to coarse-grained. The most common rock is a fine-grained greenstone, which is characterized by an amazing number of hornblende stringers, fractions of an inch in width, which ramify through the rock in all directions. This rock has been named sudburite by Coleman. Between Mount Nickel mine and the Blezard there is a belt of medium-grained gabbro, having a width of two or three hundred feet down to a few feet. It somewhat resembles the norite, but has a green colour. This gabbro is older than the norite, since the latter has caught up fragments of the gabbro. In addition to these two types—gabbro and fine-grained greenstone—there is a coarse-grained greenstone, of a very basic nature which consists largely of hornblende or pyroxene. It occurs between Mount Nickel and Stobie mines. The age relations of these three types of rock, one to another, are obscure. Whatever their age relations may be, it is certain that the norite is a younger rock than any of the other three.

The ore body has been worked by an open pit, which is about 150 feet long and from 25 to 75 feet wide. A shaft has been sunk to a depth of 165 feet. The ore body, as shown by diamond-drilling, is said to dip at an angle of about 30 degrees to the north.

The commercial part of the deposit occurs wholly in the footwall which consists of greenstone. The norite is found from a few feet to 100 feet to the north, and shows little mineralization.

The nature of the Mount Nickel ore body does not differ from that of the other deposits in the Sudbury area. The greenstone and gabbro have been brecciated into round or angular fragments, and the sulphides fill the spaces between the fragments, cementing them together. The ore contains 2.4 per cent. of nickel and 1.2 per cent. of copper.

The property was worked last in the year 1915 and the ore sold to the Mond Nickel Company.

[1] Economic Geology, Vol. IX, September, 1914, pp. 513-514.

The Sheppard Ore Body

The Sheppard mine is on the south half of lot 1 in the third concession of Blezard township. The deposit is near the contact of the norite and the adjacent greenstone, but the ore is largely in the greenstone. The shaft, which is said to be 110 feet deep, and from which two drifts run, is in the greenstone and about 75 feet south of the edge of the norite. In addition to the shaft there are five small pits, three of which are in the greenstone, a fourth exactly at the contact, and a fifth in the norite, 15 feet to the north. At the latter pit the norite is "spotted" with blebs of sulphides, some of the blebs being arranged in parallel lines which are roughly parallel to the contact. A small quantity of ore, over 125 tons, was shipped from this property.

To the east of the Sheppard mine, on lot 10 in the third concession of Garson township, some ore occurs and a test pit has been sunk.

The Kirkwood Ore Body

The Kirkwood mine is on lot 8 in the third concession of Garson township, about a mile and three-quarters west of the Garson mine. It was last worked in 1915 by the Mond Nickel Company, the ore being carried by an aerial tramway to the Garson mine.

The deposit occurs near the contact of greenstone and the norite, both of which rocks have been sheared and metamorphosed to schists and gneiss.

The norite has been more or less altered to schist or gneiss for two or three hundred feet north of its contact with the greenstone. It is, indeed, so much metamorphosed that it little resembles the same rock a few miles to the west, at Blezard or Murray mines, for instance. The schistosity of the greenstones and norite has a more or less vertical dip.

The ore bodies occur in the greenstones, about 100 feet south of the norite. The deposit is vertical, parallel to the dip of the schists. The workings are 200 feet deep and some of the stopes are 40 feet in width. The deposit is vein-like at times. Pure sulphides are often found resting sharply against the schistose greenstone. The ore, as usual, contains many inclusions of rock.

About half a mile southeast of the Kirkwood, on the northeast corner of lot 7 in the second concession of Garson township, a shaft, said to be 60 feet deep, has been sunk. This property is sometimes called the McConnell mine.

THE EASTERN NICKEL RANGE

The ore bodies on the eastern nickel range are of the marginal class, occurring at or near the basic edge of the norite-micropegmatite. Like other marginal deposits the ore occurs largely in the rocks adjacent to the norite, only a relatively small quantity being found in the latter rock. The rocks adjacent to the norite are greenstones, in which dikes or irregular intrusions of granite often occur. The character of the ore is similar to the commercial ore elsewhere in the Sudbury area, that is to say, it consists largely of angular or round fragments of rock cemented together by sulphides. "Spotted" rocks are also of common occurrence.

Beginning at the southeast corner of the range, ore is found near the line between concessions four and five, lot 7, in the township of Falconbridge, and elsewhere on this lot; exploration by stripping, by the sinking of a small shaft and by diamond drilling has been carried on. The drill holes show that the ore extends vertically downward for 800 feet in at least one place. If the dip of the contact of the norite follows the ore, then the norite contact will also have a more or less vertical dip like that at Kirkwood, Garson, and the Longyear properties east of Garson mine, on lot 10 in the fourth concession of Falconbridge.

Three miles north of the ore bodies referred to in the preceding paragraph there is a deposit on Boland's claims, mainly on lot 8 in the second concession of Maclennan township. The ore body appears to be at some distance east of the norite, and it occurs in greenstone, with green schist enclosing a little arkose or quartzite.

About a mile to the northwest of Boland's claims there are the properties known as W D 4, W D 6, W D 3, F 8, F 7, F 6, F 5, and W D 7, all in Maclennan township. A number of large test pits and small shafts have been sunk on F 7 and F 6, and in some of them more or less massive ore occurs having a width of 5 or 6 feet. The zone of mineralization on these two claims has a length of 760 feet in a straight line, and a width of 200 feet in places. On F 5 several pits and a small shaft have been sunk. Beyond this, on a steep hill, rising from the shore of Blue lake, there are two deposits on W D 1, the larger of which is 75 feet long and 35 feet wide. Diamond drilling has been done here; this claim, W D 1, is called the Victor.

On the east shore of Clear lake, which is just to the northwest of Blue lake, in the township of Capreol, there are strippings and small pits disclosing ore on claims W 2 and W 3. Some diamond drilling has been done.

On the east side of Ella lake, on W R 10, which is partly in Capreol and partly in Norman townships, a large test pit has been sunk showing ore. Between this claim and the Whistle mine there is some mineralization of the rocks.

THE NORTHERN NICKEL RANGE

On the northern nickel range there are four main ore bodies, namely, the Whistle, Big Levack, Strathcona and Levack. In the year 1916 only the Levack mine was being operated.

The commercial ore bodies of the marginal type, like those in other parts of the Sudbury nickel area, occur almost wholly in the rocks adjacent to the norite, not in the norite itself. There is, however, some light mineralization in that rock. With the exception of the Foy offset, and what is described as a small offset on Mosquito and Ministique lakes in the township of Cascaden, the ore bodies on the northern nickel range are all of the marginal type.

The Whistle Ore Body

The Whistle mine is situated 29 miles by rail northeast of Sudbury, mainly on lot 6 in the fourth concession of Norman township. The mine is connected by a four-mile branch with the main line of the Canadian Northern railway. It is about at the junction of the eastern and northern nickel ranges.

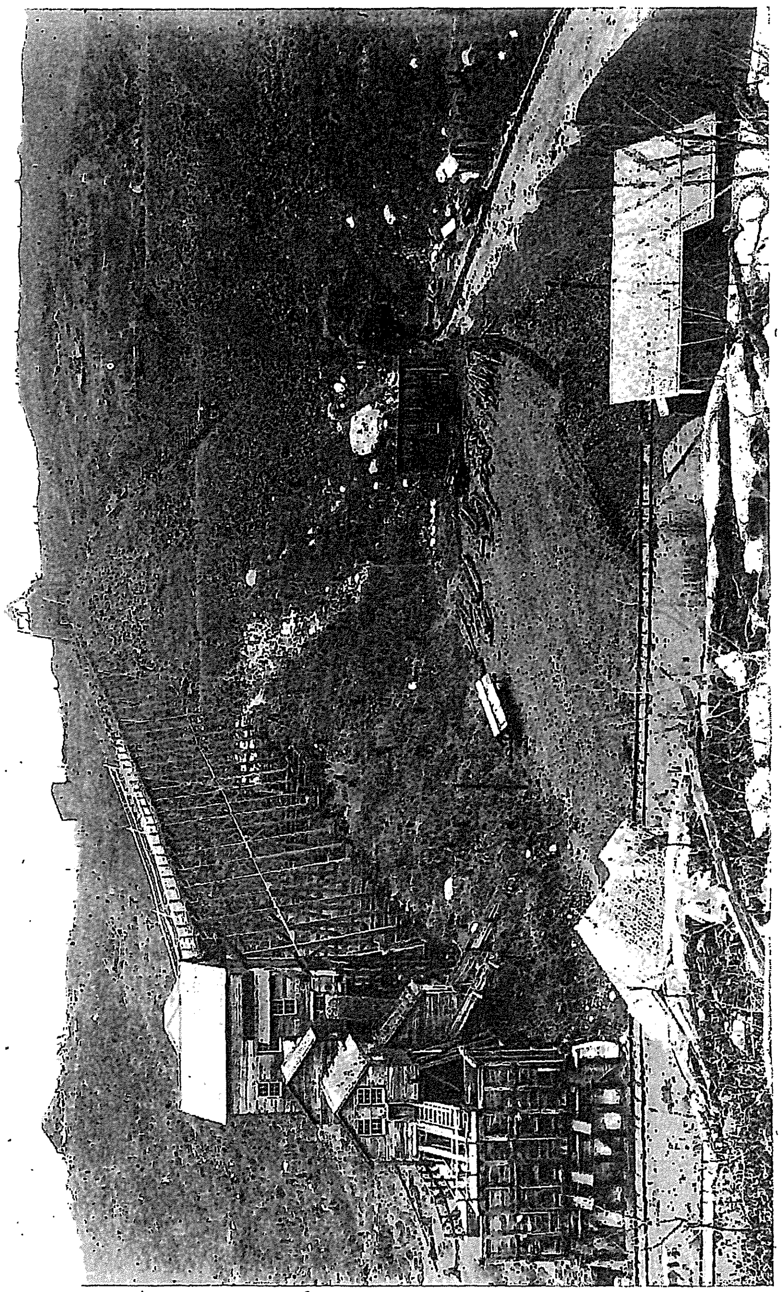

Fig. 63—Whistle mine, Sudbury area, Ontario, November 2nd, 1916.

The deposit occurs on the side and top of a prominent hill. The oldest rocks in the vicinity of the ore body are greenstones, fine, medium or coarse in grain. They sometimes have the texture of diabase, while at other times they have the appearance of diorite or gabbro. The greenstones are intersected by granite dikes, and in places are literally cut to pieces by that rock, Fig. 65. Banded gneiss has sometimes been formed by the injection of parallel veinlets of granite through the greenstone. This complex of greenstone and granite was intruded by the norite which is here a light, grey-coloured rock, having the composition shown in the table on page 119. The norite has been found in contact with the greenstone complex in several places, and wherever seen the contact is sharply defined. There is no transition between one rock and the other. The norite has caught up fragments of the greenstone.

The mineralized zone, along which the Whistle ore body occurs, is about one-third of a mile long, and a maximum of 1,000 feet wide. To the east and west

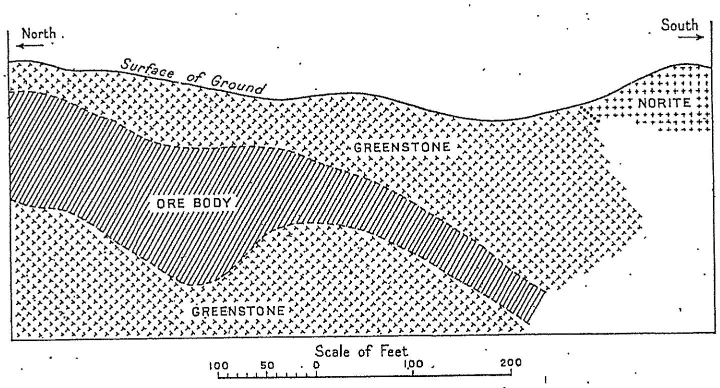

Fig. 64—Cross-section through Whistle ore body, Sudbury area, Ontario, showing how ore body occurs in greenstone.

there are smaller mineralized areas. The commercial part of the main mineralized zone is of an irregular nature; pay ore occurs in "kidneys" in an erratic manner through the rocks. The ore consists of angular and round fragments of greenstone, and to a minor extent of granite fragments, cemented by sulphides. There is, in addition, much sulphide disseminated through the greenstone, and some sulphide occurs in irregular, small veinlets. "Spotted" greenstone is of common occurrence.

The ore body occurs wholly in the greenstone-granite complex, Fig. 64. In fact, with the exception of a few square yards of impregnated norite, the entire mineralized zone, is found in the greenstone-granite complex. The mineralization as seen on the surface may extend at times for 1,000 feet from the edge of the norite into the greenstone-granite complex. Sometimes mineralization comes up to the norite and ceases at that point. At other times it does not extend to within hundreds of feet of the norite. As far as surface exposures are concerned, it may be said that little or no commercial ore extends up to the norite.

The mine workings are all in the greenstone complex, so that no information from this source exists which throws any light on the angle of dip of the contact of the norite with the greenstones. Although diamond drilling has been carried on extensively, it was done in the greenstone, and so does not show the dip of the norite contact. If, however, it has a gentle dip to the southward, the probability is that vertical diamond-drill holes to the south of the greenstone, beginning in the norite, would disclose the continuation of the ore body dipping below the norite. An enormous quantity of unexplored ore probably exists at this property.

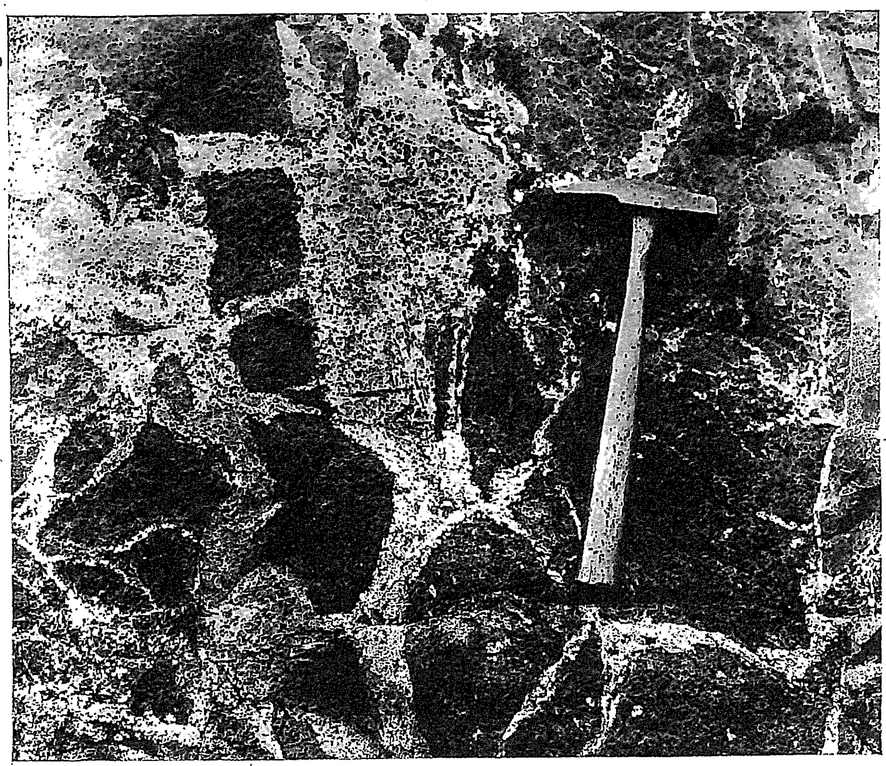

Fig. 65—Granite dikes intersecting greenstone, Whistle mine, Sudbury area, Ontario.

Some information regarding the dip of the norite may be gained by tracing the line of contact from the mine to the main line of the Canadian Northern railway, four miles to the west. On various hills a prominent set of jointing planes in the norite dips to the northward at angles of about 45 degree more or less. If these jointing planes are at right angles to the plane of contact of the norite with the underlying rocks, then the norite contact must dip to the southward at 45 degrees more or less.

The Whistle ore body is much like the Levack, Strathcona, and Big Levack deposits; in these occurrences the commercial ore is found in the rocks adjacent to the norite, not in the latter rock. At the Whistle the ore is mainly in greenstone, while at the other three deposits it is mainly in granite-gneiss.

Norman, Wisner, Bowell and Morgan Townships

Between the Whistle and the main line of the Canadian Northern railway, four miles to the west, there are a number of mineralized areas in Norman township in which small pits and shafts have been sunk. To the west of the railway about four miles, on location W D 16 in Wisner township, test pits and diamond drill cores demonstrate the presence of a considerable quantity of ore. On W D 13 and W D 15 in the same township ore also occurs. Test pits have been sunk on the former claim.

In the next township to the west, namely, Bowell, ore occurs on locations W D 13, W D 208, W D 35, W D 150 and W D 155. On the last named location test pits have been sunk and diamond drilling done. What has been called the Foy offset begins on W D 155, the offset having a width of 20 to 500 feet. It runs to the westward for six miles, and is described as "fairly continuous." It is mineralized here and there, and is thought to be a dike from the norite-micropegmatite, though difficulty may be met with in distinguishing it from other basic rocks associated with the granite. There is an ore body at the west end of the offset, on location W R 5, known as the Ross mine, in Foy township. The ore from this mine is reported to contain 2.75 per cent. of nickel. In the southwest part of Bowell township, on locations W D 238, W D 37, W D 231, W D 241, W D 251, ore has been disclosed by strippings and test pits.

Save for two patches of gossan at the northeast corner of Morgan township there is said to be neither gossan nor ore in this township.

Strathcona and Big Levack Ore Body

The names Strathcona and Big Levack have been applied to a single deposit, the former name being given to the west part and the latter to the east part. The ore body is located about 3½ miles northeast of the Levack, on lots 2 and 3 in the fourth concession of Levack township. An old waggon road connects the two properties.

The geology is similar to that at the Levack mine. The deposit, which has been called a marginal one, occurs at the contact of norite and granite-gneiss, the latter being identical to that found at Levack. The contact of granite-gneiss and norite is exposed a short distance west of the small lake; it is seen that the norite comes sharply against the granite-gneiss footwall without a transition zone, and that the contact dips about 45° to the southeast. The dip is shown in a cliff which cuts across the norite contact at right angles.

The mineralized zone has a length of half a mile, more or less, and a width of as much as 700 to 800 feet at the widest point. The ore lies almost wholly in the granite-gneiss. At the southwest end the ore is mainly in the granite-gneiss, though a little mineralization occurs in the norite. Towards the northeast, however, the ore body is entirely in the granite-gneiss. In places it is nearly a quarter of a mile from the norite.

The mineralization appears to be very irregularly distributed. Its character is seen particularly well on the side of a cliff. Here barren masses of granite-gneiss, 5 to 30 feet long, are surrounded by mineralized portions of the same rock. It is evident that the rock has been brecciated and shattered, and that the sulphides have been deposited in the cracks. At the west end a mineralized zone, about 7 feet wide, extends into the norite about 100 feet, at right angles to the norite-gneiss contact. It is evident that this mineralized zone in the norite, like the entire deposit, was formed by solutions circulating along a weak or crushed zone in this rock.

There are two shafts on the Strathcona, having a depth of 45 and 30 feet respectively. The deposit has been diamond-drilled.

Levack, Cascaden and Trill Townships

The Levack, Strathcona and Big Levack ore bodies all occur in the township of Levack. In addition to these deposits there are found in Levack township a few other mineralized areas. A pit above five feet deep has been sunk 300 yards northeast of the small lake at the north end of lot 5 in the third concession of this township. On the hillside to the west of the southern end of the lake some stripping has been done. There is another small lake at the northeast corner of lot 6, in the second concession of Levack township. At the south end of this lake some mineralization occurs in the granite-gneiss, and it would appear that the area covered by the lake is likely to contain ore bodies.

The gossan at the last mentioned lake continues to the southwest for a few hundred yards to a deposit known as the Little Levack. The latter is half a mile northeast of the Levack mine. The workings of the Little Levack consist of an open pit, 30 or 40 feet wide and 100 feet long. The ore occurs in granite-gneiss in the form of veinlets, in irregular masses and in disseminated grains. The pit is on the side of a hill near the base, and the norite is exposed across the drift-covered valley 150 feet to the southeast.

At the south end of Cascaden township some mineralization occurs on the west shore of Mosquito lake, on lot 8 in the first concession of the township. Ore is also said to occur on the shore of a long southeastern arm of Ministique lake, immediately west of Mosquito lake.

In the township of Trill there is a hillside about a quarter of a mile south of the fifth concession on the line between lots 10 and 11. Ore is found on the south side of the hill and some test pits have been put down.

At the Trillabelle mine ore occurs in several places on a hill at the corner post between lots 10 and 11 on the line between concessions three and four. Pits and shafts have been sunk and some stripping done. The ore body occurs in greenstone.

A quarter of a mile southeast of the Trillabelle, a pit showing ore has been sunk, and 200 yards south of it there is another pit.

ORE BODIES NOT OF MARGINAL OR OFFSET TYPE, SUDBURY

There are a number of ore bodies in the Sudbury area which cannot be classed with the marginal or offset types. They occur neither in offsets nor at the contact of the main mass of the norite, but, on the contrary, are found in the country rock, as distinguished from the norite, from a mile to 20 miles from the main mass of the norite. Occurrences of this class are met with in Drury, Lorne and Nairn townships to the southwest of the main nickel area. More remote still are those found about 20 miles to the northwest of the northern nickel range, at the northwest corner of Moncrief township and the eastern part of Craig township. There are also deposits northeast of Lake Wanapitei which deserve mention. The locations of most of these occurrences, together with others, are shown on Bell's old map of the Sudbury area which accompanies his report in the annual volume of the Geological Survey of Canada for the year 1890-91. Beyond a few brief references to the deposits by Coleman[1], Bell[2], and Hoffman[3], little has been written concerning them. They appear to be of much less importance than the ore bodies which are found in the main nickel area.

COMPOSITION OF MINE WATERS AT SUDBURY

Most of the nickel mines in the Sudbury district were worked in the early days by open pits. Some were closed down and have not been worked for years. In the course of time these pits became filled with water. The water in the Stobie pit has a dark muddy brown colour, while that at the Elsie has a pale green tint, the green probably due to the presence of a solution of nickel. Samples of the waters were collected for quantitative analyses, to ascertain the amounts of nickel, copper and iron present. The Elsie, Blezard and Stobie mines were selected for the purpose, and the results of the analyses are given in the table below.

Table showing the number of grains per gallon, of nickel, copper and iron contained in the mine water in the open pits at the Elsie, Blezard and Stobie mines, Sudbury district, Ontario, Canada.

	1	2	3	4	5
Nickel	0.3208	0.9625	1.6917	1.69[4]	1.7108
Copper	None	None	0.5250	None	0.7583
Iron	Trace	0.5833	10.2086	9.6836	12.6587

1. Elsie mine, west pit, surface water.
2. Elsie mine, east pit, surface water.
3. Blezard mine, surface water.
4. Blezard mine, 12 feet below surface.
5. Stobie mine, surface water.

Four out of five of the samples were taken at, or within a few inches of, the surface of the water. Of the two samples from the Blezard, one, No. 4, was obtained 12 feet below the surface. No copper was found in the latter sample, whereas the surface water of this mine contained 0.5250 grains of copper per gallon.

[1] The Nickel Industry, Dept. of Mines, Canada, 1913, pp. 47-48, Ont. Bur. Mines, 1905, Vol. 14, Part III, p. 145.

[2] Geol. Sur. Can., 1890-91, Vol. 5, Part F, pp. 52-53.

[3] Geol. Sur. Can., 1890-91, Part R, pp. 39-48.

[4] W. K. McNeill states that there was not sufficient solution in the sample to make a quantitative determination of the nickel; a qualitative test appeared to show that there was about as much nickel present as that contained in No. 3. All the samples of mine water referred to in the text were taken in the summer of 1915.

The analyses show in every case that nickel is always present in the water, and that there is more of this element than copper in solution. This corresponds with the relative percentages of nickel and copper in the ore at the Stobie and Blezard; *i.e.,* there is more nickel than copper in the ore at these two mines.

It is interesting to calculate the total amount of nickel and copper which is present in the mine water of the Stobie. Of course it is impossible to estimate the volume of water in the mine without the assistance of the old mine plans, but if it be assumed that the workings have a volume equal to a rectangular prism 200 feet long by 100 feet wide by 100 feet deep, then the total nickel content amounts to 3,660 pounds, and the copper to 1,621 pounds.

LITERATURE ON SUDBURY GEOLOGY

It is felt that the present report on the geology of the Sudbury nickel-copper area is not the proper place in which to discuss the numerous papers and memoirs which have been published. Any reader desiring to peruse the literature will find a list of the works in the bibliography published in this volume. However, a few words may not be out of place respecting this matter.

If the literature relating to the geology of the area be studied it will be found that three workers stand out conspicuously from the others. These men are Robert Bell, A. E. Barlow and A. P. Coleman. Of Robert Bell it may be said that he outlined the foundation on which later geologists based their work. He succeeded in subdividing the rocks into their main groups; *i.e.,* (1) Grenville series, (2) Huronian series [Timiskaming], and (3) Upper Huronian series [Animikie]. These three principal subdivisions have remained substantially correct to the present day. In the course of his work Bell outlined, in the central part of the area, the "distinct geological basin," the delineation of which has proved of importance, for it was near its borders that most of the economic nickel-copper ore bodies have been discovered. More credit is due to Bell for the recognition and mapping of the Sudbury basin than is generally vouchsafed to him. He appreciated the significance of this well-defined geological feature and referred to its importance.[1]

While A. E. Barlow wrote an important report[2] on the Sudbury area, the maps which accompanied that report were also of great importance. Barlow had few, if any, equals in Canada as a geological map-maker.

Of all the reports which have appeared from time to time on the geology of the Sudbury area it may be said that those of A. P. Coleman have been of more assistance than have those of any other worker. In the preparation of the present Report for the Ontario Nickel Commission the writer wishes to particularly acknowledge his indebtedness to Coleman's works. This author's final report[3] has been freely drawn on, especially in describing the ore bodies on the eastern and northern nickel ranges.

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[1] Geol. Sur. Can., Vol. 5, 1890-91, Part F, p. 12.
[2] Ibid, Vol. 14, Part H. 1904, reprinted in 1907.
[3] The Nickel Industry, 1913, Dept. of Mines, Canada.

The above brief references to the work of geologists who have studied the Sudbury deposits would not be complete without mention of T. L. Walker and Chas. W. Dickson. Walker was the first geologist to discover that magmatic differentiation had taken place in the norite-micropegmatite. In respect of Dickson's work, which was published in 1903, it may be pointed out that he urged in a more convincing manner than any previous worker that the nickel-copper ores were deposited from hot circulating waters, and that the ores replace the norite.[1]

[1] While the Report of the Ontario Nickel Commission was going through the press an important publication by C. F. Tolman, Jr., and Austin F. Rogers was received. These authors have substantiated, by laboratory work, Dickson's main contention; namely, that the ores replace the norite. Their paper is entitled: "A Study of the Magmatic Sulphide Ores"; Leland Stanford Junior University Publications, University Series, 1916. A brief summary of their Report is given in the foot-note on page 133.

Fig. 66—Commencement of No. 3 shaft, 5 compartments, Creighton mine, 1915.

METHODS OF MINING IN SUDBURY AREA*

The ore bodies of the Sudbury district vary greatly in size, dip and configuration, and the methods of mining are dependent on these factors. The ores are essentially pyrrhotite, chalcopyrite and pentlandite. The enclosing rocks are hard, like the ore bodies, and but little timbering is required. They comprise norite, greenstones, quartzites, greywackés and granites. The ore bodies dip at angles of from 36 degrees to 90 degrees.

The problem of extracting the ore after the size and configuration of the ore body is known is a simple one owing to the nature of the ores and the enclosing rocks. Elaborate systems of timbering, caving, slicing or filling do not have to be considered. Where large stopes are to be worked out, pillars are left, and the backs are kept arched while the ore is being removed. Afterwards the pillars are robbed.

Ore was first mined in the Sudbury district by the open-pit method. The surface material was stripped off; the gossan, and overburden, the latter averaging up to ten feet in depth, was removed, and the open-pit method of mining followed. The ore was handled by derricks at first. Later a shaft was sunk adjacent to the open pit in the footwall, and connections were made with the open-pit at different levels. The ore was trammed to the shaft and dumped directly into skips. By this method about 3,000,000 tons were taken from the Creighton. Properties mined by this method were the Evans, No. 2, No. 4, No. 5, No. 6, Frood, Stobie, Crean Hill, Kirkwood, North Star, Victoria, Blezard, Murray and Creighton. Of these the Creighton was the largest pit, being about 670 feet long, 180 feet wide, and 200 feet deep. As the Creighton ore body dips at an angle of about 45 degrees, it was necessary to remove a large tonnage of waste from the hanging-wall. When all the ore, that could economically and safely be mined by the open-pit method, was taken out, the shafts were sunk to lower levels and overhand methods of stoping were adopted, a floor being left below the open pit. Where the ore bodies were narrow, the drifts were timbered over and the ore broken on the timbers. In wide ore bodies, dry-wall drifts were used and circular pillars left where necessary.

As the nickel industry grew, and increased tonnages were demanded, it became necessary to more thoroughly prospect the ore bodies and plan the work so that a constant large tonnage could be produced. The method of prospecting the ore bodies was by means of magnetic surveys and diamond drilling, the relative importance of these two methods being governed by local conditions at each property. In general it may be said that the magnetic survey serves only as an aid in locating an ore body. The prospecting is done by means of diamond drilling. Properties thoroughly drilled were the Frood and Creighton, of the Canadian Copper Company, the Levack, of the Mond Nickel Company, and the Murray, of the British America Nickel Corporation. In the latter property, for instance, the

*The Commissioners are indebted to Mr. T. F. Sutherland, Chief Inspector of Mines for Ontario, for the description of Mining Methods in the Sudbury Area, together with the notes on Power Plants, Mining Costs, and Workmen's Compensation.

surface was divided into 200-ft. squares, and a vertical hole drilled at the corners of the squares. By this means the dip, strike, configuration, assay and tonnage are pretty thoroughly known before any ore is removed. This information is sufficient to enable the whole operation of mining the ore to be planned in advance. Power plants, hoisting and sorting arrangements, shafts and equipment are all planned for the most economical handling of certain tonnages.

The magnetic surveys are made by the companies themselves. The diamond drilling is done under contract by drill companies located in Sudbury. The price varies from $2.75 to $4.00 a foot, depending on the location and size of contract.

CANADIAN COPPER COMPANY'S MINES

Crean Hill

The Crean Hill mine, situated in lot 5, concession 5, Denison township, has been developed to the 9th level at 830 feet by means of a 4-compartment shaft. This shaft is inclined at 57 degrees to the 5th level and at 71 degrees below this. A considerable tonnage was obtained from this property by the open-pit method of mining in the early days.

The present method of mining follows closely the system at the Creighton mine, described elsewhere, except that circular pillars are left instead of rib pillars. The ore body dips to the east at an angle of 60° and averages 2.9 per cent. of copper and 2.1 of nickel. By hand-picking from belts in the rock house about 50 per cent. of waste is removed. Up to the end of 1915, 660,000 tons of sorted ore had been shipped from this property. At the end of 1916, the ore reserves amounted to about 2,000,000 tons.

The equipment comprises the following: One Canadian Rand 1,600-cu. ft. compressor running at 120 r.p.m., with direct-connected motor drive. The cylinders are 25-in. diameter by 24-in. stroke and 16-in. diameter by 24-in. stroke. The motor is a 300-h.p., A.C.B. 3-phase 550-volt machine, at 125 r.p.m.

One Canadian Rand 2,500-cu. ft. machine, 2-stage, 17 inches and 28 inches by 24 inches with intercooler and aftercooler, driven by a 425-h.p. Canadian Westinghouse motor, 360 r.p.m., 550 volts, 3-phase, 25 cycles.

The hoist is a 3-drum motor-driven geared hoist built by the Denver Engineering works. The drums are 4-ft. 9-in. diameter and 4-ft. 10-in. wide. The hoisting speed is 500-ft. per minute. The motor is a 150-h.p. A.C.B., 500 r.p.m., 500 volts, 3-phase, 25 cycles.

Creighton

The Creighton mine is situated in lot 10, concession 1, Snider township, and lot 1, concession 1, Creighton township. The property was acquired by the Canadian Copper Company in 1890, but did not become a shipper until 1900. The ore averages 4.4 per cent. of nickel and 1.5 per cent. of copper. The production to the end of 1915 amounted to 4,611,577 tons. The ore body has a maximum length of about 1,000 feet, and has been proven to a depth of 2,000 feet measured along its dip, the present ore reserves amounting to about 10,000,000 tons. It dips to the west at an angle of about 45 degrees.

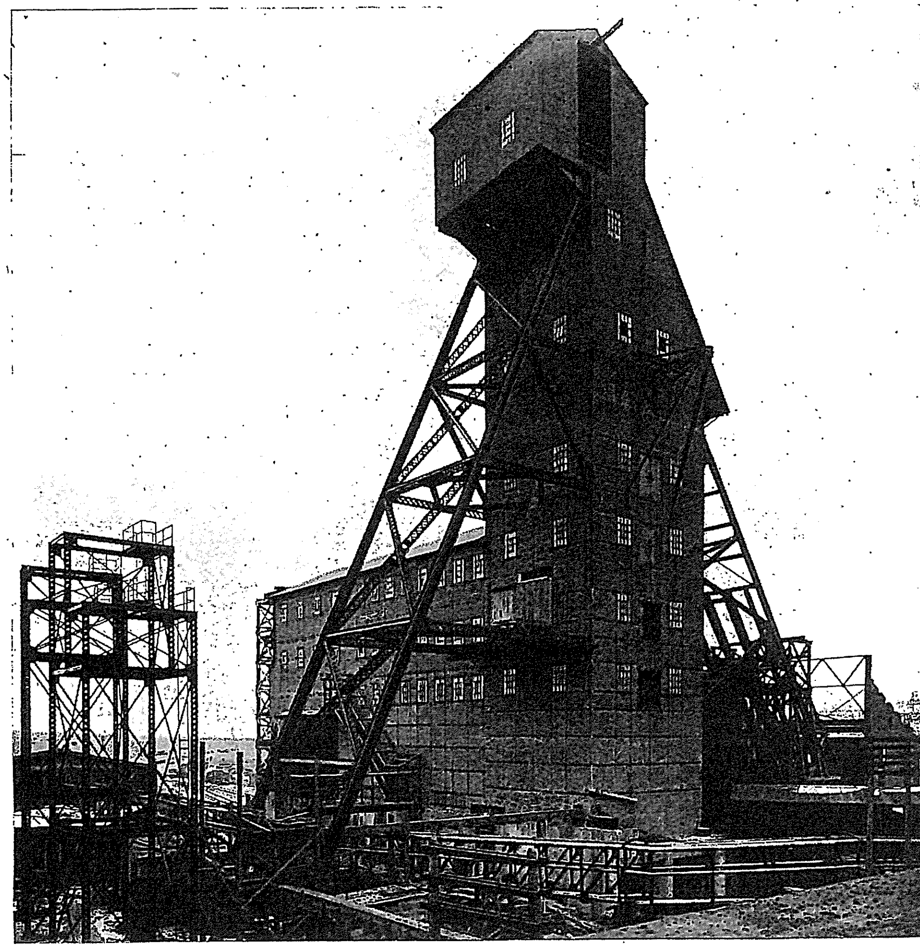
As mentioned before, a large tonnage was removed from this property by the open-pit method of mining, the ore being removed through a 3-compartment shaft sunk in the granite footwall at an angle of 59 degrees near the east end of the ore body. As the depth of workings increased, it became necessary to change from the open-pit method to underground mining.

A second shaft was therefore sunk in the footwall. This was a 4-compartment shaft comprising a manway, two skipways and a compartment for handling men and material. This shaft was sunk near the westerly end of the open pit, and was carried to a depth of 830 feet on an angle of 47 degrees. On the 6th and 10th levels of this shaft a Farrel jaw crusher, with a 30-in. x 42-in. opening, crushing to 6 inches is installed. These crushers are each driven by two 100-h.p. motors and discharge into storage pockets holding approximately 400 tons. The ore from the storage pocket passes into a measuring pocket at the loading station about 60 feet below the haulage level. By this method the skip is loaded in about 10 seconds and the time for a return trip from the 6th level loading station, including loading, is 1¾ minutes. The skips, 5-ton capacity, are operated in balance, the hoisting speed being about 1,100 ft. per minute. On the main haulage levels 4½- and 5-ton storage-battery locomotives are used, hauling trains of four 56-cubic foot side-dumping steel cars, which are mechanically dumped at the crushers.

All the ore goes through these crushers, the ore from the upper level being passed down through ore-passes, which discharge into a crusher. Waste rock is handled through separate rock passes and storage pockets, which discharge into the skips 30 feet below the haulage levels.

A third shaft, known as No. 3, is being sunk in the footwall 145 feet southwest of No. 2. It dips at an angle of 55 degrees and is to be continued to the 16th level. This shaft measures 8 feet by 33 feet, and is divided into five compartments, which consist of a manway, two skip compartments, and two cage compartments. The shaft is concreted for a distance of 40 feet below the collar. The skip-track consists of 85-pound rails, resting on wall-plates, which in turn are supported on concrete piers. It is planned to place a crusher below the 14th level station with storage and measuring pockets of the same type as used in No. 2 shaft. Ore-passes will extend downward from the upper levels to this crusher. Skips of 8-ton capacity, hoisting in balance, are to be used. The hoist will have 12-foot drums and a rope speed of 2,500 feet per minute. Stations have been cut in this shaft at the 6th, 8th, 10th, 12th and 14th levels. The first three levels correspond with similarly numbered levels from No. 2 shaft. The distance between levels is 150 feet measured along the incline. Intermediate or sub-levels are to be driven halfway between these main levels in the footwall and will be numbered 7, 9, 11 and 13. These sub-levels are necessary to remove the broken ore from the footwall owing to the low angle at which the ore body lies.

The main level stations are 25 feet wide and are cut in the footwall. The main drifts are driven in the footwall parallel to the ore body. Levels Nos. 6, 10, 12 and 14 and motor-haulage levels are driven 10 feet wide and 9 feet high, laid with 40-lb. rails, and have ½ of 1 per cent. grade to the crusher station. The other levels are driven the ordinary size, 8 ft. by 8 ft., and are laid with 25-lb. rails, with a grade of 2/3 of 1 per cent. to the ore-passes which lead to the crusher on the first haulage level below. Rib pillars, 15 feet wide, are left every 75 feet approximately at right angles to the strike of the ore body. In these rib pillars crosscuts are driven from the main levels to the hanging side of the ore body. These crosscuts are carried on a 2/3 of 1 per cent. grade. This gives a series of parallel stopes 60 feet wide traversing the ore body throughout its entire length. From each side of the crosscuts box holes are cut at 30-foot centres up into the stopes. As far as possible these box holes are staggered in the crosscuts and also as regards



Rock house at No. 3 shaft, Creighton mine.

the stope. The box holes are carried up about 15 feet, then chambered out and stoping commenced. A 15-foot floor is left in the bottom of each stope. The chutes are $4\frac{1}{2}$ feet wide and are built of 12-in. by 12-in. timbers. They are lined with 6-in. by 6-in. or 6-in. by 8-in. timber, the bottom sloping at an angle of 25 degrees, and protected by a $\frac{1}{2}$-in. steel plate. Formerly steel arc gates, air-operated, were used on the chutes, but these have been discarded and a stop log is now used.

In the stopes the shrinkage method of mining is followed. As soon as a stope is started manways are carried up along the footwall in the pillars and connected with the stopes every 25 feet. All pipe-lines, etc., are carried in these manways.

For development work $3\frac{1}{8}$-in. piston drills are used, and for stoping both piston and Leyner drills are employed, 8-ft. to 10-ft. holes being the rule. Block holers follow the big machines in the stopes. The drills are supplied with air at a pressure of 90 pounds and 40 per cent. forcite is used for all blasting operations.

In the rock house the skips dump over grizzlies and the coarse material is fed through 18-in. by 30-in. jaw crushers, which discharge upon travelling picking belts, where about 17 per cent. of waste material is removed by hand-picking. The ore falls into ore bins, which discharge directly into railway cars beneath the rock house.

The equipment comprises the following: One Bellis and Morcom compressor, 2-stage, 42-in. and 25-in. by 21-in., 5,000-cubic foot capacity at 100 lbs. pressure and $187\frac{1}{2}$ r.p.m., driven by a 900 k.v.a., 3-phase, 2,400-volt, $187\frac{1}{2}$ r.p.m. auto-synchronous motor with a 22 k.w. 25 to 35-volt direct-connected exciter.

One Canadian Rand 1,600-cubic foot machine running at 120 r.p.m. with direct-connected motor drive. The cylinders are 25-in. diameter by 24-in. stroke and 16-in. diameter by 24-in. stroke. The motor is a 300-h.p. A.C.B., 125 r.p.m., 3-phase, 550-volt, 25 cycles.

One Canadian Rand 2,500-cubic foot machine, 2-stage, 17 inches and 28 inches by 24 inches, with intercooler and aftercooler, driven by a 425-h.p. Canadian Westinghouse motor, 360 r.p.m., 550 volts, 3-phase, 25 cycles.

One Canadian Rand 2-stage compound 1,200-cubic foot machine, 12 inches and 20 inches by 18 inches, driven by a 200-h.p. Crocker Wheeler motor, 500 r.p.m., 550 volts, 3-phase, 25 cycles.

Hoisting through No. 1 shaft is done by a 2-drum hoist of the Denver Engineering Works, motor-driven. The drums are 4-ft. 9-in. by 4-ft. 10-in. wide, with friction band brake. The hoisting speed is 500 feet per minute. The motor is a 150-h.p. A.C.B., 500 r.p.m., 550 volts, 3-phase, 25 cycles.

At No. 2 shaft ore is hoisted by a double-drum electric hoist, built by the Nordberg Manufacturing Company. The drums are 7-ft. diameter and 4-ft. face, using a $1\frac{1}{8}$-in. diameter rope. The hoist is equipped with parallel-motion post brakes operated by oil-thrust cylinders. The hoisting speed is 1,100 feet per minute with a 5-ton load of ore. The hoist is operated by a 350-h.p. 500-480 r.p.m., A.C.B., 25-cycle motor with limit switches positively geared to each drum.

The man-cage hoist at this shaft is one drum of a 3-drum hoist built by the Denver Engineering Works, driven by a 250-h.p., A.C.B., 500 r.p.m., 550 volts, 3-phase, 25-cycle motor, and equipped with both band and post brakes. The drum is 4-ft. 9-in. diameter by 4-ft. face. The hoisting speed is 690 feet per minute. At No. 3 shaft a Wellman Seaver Morgan Company double-drum electric hoist is in use temporarily during construction. The drums are 72-in. diameter by 48-in. face. The brake is a post brake air-operated. The hoisting speed is 800 feet per minute with a load of 11,700 lbs. The hoist is driven by an A.C.B., 250-h.p. motor 500-480 r.p.m., with limit switches and brake solenoids.

No. 2 Mine

No. 2 mine of the Canadian Copper Company is situated in the town of Copper Cliff. It was opened up in 1898 and operated until 1903. It was re-opened in 1911, and up to the end of 1915 had produced 656,000 tons of ore.

The mine has been developed by a 3-compartment shaft at an angle of 87 degrees. This shaft extends to the ninth level, a distance of 721 feet. Below this level a winze has been carried to the eleventh level, 360 feet deep.

The ore body is columnar in form, being nearly vertical, and averaging 230 feet in length by 115 in width. It averages 2.6 per cent. of nickel and 1.8 of copper. About 12 per cent. of waste is sorted out in the rock house.

The equipment comprises one Canadian Rand 1,600-cu. ft. compressor, running at 120 r.p.m., with direct-connected motor drive. The cylinders are 25-in. diameter by 24-in. stroke and 16-in. diameter by 24-in. stroke. Hoisting is done by a 2-drum motor-driven hoist built by the Denver Engineering works.

No. 3 Mine

The Frood, or No. 3 mine, lot 7, con. 6, McKim township, is the largest body of ore known in the Sudbury district. The original No. 3 mine lies a quarter of a mile northeast of the present workings, and was operated from 1899 to 1903, producing 110,545 tons of ore averaging 2.66 per cent. of nickel and 1.39 of copper.

The present ore body was thoroughly prospected by diamond drills, and about 45 million tons of ore proven, carrying 2 per cent. of nickel and 1½ of copper. Preparations were made to mine a large tonnage from this property, but developments at the Creighton mine were such that this property was closed down in 1914 after about 87,000 tons had been hoisted that year. The mine was being developed from two shafts,—No. 1, a 4-compartment shaft dipping at an angle of 77 degrees, 420 feet deep, and No. 2 shaft, a 3-compartment vertical shaft, 350 feet in depth. No. 2 shaft lies 625 feet northeast of No. 1. These shafts are connected by drifts on the 300-ft. level.

The method of mining used was to drive a main drift a short distance south of the ore body and following the general direction of the ore body on the south side. Crosscuts 50 feet apart were driven north from the main drift at right angles to it. Raises were put up in the crosscuts about 50 feet apart and placed alternately on either side of the drift. These raises were breasted out and joined at a height of 15 feet above the floor level, thus merging into a large stope. Pillars 25 feet in diameter were left to support the back, and the shrinkage method of mining was followed.

A railroad 5 miles in length was built by the company from Copper Cliff to the mine and a town laid out. Over 100 company houses were built. The town was incorporated under the name of Frood Mine.

Dill Quartz Quarry

Quartz for the smelter at Copper Cliff is obtained by the Canadian Copper Company from a quarry owned and operated by the company in Dill township.

This quarry is worked only during the summer, a sufficient supply of quartz being stock-piled at the smelter to carry the plant through the winter months.

The open-pit method of mining is followed, the pit now being about 55 feet in depth. The quartz is hoisted in small cars on an incline and dumped into a storage bin which discharges into railway cars.

MOND NICKEL COMPANY MINES

Frood Extension

The Frood Extension mine is situated in the north half of lot 7, concession 6, McKim township. The ore body is an extension of the Frood ore body of the Canadian Copper Company. On the outbreak of war development work at this property ceased, and the company hastened the development of the Levack mine.

A vertical 4-compartment shaft, 21-ft. by 7-ft., has been sunk to 1,005 feet.

On the first, or 400-ft. level, a drift runs southeast 230 feet. From the end of this drift a raise extends to the surface, and a winze has been sunk to a depth of 170 feet below the level.

On the second, or 750-ft. level, a drift runs southeast 220 feet. Near the end of this drift a raise was started to connect with the winze from the first level. A winze has also been started near the end of this drift, and is 70 feet deep.

On the third, or 900-ft. level, the station has been cut and 210 feet of drifting done southeast of the shaft.

About 500,000 tons of ore have been proven by diamond drilling containing about 2 per cent. of nickel and the same percentage of copper.

The power house has been completed and contains:—One Nordberg geared hoist, 23-in. and 23-in. by 48-in., with two drums, 10 feet in diameter with 78-in. faces. It is equipped for air but can be run by steam. Provision has been made whereby a third clutched drum for hoisting men may be added when desired.

There are one 2,800-cu. ft. Nordberg air compressor, and one 1,750-cu. ft. Rand air compressor, belt-driven.

The Garson Mine

The Garson mine, lots 4 and 5, concession 3, Garson township, up to the end of 1915 had produced 872,179 tons of ore averaging about 1.7 per cent. of copper and 2.4 of nickel. This has been the most important producer for the Mond Nickel Company. It is connected with the Canadian Northern railway by a spur, 3½ miles long. During 1915 the monthly production averaged about 18,000 tons of ore and quartz.

The main shaft is a vertical 3-compartment shaft, lined with 4-in. by 8-in. cribbing, and has been sunk to a depth of 870 feet. It is equipped with 3-ton skips hoisting in balance. At first the cars on each level were dumped directly into the skips, but later this was changed and the greater part of the ore is now lowered through raises to a chute below the fourth level leading to measuring pockets on the fifth level which load into the skips. Similar loading pockets are being put in on the seventh level to handle the ore stoped between the fourth and sixth levels.

The ore body is very irregular in form and may be said to comprise two main ore bodies, very erratic in character, and lying somewhat in the form of a quadrant of a circle, as well as a number of smaller ore bodies which radiate out from the main ones. In the main the average contents of these veins are much alike, but one of the smaller bodies is very rich in copper, the ore sometimes running as high as 10 per cent. of copper. Pentlandite, in visible form, also occurs in some places. The ore bodies dip to the southeast at angles of from 50 to 60 degrees and the two main ore bodies intersect about the sixth level, forming a considerable enlargement. While not definitely known, it is believed that the ore body forks below the sixth level and continues down as separate bodies. No work has yet been done below the sixth level to verify this.

Each of the ore bodies has its own peculiarities and as these do not persist from level to level it has been hard to adopt any general mining system which will satisfy all conditions.

The ore has always been developed by means of drifts and then section-cutting in the ore till the body is outlined on that level. Afterwards the workable portion, as shown on the assay map, is mined, the poorer portions being left for pillars, if any are considered necessary. Above the fourth level the practice has been to build dry walls leaving, as first developed, chutes and later heavy timbered shovelling places, for handling the ore. A filled stope extends above the dry wall, leaving only a ten-foot floor between the back of the stope and the level above. From time to time, as the work below progresses, these floors are removed by underhand work. No timber has been used in the stopes and in general the ground stands remarkably well.

On a portion of the fourth level and below, the method has been changed to cutting mill holes out of the solid and leaving a portion of the back over these for protection of working place. Platforms slightly higher than the tram-cars are built below these openings, and from these the ore is shovelled into the cars.

On the footwall of one of the main ore bodies was a quartz vein carrying small values and running from 6 to 12 feet in width. This was mined separately and used as a flux in the company's smelter.

Hoisting is done by an Allis-Chalmers hoist with two 7-foot drums, and 6-foot faces, driven by a 250-h.p. motor.

Air for underground operation is supplied by 4 compressors, 3 of the Rand compound type, 1,800-cu. ft. capacity each, and one Ingersoll-Sargent 1,700-cu. ft. capacity. All are electrically driven.

Double transformer arrangements are provided for receiving 44,000 and 16,500 volts, the former being supplied by the company's plant at Wabageshik and the latter by current from the Wahnapitae Power Company.

Sorting arrangements in the shaft house follow the usual custom in the district. About 25 per cent. of waste is picked out on bumping tables.

Levack Mine

The Levack mine is situated in lots 6 and 7, concession 2, Levack township. Diamond drilling has proved the presence of a large body of ore near the contact of the norite and gneiss.

A branch railway, four miles long, leads to the mine from Levack station on the C.P.R. main line, 23 miles west of Sudbury, and 31 miles from the smelter at Coniston. This spur is owned by the mining company.

An electric transmission line, 28 miles long, delivers power, from the Wabageshik plant of the Lorne Power Company, to the mine at 44,000 volts

The power house at the mine has a brick exterior and cement Hyrib interior. It contains an 1,800-cu. ft. Rand compound duplex compressor, belt-driven by a 300-h.p. motor; a 3,200-cu. ft. Ingersoll-Rand Rogler-valve compressor, direct-driven by a 550-h.p. synchronous motor. In a separate building a 1,100-cu. ft. Rand, steam or electric, compressor, will serve as a reserve. Three General Electric water-cooled transformers are set up in a wing off the power house.

The hoist house is of the same type of construction as the power house. It contains an Allis-Chalmers hoist with two cylindrical drums, 7-ft. diameter and 6-ft. face. This hoist is capable of handling a 4-ton load in the skip, and is driven by a specially designed Allis-Chalmers motor of 250-h.p.

In the rock house considerable storage capacity is provided above two Hadfield jaw crushers. The latter have an opening of 18 inches by 24 inches, and are automatically fed by a short Stephens-Adamson pan conveyor from which coarse waste is picked. The crushed product is screened and the oversize sorted on belt conveyors. In all about 33 per cent. of waste is removed.

A 5-compartment shaft, pitching to the southeast at an angle of 65 degrees, was begun in April, 1914. A concrete collar extends to a depth of 12 feet, and from the bottom of the collar to 75 feet in depth concrete has been poured behind the timbers. This shaft was sunk in a fold of the footwall which extends well into the ore body. The first level was cut at 168 feet measured on the incline and subsequent levels at 100-ft. vertical intervals.

The general mode of attack is to drive a main drift north and south from the shaft through the centre of the ore body, which is then blocked out into 100-ft. stopes separated by 40-ft. rib pillars. From the main drift crosscuts are driven centrally through these pillars to the foot and hanging walls for exploratory work and manway connections. Two crosscuts are driven from the main drift under each stope for drawing the stopes. When this preliminary development is completed, a main haulage drift is driven from the shaft in the footwall connecting with the different crosscuts under the stope sections. By this means the empty cars from the shaft are brought in through the main drift, loaded in the crosscuts and returned to the shaft by the footwall drift.

Tramming is at present done in 2-ton cars dumping directly into the skips. Ultimately storage pockets will be cut out below certain levels.

Stoping will be done by slicing from the footwall to the hanging-wall, keeping the back of the stope at such an angle that only wet holes will be drilled. Both chutes and shovelling platforms are used.

This property has been thoroughly prospected by diamond drill and about 4½ million tons of ore proven, carrying about 1.5 per cent. of copper and 3.2 of nickel.

Victoria Mine

The Victoria mine, situated in lot 8, concession 4, Denison township, is the deepest mine in Ontario. The mine is situated on the Algoma Eastern Railroad, 34 miles west of Coniston. At the end of 1916 the 3-compartment vertical shaft was 2,618 feet deep. The ore occurs as two inclined columns about 169 feet apart, which dip uniformly to the southeast at 70 degrees.

Up to the end of 1915 this property has produced 619,612 tons of ore averaging about 1.6 per cent. of nickel and 3.3 of copper. The production during 1915 was at the rate of about 5,000 tons a month.

The vertical shaft was sunk between the two ore bodies and, owing to the dip of the ore, it has been found good practice at depth to run the levels at 300-ft. intervals. The method is to underhand-stope the upper 200 feet and overhand-stope the lower 100. The ore is hoisted on cages and the ordinary methods of crushing and picking are followed. About 25 per cent of waste is picked out.

The equipment comprises one 1,800-cu. ft. duplex 2-stage tandem Rand compressor driven by a 300-h.p. motor, and a Nordberg hoist with 10-ft. drums and 78-in. faces driven by a 400-h.p. Siemens motor capable of hoisting a 4-ton load from 4,000 feet. The hoist is equipped with the latest Welch safety devices, and has a hoisting speed of 1,000 feet per minute.

Worthington Mine

The Worthington mine, lot 2, concession 2, Drury township, was first operated in 1890, and up to the end of 1915 had produced 117,794 tons of ore. The property was re-opened in 1914 by the Mond Nickel Company. The mine is situated on the Soo branch of the Canadian Pacific railway, 34 miles west of Coniston.

The Worthington ore contains a little niccolite and considerable pentlandite. The picked ore as shipped averages about 3 per cent. of copper and 3.5 of nickel.

A 3-compartment shaft, dipping to the southeast at an angle of 80°, has been sunk to the 600-ft. level.

The ore body is unusual in that the rock content is greater than that of any of the other working mines of the district, and consequently closer attention has to be given to sorting in order to obtain a shipping product without too high a loss in the waste product. In the rock house the run of mine is dumped over grizzlies upon sorting platforms where a preliminary sorting is made, the ore and rock falling into separate bins. The rock and ore bins feed into separate 18-in. by 24-in. jaw crushers, crushing to a 2½-in. ring, which discharge upon bumping tables where the crushed material is washed and sorted by hand, the waste being discharged onto a travelling belt. The fines from the grizzly also pass over a bumping table, where waste is picked out and discharged onto this travelling belt. The travelling belt feeds an 18-in. by 24-in. jaw crusher, set at 1½-in., which discharges into railway cars, this crushed material being sold to the Canadian Pacific railway for ballast. About 60 per cent. of waste is sorted out by this treatment.

The power house contains an Allis-Chalmers hoist with two cylindrical drums 7-ft. diameter and 6-ft. face, driven by a 250-h.p. motor and capable of handling a 4-ton load in the skip. The compressor is a 2,100-cu. ft. compound Rand type driven by a 350-h.p. motor.

Bruce Mines

The Mond Nickel Company in 1915 bought the Bruce mines and commenced mining operations. The Bruce mines are situated in Plummer Additional township, on the Soo branch of the Canadian Pacific railway, 152 miles west of Coniston. The ore is quartz, contaning about 85 per cent. of silica, and about 6 of chalcopyrite. It is used as a flux at the company's smelter at Coniston. About 50,000 tons a year will be required for this purpose.

The Bruce mines were discovered in 1846, and opened up in 1849. Before being acquired by the present company the mines had been operated at various times and a total of about 250,000 tons of ore had been mined. The chief mine has been developed by a 3-compartment shaft to the 400-ft. level. The vein averages 5 feet in width and has been proven by underground workings for over 5,000 feet. The workings from the main shaft extend over 2,400 feet. The plant is operated by steam, coal being the fuel used.

POWER PLANTS

The Canadian Copper Company and the Mond Nickel Company operate their mines and smelters in the Sudbury district by hydro-electric power, the Canadian Copper Company obtaining their power from the Huronian Power Company, a subsidiary company, and the Mond Nickel Company from the Lorne Power Company, also a subsidiary company. There are power plants both on the Vermilion and Spanish rivers. The Mond Nickel Company also buy hydro-electric power from the Wahnapitae Power Company, which generates power on the Wanapitei river, and supplies the town of Sudbury, the Long Lake Gold mine, and the Whistle mine of the British America Nickel Corporation. The latter company is the successor to the Dominion Nickel-Copper Company. In general it may be said that hydro-electric power costs from $12 to $20 per horse power per year, depending on the capital expenditure and the cost of operation. The following is a description of the power plants:

Lorne Power Company

1. Nairn Falls Power Plant, Spanish River

The Nairn Falls power plant of the Lorne Power Company, Limited, is located on the Spanish river at Nairn Falls. The head developed is 30 feet, being the maximum obtainable at this point on the river. The dam is of reinforced concrete and rests on solid rock. It is designed to allow the maximum known flow of the river to pass through the dam without raising the head water of the river. The stop-logs for controlling the river are raised and lowered by an electrically operated stop-log winch.

The forebay is protected by steel trash racks. The power house is further protected by steel rack, supported by concrete and steel piers. The power house is designed for three vertical units. The vertical turbines develop about 2,300 h.p. and are set in reinforced concrete scroll chamber inside of speed rings. The draft tubes are concrete and reinforced with steel where required.

The vertical generators are directly coupled to the turbine shaft and develop 1,200-k.w. at 80 per cent. of power factor, 60-cycle at 100 r.p.m. The weight of runner, shaft and water thrust is taken by Kingsbury thrust bearings. Only two units are installed at the present time.

There are two exciters, one turbine-driven and one motor-driven, each large enough to furnish excitation for three main units. The hydraulic units are governed by Allis-Chalmers oil-pressure governors at 125-lb. pressure. The entire plant is lubricated from gravity oil tanks, and a complete system for filtering and storing oils is installed in the basement of the power house.

There are three water-cooled transformers, 1,600 k.v.a. capacity, 60-cycle, 3-phase, which take the current from the generators at 2,200 volts and deliver it to the transmission line at 44,000 volts. A 50-ton electric-operated crane travels above the main floor of the power house. The plant is fully protected by horn gap and electrolytic lightning arresters.

2. Wabageshik Power Plant

The Wabageshik power plant of the same company is situated on the Vermilion river at Wabageshik.

The main dam, forebay and power house are built of concrete on rock and are of heavy design and permanent construction.

The penstocks are 450 feet in length and 8 feet in diameter. They are provided wtih two expansion joints each and are supported on concrete piers. Steel head gates are provided, and stop-log checks have been constructed in the forebay with a 12-inch drain pipe to provide for examination of the head gates if this becomes necessary.

There are two units, each consisting of a horizontal twin turbine, 2,200 h.p., 300 r.p.m., built to operate under 50 feet head; direct-coupled alternator, 1,500 k.w. (or 1,200 k.w. at 80 per cent. power factor), 60-cycle; exciter turbine, 110 h.p., 875 r.p.m.; exciter generator, 60 k.w., 120 volts; Allis-Chalmers Company oil governor for both main and exciter turbines. The exciter-turbine penstocks are branched from the main penstocks, and are coupled together in such a manner that either exciter turbine may be operated from either main penstock. Similarly either exciter may be used with either alternator. The 3-phase current is stepped up from 2,200 volts through three 800 k.w. transformers and delivered to the lines at 44,000 volts. The plant is provided with a 10-ton crane and the usual switchboards and other apparatus, and is protected by two sets of lightning arresters.

Huronian Power Company

The Canadian Copper Company operate all their mines and works by hydro-electric power. This power is obtained from a subsidiary company, the Huronian Power Company, which have developed a water power at High Falls, on the

Spanish river, in the township of Hyman, about four miles from the "Soo" branch of the Canadian Pacific railway, and at a point about 23 miles west of Copper Cliff station. The plant is connected with the railway by a spur line from Turbine station.

The natural head was 67 feet. This has been increased by dams to 85 feet. The effective water-shed is upwards of 2,000 square miles, practically all improved, containing much lake surface. The dams are all of concrete construction on solid rock. From the bulkhead wall four 9-foot penstocks for generators, and one 4-foot for the exciters, are carried down the slope to the power house.

The power house is of brick on a concrete substructure, with steel roof trusses. The building is 110 feet long by 74 feet wide, with an annex 52 feet by 36 feet at one end for workshop and heating boiler. The blower system of heating is used. The generator room is 55 feet wide, leaving 16 feet along one side for transformer rooms and switch tower, which are separated from it by fireproof brick walls and steel doors. Four generating units are installed. Each unit consists of a 2,000-k.v.a. generator, 3-phase, 25-cycle, 2,400-volt, direct-connected to the shaft of a 3,550 h.p. turbine, on which are mounted two 48-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.

Four sets of transformers, of three each, step up the voltage from 2,450 to 32,000. It is transmitted at the latter figure.

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 used to provide air for cleaning purposes and for handling oil.

For fire protection there is a 500-gallon, 2-stage turbine pump, direct-connected to a 40-h.p. d.c. motor, operated from the exciter. The pump suction is connected to the penstocks.

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.

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-ft. centres, bolted to a common cross-arm.

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. The pole stands are placed 120 feet apart.

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.

Electrolytic lightning arresters are provided outside of the power house and at the sub-stations at Copper Cliff, Creighton and Crean Hill.

A telephone line running along the right of way of the transmission line connects the switchboards in the power house and smelter sub-station. It is carried on a short cross-arm, 6 feet below the main cross-arm, with the wires transposed every fifth pole. 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 station, and also with Crean Hill and intervening points.

Preparations are being made for the development of an additional 5,000-h.p. at this plant.

MINING COSTS

Mining costs in the Sudbury district during the year 1915 were higher than may be expected under normal conditions. Supplies in all cases have shown a marked increase due to the war. Moreover, the increased demand for nickel came at a time when the companies had just started extensive development work and were equipping the properties for increased tonnages. This demand had to be met while the developing and equipping of the mines was under way. Consequently current operating costs became a matter of secondary consideration. In general it may be said that the cost of a ton of ore loaded on railway cars at the mines varies between $2.50 and $4.50 per ton, depending on the nature of the ore body, the tonnage mined and the sorting necessary. On a return to normal conditions and the completion of the present schemes of development, these costs, especially at the larger properties, will be materially reduced.

LABOUR

The labour in the district is principally foreign, probably not more than 25 per cent. being Canadian or American. The more skilled workmen, such as foremen, mechanics and carpenters, are Canadian or American. Underground, the drill runners and helpers are principally Finns and Austrians; the trammers are generally Poles, Italians, Austrians and Russians. During the past 10 years the scale of wages has increased about 50 per cent. and the hours of labour have been shortened from 20 per cent. to 33 per cent.

The scale of wages paid for ordinary mine labour is as follows:

	Cents per hour
Drill runners	40½–47
Drill helpers	34½–40½
Trammers	25 –31
Timbermen	40 –47
Scalers	34½–47
Pumpmen	40½
Hoistmen	37½–50
Chute blasters	37½–44
Cage tenders	34½–37½
Surface labourers	25
Rock pickers	25
Machinists	31½–50
Blacksmiths	37½–50
Carpenters	40½–50
Electricians	40½–50

One dollar per month is deducted for medical and hospital attention. Board varies from 60c. to 75c. per day.

In shaft work 3c. an hour extra is paid and a bonus for anything over a specified minimum.

An eight-hour law is in effect for underground labour in Ontario mines. This law requires that men underground in mines shall not work more than eight hours in any consecutive twenty-four hours, such eight hours being reckoned from the time the workman arrives at his working place until he leaves such place. The hours of surface labour at mines are not regulated by statute, and vary from eight to ten, depending on the nature of the work.

WORKMEN'S COMPENSATION ACT

Compensation for accidents in the industry is paid out of a fund administered by a Board appointed under the Workmen's Compensation Act, which came into force January 1, 1915. The mining industry is included in Schedule 1. Industries so classified are not individually liable. The Board levies an assessment and collects an accident fund, out of which the compensation to workmen is paid. Compensation is paid on all accidents arising out of and in course of the employment, except:—

1. Where the disability lasts less than seven days.
2. Where the accident is attributable solely to the serious and wilful misconduct of the workman and does not result in death or serious disablement.

The scale of compensation is as follows:—If the accident results in death and the workman leaves a widow but no children, the widow is entitled to a monthly payment of $20.

If he leaves a widow and children, the payment to the widow is $20 a month and $5 a month for each child under 16 years of age, not exceeding $40 in all.

If he leaves children only, the payment is $10 a month for each child under 16, not exceeding $40 in all.

If the workman was under 21 years of age, and his dependants are his parents, or one of them, such parents or parent will be entitled to $20 a month until the workman would have become 21 years of age, or for such longer time as the Board may determine.

In the case of other dependants, they are entitled to a sum reasonable and proportionate to the pecuniary loss occasioned to them by the workman's death, as determined by the Board.

The necessary expenses of burial, not exceeding $75, are also in all cases to be paid.

All the above is governed, however, by the provision that in no case is the compensation to exceed 55 per cent. of the workman's earnings in the employment, and all provisions for compensation are subject to the proviso that no salary or wages of a workman shall be reckoned at more than $2,000 a year.

In the case of a widow who marries again the periodical payment ceases on her marriage, but she is entitled within a month after her marriage to a lump sum equal to two years' payments.

Where the accident results in total disability of the workman, he is entitled during the continuance of the disability, whether for life or temporarily, to a weekly or monthly payment equal to 55 per cent. of his earnings in the employment. Where the workman is only partially disabled he is entitled to 55 per cent. of the impairment of his earning capacity.

Where less than six workmen are usually employed in mining, including prospecting and development work, except in producing mines where the workmen are in the employ of the owner, lessee or recorded holder thereof, the industry is withdrawn from its class in Schedule 1.

An industrial disease is considered a personal injury by accident, and a workman or his dependants is entitled to the regular scale of compensation. The most common industrial disease in mining is miners' phthisis.

Employers are required to give notice to the Board by registered mail of an accident within three days of its occurrence.

The rate assessed per $100 of payroll on the labour employed in the Sudbury district during the years 1915 and 1916 is as follows. This assessment is collected in two equal instalments, payable in the 1st and 3rd quarters of the year:

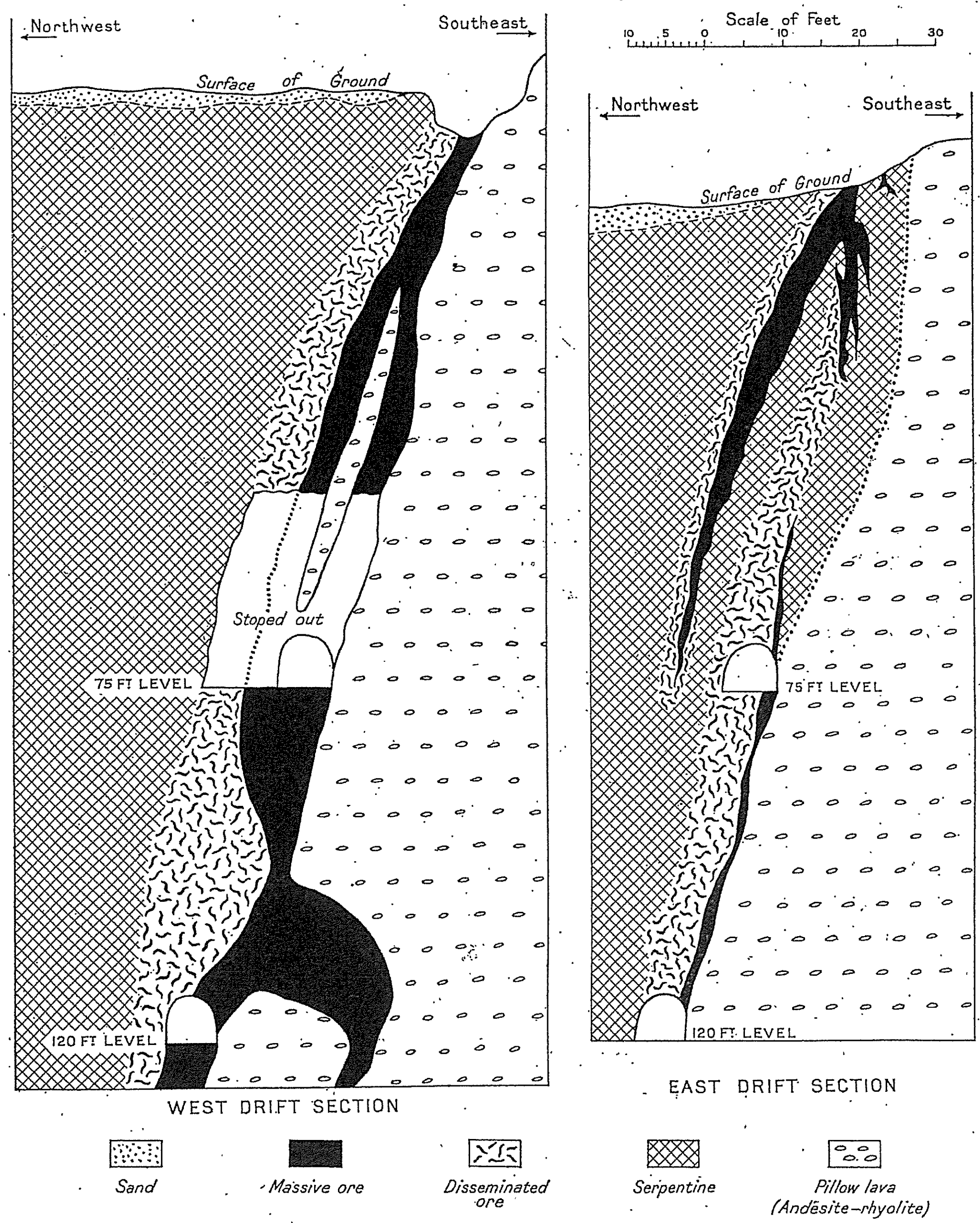
	1915	1916
Mining	$3 00	$2 50
Concentrating, stamping, or other preparations of metals or minerals (without heat)	0 80	0 70
Reduction of ores (with heat), smelting or refining of other metals or minerals	1 50	1 20
Quarries	2 50	2 50
Railroads	6 00	4 00
Power (electrical)	2 50	2 00

CONCENTRATION OF ORES

Under present conditions there is little incentive to employ concentration methods for the nickel-copper ores of Sudbury. Large bodies of ore are worked, the product from which requires little but hand sorting. Some years ago experiments were conducted with magnetic concentrators, the object being to increase the percentage of nickel in the material smelted. No success was achieved. More recently the Mond Company has been experimenting with oil flotation.

Recently H. E. T. Haultain has achieved interesting results in the separation of most of the chalcopyrite from the pyrrhotite and pentlandite.[1]

[1] Can. Mining Journal, Aug. 15, 1916.



Cross-sections through the Alexo ore body, Dundonald and Clergue Townships, Timiskaming District, Ontario. The Figure on the left is a vertical cross-section through the "west" drift; the Figure on the right is a vertical cross-section through the "east" drift. From notes and drawings furnished by Capt. Denmead, of the Alexo mine, and Cyril W. Knight.

TIMISKAMING DISTRICT

The Alexo Nickel Mine*

An area that has attracted recent attention as a source of nickel is situated 150 miles due north of Sudbury. At various places in the Porcupine area and farther north, areas of serpentine have been found, many of which carry pyrrhotite that is frequently nickeliferous. The best of such deposits, yet discovered, is located in lot 12 in the third concession of the township of Clergue and lot 1 in the same concession of the township of Dundonald, and has been given the name Alexo mine from the name of the discoverer, Alex. Kelso.

The rush to the Porcupine gold area, the trail to which passed over this deposit, quite obscured its importance for a while. A drilling option was taken by the Canadian Copper Company, and after an apparently unsatisfactory test, the option was dropped. The owners were not discouraged, however, and decided to open up the property themselves. Major Pullen, one of the owners, undertook the management, and in 1912 he shipped 1,350 tons of ore to the Mond Nickel Company. The mine has continued to ship since that time, and by the end of 1915 had 60,000 tons of developed ore above the 120-ft. level, and with every prospect of further success at greater depth.

During 1916 the company did no further development work, but continued to ship regularly as much ore as possible, in view of the needs of the war office. It is the intention of the owners to resume sinking, and develop deeper levels as soon as power can be spared for this purpose.

The oldest formation in the area is a very compact, hard pillow-lava, of dense texture and a greenish grey colour, when freshly broken; it sometimes has the composition of rhyolite, but more often andesite. There seems little doubt that it is the characteristic Keewatin pillow-lava, so abundant in Northern Ontario. Only twenty miles to the southwest of this, A. G. Burrows has found absolutely similar rocks overlaid by Timiskaming sediments, so their age seems certain. This pillow-lava is so much harder than any other rock of the area, that it always stands up as a prominent feature of the landscape, and thus forms the high hill at the Alexo mine, at the northwestern base of which the ore occurs.

In contact with this pillow-lava is a large mass of peridotite now altered to serpentine. The softer peridotite forms the low, flat, more or less swampy ground about the higher andesite hills. This is an important point for future prospectors of this rock. It is almost invariably the lowest ground to be found in the areas in which it occurs. That these masses are post-Keewatin in age is clear, since they contain fragments of the andesite as inclusions near their contact. This peridotite is so completely altered to serpentine, that it is usually referred to under the latter name.

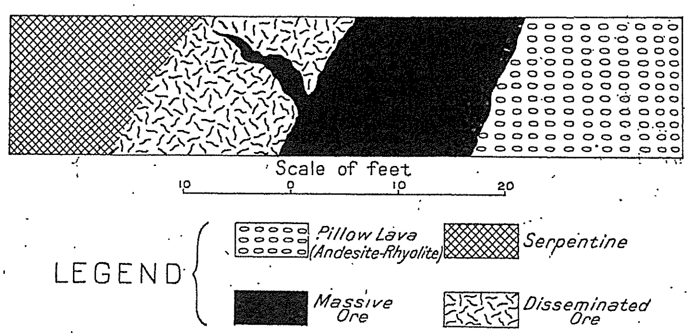
The ore body at the Alexo mine is at the contact of the peridotite with the earlier pillow-lava. The ore is one of two distinct types. The first is disseminated throughout the peridotite. The second is pure or massive sulphide which occupies spaces, cracks, or other openings along the actual contact, or finer fractures in either wall. The contact of the two rocks strikes northeast and southwest, and has a dip

* M. B. Baker, Professor of Geology at Queen's University, Kingston, Ontario, has written for the Commissioners the following account of the Alexo mine.

of 65 to 80 degrees to the northwest. The deposit has a proven length of 700 feet, and has been opened up to a depth of 120 feet, and diamond drilling has shown ore at a depth of 240 feet. The width of the ore body, counting both the massive and disseminated ore, is variable. On the 120-ft. level, for example, it is 40 feet wide, while at places on the 75-ft. level it is not more than 3 feet. It will average, on all the work done so far, probably 10 feet.

The massive ore consists almost entirely of pyrrhotite, with small amounts of pyrite, chalcopyrite, and pentlandite in mere filaments through the mass. The pentlandite can only rarely be seen with the naked eye, but polished and etched pieces of the ore show it in very fine veinlets threading their way through the massive sulphides. Chalcopyrite is not at all abundant, and occupies small fractures, as if introduced after the pyrrhotite. The smelter returns show less than one per cent. of copper. This massive ore rests directly on the footwall of andesite.

The hanging wall of the massive ore is disseminated ore, wherever the normal structure has not been disturbed by faulting. The contact between massive ore and disseminated is just as clean and sharp as is that between massive ore and the andesite. Small stringers of massive ore also penetrate the disseminated, and fragments of the latter are sometimes enclosed in the massive; all of which goes



Cross-section at the Alexo nickel mine, on the 120-foot level, Dundonald and Clergue Townships, Timiskaming District, Ontario. The massive ore cuts through the disseminated ore, and was deposited at a later period in the history of the ore body than the disseminated ore. This age relation between the massive and disseminated ore is also shown in the two preceding cross-sections.

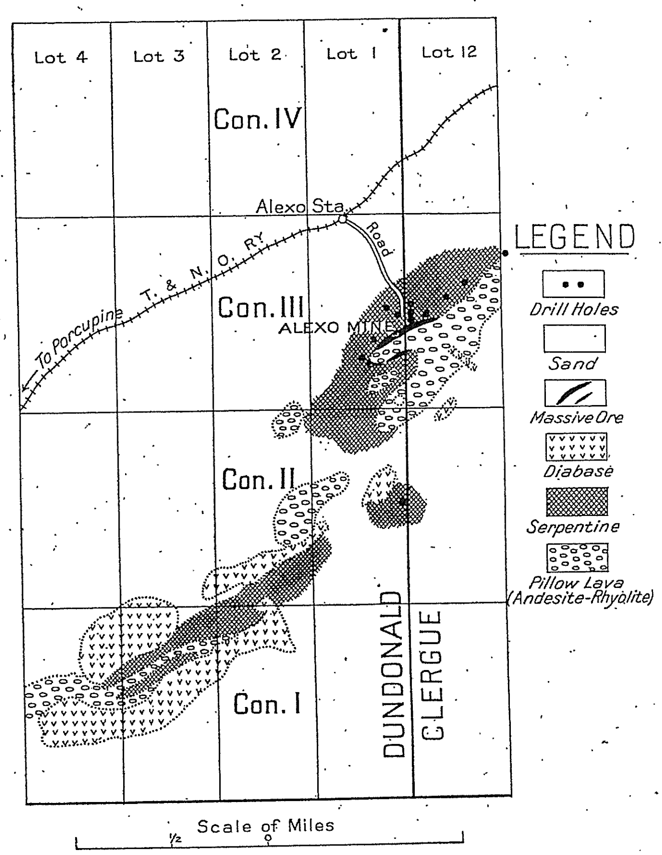
to show that there were two distinct periods of ore deposition, and that the massive ore was the later of the two.

Since this property was described by A. P. Coleman,[1] and W. L. Uglow[2] much work has been done underground, permitting a closer examination of the ore body than was possible at that time. They claimed that the massive ore, the disseminated ore, and the serpentine rock blend into one another. This is certainly not the case, for a sharp contact exists, which is actually slickensided, between the massive ore and the disseminated. The disseminated ore is always scattered throughout the rock, forming part of its texture and structure, and grades off into barren serpentine; it is only mined as far as it is economical to

[1] Dept. of Mines, Canada, 1913, The Nickel Industry.
[2] Ont. Bur. of Mines, Vol 20. Part II.

do so, there being no wall in the ordinary conception of that term. Beyond this transitional phase of the ore, the serpentine is absolutely barren of sulphides, even when viewed microscopically.

Coleman and Uglow differ in their opinion as to the origin of the ore body. Coleman compares it to the deposits of nickel-copper ore at Sudbury, and claims that the massive and disseminated ore are due to magmatic segregation, whereby the sulphides settled out as would matte from slag, and therefore occupy the base or margin of the peridotite body, and gradually passes up into it.



Geological map of the Alexo mine and vicinity, Dundonald and Clergue Townships, Timiskaming District, Ontario.

Uglow, on the other hand, claims that the Alexo ore body is the result of metasomatic replacement of the serpentine rock by sulphide solutions, which worked inward from the contact, replacing partly to completely the serpentine rock.

A study of the ore body, microscopic examinations of polished ore specimens and of thin sections by the writer, cause him to differ from both of these theories. While it is impossible to enter into a full discussion of this subject here, the following points will summarize the results of the writer's observations.

1. It has been already shown that the massive ore is distinctly later in age than the disseminated, and is therefore not a magmatic segregation of the main intrusive mass.

2. The disseminated ore preserves perfectly the rock texture and structure of the mass.

3. Even the richest of the disseminated ore shows the original olivine crystals intergrown with and surrounded by pyrrhotite but in no case replaced by the latter. The intergrowth is as sharp and clear cut as is that between quartz and feldspar in graphic granite.

4. Even in the leanest ore there is no sign of attack of any replaceable mineral. The few grains of sulphides visible are in sharp, angular, clean cut contact with the idiomorphic olivine crystals.

5. In no single case was absorption of the olivine crystals visible, although it is clear that the olivine crystallized before the sulphides.

6. Apparently barren peridotite, away from the ore body, shows by analysis 0.59 per cent. of nickel oxide.

It seems clear, therefore, that the disseminated ore was formed as an original constituent of the peridotite, that it settled to the base of the magma by its greater specific gravity, but remained liquid through its lower fusion point. Finally it solidified about and around the olivine crystals which had already formed, and had settled down into the liquid sulphides. This accounts for the disseminated ore.

After the whole mass had solidified, it continued to cool, and therefore to shrink, and a channel was opened along the contact to deeper portions of the mass, where solidification had not yet taken place. This allowed further sulphides to well up and fill all openings and fissures, thereby forming the massive ore as now found. This being the case it is evident that prospectors searching these serpentines will find deposits of disseminated ore, which will carry no massive ore, and vice versa. It is doubtful whether a deposit of disseminated ore alone, could be worked at a profit. The massive ore of the Alexo mine carries 6 to 8 per cent. of nickel, while the disseminated carries 3 per cent. The two varieties are mined and shipped together, about 40 per cent. of the former with 60 per cent. of the latter. This makes a shipping product of about 4½ per cent. nickel ore.

An interesting feature of this ore is its magnesium content. This is important for while the Canadian Copper Company requires to add dolomitic limestone to its smelter charge, the Mond Nickel Company is able to use Alexo mine ore. The barren limestone is bound to slag off some nickel in the process of smelting, whereas the serpentinous Alexo ore, with its even distribution of ingredients, contributes as much nickel contents as would any other ore, and adds the fluxing requirements as well.

NICKEL ORES ELSEWHERE IN CANADA

Metallic nickel and nickel oxides are produced in small quantities by refiners of the silver-cobalt-nickel-arsenic ores of the Cobalt, Ont., deposits. Numerous descriptions of these deposits have been published, and it is not necessary to repeat them here.[1] It may be added, however, that these ores are not worked primarily as a source of nickel, but chiefly for their silver, the other metals, cobalt, arsenic and nickel, being more of the nature of by-products.

If the mines of Sudbury, Alexo and Cobalt are excepted, it can be said that Canada possesses elsewhere no known deposit of nickel of economic importance. Barlow has published a good description of the occurrences of nickel ores or minerals in the Dominion, which have not been proved to be of commercial value.[2]

Among these the only deposits worthy of note, as being of possible commercial importance, are those near St. Stephen, New Brunswick. These deposits resemble in many respects those of Sudbury, but are of small size, in so far as is known, and carry lower percentages of nickel and copper.[3]

NICKEL DEPOSITS OF OTHER COUNTRIES

The nickel deposits of Canada having been described on preceding pages, a brief survey of the nickel resources and industry in other countries will now be undertaken. The deposits first to be discussed will be those of New Caledonia and Norway, which are the largest producers of the metal after Ontario. Brief descriptions will then be given of deposits in other parts of the world, although most of them are of comparatively little economic importance. They are small, and were the price of refined nickel to be materially reduced they would be of practically no value. Indeed, there is reason to believe that in a real competition for the markets of the world, which would mean a lowering of the price of refined nickel, Sudbury would easily vanquish all competitors.

It is an interesting fact that the British Empire and French possessions now control the market. Nickel deposits of the Empire, in addition to those of Canada, are represented by small ore bodies in Tasmania, from which a few thousand tons of ore, similar mineralogically to that of Sudbury, have been shipped. Silicate ores, similar to those of New Caledonia, occur in Egypt, and there are the small deposits of pyrrhotite-chalcopyrite ores of South Africa. In addition to the New Caledonia deposits, France possesses ores of similar character in Madagascar. Norwegian ores are similar to those of Sudbury, but occur in small deposits, and are of low grade. Greece possesses silicate ores, resembling those of New Caledonia, and has made shipments during recent years to smelters in Norway and elsewhere. Germany and Austria possess a number of small deposits of various kinds of ores that can be worked when nickel is high in price. The nickel resources of the United States, briefly described on a following page, are of little importance. Brief descriptions of the nickeliferous iron ores of Cuba and of one or two other countries are also given on following pages.

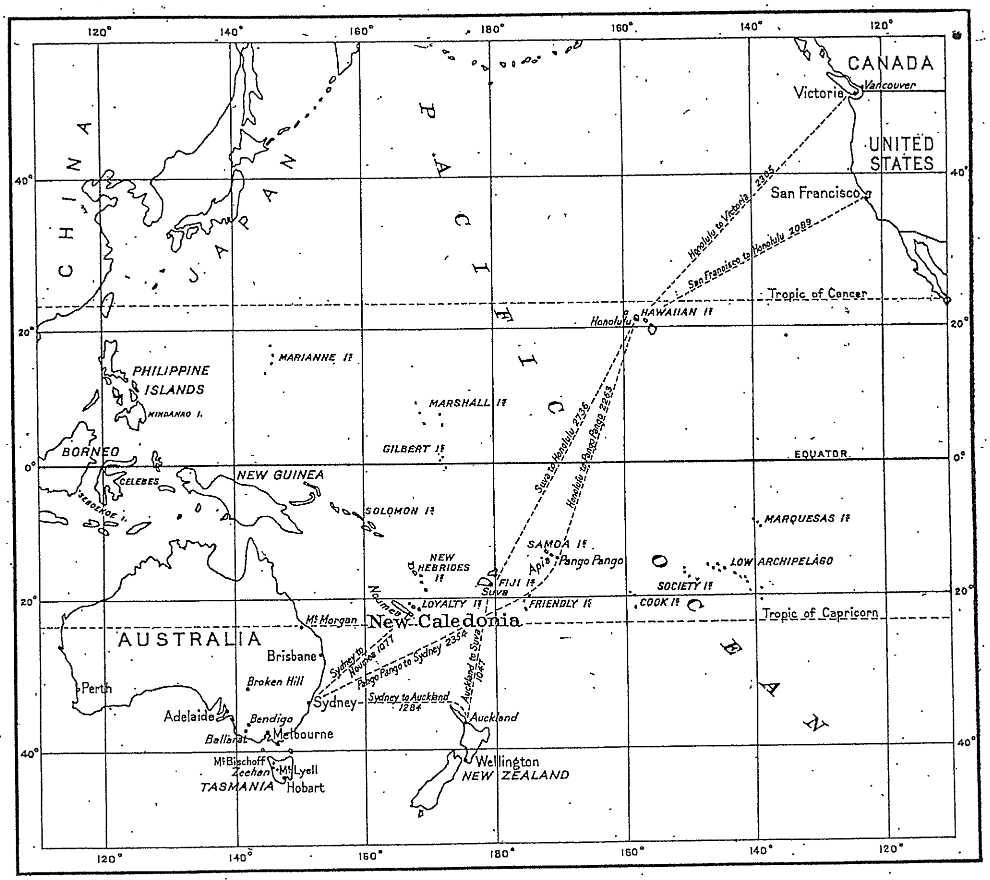
[1] Ont. Bureau Mines, Vol. 19, Part II, 1913.

[2] A. E. Barlow, Nickel and Copper Deposits of the Sudbury Mining District, Geol. Sur. Canada, No. 961, pp. 145-164, 1907.

[3] C. W. Dickson, Can. Mining Inst., Vol. IX, pp. 234-260. H. P. H. Brumell, Geol. Sur. Can., Vol. IV, 1890-91, Part SS, pp. 112-114. R. W. Ells, Summ. Rept. Geol. Sur. Can., 1903, pp. 156-159.

NEW CALEDONIA

In several official reports descriptions are given of the island and of its mineral deposits. The last and most detailed report on mining operations, published in 1904, is by E. Glasser, and is addressed to the French Minister of the Colonies. The title is "Les Richesses Minérales de la Nouvelle-Calédonie," and it contains references to earlier literature.[1] Since Glasser's report was issued little has been published that gives a general description of the mineral resources and the mining industry of the colony. Reference should be made, however, to a few



Map of Part of South Pacific Ocean.

papers. Two of these are by G. M. Colvocoresses, one entitled, "New Caledonia and its Mines," and the other "Nickel Mining in New Caledonia," Engineering and Mining Journal, New York, Sept. 21st and 28th, 1907. These papers, while consisting of only about eight pages, give a clear and interesting account of mining and other conditions. Another instructive paper dealing with the physical features together with the fauna and flora, and referring briefly to the mineral wealth, was read before the Royal Geographical Society in 1916, by R. H.

[1]The chief reports preceding Glasser's are by the following authors: Garnier, Annales des mines, 1867; Heurteau, ibid, 1876; Pelatan, Journal le Genie civil, 1892; Levat, Ass. Fran. Ad. Science, 1887.

Compton, who spent the whole of the year 1914 in the island. There are other papers in English that should be mentioned. Two of these are published in the Transactions of the Institution of Mining and Metallurgy, the earlier one, "Nickel Mining in New Caledonia," by J. Garland, in volume II, and the later, "The Mineral Resources of New Caledonia," by F. Danvers Power, in volume VIII. A. G. Charleton published two useful papers in the Journal of the Society of Arts, volumes 42 and 43.

Historical Notes

A few notes may not be out of place on the discovery of New Caledonia and its subsequent history.

The following brief description of the discovery of the island, on the 4th of September, 1774, owing to the keen and accurate observations and the useful information it contains, make it worthy of consideration at even this distant date. The quotations are from Captain Cook's "Voyages Round the World," and the language is that of the great navigator himself.

> Having now finished the survey of the whole archipelago [New Hebrides], the season of the year made it necessary for me to return to the south while I yet had some time left to explore any land I might meet with between this and New Zealand, where I intended to touch, that I might refresh my people and recruit our stock of wood and water for another southern course.
>
> No more land was seen till eight o'clock on the 4th, when land was discovered bearing S.S.W., for which we steered. We had hardly got to an anchor before we were surrounded by a great number of the natives in sixteen or eighteen canoes, the most of whom were without any sort of weapons. At first they were shy of coming near the ship, but in a short time we prevailed on the people in one boat to get close enough to receive some presents. These we lowered down to them by a rope, to which in return they tied two fish that stunk intolerably. These mutual exchanges bringing on a kind of confidence, two ventured on board the ship, and presently after she was filled with them, and we had the company of several at dinner in the cabin. Our pea-soup, salt beef, and pork they had no curiosity to taste, but they ate of some yams which we happened to have yet left. Like all the natives we had lately seen, the men were almost naked. They were curious in examining every part of the ship, which they viewed with uncommon attention. They had not the least knowledge of goats, hogs, dogs, or cats, and had not even a name for one of them.
>
> We landed on a sandy beach before a vast number of people. Many of them had not a stick in their hands, consequently we were received with great courtesy, and with the surprise natural for people to express at seeing men and things so new to them as we must be. Here we found the chief, whose name we now learned was Teabooma, and we had not been on shore above ten minutes before he called silence. Being instantly obeyed by every individual present, he made a short speech. It was pleasing to see with what attention he was heard.

Captain Cook's reasons for not further exploring New Caledonia are given by him as follows, and they seem sufficient answer to those writers who have criticized him, in this connection, at various times.

> We also found on the isle a sort of scurvy-grass and a plant called by us lamb's quarters, which when boiled ate like spinach. I had now to consider what was next to be done. We had from the top-mast head taken a view of the sea around us, and observed the whole to the west to be strewed with small islets, sandbanks, and breakers to the utmost extent of our horizon. But when I considered the great risk attending a more accurate survey, and the time it would require to accomplish it, on account of the many dangers we should have to encounter, I determined not to hazard the ship down to leeward, where we might be so hemmed in as to find it difficult to return, and by that means lose the proper season for getting to the south.
>
> Next morning at daybreak we got under sail, with a light breeze at E. by N.
>
> On the morning of the 3rd [Oct.] the wind veered to S.W., and blew a strong gale by squalls, attended by rain. I now gave over all thought of returning to the land we had left. Indeed, when I considered the vast ocean we had to explore to the south, the state and condition of the ship, already in want of some necessary stores, that summer was approaching fast, and

that any considerable accident might detain us in this sea another year, I did not think it advisable to attempt to regain the land.

Thus I was obliged, as it were by necessity, for the first time to leave a coast I had discovered before it was fully explored. I called it New Caledonia, and, if we except New Zealand, it is perhaps the largest island in the South Pacific Ocean.

The language at Atooi is almost word for word the same as Otaheite. How shall we account for this nation's having spread itself in so many detached islands, so widely disjointed from each other, in every quarter of the Pacific Ocean? We find it from New Zealand in the south as far as the Sandwich Islands [Hawaii] to the north; and in another direction from Easter Island to the Hebrides.

French Possession

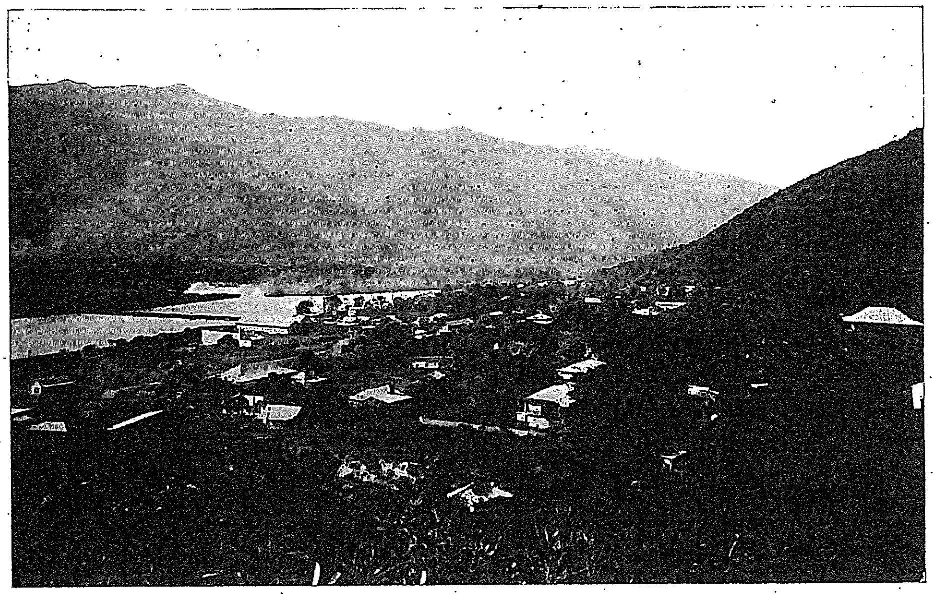
For over three-quarters of a century, after Captain Cook's discovery, no civilized nation laid claim to the island. However, missionaries to the natives established themselves there, and in 1854 the French took possession. It is said that a French and a British frigate started at the same time from Sydney,

The Great Prison of Isle Nou, New Caledonia.

Australia, for the island in order to take possession of it, but that the Frenchman had the good luck to be the first to find a passage through the barrier reef and thus secure for his nation this island that is, as Cook conjectured ".... if we except New Zealand, ... the largest island in the South Pacific Ocean." Thus was gained for France and lost to Britain the largest mineral territory, excepting Australia and New Zealand, in that quarter of the world.

In 1864, the French established a penal settlement, and the island has become widely known as an abode of criminals, as well as a producer of nickel, cobalt and chromium. For some time after mining began, the industry was assisted by cheap convict labour, there being at one time more than 12,000 convicts. For nearly twenty years, however, no convicts have been sent to the island, and other labour supply has been obtained. It may be added that several hundred men still linger as prisoners in the colony. Since transportation of convicts ceased its prosperity has declined.

It is a striking fact that two countries, so widely separated as are Ontario and New Caledonia, not only by distance, but in almost every other way, should alone be rivals not merely in the production of nickel, but in that of cobalt as well. In preceding pages it has been shown that, before the advent of Sudbury, nickel from New Caledonia controlled the world's market. Likewise, before the discovery of the cobalt-silver deposits at Cobalt, New Caledonia had a monopoly of the cobalt market; the industry on the island colony has now been killed by that of Ontario. It may be added that New Caledonia is an important producer of a third mineral product, chromium ore. One of its mines, the Tiebaghi, is among the world's largest producers of this ore.



New Caledonia Topography.

Physical and Other Characteristics of New Caledonia

The island of New Caledonia is situated between latitude 20°5′ and 22°16′ S. and between longitude 164° and 167°50′ E. It has a length of about 250 miles and an average breadth of less than 30 miles, the maximum being about 40; the longer axis lies in the direction N.W.—S.E. The port of Nouméa, the capital of the island, is distant about 1,077 nautical miles northeast of Sydney, Australia, and a passenger service is maintained between the two places. The coast of Queensland lies about 700 miles from the island.

An almost unbroken barrier reef, distant one to seven miles, skirts the west shore of the island, enclosing a channel which is navigable along most of the coast. On the east coast, which is rugged, the reef is more broken.

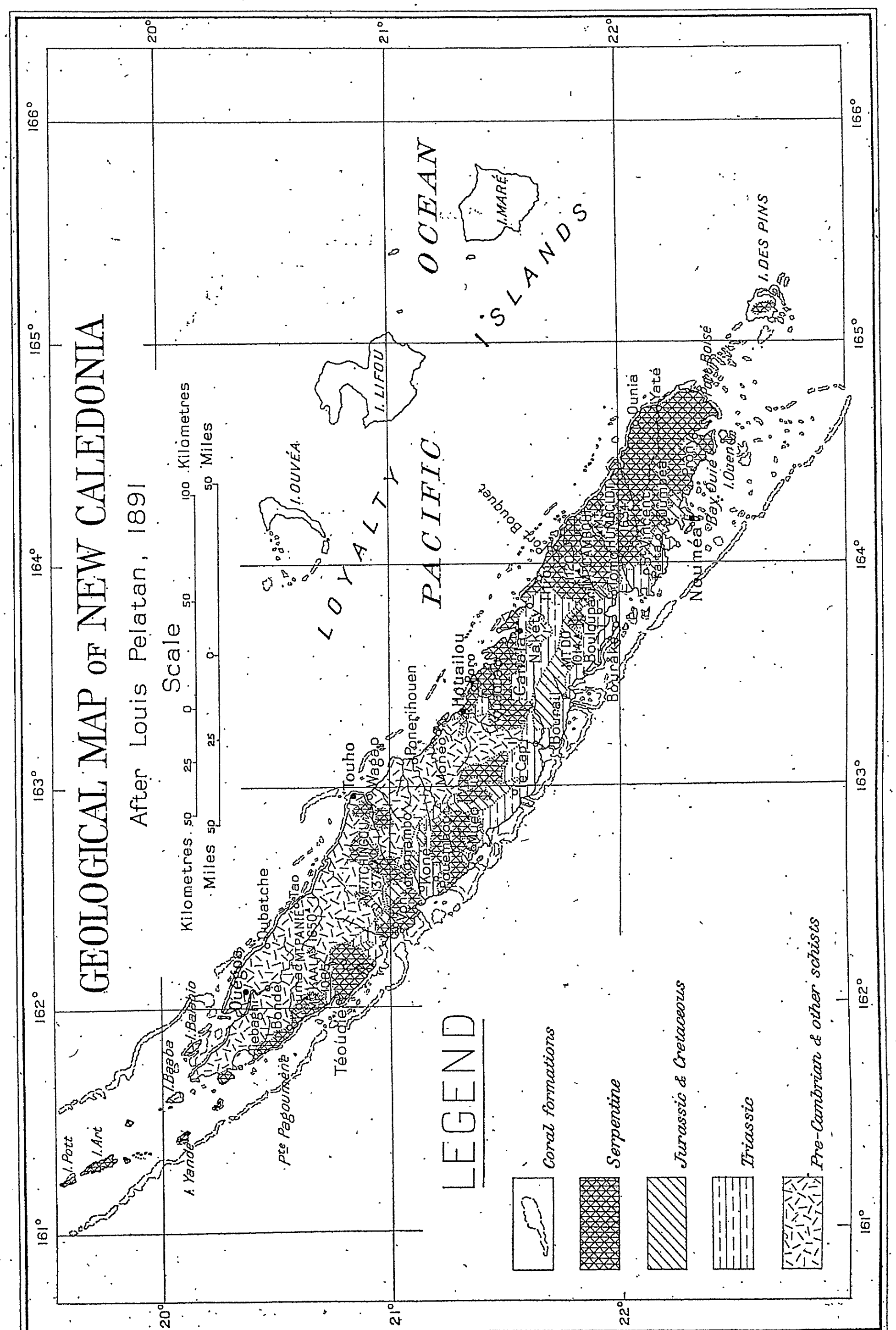
The island is exceptionally mountainous, the highest points being Mount Humboldt, 5,360 feet, in the south, and Mount Panié, 5,345 feet, in the north. The assemblage of mountains is frequently spoken of as the "chaine centrale," but this term, as has been pointed out by several writers, does not give a correct description. The island consists largely of confused masses and ranges of mountains, which, over much of the colony, lie near the coast, especially on the east, and cannot be said to form a chain running lengthwise through the central part. Many of the plains are deltas of rivers. The coastline is broken by numerous small bays into which flow streams rarely navigable even for short distances. The rugged bare mountains, with a fringe of small areas of level land here and there along the coast, frequently supporting cocoa palms or other tropical vegetation, present a scene of great contrast that is impressive and beautiful.

The accompanying geological map, after Pelatan, shows the distribution of rocks of various kinds in the island. It will be seen that supposed Archean or pre-Cambrian rocks occur in small volume, more especially in the north of the island. Sedimentary rocks are classed as of Triassic, Jurassic and Cretaceous age, the latter containing unworked beds of coal. The serpentine series, which occupies about one-third of the surface of the island, is thought to be of post-Cretaceous

Natives.

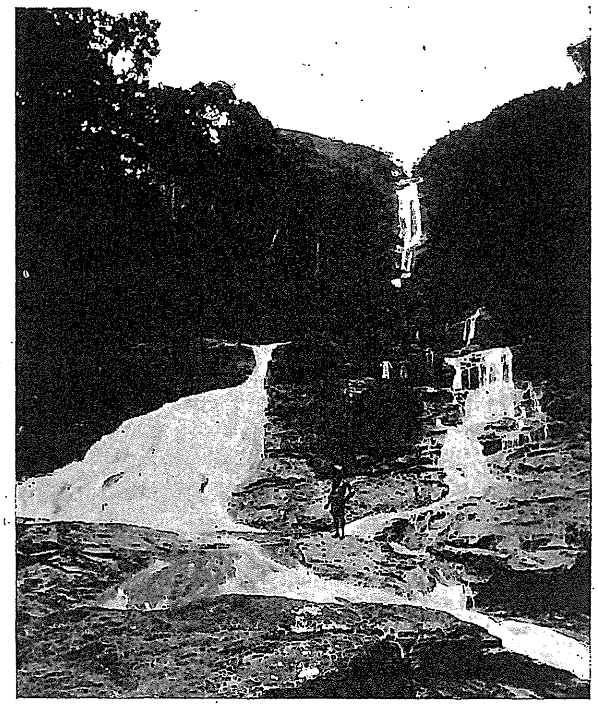
age. From the mining point of view, this series is the most important in the island, as associated with it are the deposits of nickel, cobalt and chromium. Over much of its surface the serpentine series has deposits of nodular iron ore, many of the nodules being little larger than a pea, together with other products of weathering, including deposits which are workable as sources of nickel and cobalt. The serpentine forms mountains with steep sides and usually with narrow summits, thus differing from the areas of similar rock in Cuba, which form more plateau-like structures on which lie productive iron ore deposits. Recent limestones are represented by coral reefs along the coast of New Caledonia.

The climate of the island is not unlike that of Cuba, which lies about the same distance north of the equator as New Caledonia does to the south. The


GEOLOGICAL MAP OF NEW CALEDONIA
After Louis Pelatan, 1891
Scale
Kilometres 50 25 0 50 100 Kilometres
Miles 50 25 0 50 Miles
LEGEND
Coral formations
Serpentine
Jurassic & Cretaceous
Triassic
Pre-Cambrian & other schists
LOYALTY ISLANDS
PACIFIC OCEAN
I. OUVÉA
I. LIFOU
I. MARÉ
I. DES PINS
I. Pott
I. Art
I. Yande
I. Baaba
I. Balabio
Pte Pagoumène
Téoudié
Ouébia
Touho
Wagap
Ponerihouen
Houailou
Bourail
Bouloupari
Nouméa
I. Ouen
Baie Boisé
Ounia
Yaté
Bouquet
161° 162° 163° 164° 165° 166°
20° 21° 22°

highest temperature on record is 103°F. and the lowest 38°, but the maximum does not usually exceed 97°. The mean minimum is 63° and the mean maximum 83°. December, January and February are the hottest months and June, July and August the coolest. Trade winds modify the summer temperatures.

According to statistics compiled by Compton, the average rainfall from 1908 to 1912 was 1,845 mm. (72.6 inches) per annum distributed over 142 rainy days. Heavy rains may occur throughout the year, but, generally speaking, it is possible to distinguish a rainy season in January, February and March, and a dry season in September, October and November. The total rainfall varies greatly in different years. The mean in 1910 was 2,439 mm. (96 inches) and in 1911 it was 1,264 mm. (49.7 inches).



A New Caledonia Water Fall.

The island is visited by cyclones, which occur almost exclusively in the months of January to March, and are often destructive to buildings and to cocoanut and other trees. For this reason many buildings of light structure are supported by wire cables.

Although there is merchantable timber, little is cut, owing chiefly to the mountainous character of the country.

Cattle do well on the island, but in seasons of drought there are sometimes excessive losses. More attention to water supply, by the building of dams, would largely overcome these losses. Sheep are not a success; horses appear to thrive.

New Caledonia coffee brings a high price as compared with that from many other countries, but during recent years the plants have been attacked by a fungus which has been very destructive.

The agricultural exports are preserved meats and other animal products, coffee, copra and cotton, although maize, rice, bananas, oranges and various vegetables, are grown. On the whole agriculture has been neglected. In addition to ores, other exports are pearl shells, essences, sandalwood, a little rubber, and a few other materials.

The flora of New Caledonia, according to Compton, who made a special study of it, is large and varied and presents many exceptional features. The most striking feature of the fauna is the almost complete absence of mammals. The only representatives of this group native to the island are the bats and flying-foxes together with a rat and a pig, the latter two apparently dating from pre-historic times. An East Indian stag or deer has been introduced, and is now locally so abundant as to be almost a nuisance.

There are no marsupials or amphibians, though the French have introduced a species of frog. Land snakes are absent; but lizards are represented by several species of skink and gecko, including one of exceptional size. Birds are not numerous in species, but contain representatives of most of the families. The kagou is perhaps the most remarkable; it has large, well-developed wings, but is entirely flightless.

Of the insects it need only be said that mosquitoes are a great pest in certain localities, but they are fortunately not of the disease-breeding varieties. There are spiders and scorpions, and a variety of molluscs, including the "oyster on trees." Troca-shell and biche-de-mer are exported. There is an abundance of good sea fish; sharks are numerous.

To again quote Compton: "The native population of New Caledonia is a branch of the Melanesian stock, and there is some reason to think it may be among the most primitive of that group of races. As to the relations of the New Caledonian race with those of the surrounding land masses, it appears probable that they are more closely connected with the natives of Australia than with those of the New Hebrides or the Solomon Islands." Cannibalism was formerly frequent.

The cosmopolitan character of the population is well described by Colvocoresses in the following sketch of Nouméa, the capital and chief town of the island:—

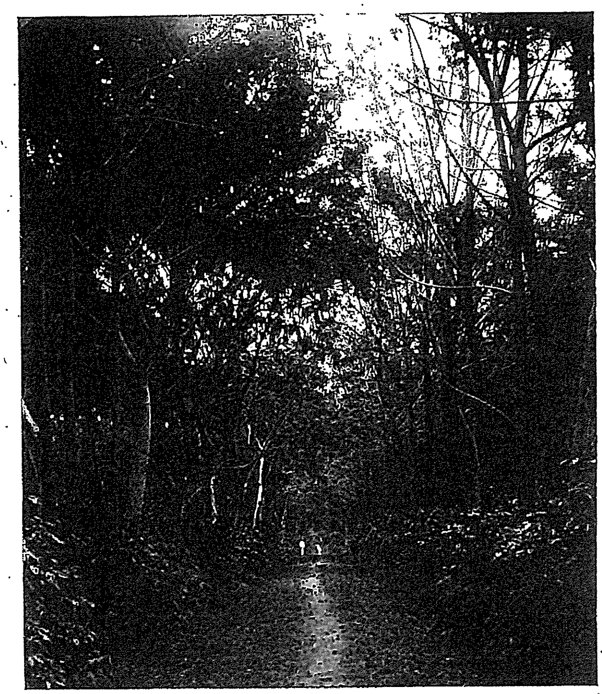
> But for other reasons Nouméa is one of the most curious and interesting of towns to be found anywhere. It is all white and green, with the bluest of blue skies overhead, and the tropical sun is reflected from the sheet-iron roofs and seems actually to shine up from the limestone pavements, so that the continual glare is most trying on the eyes. Yet a cool breeze almost always blows, and water from the reservoir on the hill trickles pleasantly down on either side of the streets, and the cocoa-palms and flamboyants (a species of locust tree with brilliant red flowers) lend shade and colour. Its population is about 8,000, and on the streets one sees the most motley crowd of people, especially on Sundays, when all are out in the square to listen to the music, patronize the Italian bazaars and cake stalls or risk their money on the "petits-chevaux." French officers and business men, English and Australians of all classes, Austrian and French labourers, traders, beach-combers, and ex-convicts, make up the European element. Next the Arab convicts and exiles from Algeria. Then come all shades of colour—Japanese, Chinese, Tonquinese, Annamites, Javanese, Singalese, Malabars, Hindoos, Polynesians from the Loyalty islands and the Malaysian race of islanders from the New Hebrides, Solomons and New Caledonia itself. Each nationality clings largely to its national costumes and talks its own language with "pidgin-French" or "Bech-de-mer" as a means of communication between all. The square on Sunday is truly a babel.[1]

[1] Eng. & Min. Jr., Sept. 21, 1907, pp. 532-3.

According to the census of March, 1911, the population of the island was 50,608, made up as follows: Whites, 19,319; Asiatic immigrants, 3,214; natives, 28,075. The white population at that time consisted of 13,138 free, 396 troops, 114 mercantile marine crews, and 5,671 convicts.

Fevers that are prevalent in certain tropical or semi-tropical islands are absent and the climate is healthful, but the natives suffer from a number of diseases such as consumption, elephantiasis and leprosy, the latter of which is making some headway even among the white population.

Means of communication throughout the colony are poor. Little in the way of road building has been attempted. Trails lead across the island here and there, but, owing to the mountainous character of the country, they are unsuited for



Coffee Plants Growing in Shade of Trees.

transport. The only waggon road of importance is that connecting Nouméa with Bourail, about 100 miles in length. A narrow-gauge railway connects Nouméa with Paita, and there are two or three short lines of railway, used for carrying ore, connecting the interior mines with the coast. The chief means of transport are the small steamers which ply about the coasts.

Mining Progress [1]

Although Garnier discovered nickel in New Caledonia in 1865, it was not known to occur in economic quantities till the end of 1874, when Heurteau made his optimistic report. Discoveries multiplied rapidly, and over 300 tons were exported in

[1] Tons referred to in this section are metric tons of 2,204 lbs. each. Kilogram=2,204 lbs. Franc=19.3 cts.

1875. In the years 1876-7 a total of nearly 8,000 tons of ore containing 8 or 10 per cent. of nickel was shipped from the island. Mining was completely arrested in 1878-9 owing to the Kanaka insurrection.

Finding the freight, about 100 francs a ton, on ore to Europe excessive, furnaces were erected near Nouméa and ore was smelted between 1879 and 1885, about 4,000 tons of matte being exported. It is interesting to note that half of the ore smelted during that period came from the mines on the Plateau of Thio which are still in operation. In this period only the rich ores were sought for in these mines, at first especially the green-coloured material and later the chocolate.

The value of metallic nickel fell lower and lower as production increased. At the end of 1881 it had fallen to 8 francs a kilogram and to 6 at the end of 1884. On the other hand the production, which was 400 tons annually for the entire world at the time of the discovery of the New Caledonia deposits, was more than doubled in the course of less than a dozen years, and quickly passed the needs of consumers.

At the end of 1884 the stocks of ore accumulated in New Caledonia, as well as those of metal in Europe, caused the demand for nickel to be lessened to such a point as to arrest the working of the mines; the furnaces at Nouméa ceased operations at the end of 1885.

Exports, already lessened in 1885, fell to 920 tons of ore in 1886, those of matte having already ceased; prices had also fallen to such an extent that ore carrying 10 per cent. of nickel, valued ten years before at 1,000 francs a ton, now brought only 200.

Mining development kept pace with the demand for nickel and conditions changed as time went on. The percentage of metal in the ores exported decreased from 10 or 12 to 7 or 8, and the price fell to 125 francs a ton, or 1.50 to 1.60 francs a kilogram of metal contained, as compared with 2 francs in 1885 and 10 francs in 1876. A new era of production opened under these conditions and exports of ore increased rapidly. Consumption increased owing to the extension of the older industries that used nickel as a raw material and especially to the introduction of nickel steel. Smelting was again undertaken on the island and exports of matte were made in the years 1889-90-91.

This period of prosperity of some years' duration, unfortunately for New Caledonia, was abruptly checked by competition from the Sudbury deposits, nickel from which began to be produced in 1887. Initial difficulties in treatment of the ores and trade prejudices, as regards the character of the metal, having been overcome, Sudbury in a few years became a serious competitor. New Caledonia exported ore and matte, representing together a total of about 55,000 tons of ore in the year 1891, and did not again reach so large an output for a period of five years, the shipments for these periods being: 1892, 35,951 tons; 1893, 45,613; 1894, 40,089; 1895, 38,976; 1896, 37,467, and 1897, 57,639. This illustrates the effects of competition with Sudbury.

During the period of competition the price of nickel was lowered materially, and, as the costs of freight on ore to Europe and treatment were susceptible of little change, the tendency was to lower the price paid for ore in New Caledonia; from 125 francs in 1888 it had already fallen to 80 at the beginning of the period of competition, and it fell to 35 francs for 7 per cent. ore in 1897, which represented not more than 0.50 franc a kilogram of metal. According to Glasser the period of competition was ended by an understanding between the refiners of New Caledonia ores and those of Sudbury by which the nickel output from each country was controlled.[1] This permitted the resumption of exportation of ore from New Caledonia under more normal conditions and shipments increased, being 74,614 tons in 1898 and 103,908 in 1899. At the same time the price of ore in New Caledonia, which had fallen to 35 francs a ton, rose to about 50. Over-production, as has happened at various times, caused a lowering of the quantities exported in 1902 and 1903 as compared with those in 1901.

Referring to the output of the mines in the period of increased production preceding the year 1903, Glasser notes that the increase was not accompanied, as in former periods of expansion, by a reduction in the nickel content of the ores. Freight costs on ore to Europe did not permit the shipping of ores of much lower grade. The increased production was due not only to the older mining centres, those of Thio, Canala, Kouaoua and Koné, and also to a less extent to those in the district tributary to Nouméa, but by the development of new centres; these centres were multiplied along the west coast of the island, where the green silicates and chocolate ore are relatively rare, but where masses of nickeliferous breccias and altered nickeliferous serpentine, which are abundant and had been recognized for some years as being more profitably mined than the ores formerly sought.

The following table gives the quantities of ore and matte exported during each of the years, 1900-1915. The shipments of matte show that during the last six or seven years smelting has been revived. That it has been a success is evident from the fact that smelting plants are being enlarged and the production of matte will soon be increased. Hydro-electric power is being developed, which may be used to some extent in smelting operations.

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[1] On another page Glasser has the following to say concerning the effects of Sudbury competition, but of course he wrote in 1904, and New Caledonia no longer holds first place as a producer:—

"Canada, on the contrary, has shown herself to be a formidable competitor of New Caledonia, and, if the figures we have given above show that, in spite of this competition, our colony remains to-day the premier producing country of nickel in the entire world, it has not been without a strenuous struggle, in the course of which the price of nickel fell to 2 fr. 40 a kilogram, [or 21 cents per lb.], causing the closing of nearly all the mines of the colony, and obliging La Société le Nickel, the principal exploiter of nickel in New Caledonia, to suspend all distribution of dividends during a period of five years." Page 233, Glasser.

"The price of metallic nickel has been lowered considerably during the last twenty-five years, since at the time of the discovery of the ore in New Caledonia it was 18 francs a kilogram, afterwards falling rapidly to 10 francs, then successively to 8.6 and 5 francs (1892), to 4 francs (1894), and 3 francs (1895), and then even to 2 francs 40 (end of 1895), owing to Canadian competition; it oscillates mainly between 3 francs 50 and 4 francs a kilogram." Page 207.

N*95.—Price 2 fr. .40 per kilogram=21 cents per lb.
" 3 fr. .50 " " =30.6 " "
" 4 fr. " " =35 " "

EXPORTATION OF NICKEL FROM NEW CALEDONIA, 1900 TO 1915, METRIC TONS.

Year.	Ore.	Matte.
1900	100,319	.....
1901	133,676	.....
1902	129,653	.....
1903	77,360	.....
1904	98,655	.....
1905	125,289	.....
1906	118,890	.....
1907	119,000	.....
1908	108,000	.....
1909	86,000	.....
1910	99,000	768
1911	142,000	2,993
1912	74,314	5,908
1913	93,190	5,893
1914	94,154	5,277
1915	48,576	5,529
Total	1,648,076	26,368

STATEMENT GIVING DETAILS OF NICKEL ORES AND NICKEL MATTES EXPORTED FROM NEW CALEDONIA DURING THE YEARS 1913-14-15.

Shippers.		Tons of 1,000 kilos.
1913.		
Nickel Ore.		
Société le Nickel	51,306,642	
G. de Béchade	9,111,000	
		60,417.642
Société Hauts-Fourneaux de Nouméa (Ballande)		27,097.225
Société des Mines du Mont Do		5,675.394
Total		93,190.261
Nickel Matte.		
Société le Nickel		2,314.460
Société de Tao		123.995
Société Hauts-Fourneaux de Nouméa (Ballande)		3,454.743
Total		5,893.198
1914.		
Nickel Ore.		
Société le Nickel	57,283,615	
G. de Béchade (Le Nickel Corporation)[1]	15,626.960	
		72,910.575
Société Hauts-Fourneaux de Nouméa (Ballande)		18,346.596
Société des Mines du Mont Do[2]		2,800.000
J. Birch & Co.		97.265
Total		94,154.436
Nickel Matte.		
Société le Nickel		2,493,650
Société Hauts-Fourneaux de Nouméa (Ballande)		2,753.712
Société de Tao		29.779
Total		5,277.141
1915.[3]		
Nickel Ore.		
Société le Nickel		43,584.000
G. de Béchade		4.992.000
Total		48,576.000
Nickel Matte.		
Société le Nickel		1,400.000
Société Hauts-Fourneaux de Nouméa (Ballande)		4,129.167
Total		5,529.167

[1] Le Nickel Corporation is a subsidiary of the International Nickel Company.
[2] This company is said to have been a subsidiary of Krupp's.
[3] According to Le Bulletin du Commerce, Noumea, February 10, 1917, p. 13, the production of nickel ore in New Caledonia for 1916 was 30,679.245 metric tons, and of nickel matte, 4,935.167 metric tons.

Details at hand concerning the industry are more complete for 1914 than for 1915. The centres which increased their output in the former year were: Thio, Port Bouquet, Ny, Dumbea, Kopéto, Ouazanghou and Kalla. The new centres were Nakety and Camboui. There was a falling off in production at the following centres: Poro, Canala, Uie bay, Mont Do, Koné, Koniambo, Kaféate and Port Boise.

The estimated quantity of nickel ore at the mouth of the mines and at the smelters on 31st December, 1914, was 98,168 tons.

With the exception of the ore from Mont Do, which is said to have been mined by a subsidiary of Krupp's and sent to Germany, the other shipments went practically all to plants controlled by La Société le Nickel in England, France and Germany, and to the plant, near Antwerp, of La Société des Hauts-Fourneaux de Nouméa (Ballande). The last-named company has a refinery at New Brunswick, N.J., to which it has made all its shipments, chiefly matte, since the beginning of the war. Prior to the war the matte of this company from New Caledonia was sent to Antwerp. It was there further treated to bring up the percentage of nickel and a part of it sent to the New Jersey plant.

Return Showing Countries to Which Nickel Products Were Exported from New Caledonia During the Years 1912-14.[1]

To	Nickel Ore			Nickel Matte		
	1912	1913	1914	1912	1913	1914
	Tons	Tons	Tons	Tons	Tons	Tons
United Kingdom	44,638	31,862	44,426	....	1,500	2,494
France	3,251	14,000	23,380	1,731	993	....
Belgium	12,996	17,847	16,346	2,997	3,309	2,457
Netherlands	....	2,220	....	....	....	....
Germany	13,423	7,906[2]	7,906	....	....	....
United States	....	....	....	....	....	305
Australia	....	95	96	368	....	....

Value of Ore and Matte Exported in 1914.

To	Nickel Ore	Nickel Matte
	Francs	Francs
United Kingdom	1,263,768	1,754,138
France	700,794	....
Belgium	550,386	1,657,851
Germany	306,178	....
United States	....	213,578
Australia	2,894	....
Total	2,824,020	3,625,567

[1] These tables are taken from the British Diplomatic and Consular Report for the year 1914. Publication of this Report has ceased during the war. Ore sent to Australia and the Netherlands was en transit to other countries. In 1916, 3,000 tons of ore were shipped to Japan, where a refinery has been established.

[2] Figures for shipments to Germany in 1913 do not appear to be correct, but they are as given in the Consular Report.

Table Showing Producing Areas and Ports from Which Nickel Ore Was Shipped in the Years 1913-14.

Port of Exportation	Exportation Nickel Ore. 1914	Exportation Nickel Ore. 1913
	Tons[1]	Tons
Poro	6,420	12,588
Canala	3,050	....
Nakety	....	....
Thio	45,507	28,160
Port—Bouquet	5,705	6,919
Camboui	....	....
Ny	....	....
Port—Boise	....	....
Baie Uie	97	....
Nouméa	....	2,318
Bouloupari	2,800	5,675
Pouembout	15,627	6,800
Koné	....	2,700
Voh	9,970	16,742
Teoudie	2,206	8,814
Kaala—Karembe	2,772	2,474
Totals	94,154	93,190

Place of Production	Production Nickel Ore 1914	Production Nickel Ore 1913
	Tons	Tons
Poro	29,605	29,950
Canala	3,014	4,914
Nakety	1,211	....
Thio	50,643	48,011
Port—Bouquet	10,124	9,665
Camboui	184	....
Ny	1,661	1,369
Port—Boise	....	8
Baie Uie	2,000	2,495
Dumbea	7,013	6,713
Mont Do	4,955	5,513
Kopéto	15,592	9,878
Koné	15,343	
Koniambo		42,619
Kaféate	22,647	
Ouazanghou	4,573	1,700
Kaala	3,800	1,569
Totals	172,365	164,404

[1] Metric tons of 2,204 lbs. each.

Composition of New Caledonia Ore

Analyses of New Caledonia nickel ores are based on the weight after drying at 100°C. Since the ores as mined contain 20 per cent. or more of uncombined water, what is called a 7 per cent. ore contains before drying only about 5.6 per cent. of nickel. As the ores are not dried before shipping, freight is paid on the large quantity of water as well as on the other constituents which they contain.

According to Glasser the following represents a composite or average analysis of the 7 per cent. ores after heating to 100°C.:—

Silica	42.
Magnesia	22.
Lime	0.10
Alumina	1.
Ferric oxide	15.
Nickel oxide	9.
Cobalt oxide	0.15
Manganese oxide	0.70
Chromic oxide	traces
Combined water	10.00
	99.95

The Commissioners have been furnished with the following table of analyses of ores from various mines. With the exception of the uncombined water, the analyses represent the compositions of the ores after drying at 100° C.

Selected Analyses of Types of Nickel Ores.

Name of Mine.	Situation.	Per cent H_2O dried at 100°C	Ni	Co	Fe	Al_2O_3	CaO	MgO	SiO_2	Loss on ignition.	Cr_2O_3
Fathma	Poro, East Coast	?	6.51—(Ni & Co)		9.32	1.20	traces	16.36	49.60	?	?
Houailou	" "	?	4.84	....	10.63	0.52	"	22.16	45.64	10.78	1.40
Circé	Between Thio and Nakéty	?	6.97	....	10.20	1.27	"	17.40	50.62	?	?
Elise	Thio	26.61	6.80	....	11.92	1.30	"	19.30	38.52	?	?
Prises Alma & Rivoa	Port Bouquet E. Coast	22.86	6.46	0.13	12.81	0.20	"	24.95	36.82	?	1.20
" "	" " "	23.79	6.77	0.10	12.21	0.62	"	26.30	34.72	?	1.20
Puy de Dome & Lucie	S. " "	?	6.47—(Ni & Co)		Fe_2O_3 & Al_2O_3 =	16.79	?	27.89	35.78	12.09	*
Etoile du Nord	Massif Kaala, W. Coast	22.53	6.82—(Ni & Co)		12.51	0.63	......	22.39	38.74	....	*
Nouvelle-Espérance	Massif Ouazangou W. Coast	26.30	6.78—(Ni & Co)		12.27	1.42	......	23.19	39.76	....	*
Mines de Voh	Massifs Katepahie & Koniambo	22.60	6.67	0.13	13.83	0.77	......	21.11	42.10	....	*
Katavití	West Coast	23.91	6.19	0.10	9.10	0.73	......	24.18	41.20	....	1.24
"	"	24.00	5.71	0.12	9.95	0.77	......	23.91	45.88	....	*
Annie	Massif du Kongouhiou	?	7.74—(Ni & Co)		12.18	0.73	......	18.02	47.79	....	*
Souza	Region Dumbéa	?	5.45	?	12.65	1.42	......	23.26	38.56	....	*
Monnaie	" "	?	4.68	?	9.44	{ 1.07 1.10	....	{ 20.43 18.90	46.69 49.98	9.08 9.30	0.60 0.57
Gracieuse	" "	27.50	7.26	0.15	11.10	0.41	......	27.03	36.90	8.95	1.38
Le Pic	" "	26.04	6.35	0.11	12.59	1.24	0.08	24.21	37.75	10.30	0.60
Barbouilleurs	" "	?	6.67—(Ni & Co)		13.58	1.17	......	15.40	48.60	....	*
Tip Top	" "	?	4.75—(Ni & Co)		12.38	1.28	......	29.43	35.11	10.23	1.47
Tamanou	Uié bay, S. of Island	?	5.93—(Ni & Co)		{ 11.15 11.55	{ 0.59 0.59	....	{ 27.38 28.51	34.73 34.59	14.10 16.02	....

* Comprised in silica.

Cost of Refining Nickel from New Caledonia Ores

The only official statement available regarding the cost of refining nickel from New Caledonia ores is contained in the report by Glasser to the French Minister of the Colonies, published in 1904.

This cost, while a little higher than estimates obtained from other sources of the cost at present, is, for all practical purposes, about the same. While costs may have been lowered somewhat during late years owing to mechanical improvements in plants and to smelting on the island, they have been increased in other ways; the cost both of labour and supplies has increased. During the war freight and other charges are abnormally high.

The following is a free translation of Glasser's Summary, pages 205-207:—

Nickel ores that are mined in New Caledonia are sent for the most part to Havre, Glasgow, or Rotterdam; in the immediate vicinity of the first two ports are plants which belong to the Société le Nickel. The plants at Havre and at Kirkintilloch have each produced during late years from 1,500 to 1,800 tons of nickel annually; from Rotterdam the ores are sent to Germany where they are treated, the production there of refined nickel being from 1,000 to 1,200 tons per year. Recently, in 1901, there have been shipped to America about 30,000 tons of ore.

The freight charges to Europe naturally vary with conditions in general, depending upon the charges elsewhere in the world; they oscillate usually between 30 and 40 francs per ton, a price to which it is necessary to add an insurance charge of 3 per cent. *ad valorem*. This freight charge is that which is made by French sailing ships, carrying from 3,000 to 4,000 tons of ores, which come from Europe to New Caledonia by the Cape of Good Hope and return to Europe by Cape Horn, making a voyage of about seven months in length, the ore frequently serving as ballast. Ships make on a voyage, outside the freight which they carry, between 100,000 and 150,000 francs, the bonus given to navigation by the French Government, a bonus which amounts on an average to about 125,000 francs per voyage and which covers nearly the whole cost of the voyage. According to the information which we have been able to obtain, the ships would not be able to accept freight at less than 50 francs per ton if a bonus were not allowed them; English ships which are not thus bonused will sometimes take freight at 40 francs.

We thus see that the freight represents a cost of from 48 to 55 francs per ton of dry ore, which would correspond to 70 or 75 centimes per kilogram of metal, thus doubling on arrival in Europe the cost of the nickel ore shipped (*i.e.*, the cost of freight represents about the same as the cost of the ore landed on board at New Caledonia).

The treatment of the ore in Europe consists of fusion to matte in a water-jacketed-furnace. In smelting, the ore is mixed with 20 per cent. of limestone and 10 per cent. of gypsum (or a quantity of soda ash containing an equivalent in sulphur) and 37½ per cent. coke. The resulting matte contains about 45 per cent. nickel, 40 per cent. iron and 15 per cent. sulphur; the silica, lime, magnesia and other materials pass into the slag, carrying with them only a small quantity of nickel. This matte is then converted, and the product is about 75 per cent. nickel, less than 1 per cent. iron and 24 per cent. sulphur; this high-grade matte is reduced to a fine powder and roasted to remove the sulphur; the oxidized product is then reduced by carbon (flour, meal and other material being used to make a paste to mould the oxide into cubes, etc.)

We have not been given the exact cost of this treatment. We believe, however, that it does not exceed one franc per kilogram of metal produced; a half of these costs is represented by the first fusion.

Refined nickel is sold in Europe, depending on the state of the market, etc., at between 3.50 and 4 francs per kilogram. It might be added that the nickel which is extracted from New Caledonia ores by the process that has been indicated is very pure; it contains 99 to 99.5 per cent. nickel; it is freed so completely from the sulphur that has been added by the first fusion that it holds less than 1/1000 part; it is freed from arsenic and phosphorus and contains only a trace, less than 1/1000, of copper, which is introduced in treatment but which is not contained in the New Caledonia ore.

It will be noted that Glasser puts the cost per kilogram of metal at approximately 70 to 75 centimes f.o.b. New Caledonia, and he gives the same cost for freight to Europe, or say a total cost landed in Europe of 140 to 150 centimes per kilogram of metal. Then he says that he has reason to believe that the cost of smelting and refining does not exceed one franc per kilogram, half of this being represented by the first fusion, or in the making of the low-grade matte. This would make the cost of refined nickel between 19 and 20 cents a pound. From what is said on a following page it will be seen that the cost at the present time is about the same.

Character and Modes of Occurrence of Ores

Before discussing the methods of mining employed in New Caledonia, a few notes may be added, in addition to what has already been said, concerning the nickel ores and the serpentine with which they are associated and from which they have been derived. The serpentine represents the product of weathering of various basic rocks, under tropical or sub-tropical conditions in a country in which there is considerable rainfall. The total denudation of the surface of the island, since the intrusion of the rocks that have been altered to serpentine, is not known. That it has been great is evident from the appearance of the present surface. Among the serpentine masses themselves there are mountains, in the case of Mt. Humboldt, which reach to a height of over 5,000 feet, together with valleys and low lands that are at sea level or project beneath the water.

Over much of this weathered and denuded surface, which of course has not been glaciated like that of Ontario, loose products of decomposition of the serpentine are found, among which occur, here and there, deposits that contain sufficient nickel to make them of economic importance. Although the serpentine occupies about one-third the surface of the island, areas of considerable extent of this rock are without nickel deposits. Few deposits are found at as low an altitude as 400 feet and none at the highest elevations. Moreover, they are confined largely to the spurs of the mountains.

Various writers have attempted to classify the workable nickel deposits, but this can be done only in a general way. The variation in the character of the deposits is due to differences in the steepness of the surfaces on which they lie, to differences in the breaking up of the weathered surface of the serpentine into blocks or fragments of various sizes, and to the presence or absence of distinct fissures and joints or other cracks in the serpentine. Where a surface is fairly steep there is more of a tendency for water to sort the loose products of weathering than there is on a flatter surface. Moreover, on a steeper surface waters tend to take the nickel dissolved out of the rock and carry it downward a considerable distance before it is deposited. Where fissures occur in the rock nickel tends to become concentrated in them. The absence of workable nickel ores on the Tiebaghi plateau, which has a considerable thickness of iron oxides and other decomposition products, and their presence on the faces of many hills and mountains, illustrate the statement as to the influence the characters of surfaces have on ore concentration. Another instance that may be cited is in connection with the iron deposits of

A New Caledonia Nickel Mine.

Cuba, that lie on the surface of serpentine but associated with which no deposits workable for nickel alone have been found. Nickel occurs in these Cuban deposits in sufficient quantity to produce workable ores in the process of weathering, were the surfaces not plateau-like on the whole and therefore not suitable for concentration of nickel.

Glasser distinguishes four types of nickel deposits in New Caledonia, *viz.*, vein-like deposits, brecciated deposits, masses of altered serpentine impregnated with nickel and nickeliferous earths. But two or more of these classes usually occur in the same workings. In the deposits first worked, much of the ore had the characteristic green colour of garnerite, the nickel-bearing mineral, but most of the ore now produced is the well known "chocolate" variety, the colour being due to oxides of iron.

Ore Reserves and Competition

Statistical tables on other pages of this Report show the part that New Caledonia plays in the world's production of nickel. Controlling the world's markets at the time of Ontario's advent as a producer, New Caledonia has not kept pace with her younger rival, although having the financial support of the house of Rothschilds, together with the accumulated experience, gained both before and after the discovery of the Sudbury deposits, and a tied market with a number of the greatest steel makers of Britain, France, and Germany.

The chief factor that has enabled Sudbury to outdistance her rival is the difference in the size of the ore bodies in the two countries. The greater of the Ontario deposits contain ore that is measured in terms of millions of tons, while those of New Caledonia are reckoned in a few hundreds of thousands, the greatest of her deposits having contained about 600,000 tons; few reach 250,000.

A determination of the ore reserves in New Caledonia is not possible owing to their uncertain character, but it might be fair to say that the colony possesses at least as much undeveloped ore of the same grade as she has already mined, in the

Nickel Mine at Dumbéa.

forty years of her existence as a producer, or say 160,000 tons of metal, a little over four years' output of Sudbury at the present rate of production. There are large quantities of lower grade ores which it has not yet been found feasible to treat.

The first mines to be worked in New Caledonia, there being many deposits to choose from, were naturally those that were the most accessible, usually those near some harbour. Many deposits that were once worked are now abandoned, including the Bornet mine near Thio, which has the record of having been the largest producer. The production of others of the larger mines is decreasing and new mines, such as the Emma, in more inaccessible situations are being opened up, necessitating the extension of the railways farther into the interior of the island. There is no evidence to show that any of the new mines are larger than certain of the old ones or that ore can be produced more cheaply from them.

The pith of the whole matter in so far as New Caledonia is concerned is the cost of refined nickel produced from her ores. More than a dozen years ago the cost was approximately 19 cents. Immediately prior to the present war it had not been lowered. To-day, with excessive freight rates and higher prices for supplies, the cost is much increased.

While prices of nickel remain about the same as they have been during recent years, New Caledonia will have an important industry. It will probably expand somewhat, owing especially to the activities of the newer of the two companies that are shipping ore and smelting on the island, but there is no reason for believing that competition with the Ontario industry will become any stronger than it has been in the past. Should the price of nickel fall to say twenty-five cents a pound or less, New Caledonia will have difficulty in keeping her mines in operation. But no right-thinking man will wish to see any French industry crushed or crippled.

A description of mining, smelting and refining as they concern New Caledonia, together with costs of the various processes, will be found on following pages.

The following table shows, approximately, the quantities of refined nickel produced from the ores of Ontario and New Caledonia at periods of five years, 1890 to 1910, together with those of 1913 and 1915. It illustrates the relative growth of the industry in the two countries, mining having begun in the former in 1886 and in the latter in 1875.

	1890	1895	1900	1905	1910	1913	1915
Ontario.................tons	1,780[1]	2,316	3,540	9,503	18,636	24,838	34,039
New Caledonia ....tons	2,160[1]	2,737	6,584	6,627[2]	5,237	4,929	2,569

The largest and most important owners of nickel-holding lands in New Caledonia, in relative order of the importance of their holdings, are: (1) La Société le Nickel, a company which has been mining in the island for many years. (2) The International Nickel Company, represented in New Caledonia by its two subsidiary companies, The Nickel Corporation and La Société Miniere Caledonienne. The International does not mine in the island, but some of its lands are worked on lease by persons associated with Le Nickel. (3) Les Hauts-Fourneaux de Nouméa (Ballande). This company, much younger than Le Nickel, like the latter, mines and smelts part of its ore on the island. Since the beginning of the war it has shipped little ore, but is increasing its smelting capacity.

Methods of Mining*

The ore, nouméaite or garnierite, occurs as a hydrated silicate of nickel and magnesia and may best be described as an alteration product of the serpentine in which the magnesia and iron has been replaced by nickel. The ore formed by the replacement of magnesia by the oxide of nickel is termed "chocolate ore," and the replacement of the iron oxides by nickel oxide is known as "green ore." This alteration or replacement does not extend more than 25 feet to 35 feet on an average, in so far as workable ore is concerned.

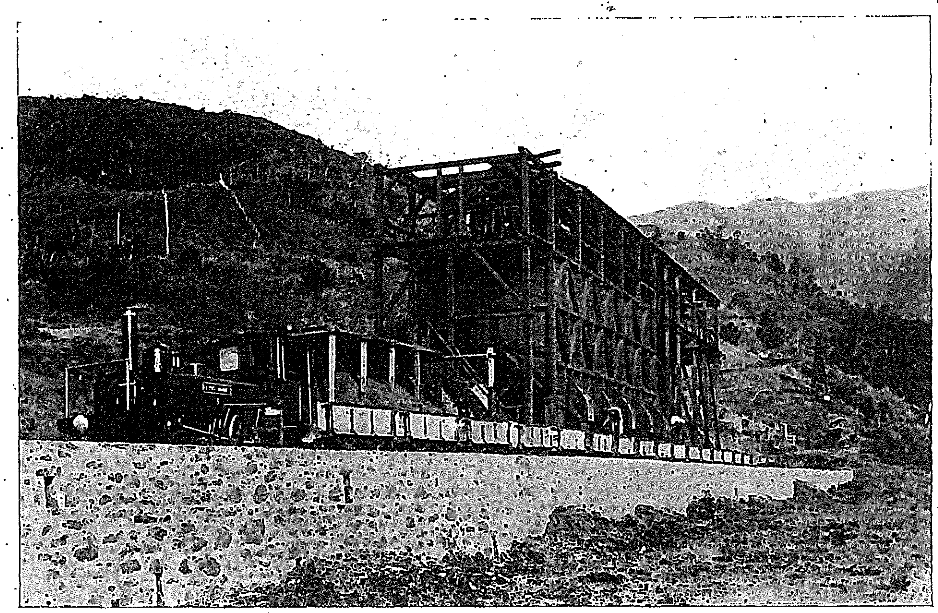
[1] Tons of 2,000 lbs.

[2] It is assumed that ore shipped in this and succeeding years averaged 4.8 per cent. of nickel in the wet ore and 45 per cent. of nickel in the matte. Ores shipped during recent years average 6 to 6.25 of nickel after being dehydrated at 100° C., or say 4.8 wet.

* The following description of mining in New Caledonia and data on the cost of refined nickel are by Mr. T. F. Sutherland, Chief Inspector of Mines for Ontario, who accompanied one of the Commissioners to the colony in 1916.

In appearance most of the ore resembles a brownish yellow clay, has a specific gravity and hardness of 2.5 and carries from 10 to 25 per cent. of uncombined moisture. The workable deposits always occur on the saddle of spurs from the main mountain ridge, at elevations of from 400 to 2,500 feet, the latter elevation being the more common. The ores are overlain by soil, barren decomposed serpentine or a pisolitic iron varying in depth from a foot or two to 15 or 20 feet, and in some cases up to 75 or 100 feet. The ores are generally richer on the upper part of the deposit.

The replacement of the serpentine by nickel follows the joints and fractures in the serpentine and the undecomposed blocks and boulders of serpentine are as a rule covered by a shell of ore which has to be picked off.



Loading Station and Aerial Tram.

Owing to this mode of occurrence of the ore, underground methods of mining are not attempted. The overburden is removed and the ore quarried out. Many properties in former days were worked by contractors. These men sold their ore to the large companies on a graduated scale depending on the nickel content. This scale was such that to make any profit ore carrying 7 or 8 per cent. of nickel had to be obtained. No attempt was made by these men to systematically open up a mine. They simply dug out any patches of high grade ore they found. In later years these properties have been acquired by large companies, but much ore was either lost or made unavailable by the early methods of mining. Ore is now bought on the following basis:—

6 per cent. ore (dry)	.50	centimes[1] per kilo[2] of nickel
6½ " " " "	.55	" " " "
7 " " " "	.60	" " " "
7½ " " " "	.65	" " " "

[1] 9.65 cts. [2] 2.2 lbs.

The mining practice at present is as follows: Where surface indications of ore are found prospecting pits are dug into the hillside, and if a good grade of ore is discovered without too great an overburden, a series of pits are dug across and along the slope to define the extent of the ore occurrence. If the overburden is over 9 feet in thickness and the grade of ore below 5 per cent. of nickel the prospect is not considered favourably. If the preliminary work shows an ore occurrence of sufficient tonnage and grade to be profitably worked, 25-foot contour lines are run along the hillside. These lines are graded out and are called levels. Tracks are laid and mining commences. The overburden for a few feet back is removed, loaded into cars and trammed to the dump. The ore is then picked or barred down and carefully sorted. The shell of ore around the boulders or blocks of serpentine is picked off, the waste trammed to the dump and the ore carefully gathered into

Transporting Ore by Horse Tram.

piles and sampled. This procedure is repeated until the face becomes too low grade to pay. Occasionally it is necessary to drill and blast the harder portions of the serpentine and for this work hand steel is used. Large blocks of low grade ore or waste are worked around and left standing on the bench. The ore is gathered from the different levels into a central loading station and transported from the mine to the foot of the mountains by aerial tram. The only equipment at the mine is the ore cars, tracks, picks and shovels and a few wheel barrows. If the mines are near the sea the aerial tram may discharge direct into stock piles, but generally a narrow gauge railway is built from the shipping port up a river valley and the aerial trams discharge into loading bins built along the railroad. At the shipping front the ore is stock-piled until there is a sufficient tonnage for shipment.

One noticeable feature of the nickel mining in New Caledonia is the extreme care used in sorting and sampling the ore. After the overburden is removed the floor of the quarry is swept clean before the ore is picked or barred down. Then any large pieces of ore are broken by hammers to a 2 inch ring and carefully sorted by hand. In some cases the fines are screened. The shell of ore on the boulders of undecomposed serpentine is chipped off as completely as possible with sharp picks, the waste is trammed to the dump, and the ore is swept up and gathered into 10-ton lots which are carefully sampled. The result of the assay is marked on each lot. In this way ore of a certain grade can be shipped. The necessity for this extreme care is due to the fact that the ore is not uniform in grade, that it is impossible to judge closely the grade of ore by appearance, and that in the past it has not been considered economical to smelt ore of a lower grade than 4.5 per cent. nor to ship ore of a much lower grade than 6.5. The average content in nickel of the

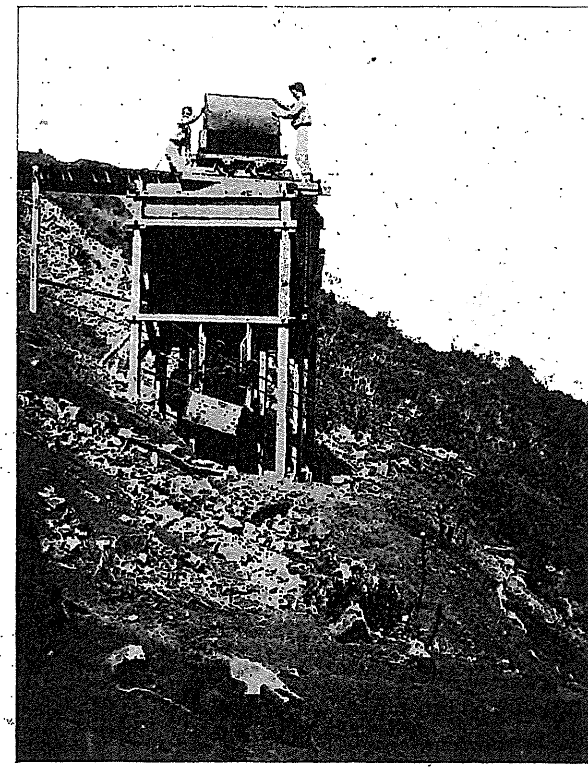
Sacks of Ore at Upper Terminal of Aerial Tram.

ore shipped in the three years 1913-14-15 was between 6 and 6.25 per cent., some shipments being above and others below this percentage.

As regards mining costs there is a wide variation depending upon the location of the property, the tonnage of the ore bodies, the amount of overburden to be removed, the grade of ore and the amount of sorting necessary to obtain a shipping grade of ore. On the location of the property depends the amount of capital expenditure necessary to provide transportation facilities, aerial tram and railroad to shipping front or smelter, and the tonnage and grade of ore will decide whether such an expenditure is justified or not. As a rule it may be said that the individual deposits are small, under 100,000 tons, and the largest mine yet worked produced under 600,000 tons.[1] A group of properties is often served by the one aerial tram,

[1] Metric tons of 2,204 lbs. each.

aided by branch lines and surface trams, while several such groups may be served by the one railroad. The amount of overburden to be removed has often prevented the working of an otherwise favourable prospect, though after the property is once operating it has been found economical to remove a considerable depth of overburden; in one case 72 feet of ferruginous earth overlying a good grade of ore was removed. The sorting necessary is generally from 8 to 10 tons of waste to one of ore, and 27 francs ($5.21) per ton (2,204 lbs.) of ore landed at the shipping front can be taken as a fair average of the mining costs.



Loading Station at Mine.

Smelting

The first attempt to smelt New Caledonia nickel ores on the island was made in the year 1879, when two furnaces were erected at Nouméa. A 9 per cent. ore was treated, and a "fonte" made containing about 65 per cent. of nickel. Fifteen and one-half tons of ore were treated daily. The charge consisted of one ton of ore and 450 kilos of limestone and a 49 per cent. coke charge. The smelting costs amounted to about 85 francs per ton of ore, or about 95 centimes per kilo of nickel (or 8.3 cts. per lb.).

As it was found to be impossible to bessemerize this fonte, necessitating a second operation in which the fonte was sulphurized, this method of smelting was abandoned and the furnaces were used to make a matte, the charge consisting of

1,000 parts of ore, 385 parts limestone and 72 parts gypsum. About 20 tons of ore were smelted per day, producing a little less than 3 tons of matte averaging 62 per cent. of nickel. This change reduced the smelting costs to about 76 francs per ton of ore, or 85 centimes per kilo of nickel (7.4 cts. per lb.).

The next step in the metallurgy of New Caledonia nickel ores was cupola smelting. The cupolas were water-jacketed, with inside diameter of 5 feet. The first cost of these furnaces was small, but they required constant attention, and owing to the shallowness of the charge, height of charge from tuyeres being only 3 feet, much heat was lost, and there was a smelting loss of 11 per cent. in fine dust being carried off by the blast. The slag loss was not great, being only 0.3 per cent. nickel, but the slags had to be kept constant. The coke consumption was about 33 per cent. In operation the ore was mixed with coal dust, 75 per cent. of the necessary limestone, and the right percentage of sulphur, about 2½ per cent.,

Nickel Smelter at Nouméa.

briquetted and charged into the furnace. The remainder of the limestone was distributed loosely over the charge together with slags, etc. One advantage was that a lower grade ore could be utilized, down to 6 per cent. of nickel. The cost was about 30 francs per ton of ore smelted, or 65 centimes per kilo of nickel (5.7 cts. per lb.), after allowing for the smelting loss.

Present day smelting practice is to replace the cupola furnaces with modern water-jacketed blast furnaces. The two large operating companies, Sociéte le Nickel and Société Hauts-Fourneaux de Nouméa, operate smelting works, the former at Thio and the latter at Nouméa. The capacity of each works is from 100 to 120 tons of ore per day, producing about 9 tons of matte carrying from 40 to 46 per cent. of nickel, ore assaying as low as 4½ per cent. of nickel being used. A small quantity of ore has also been smelted in an electric furnace by the former company at Tao.

Le Nickel's matte is said to carry 45-48 per cent. of nickel and that of the other company 42-45. The former company smelted 20,000 tons of ore in 1913, the same quantity in 1914, and 29,000 in 1915; the latter company smelted 20,000, 22,000 and 35,000 respectively in these years.

The ores are delivered to the smelters by rail or water transportation and stock-piled under sheds to be kept dry, the sun dried ore carrying from 5 to 11 per cent. of uncombined water, while, if not protected, in wet weather the moisture will approach 25 per cent. Ores from different sections are kept separate and will vary in silica content from 35 to 50 per cent. The different grades are mixed before briquetting and this material is fed into pug mills with the necessary quantity of gypsum and some flue dust added. The pug mills discharge into briquetting machines. The briquettes which weigh 2½ kilos (5½ lbs.) are then stored in

Smelter Yard at Thio.

drying sheds, where they are allowed to dry and harden. The furnaces are charged in the ordinary manner, the limestone or coral being added with the coke and also any fluorspar or slags that may be necessary for the free working of the furnace. A 30 per cent. coke charge is used.

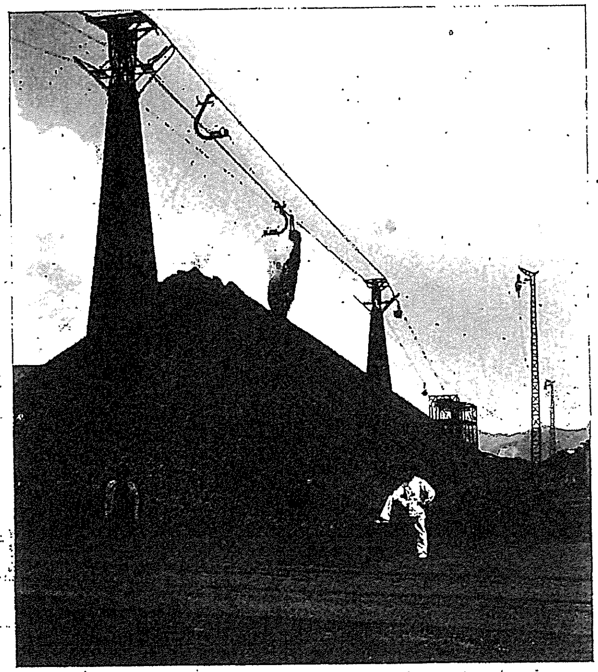
The ores, briquettes and slags on analysis show about the following composition:

	SiO_2	Al_2O_3	FeO	Fe_2O_3	MgO	CaO	SO_3	H_2O
Ore	41-52	...	...	9-19	20-22	...	...	8-11
Briquettes	37-40	3-5	...	11-15	18-20	3-5	5-7	10-12
Slag	45-50	8-12	10-12	...	17-22	9-14	...	...

Limestone, gypsum, fluorspar and coke and coal necessary in the smelting operations have to be imported. The New Caledonian limestones are only of medium quality and are often high in silica due to quartz stringers. At the present time, 1916, due to the high ocean freight rates, it has been found economical to use coral. Analyses of New Caledonian limestone and coral are as follows:—

	SiO_2	$CaCO_3$	$MgCO_3$	Fe_2O_3	H_2O
Limestone	17.05	78.15	1.46	2.70	....
Coral	3.30	77.70	8.20	3.80	4.35

Gypsum was formerly imported from France, being carried out as ballast by sailing ships in the ore carrying trade, but at the present time the supply is imported from Australia. The price is 20 shillings per ton f.o.b. Port Marian, South Australia, and about 36 shillings per ton f.o.b. Newcastle, Australia. The gypsum must grade 16 per cent. sulphur. Freight from Australia to New Caledonia at the present time is from 20 shillings to 40 shillings per ton. The New Caledonian gypsum costs just about as much as the Australian gypsum landed at the smelters,



Ore Carrier, Aerial Tram.

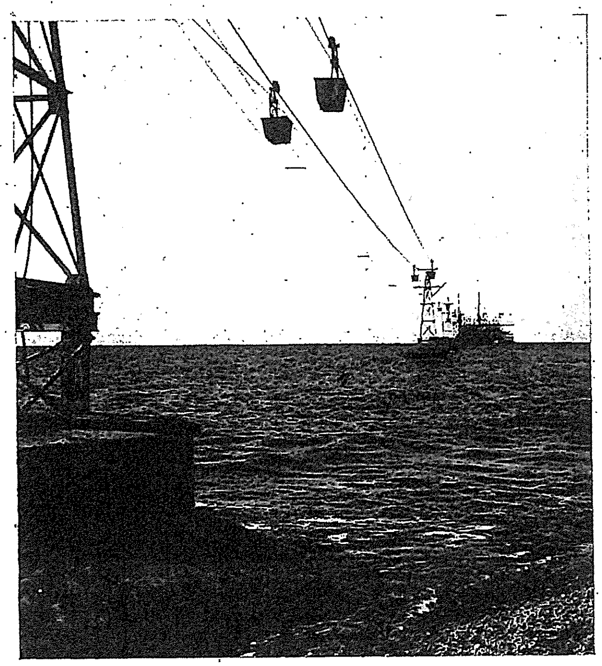
as it has to be hand-sorted in order to get a suitable grade. Coal and coke before the war were brought out by the ore ships from France and England, but are now obtained from the Newcastle district, Australia. A coke analysis gave:—

Volatile matter 0.46, fixed carbon 90.88, ash 7.93, sulphur 0.42, water 0.31. An ash analysis gave: Silica 51.20, lead 0.70, alumina 34.30.

The price of coal f.o.b. Newcastle, Australia, is 12 shillings per ton and of coke 15 to 20 shillings per ton, depending on the quality. Before the war, freight on coal from Newcastle to New Caledonia was 10 shillings per ton. Coke freights are 50 per cent. higher than coal freights. Some fluorspar is used in smelting operations in order to obtain a more fluid slag. This is imported from Australia, where it costs 100 shillings a ton, only 10 tons being imported in the five months preceding September, 1916.

Transportation

The shipment of ore or matte to foreign markets, or the transportation of the ore from the loading port to the smelters, is a serious and expensive problem with which the operating companies have to contend. The island is surrounded by a coral reef, and within this reef is a fairly safe anchorage for vessels except during the hurricane season, December to March, inclusive. Very few of the mines happen to be situated adjacent to good harbours, and it is necessary for the shipping to anchor a considerable distance off shore. Incoming material has to be discharged into lighters, which are towed ashore, and ore and matte have to be shipped out the same way. Windy weather which will not endanger the ship at anchor still makes it impossible to tow the heavily laden lighters back and forward between the shore and ship, and much time is lost. A small dock is generally



Marine Terminal at Thio.

built at the loading front so that the ore can be trammed in cars from the stock pile and dumped direct into the lighters. At the ship the ore has to be loaded into buckets by hand. The docks at the smelting works at Thio and Nouméa are equipped with locomotive cranes to assist in unloading the ore or fluxes from the lighters.

At Thio a marine terminal was built, one kilometre (1,093.6 yds.) from the shore and connected with the shore by a Bleichert aerial ropeway, but this loading terminal was partly destroyed by a hurricane and the company have reverted to lighters for loading and unloading ships.

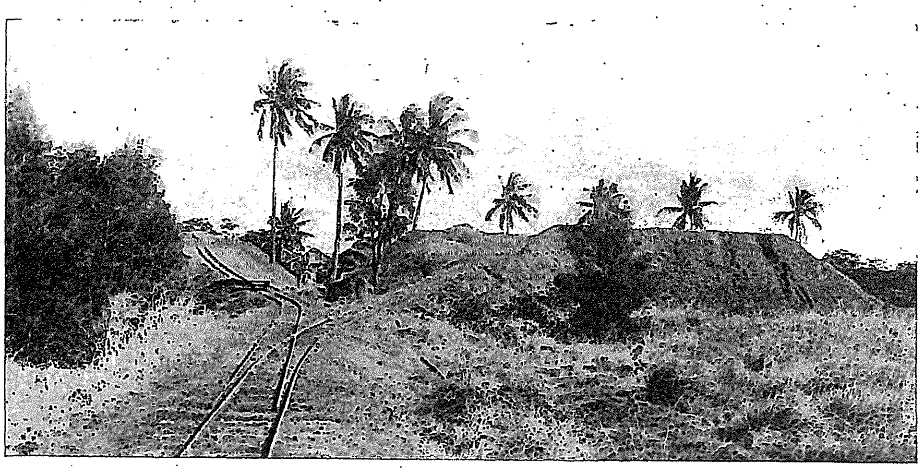
The cost of loading ore on ship, transporting to smelter and unloading may be put at 8 francs a ton.

Before the war freights on nickel ore in bulk per ton of 2,240 lbs. from Nouméa to Hamburg were from 21 shillings in 1908 to as high as 35 shillings in 1913. Freight on matte from Nouméa to Glasgow by Sydney was 40 shillings. Present freight rates, 1916, are 300 and 400 per cent. higher.

Labour

At the present time the principal labour employed at the mines is Japanese and Javanese, with a few natives from neighbouring islands. The New Caledonia native will not work at the mines.

When the nickel mines were first opened in 1876 convict labour was employed. The convicts were hired from the Government at a nominal sum, and as the mining



Stock Pile at Shipping Front, Kataviti.

was simply pick and shovel work in the open, this class of labour, while troublesome and inefficient, was still cheap. The importation of convicts to New Caledonia ceased in 1898, and at the present time only a few ex-convicts are employed by individual operators who sell ore to the larger companies. The majority of the workmen employed by the large companies are Japanese, and this class makes the most satisfactory labour that can be procured at the present time. They are imported under a three or a five year contract and are paid about 5 francs (96.5 cts.) a day. There are certain stipulations regarding food, housing, etc., and a Japanese representative is resident on the island who looks after the men's interests and acts as a medium in any disputes that arise between the men and the companies. Some Javanese are employed in actual mining and much of the domestic work is done by this nationality. Natives from the neighbouring islands are used around the shipping ports for lightering, etc. At the smelters many Arabs are employed where the heat is severe. Superintendents, foremen and many of the clerical staff are from France.

Mining Laws

Title to a mine is only acquired by concession, which gives the right to mine for, in their vertical dip, and to dispose of, the substances named in the concession. Minerals which may be acquired by concession are divided into four classes:—

1. Combustibles, *i.e.*, petroleum, coal, etc.
2. Salts, nitrates, phosphates.
3. Nickel, chrome, cobalt, manganese and iron.
4. All other substances.

The concession to mine one mineral includes the right to mine all substances of the same class.

An annual rental of 40 centimes (7.32 cts.) per hectare (2.47 acres) is charged by the Government for prospecting areas and for concessions, until such time as the concession is opened up, when the following schedule of taxes applies:—

Class 1.

Francs.		
0.50	per hectare	up to 5,000 hectares.
0.74	do	from 5,001 to 10,000
1.00	do	over 10,000

Classes 2, 3, 4.

0.75	per hectare	up to 500 hectares.
1.00	do	from 501 to 1,000
1.25	do	from 1,001 to 2,000
1.50	do	from 2,001 to 5,000
1.75	do	from 5,001 to 10,000
2.00	do	from 10,001 to 15,000
2.50	do	from 15,001 to 20,000
3.00	do	from 20,001 to 30,000
3.50	do	from 30,001 to 40,000
4.00	do	over 40,000

A permit to prospect is obtained from the Government and gives the exclusive right to prospect a block of ground. The minimum for a prospecting area is 300 metres (327 yds.) square and the maximum 5 kilometres (3.1 miles) square, or 6,150.4 acres. The boundaries of such an area must run north and south and east and west. This permit is good for one year from the date of issue and is renewable.

If mineral is discovered the holder of a prospector's permit may apply for a concession; such concession must be in the form of a rectangle, the shorter side of which is not less than one-quarter the length of the longer side, and such concession must be entirely within the prospecting area held under permit. The concession must not be greater than 2,500 hectares nor less than 100 hectares for Class I., and a maximum of 2,000 hectares with a minimum of 5 hectares for the 2nd and 3rd and 4th classes.

Mining rights cannot be subdivided without the authority of the Department and can only be transferred with the consent of the Department. Concessions which are not worked or sufficiently exploited after a period of five years are subject to a special tax. By "sufficiently exploited" is meant a production of one ton of nickel per hectare per year, one-half ton of chrome iron per hectare per year, 125 kilograms of cobalt per hectare per year, one ton of copper per hectare per year, and for any other mineral four days' work per hectare per year.

Export Duty

The export duty on New Caledonia ores is 5 per cent. *ad valorem* per wet ton. Values are fixed half-yearly by the Government. For purposes of this tax the following values are assumed:—

	Tenor.	Value per wet ton. 1st half 1916.	2nd half 1916.
Nickel	Up to 5.74 per cent.	22 francs	46 francs
"	5.75 to 5.99	31 "	54 "
"	6 to 6.24	37 "	60 "
"	6.25 to 6.49	41 "	65 "
"	6.50 to 6.74	46 "	79 "
Chrome	Up to 50 per cent.	37 "	40 "
"	Plus 2f50 per additional unit.		
Cobalt	Up to 4 per cent.	40 "	40 "
"	4 to 5 per cent.	50 "	50 "
"	5 to 6 per cent.	70 "	70 "
"	6 per cent. and over	90 "	90 "
Copper	Any grade	50 "	50 "
Phosphates	"	60 "	60 "
Antimony	15 to 29 per cent.	.. "	200 "
"	30 to 49 per cent.	.. "	400 "
"	50 per cent. and over	.. "	700 "

Shipments of any other mineral products, 5 francs per ton.

The export duty on ore, together with the cost of freight on water and other useless material contained in it, encourages the smelting to matte, which is free from export duty, on the island.

Cost of Refined Nickel

The cost of producing nickel from a 6 per cent. New Caledonia ore, before the war, was between 19 and 20 cents a pound. It is probable that under present conditions this cost is increased at least 20 per cent.

NORWAY

Prior to the advent of New Caledonia as a producer, Norway, where mining began in the forties, and reached its greatest importance in the period 1870-1877, controlled the nickel market. The total output of nickel ore between 1850 and 1893 is said to have been about 330,000 tons. The maximum of production was attained in 1876 with an output of 42,500 tons of ore containing 360 tons of nickel, conditions at that time permitting the smelting of ores with 0.9 to 1.5 per cent. of the metal.[1]

On a preceding page mention has been made of the effects of New Caledonia competition on the Norwegian industry, resulting in the closing of the mines. The introduction of the Hybinette electrolytic process of refining, together with an increased demand for nickel, has brought about the reopening of the mines during recent years. In addition to ores of local origin, comparatively small quantities of ores from Greece and elsewhere have been treated in the Norwegian plants. Most of the output has gone to Germany. Copper and precious metals, as well as nickel, are produced from the Norwegian ores. Statistics of production are given on another page.

[1] Beck, The Nature of Ore Deposits, Weed's translation, p. 38.

The richest nickel mine in Norway is, however, the above mentioned Flaad mine, which works an ore body occurring in a mass of uralite gabbro about 75 sq. km. in extent. The production so far, that is between 1872 and 1908, has been about 75,000 tons of ore, equivalent to 1,350 tons of nickel and 800 tons of copper. The present depth is about 90 m. [290 feet], though the ore body is far from exhausted to that depth. . . . . Latterly only one mine, the Flaad, continues working. In the whole of Norway roughly 400,000 tons of nickel ore have been mined and smelted. The hand-sorted ore usually yields 1.4 to 1.7 per cent. of nickel, though exceptionally the yield may be as much as 2 to 2.5 per cent.[1]

The ore deposits of Norway are similar to those of Sudbury in mineralogical character, consisting essentially of pyrrhotite and chalcopyrite together with more or less pyrite and other minerals, and in the nature of the rocks, norite, associated with them. They are, however, small and contain comparatively low percentages of the metals. Considered as competitors with New Caledonia or Sudbury they are of little consequence.

Deposits of ore of the character mentioned have been found at various places not only in Norway but in Sweden as well. In the latter country the ores have not been worked during recent years.

In 1913 about 28,500 tons of ore from the Flaad mine, 2,000 from the Faeo and 2,000 tons of Grecian ore are said to have been smelted in the Evje plant. At the other smelter, the Ringerike, 13,000 tons of Ringerike ore and 1,250 tons purchased abroad were smelted.

At the Kristianssands refinery in that year there were received about 458 tons of nickel and 274 tons of copper in the form of matte from the Evje plant and about 207 tons of nickel and 118 tons of copper from the Ringerike plant. From this matte there was refined and shipped about 602 tons of nickel and 388 tons of copper. Shipments of precious metals obtained in the refining process were also made. In the same year arrangements were made to increase the capacity of the refinery to 1,200 tons a year of nickel, and to enlarge the smelters. In 1914 the production of nickel was 841 tons and in 1915, 793 tons.

BORNEO, ISLAND OF SEBOEKOE[2]

From the description it will be seen that the iron ores of this island are similar in character and mode of occurrence to those of Cuba, that contain nickel and chromium. They have had the same origin as the Cuban ores and the nickel-bearing ores of New Caledonia, the deposits of all three countries representing the weathered surface of serpentine. The situation of Seboekoe is shown on the map, page 234.

The following notes are taken almost verbatim from letters written by H. N. G. Cobbe to the Chairman of the Commission:

In the island of Seboekoe, lying off the southeast coast of Borneo, there exists a large surface deposit of porous limonite about 15 feet thick overlying serpentine. A great part of the deposit lies along and near the sea shore, facing the channel which divides the island from its larger neighbour, Laoet. The channel affords good anchorage. The deposit has been well prospected by pits and drill holes and extends for four miles parallel to the coast rising from the sea level to a hill in

[1] Beyschlag, Vogt and Krusch, Ore Deposits, 1909, Truscott's translation, p. 297.

[2] Having discussed the occurrences of the nickel ores of Sudbury, New Caledonia and Norway in preceding pages, those of other countries will now be dealt with in alphabetical order.

places 300 feet high. There is no over-burden but the deposit is to some extent grown over with timber.

The ore can be divided into two classes; the first class, from the surface to about 7 feet deep, is a little heavier and a little richer in iron and is more gravelly than the deeper-seated ore, and is of a reddish brown colour. The second class, about 8 feet in thickness, is more earthly in texture and is yellowish brown in colour.

Both classes of ore have nearly the same composition in the dry state. The upper layer contains about 40 per cent. "gravel," *i.e.*, material from 1/4" to 6" or upwards, the remaining 60 per cent. being fine soft ore. The deposit contains at least 300,000,000 tons of porous limonite ore which, when dried, contains over 50 per cent. Fe, and when calcined over 60 per cent. Fe and about 0.5 per cent. Co and Ni.

The following is a table of analyses made on many samples taken and grouped as shown.

Separating Ni and Co in one sample, Ni=0.54, Co=0.08 (Dandurand, Paris).

MIXED ORE.	From Depth 0 to 6 ft.	From Depth 6 to 9 ft.	From Depth 9 to 15 ft.
CALCINED ORE.	Per Cent.	Per Cent.	Per Cent.
Fe	61.30	60.30	60.69
DRIED ORE.			
Fe	53.09	50.01	51.69
SiO_2	2.75	2.35	2.30
Mn	0.43	0.37	1.05
S (average 0.18 per cent.)	0.21	0.12	0.19
P	0.06	0.037	0.029
Cr	2.30	2.20	2.05
Co and Ni	0.39	0.41	0.45
Insolubles	4.95	5.45	5.50
	64.18	60.947	63.259

The island is a Dutch possession and the title is held direct from the Government under the mining act and is current for 75 years. The extent of the concession is 15,654 acres.

Apart from the favourable physical condition and situation of the ore, the property is well placed as regards fuel, limestone, aluminous flux, transport and the eastern market generally.

Mr. Cobbe quotes the following from the owner of the property:—

On this question of analysis I have the letter of the Director of the Society Francaise d'Etudes et d'Entreprises, who sent out the French expert Gascuel in 1906. He writes me the following concerning the sample taken by Gascuel himself:—

The average composition of the ore in chromium, nickel, sulphur, phosphorus and arsenic has been on 15 samples of the upper layer:—

	Per Cent.
Cr.	2.21
Ni.	1.00
S.	0.03
P.	0.04
As.	0.012

This analysis is by Campredon of Nantes.

Mr. Cobbe further says:—

I smelted some of the ore which I have in bags here, and which was taken indiscriminately from a cargo, and the resulting iron analyzed 1.2 and 1.26 nickel, which indicates the presence of that metal in the original ore in greater quantities than shown in the table.

The island of Seboekoe is about 20 miles long and 3 to 6 wide. It is practically uninhabited and well timbered. It lies no great distance to the south of one of the largest oil refineries in the East and is not more than 20 miles from a coal mine on the island of Laoet, owned by the Dutch government, who paid £360,000 (sterling) for it and who work it. The coal on Seboekoe is the same bed, which has been eroded between the islands.

The average temperature lies between 70 and 85 F., above which it seldom goes. There are no hurricanes, being situated almost on the Equator, and the steady S.E. winds do not raise any sea between the islands where the anchorages are.

There are many trade routes. Kota Barus is quite a place, and just across is the Dutch coal mine on the mainland. A route is easily induced in this part of the East, where there are 50 million souls. Macassar, to the S.E., is a great port, in direct service with Europe—Amsterdam, London and Hamburg—and steamers would call at Seboekoe and bunker coal or load pig at Seboekoe at (probably) Macassar rates. It is about a six shilling rate to Japan, and practically on the fair weather cargo route, England to Australia, via Singapore, from which it is no distance.

CUBA

The nickeliferous iron ores of the island of Cuba, in the districts of Mayari, Moa, and San Felipe or Cubitas, have attracted much attention during recent years. Several important papers descriptive of these ore fields have been published. An excellent paper by J. F. Kemp deals with the Mayari deposits, the only deposits that have yet been worked.[1] The following quotations are from this paper.

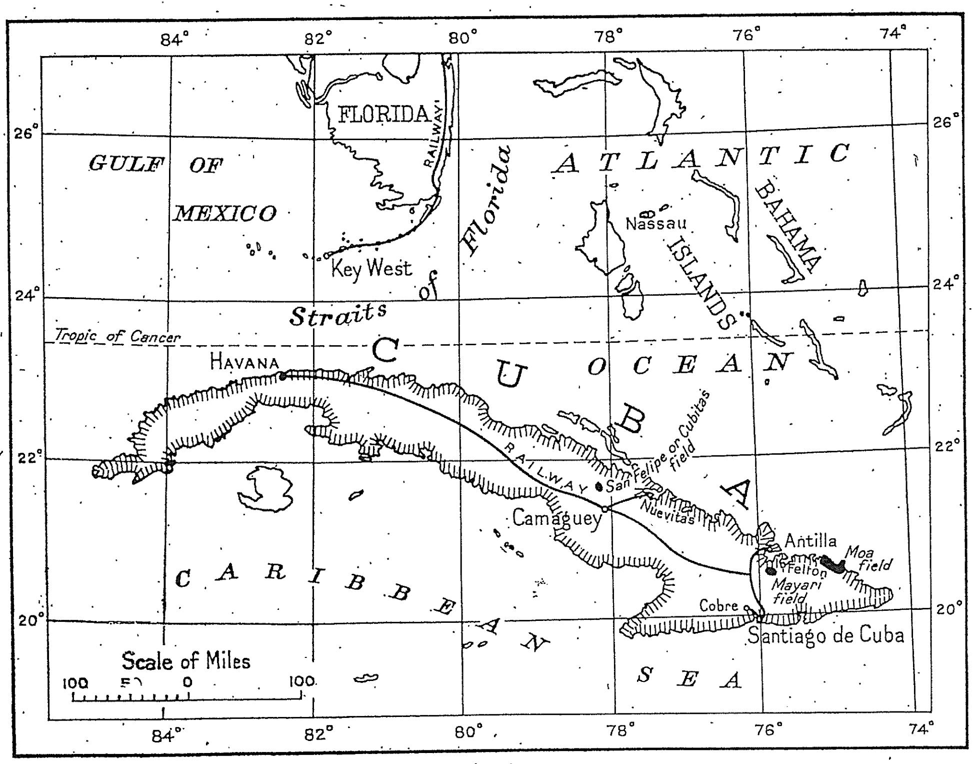
Crusts and concretionary masses of brown iron ore were early noted in northeastern Cuba. J. S. Cox, Jr., writing in 1911 ...., states that claims were located upon them in the Moa district more than 20 years earlier. A. C. Spencer remarked them in 1901 as appearing in red clay, but no one seems to have realized until three or four years later that the entire mass was high enough in iron to be an ore. Under J. S. Cox, Jr., explorations were begun in the Mayari district in 1904 upon the crusts or "plancha," and then analyses revealed the fact that not only the upper, dull-red portion of the so-called clay was valuable, but also the lower yellow parts as well. The construction of the Mayari plant of the Spanish-American Iron Co. was begun in 1907 and was completed in December, 1909. Shipments have been active ever since. The plant and mines were well described with maps and views by J. E. Little in 1911, ... The chief changes since then have been the greater extent of the pits on the plateau at Woodfred, and the improvements in the village of Felton, the shipping port on Nipe Bay. The ore is principally treated at Sparrows Point, Md., and Steelton, Pa. It is shipped both in the crude state and as so-called "nodulized ore," or the product of kilns similar to modern cement kilns, in which the water, both absorbed and combined, is driven off and the fine ore is half fused or fretted into nodules. Mushiness in the stack is thereby prevented and the rather heavy percentage of water (25 per cent. absorbed and 14 per cent. combined) is driven off, to the diminution of freight charges. Three or four per cent. of water is again absorbed in the cooling vats into which the kilns discharge. Analyses of the raw ore are customarily made on samples dried at or above 100°C. They have averaged by the year: Fe, 48 to 49; Ni, 1; SiO_2, about 3; Cr, 1 to 2; Al_2O_3, 11 to 11.5; combined H_2O, 13 to 13.5. The nodulized ore runs: Fe, 55 to 56; Ni, 1 to 1.2; SiO_2, 4 to 4.4; Cr_2O_3, slightly more than the raw ore; Al_2O_3, 13 to 14; absorbed water, 3 to 3.5. In both, sulphur and phosphorus are negligible. In time, the great purity of these ores, combined with their percentages in nickel, and their convenient shipment from deep-water docks, should win a European as well as an American market.

Geologists who have studied these Cuban iron-ore deposits are agreed as to their origin. The ores have been formed, like the New Caledonia nickel deposits,

[1] The Mayari Iron-Ore Deposits, Cuba, Am. Inst. M. E., Vol. LI, 1915. This paper gives a list of earlier publications.

through the weathering of basic rock, now represented by serpentine, and rest practically on the surface of the rock from which they have been derived.

In the faces of the pits as now extensively exposed, the observer can readily note that there are three distinct layers: An upper, of crimson-brown hue; a middle one, yellowish brown, and a bottom layer of a lighter shade of yellowish brown. In one face, called the Three-Hill cut, the upper was noted at 5 to 6 ft.; the middle[1] at 6 to 12 ft.; and the lower at 4 to 6 ft. . . . Analyses of each layer, but from another station, will be subsequently given. As distinct from these varieties the engineers in charge have noted that in the occasional and rather rare spots in the residual mantle where the iron percentage is too low for mining there appears at the surface a peculiar purple color, quite easily recognized and an indication of high alumina in the samples. The color appears to be due to the relatively rich admixture of normally white bauxite with a darker-hued brown iron ore. The explanation of the higher alumina is to be found in local changes in the original rock, as later set forth.



Map of Cuba.

In some places, at the surface or a few feet below it, slabs and even continuous sheets of solid iron hydrate appear and afford the cellular varieties of brown ore, very similar to the crusts and lumps long familiar in the mines of the Appalachian belt. As earlier stated, the solid ore is called plancha. In the residual mantle shots and larger lumps of solid brown ore are at times intermingled, chiefly in the upper, darker layer. The general run of the ore is, however, earthy, and reminiscent in the strongest degree, alike in color and texture, of the Mesabi ores. The higher content of absorbed water, the higher alumina, and the lower silica of the Mayari ores give them perhaps a somewhat more spongy aspect than one notes on the Mesabi range; on the other hand, at Woodfred there is no overburden whatsoever, and the ore is obtained from grassroots to bedrock.

The recently mined ore has a peculiar mealy character, reminding one of nothing so much as dampened meal, but as it dries out this character disappears. No doubt the colloid nature of the hydrates of alumina and iron is the cause of the peculiarity.

The following analyses made by T. C. Kraemer, chemist of the Spanish-American Iron Co., were based upon samples gathered by the writer to illustrate the three contrasted layers. The samples were taken as nearly as practicable in a vertical section.

	I. Surface Ore. Sta. 11, 35, 10. Crimson-brown.	II. Middle Layer. Sta. 11, 35, 10+15. Yellow.	III. Bottom Layer. Sta. 11, 35, 11, Yellow.
SiO_2	2.26	2.70	7.54
Al_2O_3	14.90	7.13	4.97
Fe_2O_3	68.75	71.89	64.81
Cr_2O_3	1.89	3.17	3.66
FeO	0.77	1.29	1.49
NiO	0.74	1.60	2.75
MgO	....	....	1.50
H_2O (combined)	11.15	12.90	12.75
Total	100.46	100.68	99.47
Metallic iron	48.65	51.32	46.52
Metallic nickel	0.59	1.20	2.10
H_2O absorbed (a)	4.62	9.72	27.00

(a) Determinations of absorbed water based on original sample. Other determinations on dried sample at 110°C.

The following quotation is from a paper by J. S. Cox.[1]

The partial or complete elimination of the chromium and the production of a satisfactory steel were accomplished after patient experiment. Steel rails made from this ore have demonstrated their superiority over ordinary rails, by actual use on the Horseshoe Curve of the Pennsylvania railroad. For more than a year the Pennsylvania Steel Co. and the Maryland Steel Co. have manufactured commercially, from Mayari steel, a steel which, by reason of its nickel content and low phosphorus, is superior to ordinary Bessemer steel and open-hearth products.

In mining a selection may be made by removing first the upper part of the layer and then the lower, the latter containing a higher percentage of nickel. The average depth of ore mined is said to be about 19 ft. Costs, under normal conditions, of nodulized ore, delivered at Baltimore, are said to be about $2.50 per ton.

As to the extent of the deposits in the three fields A. C. Spencer says:—[2]

Mayari.—The ore deposit is a blanket formation, extending as a practically unbroken mantle over a gently rolling elevated plateau, roughly 10 miles long and 4 miles wide; or more accurately about 28,770 acres. Except for a few groups of hardwood trees in moist situations, the ore field is covered by pine forest, averaging about 40 trees of medium size to the acre. . . .

A fair average depth of ore over 18,525 acres is 15 feet, which, at 20 cubic feet to the ton, gives 605,000,000 tons.

Moa.—The deposit is very much like the one at Mayari. . . . The mantle of ore is a prominent feature within an area of about 60 square miles, being practically continuous, except where it has been cut by erosion along the stream valleys. It is roughly estimated that 60 per cent. of the area taken up, or about 36 square miles, will afford ore of mineable grade and quantity. . . . Taking the area of valuable ore at 36 square miles, and, as at Mayari, taking the average depth as only 15 feet, and allowing 20 cubic feet of material per ton of dried ore, we get 752,000,000 tons for a just approximation of the valuable tonnage of iron ore in the Moa field.

Cubitas.—The ore deposits are all surface mantles covering the plateau-like mesas. . . . It is thought that there must be at least 6,000 acres of the ore ground and that at least 150,000,000 tons of ore exist within the field. .

[1] Am. Inst. M. E., Vol. XLII, 1911, p. 88.
[2] U. S. G. S. Bull. 340, p. 320.

Another estimate makes the total tonnage of the three areas about 3,000,000,000.[1]

The following table shows the quantities of ore that have been shipped from the Mayari mines to the United States:—[2]

Year.	Tons.
1910	307,700
1911	387,791
1912	446,176
1913	491,713
1914	228,949
1915	300,896
	2,163,225

The ore shipped in 1915 carried 36.32 per cent. (natural) of iron and 56.30 per cent. (nodulized).

The characters of the iron and steel produced from Mayari ores are described on other pages of this report.

CHINA

The following note on the occurrence and uses of nickel in China is by T. T. Read.[3]

Nickel is of much technical interest because of the ingenious way the Chinese have of smelting mixtures of nickeliferous copper-ores with tin, lead, and zinc-ores, forming the alloy "pai-t'ung," or "pahfong," as it is called in southern China. This is a kind of German silver, which is extensively used in the manufacture of candlesticks and other household objects. Nickel is never produced separately, and the entire supply is apparently drawn from southwestern China, where in Yunnan (at 100°20′ E. 26°50′ N.) and in Ssu-chuan (100°20′ E. 26°45′ N.) Duclos has noted the occurrence of nickeliferous copper-ores.[4]

EGYPT

A small quantity of nickel ore, similar to that of New Caledonia, has been mined in Egypt from a deposit associated with peridotite on St. John's Island, Red Sea. On the mainland, there is also peridotite, and some large areas of serpentine, which may prove to be nickel-bearing.

The following description of the St. John's Island occurrence has been furnished by Max Ismalun, through R. H. Greaves, chief of the Department of Mines, Egypt.

There is a hill 1,000 feet high, composed of peridotite, which has pierced through the Tertiary beds of the island. These beds are represented by coloured limestone and carbonaceous sandstone and gypsum, and sometimes by schists or gneisses.

The peridotitic rock has various aspects as far as colour, grain and hardness are concerned, and presents a great quantity of fractures which probably took place during the cooling stage of the peridotitic magma.

These fractures are generally filled up with serpentine. . . .

The nickel ore, similar to garnierite, also occurs in veins more or less, vertical, whose fractures have probably the same origin; but are generally of much greater size. One of these veins has been proved to have a length of 150 feet, a depth of 120, and a thickness varying from 2 to 5 feet.

[1] The Mineral Industry, 1913.

[2] Mineral Resources of the United States, 1915, Part I, p. 317.

[3] Am. Inst. M. E., Vol. XLIII, 1912, p. 45.

[4] Duclos: La Mission Lyonnaise d'exploration commerciale en Chine, 1895-7, pp. 283 to 318 (Lyons, 1898).

The filling itself is a mixture of garnierite and iron oxides, and has a banded aspect; that is to say, there is a longitudinal band of garnierite in the centre, on both sides of which occur two bands of iron oxides, then again two bands of garnierite, and so on.

When working the vein, which is very friable, it is hardly possible to separate the two kinds of ore. This, moreover, would not be advisable, as the iron oxides contain 2 to 4 per cent. of nickel.

The composition of the garnierite ore is as follows:—

	Per Cent.
Ni	9.48
SiO_2	32.26
Al	4.89
Cu	0.40
Fe	15.42
Mn	0.19
Cr	0.08
CaO	0.26
MgO	18.51
S	0.12
O	9.34
H_2O	9.01
Total	99.96

The mixture of garnierite and iron oxides averages 6.5 to 7 per cent. Ni. This ore would be first class did it not contain about 0.5 per cent. copper impurities, that are an obstacle to any smelting process. Electrical separation has been tried with success and seems to be advisable for this kind of ore.

It has been noticed that the proportion of iron oxides increases in depth and that naturally the garnierite diminishes.

Development work is not sufficiently extensive to enable us to figure the quantity of high-grade ore available. A few thousand tons are in sight at the present moment. Besides the vein filling, I have found some impregnated superficial patches of ground containing from 1 to 2.75 per cent. Ni. Should these be workable on the spot, the ore tonnage would be greatly increased.

FRANCE

Rich silver ores, with cobalt and nickel minerals, discovered in 1767, were worked at Chalanches, Dauphiné, France. The ores occurred in a network of narrow veins in crystalline schists. That the presence of nickel and cobalt was not recognized in the earlier period of working is seen from the following quotation:—

> It is not a little remarkable that although the silver is always associated in the lodes with rich nickel and cobalt ores, often with bunches of stibnite, and more rarely and erratically with gold, the government engineers took no notice of any metal other than silver. None of the valuable metals mentioned figure in the old accounts. The speiss containing nickel and cobalt was rejected with the slags, and went to fill the swamps and to form the road-beds, which, in later times, were furrowed and turned over to recover their valuable contents. . . .
>
> The possibility of utilizing three metals instead of one seems to have dawned upon the engineers quite as a discovery; and this fact stimulated the repeated spasmodic attempts to rehabilitate the old mine. The arsenides of nickel and cobalt were sold in England and Germany. More recently, a German chemist was employed at Allemont in an experiment to manufacture cobalt pigments for the arts. He was not successful, and the attempt was abandoned.[1]

GERMANY AND AUSTRIA

Although deposits from which nickel-bearing ores have been mined occur in a considerable number of localities in Germany and Austria, in normal times the production of the metal from domestic ores is comparatively small. Owing to conditions that have existed during the war, it is likely that the production from domestic ores has been increased. Certain deposits that have been lying dormant for years would probably be reopened.

[1] T. A. Rickard, Trans. Am. Inst. M. E., Vol. XXIV.

As shown on preceding pages, for many years part of the nickel ore produced in New Caledonia has been refined in Germany. But prior to the war the greater part of the nickel used in the two countries was imported in the refined state.

Several varieties of nickel ores have been mined in these countries. They include arsenides, sulphides, and silicates, corresponding to those of Cobalt, Sudbury and New Caledonia, respectively. The following deposits, some of which are of little more than historical interest, may be mentioned:—

(1) Arsenical ores carrying cobalt, nickel and other metals, such as those of Dobschau, Annaberg, Schneeberg, Joachimsthal and Dillenburg.

(2) Pyrrhotite ores of Sohland,[1] discovered in 1900, Schweiderich, and Horbach.

(3) Silicate ores:—"In recent years nickel has been extensively mined at Frankenstein in Prussian Silesia . . . At the present time the nickel deposits have been mined to a depth of 183 ft. . . . In 1901, 9,500 tons of ore were extracted and 114.3 tons of nickel were produced. There was a considerable increase of production in 1902."[2]

GREAT BRITAIN

That nickel ores have been produced in Great Britain, one of the largest refiners of foreign ores, is seen from the following notes:—

Pentlandite, a sulphide of iron and nickel, was some years since worked at Glen Essochossan, two miles from Inveraray, as well as at Craignure, in the vicinity of Loch Fyne, eight miles distant from the same town. About 300 tons of ore averaging 14 per cent. of nickel are stated to have been sold from these mines. In a sample of the ore from the Craignure mine Mr. F. Claudet found, in addition to the usual percentage of nickel, a considerable amount of tin oxide.[3]

In Great Britain nickel is found associated with iron at Voel Hiradig, Cwm, in Flintshire. Since 1870, 675 tons 14 cwt. of nickel iron ore have been raised on this mountain, of the value of £3,691, or about £5 10s. per ton. The average proportion of nickel was 2.3.[4]

GREECE

In Greece both nickeliferous iron ore, similar to that of Cuba, and garnierite, resembling the New Caledonia ore, have been produced.

The following notes concerning the Grecian deposits are taken from a paper by H. K. Scott,[5] little having been published by other writers descriptive of these occurrences.

With the exception of some mineral used by Mr. Arthur W. Richards for the production of a high-class steel in 1907, the Greek chromiferous iron ore imported into this country has been mixed with other ores for the production of ordinary steel, which has involved the elimination of the chromium at some trouble and expense. . . . Chromiferous iron ores occur in the western part of Greece in the States of Lokris and Boitio, and on the islands of Eubœa, Skyros, and others of the Grecian Archipelago. The most important deposits are situated in the district bounded by the bed of the drained Lake Copias and the west coast of the Talanta Channel. The country is mountainous, rising in places to 4,000 feet above sea level, and the climate is healthy, except on the bed of the extinct lake, where the marshy ground fosters malaria.

[1] C. W. Dickson, Jr. Canadian Mining Inst., 1906, p. 253.
[2] Beck, The Nature of Ore Deposits, 1903, Weed's translation, p. 349.
[3] A Treatise on Ore Deposits, J. A. Phillips and Henry Louis, 2nd ed., p. 321.
[4] Metalliferous Metals and Mining, D. C. Davies, 1888, p. 287.
[5] Chromiferous Iron Ores of Greece and Their Utilization, Jr. Iron and Steel Inst., No. 1, for 1913, pp. 447-467.

The deposits are all within a few miles of the coast, which, being much indented, furnishes excellent loading ports.

Chromiferous iron ore was first discovered in Greece by an Italian named Novara, who had worked at the Laurium lead-zinc mine and was prospecting in the Larmes district in 1901, on behalf of the former Minister of Marine, Boudouris. Subsequently other ore bodies were found in the vicinity and on the islands already mentioned. . . . Shipments of the mineral to the end of 1912 have been as under:—

Property.	Tons.
Lokris	430,000
Thebes	600,000
Tsouka	400,000
Lutzi	200,000
Skyros	300,000

In 1909 a discovery was made in the Thebes and Lokris deposits of garnierite (the hydrated silicate of magnesium and nickel) containing 4 to 5½ per cent. of nickel in the dry ore, and of this 24,000 tons has been exported. . . .

The principal formations represented in Greece are the Archæan, Cretaceous, and Tertiary systems, with volcanic rocks in abundance, of which serpentine, altered from peridotite, covers a large part of the Grecian mainland, as well as the island of Eubœa and others, and even extends to Asia Minor. Over the whole of this serpentinous area chrome and chromiferous iron ores are reported to occur, although they are often not sufficiently pure to have any economic value.

In the Lokris and Boitio districts, segregations of irregular character, as well as ore bodies of lenticular form, are found, either as fissures in the limestone of Cretaceous age, as at the Thebes and Lokris properties, or as contact deposits between the serpentine and limestone, as at Tsouka, Karditza, Lutzi, and probably Pavlorado. Whilst the deposits have as a rule their longer axes parallel with the lines of cleavage or contact of the enclosing rocks, those in the fissures of the limestone are more irregular in shape, presumably by reason of the substitution and erosion of the "country" rock being more general, and are distinguishable from the contact deposits, which assume a banded character.

The ore consists of hard grains or shot-like particles and nodules of irregular shape, up to half an inch in diameter, of brown hematite which has a sub-metallic fracture, associated with a variable quantity of a binder or matrix of a more hydrated, amorphous, and softer ore which often exhibits "slicken-sides."

In the Tsouka and Karditza properties the mineral is quite compact and bears transport without making small, but the greater part of the ore from the Thebes and Lokris deposits, as well as that of Lutzi, disintegrates on handling, and assumes a physical condition which is prejudicial to its use in the blast-furnace.

The composition of the ore, in the dry, of the different deposits varies within the following limits:—

	Per Cent.
Iron	46 to 52
Alumina	6 " 14
Silica	5 " 11
Chromium	2 " 3
Nickel and cobalt	0.10 " 1.2
Phosphorus	Trace " 0.03
Sulphur	0.02 " 0.05
Titanium	Trace " 0.30

The garnierite is found only in the Lokris and Thebes deposits, irregularly distributed in the serpentine on the foot wall of the chromiferous iron ore. It exists in small stringers or nests, and the mineral is invariably in a finely divided state.

Regarding the genesis of these deposits, it may be referred to a peridotite, containing appreciable quantities of chromium, nickel, and cobalt, which has been intruded into the Cretaceous limestone. . . .

By reason of the irregular occurrence of the chromiferous iron ore and the garnierite, it is not possible to estimate the quantity of either mineral in the Greek deposits likely to be available for extraction at a profit. The chromiferous iron ore deposits are, however, so large and well distributed that they will no doubt yield a large quantity of mineral for many years, although exploratory work has proved that in several of them, notably those of Lokris and Thebes, the mineral proves to be somewhat poorer in depth, the iron contents being reduced to 45 per cent. in the dry ore. . . . The Lokris and Thebes ore bodies occur on several spurs, separated by deep ravines, of the Scropo Neri mountains, seven miles to the southwest of the port of Larmes. The highest point of the outcrop is 1,200 feet above tide and 600 feet above the bed of the extinct Lake Copias. The deposits have a general north-northeast direction, and a dip varying from the vertical to 30° to the west-northwest.

The mineral is intercalated between walls of white limestone in lenticular-shaped bodies, which in places swell out into what are termed "pockets," in which the ore is much mixed with boulders of the "country." Between the mineral and the enclosing rock a ferruginous schist or altered serpentine is found, and the limestone of the hanging wall has a yellowish tinge over a limited thickness. . . .

At the time of the author's visit there was no appreciable difference in either physical condition or composition between the quarried ore near the surface, and that mined 250 feet below on the Lokris property. A number of quarry samples gave 47.5 per cent. of iron, whilst several samples from the underground workings contained 47.9 per cent. of iron in the dry. Further underground work at a lower level has, however, indicated a gradual decrease in the percentage of iron.

The average composition of the mineral in the dry ore from the Thebes and Lokris properties is as follows:—

	Per Cent.
Iron	46.00
Alumina	14.00
Silica	8.00
Chromium	2.50
Nickel and cobalt	0.60
Phosphorus	0.02
Sulphur	0.03

. . . . .

The Tsouka property is nine miles northwest of the port of Larmes. The mineral outcrop contours two conical hills, covered by a residual clay, over a length of one and a half miles, at a height of 800 feet above sea level. The deposit lies on the serpentine with limestone as the hanging wall, and dips 5° to the northwest.

The ore-body averages 10 feet in thickness, and consists of compact hæmatite either of an amorphous character with sporadic pellets which have a metallic fracture, or as a conglomerated mass of a pisolitic character. The mineral in the upper part of the deposit is somewhat softer than the rest, but even so, the physical condition of the mineral is excellent for the blast-furnace. Its average composition in the dry is as follows:—

	Per Cent.
Iron	52.00
Alumina	7.00
Silica	7.00
Chromium	2.00
Nickel and cobalt	0.70
Phosphorus	0.01
Sulphur	0.04

The Karditza deposit is five miles southwest of the Thebes property, and the ore outcrops on the summit of a hill over a length of upwards of half a mile with a southeast strike, and dips to the southwest with an angle of 30°.

The mineral lies between the limestone and serpentine, and, at the time of the author's visit, had been approached by a cross-cut 200 feet in length from an adjoining ravine through the altered eruptive. The contact with the limestone is somewhat sharp, but on the "foot" the deterioration in the quality of the ore is gradual as the serpentine is entered.

The ore-body had been drifted upon over a length of 300 feet, and was found to average 10 feet in thickness. . . .

The total cost (including State charges) of placing mineral f.o.b. loading port is about 5s. per ton, and the selling price is 5s. to 5s. 3d. per ton, with 10d. for loading, or say 6s. per ton.

The freight rate of tramp steamers to Western European ports was recently as high as 10s. per ton, but is now 7s. per ton.

From the quotations given it will be seen that certain of the nickeliferous iron deposits of Greece occur under somewhat different conditions from those of Cuba and the garnierite ores of New Caledonia. In the case of both these countries the ores form a mantle on the surface of the serpentine from which they have been derived. The Grecian deposits, in the descriptions quoted, appear to have been formed from the weathering of dikes, which occupy fissures in Cretaceous limestone, or from the weathering of serpentine over which lies a wall of limestone. Moreover, the Grecian ores are mined to a much greater depth than those of Cuba and New Caledonia.

The following note concerning the Grecian garnierite ore is of interest:—

One of the most interesting nickel deposits in Europe, on the Grecian island of Lokris, 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. Through the kindness of Dr. Mohr, of London, and Mr. V. Hybinette, of Kristianssands, 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 Kristianssands 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 Kristianssands 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.[1]

INDIA

The following notes summarize the information available concerning the modes of occurrence, consumption and uses of nickel in British India:—

Ores of nickel (nickeliferous pyrrhotite) have been found amongst the copper-ores of Khetri and other places in Rajputana. Nickel has also been detected in small quantities in chalcopyrite and pyrrhotite found associated with the gold-quartz reefs of Kolar, and in pyrite said to be from the Henzada district of Burma. Complex sulphide ores, consisting of pyrrhotite, pyrite, chalcopyrite, and molybdenite, have been received from the Tobala taluk in South Travancore. Both nickel and cobalt are present in quantities beyond mere traces, but nothing is yet known as to the extent of the deposits, nor have any proper average samples been assayed. A surface sample of ore showed 1.20 per cent. of copper, 0.64 per cent. of nickel, and 0.08 per cent. of cobalt, with 12 grains per ton of gold and 2 dwts. 12 grs. per ton of silver. Further investigations may show that the deposits are richer than is indicated by this analysis.

There is a considerable consumption of nickel in India in the form of German-silver, the annual imports of which during the five years 1909 to 1913 have averaged 1,103 tons, worth £115,388. . . . Further, on the 1st August, 1907, the issue to the public was commenced of the new 1-anna nickel coinage, consisting of an alloy of 25 parts of nickel with 75 of copper, leading to a further consumption of nickel, statistics for which are not available.

The imports of nickel received at the Bombay Mint during the period 1909-13 have totalled 175.3 tons (4,767 maunds 2,734 tolas) valued at £30,671.[2]

[1] A. P. Coleman, The Nickel Industry, Mines Branch, Ottawa, No. 170, pp. 117-118.
[2] Records of the Geological Survey of India, Vol. XLVI, 1915, pp. 281-2.

ITALY

Nickel deposits of Varallo, Piedmont, Italy, although small, are of interest, since, in mineralogical composition and in their association with basic rocks, they resemble those of Sudbury and Norway. Like many other small deposits, they were worked in the period preceding the discovery of the New Caledonia ores and a little later. In 1876 two mines had a total production of about 2,800 tons of ore, containing 1.20 to 1.44 per cent. of nickel, 0.36 to 1.00 of cobalt, 0.50 to 0.72 of copper, and 28.00 of sulphur.[1]

MADAGASCAR

During the last few years attention has been directed to an occurrence of nickel in Madagascar, where the metal is found under conditions similar to those of that other French colony, New Caledonia. The garnierite ore in Madagascar, compared with the occurrences in New Caledonia, covers only a small surface.

In a letter dated August 19, 1916, from A. E. Roberts, President, Syndicat Minier de Madagascar, the Commissioners received permission to publish the following description by him of the deposit, said to be the only proved Madagascar deposit:

> The deposit is situated immediately to the south of the village of Valzoro, District of Ambohimasoa, Province of Fianarantsoa, Madagascar. The port of Mananjary is situated 145 miles to the southeast of the property.
>
> The total area of the concession is 1.5 x 1 kilometres, or 370.5 acres. Work so far has proved the existence of nickel ore on 82 acres; further exploration will probably slightly increase this area.
>
> The nickel occurs as garnierite. By the work carried out by our engineer, the existence of nickel ore has been proved to extend over an area of 82 acres, which forms a hill, situated in the centre of the concession. This hill has a height of 500 feet above the lowest part of the deposit, *viz.*, the bed of the stream in the southeast corner. The deposit consists of a laccolith, or mass of ultra-basic rock, which probably at the time of its upheaval did not quite reach the surface, subsequent denudation having laid it bare in places. Through shrinkage in cooling, and by the pressure of the overlying gneiss, the basic rock has been split into a network of seams and cracks. Along these irregular lines of breakage the original rock has been altered to serpentine.
>
> The nickel is found in these cracks in thicknesses varying from a film to over an inch, and the nickel has also permeated into the soft serpentine. The depth to which the alteration extends has not been proved, but shafts have been sunk to a depth of 60 feet without passing beyond the altered zone. . . . .

Judging from what is known of deposits of this kind in New Caledonia, Cuba, and elsewhere, a thickness of 60 feet or more of this ore would not contain merchantable material throughout. As decomposition of the rock proceeds from the surface downward, nickel and certain other elements tend to migrate and are carried downward by water. Hence it would be expected that the upper part of the Madagascar deposit would not contain nickel in economic quantities, but that the lower part would contain a greater concentration of the metal.

From another source it is learned that ". . . . in one of the groups of nickel mines. . . . there are 125,000 tons of 5.5 per cent. ore, with a further probable 250,000 tons of 4 per cent."

There are two ports from which the ore or its products might be shipped, Tamatave, about 360, and Mananjary, 120 miles from the property. The latter is

[1] Badoureau, Métallurgie du Nickel, Paris, 1877.

an undeveloped port, and seems likely to remain so, while the construction of a continuation of the railway from the former to the vicinity of the deposit may be looked for in time.

Water power capable of producing 3,000 or 4,000 horsepower is said to be available within about 35 miles of the deposit. There is a supply of sulphur on the island, together with charcoal and other materials.

It is said that a new process of refining has been tried on these ores with promise of success.

MEXICO AND SOUTH AMERICA

Nickel has been refined in Europe from South American ores, apparently produced as by-products in the mining of silver and other ores. Both cobalt and nickel occur in a number of localities in Mexico and South America, but no important deposits are known.

PHILIPPINE ISLANDS

In the island of Mindanao are found deposits of iron ore of similar character to those of Cuba and Borneo, already described. While the only detailed analysis available, quoted below, shows chromium, it gives nickel as being absent. It is scarcely to be expected, however, that on further investigation nickel will be found to be absent in all parts of these large deposits. The Philippines can be said to be neighbouring islands of Borneo and Seboekoe. The situation of Mindanao is shown on the map, page 234.

The following notes on the Mindanao deposits are taken from a paper by W. E. Pratt[1]:

On the eastern coast of Surigao Province in Mindanao there is an area of about 40 square miles, bordering the sea for a distance of 10 miles, which is conspicuously barren of vegetation and is covered with a bright red soil. This condition is the more notable in that the surrounding country is heavily forested; and the singular barren appearance of this one section of the coast line has been a subject of interest for years to those who knew of it. But the region is sparsely inhabited, and but few boats pass along that coast; consequently it was not until the year 1914, when H. F. Cameron, an engineer who is familiar with the iron ores of the Nipe Bay region in Cuba, made an inspection trip through Surigao that the "Red Hills" . . . were found to be covered with laterite rich enough in iron to constitute an ore.

The laterite mantles a dissected plateau ranging up to 1,500 ft. in elevation and terminating along the coast in sea cliffs and steep slopes. This part of Mindanao receives a rainfall that averages about 10 ft. annually. . . .

While there are no regular harbours near the ore deposit, Dahikan Bay, at its southern extremity, is almost landlocked, and is perfectly protected at all seasons. . . .

The ore deposit and the ore itself are strikingly similar to the lateritic iron ores of the Mayari district in Cuba. . . .

The Philippine laterite, or iron ore, is a surface blanket of residual clay varying in thickness up to 60 ft. and resting upon the parent rock from which it has been derived by tropical weathering processes. . . . .

The parent rock, wherever exposed within the limits of the ore deposit, is essentially serpentine.

In composition the Surigao iron ore appears to be slightly inferior to the ores of the same character in Cuba. . . . The results of the sampling tests indicate that the Surigao ore is remarkably uniform in composition throughout the deposit. . . .

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[1] Am. Inst. M. E., Vol. LIII, W. E. Pratt, The Iron Ores of the Philippine Islands, pp. 101, 102, 103, 104, 105.

The only detailed analysis of the Surigao ore was performed upon a sample taken from the surface by Mr. Cameron. This analysis follows:

	Per Cent.
Hygroscopic water	13.50
Combined water	6.60
Silica	1.04
Alumina	10.56
Ferric oxide	66.80
Ferrous oxide	0.36
Chromium oxide	1.15
Nickel oxide	nil
Sulphur	trace
Phosphorus	trace
Total	100.01
Metallic iron, dried ore	54.29
Metallic iron, ore deprived of combined water	58.20

In its lack of nickel, as represented by the single analysis, the Surigao ore is different in an important respect from the Cuban ore. . . .

In attempting to ascertain what quantity of ore is present in the Surigao deposit and what percentage of iron is contained in the average ore, hand drills were employed to determine the thickness of the ore mantle at different places and to secure representative samples of the ore from different depths. . . . From these figures and the weight of a unit volume of the ore in place it can be calculated that the total economically important metric tonnage is 430,000,000, of which about 375,000,000 tons is contained in that part of the ore mantle which is 10 ft. or more in thickness.

RUSSIA

At Redwinsk (or Revda), in the Urals, are nickel deposits of the garnierite type, resulting from the weathering of serpentine, which is intercalated between schists and crystalline limestone. Attempts were made to mine these deposits as early as 1866, and there has been a small production at various times. Judging from the following, more serious attempts at utilizing the ore have recently been made:—

Russian nickel deposits in the Urals, which have not heretofore been worked on account of the low grade of the ore, are now being exploited. The ore mined is being treated at the Redwinsk smelting works, which are reported to be turning out at the rate of 600 tons yearly of nickel matte.[1]

SOUTH AFRICA

The occurrence of nickel-copper ores in association with a sheet of basic rocks in the Insizwa range has caused various writers to compare these South African deposits with those of Sudbury. But there is only a distant geological similarity between the two. Moreover, no workable deposits have yet been found in the Insizwa range, although attention has been directed to the occurrence for a number of years. Should large masses of picrite with disseminated ores be discovered, the probability of which has been suggested, such deposits would scarcely be serious competitors of the large massive ore deposits at Sudbury.

A very interesting and complete description of the modes of occurrence of these nickel-copper ores has recently been published by W. H. Goodchild.[2] This paper includes observations of earlier workers, besides containing much information gathered by Goodchild himself.

[1] Eng. & Min. Journal, Nov. 6, 1915, p. 759. See also Vol. XLVIII, pp. 118-124, A. I. M. E.

[2] Economic Geology of the Insizwa Range, Inst. Min. & Met., Bull. No. 147, Dec. 14, 1916, with discussion, Bull. No. 148.

The structural relations of the gabbro sheet, consisting of olivine gabbro, picrite and other varieties, are described in the following extracts from Goodchild's paper:

Overlying these hornfelses is the great gabbro mass which gives rise to a bold, steep and frequently precipitous escarpment with peaks situated a little way behind the escarpment, rising to heights over 3,000 ft. above the level of the neighbouring valley and more than 6,000 ft. above sea level. A rudely columnar structure is not infrequently shown in the cliff face. On the mountain top and at varying distances from the face of the escarpment, the upper surface of the intrusive dips inward at low angles under another series of hornfelses resembling in a general way those at the base. These pass gradually into a series of sedimentaries also similar to those at the base and, like them, they are also lying practically horizontal. . . .

The thickness of the gabbro sheet varies. It probably averages some 2,000 ft. and exceeds 3,000 ft. in its thickest parts. The dip of the sheet is inwards towards the centre of the oval, and the dip of the basal contact round the periphery of the mountain, though varying considerably from point to point, probably averages about 30°. The shape of the gabbroid mass is therefore roughly that of a thick shallow basin. It thus stands in a cross-cutting relation to the bedding planes of the encasing sedimentary rocks and is not truly laccolithic in its mode of occurrence.

According to Goodchild, the ore deposits may be classified into four distinct types:

(1) Mineralized norite or picrite containing disseminated sulphides of copper, nickel and iron.

(2) Small fissures filled almost entirely with sulphides of copper, nickel and iron.

(3) Vein-like sheets of acid rock containing similar sulphides disseminated and in masses.

(4) Dolerite dykes, cutting the main sheets and sedimentaries, containing disseminations and thin veinlets of sulphides and occasional arsenides of the same series of metals.

All four types have this feature in common, namely, that they carry sulphides only in the near neighbourhood of the lower hornfels-gabbro contact. Types (3) and (4), however, may contain ore minerals at considerably greater distances from the contact than (1) and (2).

The mineralized picrite is probably the most important kind of deposit as yet discovered at Insizwa, since it appears to possess greater economic possibilities than the others. . . . . . It would scarcely be surprising, therefore, if prospecting of the lower margin of the intrusive at greater distances from the face of the escarpment than has hitherto been attempted led to the disclosure of large bodies of mineralized picrite of profitable grade, despite the fact that nowhere along the range is there any outcrop of this mineralized rock of sufficient grade to enable it to be exploited at a profit. . . .

The solid sulphide veins are of small dimensions and irregular in all their characteristics. They occur in the near neighbourhood of the hornfels-gabbro contact, commonly passing a short distance up into the sheet and down into the hornfels. Individual fissures have been traced for a horizontal length of 100 ft. or so, and, while they occasionally attain a width of 2 ft., 6 ins. is probably a liberal estimate of their average thickness. They ramify and have no well-defined strike or dip, though there seems to be a tendency for them to strike with a rough parallelism to the contact. The fissures are filled almost entirely with sulphides of copper, nickel and iron, but the relative proportions of the minerals are subject to the widest variations from point to point. The copper contents may vary from 1.5 per cent. to 20 per cent., nickel from 1.5 per cent. to 10 per cent., while the average is probably about 4 per cent. of each of these metals. Platinum is frequently present but is erratically distributed. The average, as far as can be judged, is probably between 2 and 3 dwt. per ton, a by no means inconsiderable amount, while occasional samples containing several ounces to the ton have been obtained. Gold and silver are also present in small amounts.

The hornfelses in the near neighbourhood of these veins also occasionally contain small pellets of sulphides as well as small amounts of fine disseminated sulphide.

These veins seem to be akin to gash veins and they are the "will-o'-the-wisp" formations upon which the greater part of the mining activity along the range has been concentrated hitherto, with disappointing results. They appear to be distributed over a wide area, for the most random kind of prospecting at many points separated by wide intervals has shown their presence, even where there are no definite surface indications of their existence. It seems to have been quite the exception for an adit to be driven to the contact without striking either mineralized rock or one or more of these stringers. The exceptions generally occur where the overlying gabbroid rock is of a more acid character than picrite. . . .

"The order of separation of the sulphides in the picrite, as determined by du Toit, is (1) chalcopyrite, (2) pentlandite, (3) pyrrhotite; and, as he points out, this is exactly the reverse of that obtained by Campbell and Knight in the copper-nickel deposits of Sudbury, Norway and elsewhere.

"He [Goodchild] concluded by saying that there was nothing more than a distant geological similarity between the Insizwa and Sudbury occurrences, although Insizwa had on several occasions been dubbed 'The Sudbury of South Africa.'"[1]

Two trial shipments of some five tons each, apparently from the "solid sulphide veins," sent to Johnson, Matthey & Co., on analysis gave the following results:—

	1	2
Copper	3.40 per cent.	3.50 per cent.
Nickel and cobalt	4.90 per cent.	5.25 per cent.
Gold	6 grains per ton.	6 grains per ton.
Platinum	2 dwt. 12 grains.	12 grains.
Silver	10 dwt.	12 dwt.

The mineralized area of the Insizwa range is situated close to the boundary between East Griqualand and Pondoland, some sixty miles from the east coast of the Continent, in the well-watered region drained by the upper tributaries of the St. John's river. The Tritsa falls, said to be the second largest falls in South Africa, are distant about forty miles from the centre of the range; at the mouth of the main river is the port of Fort St. John's.

A little work appears to have been done on the copper veins in this range about 1865, but it was not until over forty years later that the sulphides, supposed to contain copper and iron only, were found to contain nickel also. Shortly afterwards the presence of platinum in the ores in variable but appreciable quantities was discovered.

In connection with the occurrence of nickel in South Africa, it may be added that considerable cobalt is contained in crude copper produced in the Belgian Congo, which, prior to the war, was refined in Germany. It has been estimated that probably 242 tons of metallic cobalt were derived from this source in 1913.[2]

SPAIN

A small quantity of nickel ore, of the garnierite type, was mined in the 'seventies in Malaga, Spain. Upper portions of the serpentine here contain secondary ores, garnierite and pimelite, and at greater depth the nickel arsenide, niccolite, is found.[3]

TASMANIA

Nickeliferous pyrrhotite occurs in deposits of small size in Tasmania, near the town of Zeehan. A few thousand tons of ore have been mined, and, although diamond drilling has been done on the deposits, but little ore has been proved to remain. While the ore is rich, the deposits are of little importance as competitors.

[1] Inst. M. & M., Bull. No. 148, p. 3.

[2] Min. Res. U. S. G. S., 1913, Part I, p. 339, and Min. Sci. Press, Feb. 21, 1914, p. 322.

[3] F. Gilman, Notes on the Ore Deposits of the Malaga Serpentines, Inst. Min. and Met., 1896.

Immediately prior to the war, January to July, 1914, about 3,000 tons of ore were mined and shipped to Germany. This ore averaged 10.368 per cent. in nickel and 5.291 in copper. The percentage of iron was about 42 and that of sulphur 38. It may be added that a little garnierite occurs near Trial Bay.

The following quotations, from two papers, one published in 1902 and the other in 1915, give the character of the deposits and associated rocks:—

1. There are two deposits of this class known in the North Dundas district, and, though there is reason to believe that neither of them is of commercial value, it is important that the facts of their occurrence should be recorded, as deposits of the same class which are of sufficient dimensions to become of economic value may be found in other parts of the coast.

The most important of the two deposits in the North Dundas district is situated on section 3510-93m, near where the Emu Bay Railway crosses the North-East Dundas Tramway. The deposit was found in the bed of a small creek which flows through the section. The creek had completely filled up the old workings and I could not examine them, but Mr. G. Beardsley, metallurgist to the Mt. Lyell M. and R. Company, who was interested in the mine at the time the work was done, has kindly furnished me with the following information:— The deposit occurred at the junction of the slate and the decomposed gabbro. On first appearance it gave promise of being a big lode, but afterwards proved to be merely a rock-cavity filled with nickeliferous pyrrhotite. This was connected with a small leader a few inches thick and 12 or 15 feet in length. The water was very heavy, and the leader was not followed down for more than 20 feet. Several parcels of ore were sold, carrying from 8 to 12 per cent. of nickel, 3 to 5 per cent. of copper, an ounce or two of silver, and a trace of gold. The ore was composed principally of nickeliferous pyrrhotite, containing in places small crystals of millerite. This occurrence is evidently of the same type as the nickeliferous pyrrhotite deposits of Sudbury, in Canada, though on an extremely small scale. These deposits are invariably found at or close to the contact of gabbro with the surrounding rocks, and occasionally form short veins in the latter. . . . The dimensions of the gabbro intrusions at North Dundas are very small in comparison with the enormous masses which occur in Canada and Norway, and this may account to some extent for the small dimensions of the ore deposits. North of the Pieman River, however, very much larger masses of gabbro are known, and it would be well worth while for prospectors in that district to be on the look-out for large deposits of pyrrhotite at the contact of the gabbro and the sedimentary rocks. . . .

The other deposit which I have referred to is situated on the old King Curtain Mine, about three-quarters of a mile north of Ringville. The formation was cut in an old tunnel which was put in from the side of the track between Ringville and the Colebrook mine. I have only examined the ore at the mouth of the tunnel. It consists of veins and bunches of iron pyrites in quartzite, with small needles of millerite through it. The quartzite also contains small needles of millerite in the joints. Just beyond the tunnel the track passes through a small patch of serpentinised gabbro, so that it is evident that this deposit is also at or close to the contact of this rock. I am not at all sure that this deposit belongs to the same type as the last, but I think it is probable. The millerite in the joints of the quartzite is evidently of secondary origin, and indeed the whole deposit may have been altered considerably by the action of underground waters since it was formed as a segregation from the gabbro.[1]

2. The two principal known occurrences of the metal are in the west of the island, one of which is in the Dundas mining district near Zeehan, and the other on the west coast at Trial bay, 14 miles away. During the past three or four years considerable development work has been done on the Dundas deposit, where four separate ore-shoots of high-grade copper-nickel ore have been found on a line of contact between serpentine and slate rocks extending for about a mile north and south. Two of the ore-shoots have been recently worked by private companies, which acquired adjoining properties. . . .

The deposits occur in the slate near its contact with the serpentine, as shown on the cross-section through one of the deposits developed. It will be seen that the irregular lenticular masses of ore that are farthest from the serpentine have pinched-out at shallow depths, while the ore-shoot nearest the contact with the serpentine continues downward from the surface so far as exposed, and has more the aspect of a contact-fissure deposit, which it may prove to be on further development.

The ore-shoots are principally composed of sulphides of iron, nickel, and copper, or nickeliferous pyrrhotite, and contain from 8 to 12 per cent. Ni and 4 to 6 per cent. Cu; lower-grade ore also occurs at a depth of 70 ft. in a portion of the lode nearest the

[1] Report by G. A. Waller to Secretary for Mines, Hobart, dated Zeehan, April 30, 1902, pp. 64-66.

serpentine, the face of the drift on it showing at one place 6½ ft. of ore, 4 ft. of which assayed 8.26 per cent. Ni and 4.2 per cent. Cu, the remaining 2½ ft. assaying 1.17 per cent. Ni and 1.80 per cent. Cu. Secondary enrichment is evidenced by the richer ore being found nearest the surface and by the ore becoming harder and more silicious with depth. The following assay of a 100-ton lot shows approximately the average contents of such ore as has been mined and shipped up to date: Ni 9.61 per cent., Cu 4.7 per cent., Fe 32.8 per cent., S 32.66 per cent., SiO_2 5.24 per cent. Some silver and platinum are present, as indicated by an assay for precious metals made by Daniel C. Griffith & Co., of London, who reported Ag 2.2 oz. per ton, Au trace, Pt 0.06 oz. per ton.

The association of nickel with serpentine is well known, and it has been proved to be one of the chief sources of the metal, though the ore deposits derived from it may be either of a secondary nature, resulting from erosion of the parent rock, or be primary deposits of magmatic origin. In the present instance the serpentine near the surface contains no traces of disseminated ore, as far as is known, yet it is quite admissible as the origin of the sulphide ore-shoots under notice, which are recognizable as contact-fissure deposits formed through the agency of ascending thermal solutions, subsequently enriched by erosion and descending surface water. It does not, however, follow that these ore-shoots, even if originating from a deep-seated source, will prove of great persistence in depth; other factors, known to students of ore deposition, require due consideration, and in the present case point to an early impoverishment with depth.

The Dundas deposits, although of unusually high grade, are of relatively small dimensions, the longest shoot of ore in any instance not exceeding 150 ft., with an average width of 4 to 5 ft.; so that richness and size are here exemplified in inverse ratio. Nevertheless, it has already been found, in one instance at least, that these deposits are workable at considerable profit, and were it not for the wet nature of the country and heavy influx of water into the mines, they would be veritable bonanzas in a small way. . . .

At Trial Bay, on the west coast, little exploration or development work has been done as yet. Within a short distance of the shore a hill of nickeliferous serpentine rises to a height of over 300 ft., and extends inland for some distance. Three adits, each about 100 ft. long, have been driven into the hill from different points of the compass. These adits have been sampled throughout their length, and samples have also been taken of the rock on the surface; the assays of the samples range from 0.34 per cent. to 0.83 per cent. Ni, their average being 0.51 per cent. The ore in the serpentine is said to be niccolite (NiAs), and to be disseminated in grains visible to the naked eye. In one of the adits a vein of high-grade ore consisting of garnierite, was intersected; this was sampled across a width of 12 ins. and assayed 13.35 per cent. Ni. The place of origin of the garnierite deposited in the vein is seen to be the enclosing rock that is impregnated with nickel, the garnierite being a secondary deposit of hydrous silicate of the metal, resulting from denudation of the serpentine and sub-aerial agencies.

The Trial Bay formation can be compared to that of New Caledonia, which is marked by the presence of nickeliferous peridotite changed into serpentine, and the occurrence of silicate of nickel as a secondary mineral. On the other hand, the Trial Bay nickel deposit bears no resemblance to that at Dundas, either in form or origin, though they both hold a common relationship to the serpentine, which is in one case impregnated with the metal, while in the other it does not appear to be so. It is worth noting that the sampling of one of the Trial Bay adits in the serpentine gave an assay of 0.83 per cent. Ni, and that the niccolite ore in the hill is amenable to water-concentration. Whether any portion of the metalliferous serpentine hill could be worked profitably as a low-grade proposition remains to be demonstrated. The garnierite deposits offer an additional inducement to further exploration of what may prove to be the most important occurrence of nickel in Tasmania. As regards local conditions, the Trial Bay deposit is without railway connection to any other place in the island, and in the matter of transport of ore to Europe, would be in a worse position than Dundas, as Trial Bay is a shallow open roadstead, so that all ore would need to be loaded into coasting vessels and taken to the ports of Strahan or Burnie for shipment to Europe by way of Melbourne or Sydney.[1]

It may be added that chromiferous iron ores, somewhat like those of Greece and Cuba, occur in Tasmania.[2]

UNITED STATES

While nickel ores have been found in numerous localities in the United States, this country's resources in the metal are comparatively unimportant. During the

[1] G. A. White, Mining Magazine, February, 1915, pp. 103-105.
[2] Journal Iron and Steel Inst., 1892.

last few years the production of nickel from domestic ores has come from the refining of blister copper, although the United States is the world's largest refiner of nickel. As shown on other pages of this Report, much the greater part of the nickel-copper matte produced at Sudbury and a minor part of the New Caledonia nickel are refined in the United States.

The following quotation from a recently published article gives a fair summary of the conditions in the United States as regards resources in nickel, and two other metals, manganese and chromium, that are of much importance in alloy steels:—

> The position of the United States in times of possible stress, as to supplies of the three most common steel-hardening metals, manganese, nickel and chromium, is not altogether reassuring. Our production of manganese and chrome ores has increased considerably under the stimulus of abnormally high prices in 1915 and 1916. In fact, the production of pure manganese ores in 1916 amounted to nearly 27,000 tons, against 9,000 in 1915. Still it is very far from filling our domestic needs. A timely attempt has been made recently by the United States Geological Survey to catalogue the occurrences of possible supplies of nickel ores, which, though not rich enough to use under ordinary conditions, might serve as emergency supplies. The result of this survey is about to be published. Aside from sporadic and poor deposits of nickel-bearing pyrrhotite, low-grade oxidized ores are known to exist, but it may well be doubted whether any process could be devised to treat such ores effectively. May we hope for discoveries of new deposits? It is possible, but doubtful. Areas of gabbro, like that of Duluth, and those of serpentine, as in California, should be closely scanned. A possible source of nickel which has recently attracted some attention is found in the iron ores of Mayari, Cuba. These limonite ores, which are derived from the weathering of serpentine, average about 0.6 per cent. nickel oxide, and experiments have been carried out recently looking toward the extraction of this nickel. It is said to have been ascertained that while most of this nickel is present as a hydrous silicate, there is a smaller part which is insoluble, and it is suspected that nickel oxide may be present. It is also well possible that in some parts of Cuba larger deposits, like those of New Caledonia, may still be found.
>
> On the whole the situation is discouraging, and this also applies to manganese and chromium. There is no use looking for chromium except in areas of serpentine, and all deposits so far found in the United States have been spotty and small. Three thousand tons of ore produced against seventy-six thousand tons imported—that tells the story.
>
> Manganese is more widespread, and many old mines, especially in Virginia, are being reopened. There are some promising low-grade iron-manganese ores, but the pure and high-grade manganese dioxide is very scarce. Such material is used, among other things, for dry batteries, and it is said that manufacturers of these have found it very difficult to obtain a supply. Aside from the unique oolitic ores of southern Russia, the manganese deposits seem to thrive best under conditions of tropical weathering such as do not obtain in this country.
>
> Cuba is rich in serpentine. There is also much manganese, and this southern neighbour of ours could possibly help us out quite a little in case of all three of these necessary metals.[1]

The catalogue of the occurrences of nickel ores by the United States Geological Survey, referred to in the preceding quotation, has been published.[2] It gives an interesting epitome of the occurrences. The following extracts from the publication contain the introductory and other notes together with the description of the Missouri deposits. These deposits are of most interest at the present time since preparations are being made for resumption of work in extracting nickel, cobalt and copper, in addition to lead, from them. The old plant at Fredericktown has been remodelled and additions made. It is expected that the production will soon be at the rate of 800 to 1,000 tons of nickel a year. The property is controlled by a Canadian company. The ore to be treated for nickel is said to contain

[1] Eng. and Mining Journal, New York, Jan. 20, 1917.
[2] Nickel in 1915, Min. Res. U. S., 1915, Part I, pp. 743-766, published January, 1917.

approximately the following percentages of metals, lead, less than 2; copper, 2.5; nickel, 0.9; and cobalt, 0.5.

No nickel ores are known to have been mined in the United States in recent years, but an equivalent of 822 short tons of nickel was saved in 1915 as a by-product in the electrolytic refining of copper. Of this output the larger part was marketed as metallic nickel and the smaller part was contained in hydrous nickel sulphate.

What part of this nickel came from American pig or blister copper and what part from foreign copper is uncertain, but it is roughly estimated that American ores produced between one-half and two-thirds of the whole. The foreign copper came from many countries and from every continent. The companies reporting a production were the American Smelting & Refining Co., Nichols Copper Co., Raritan Copper Works, and United States Metals Refining Co.

The great bulk of the nickel supply of the United States has been drawn for years from Canada. During 1915 smaller quantities were imported from New Caledonia, Australia, and Norway.

During the general stock-taking which has been going on in the United States during the last year many questions as to the country's resources in nickel have been asked, and in order to answer these questions and to show what nickel and nickel ore would be available in case of urgent need and shortage of supplies from other countries, the information available on the deposits of the United States has been epitomized in this paper.

The nickel deposits of the United States are small compared with the unrivalled deposits at Sudbury, Canada, but they have in the past made some production and will probably do so again. Nickel in quantities sufficiently large to excite attempts to exploit the deposits on a commercial scale has been found in California, Colorado, Connecticut, Idaho, Missouri, Nevada, New Mexico, North Carolina, Oregon, Pennsylvania, Virginia, and Washington under very diverse conditions and smaller deposits have been found in other States. . . .

During 1915 there was no known market for nickel ores in the United States. The large smelting companies bought only gold, silver, lead, zinc, and copper ores, and if nickel were present no allowance was made for it. As the nickel can be smelted with the copper into matte and can be separated in electrolytic refining and as nickel is now being saved by the refineries, it would seem that the purchase of nickel ores might be made mutually profitable to both smelters and miners.

No direct production of nickel from American nickel ores is known to have been made in this country since 1909, when the American Lead Co. operated a smelter at Fredericktown, Mo., for a short period. . . .

Missouri Deposits

The nickel deposits of Missouri are on the eastern side of the St. Francis Mountains, in the vicinity of Fredericktown, and on the Mine La Motte property, in Madison County. Here, according to Winslow, galena is disseminated through a Lower Silurian dolomite now known as the Bonneterre (Upper Cambrian) limestone. The dolomite grades into sandstone, which in some places contains glauconite. It is underlain by an impure sandstone, also of Cambrian age, and this sandstone in turn rests on Archean granite and porphyry.

Here and there galena is disseminated through the dolomite and in places also considerable pyrite, chalcopyrite, and some nickel and cobalt sulphides, the latter probably combined in the mineral linnæite. The sulphides, other than galena, are found in greatest quantity in the lower part of the workings, next to and in the sandstone, especially near the granite and porphyry.

The quantity present varies considerably in the different workings. The mines have generally been operated for lead, and nickel and cobalt have been produced as by-products, except from the mines worked by the North American Lead Co. Genth states that the ores from Mine La Motte had been used as a source of nickel and cobalt oxides for a number of years prior to 1857. In the milling of the lead ores the sulphides of iron, copper, nickel, and cobalt which were saved were thrown aside, though a considerable percentage seems to have been lost in the tailings.

At one time the Mine La Motte ores were smelted to matte at the mine and the matte was sold to the refinery at Camden, N.J., and to others abroad. . . .

The North American Lead Co. erected a smelter in 1906 for treating the sulphides which had accumulated on its own and adjoining properties and also the ores as mined. In 1907, 2,731 pounds of cobalt oxide were made. In 1909, 83,394 pounds of cobalt oxide, 328,403 pounds of nickel, 8,214 tons of nickel and cobalt concentrates, 600 tons of copper, and 1,353 tons of lead concentrates were produced. In 1908, a body of ore 400 or 500 feet from the granite was 12 feet thick, and was said to carry 10 per cent. copper, 4 per cent. nickel and cobalt, and 4 per cent. lead. This ore had been reached by a long drift in which the ore had been 1 to 2 feet thick, gradually increasing in thickness to the point noted. The company's affairs later became so involved that the property was sold at a forced sale in 1910 and has since remained idle. Plans for again starting work have repeatedly been reported.

Besides the properties named, those of the Hudson Valley Lead Co., Madison Lead and Land Co., 4 miles from Fredericktown, and the Jackson Revelle Co., 8 miles south of Fredericktown, are said to carry similar nickel deposits. From the meagre data at hand it seems probable that some hundreds of tons of nickel per year can be produced, with possibly one-fourth to one-third as much cobalt and several times as much copper.[1]

Other Deposits

It is unnecessary to say much concerning other deposits of nickel-bearing ores in the United States, all of which are lying idle and, moreover, are described in various publications which are readily accessible. But it may be said that all classes of nickel ores have been found, with the exception of laterite or nickeliferous iron deposits, such as those of Cuba. Silicate ores are represented by those of Webster, North Carolina, and Riddle, Oregon. Arsenical ores, associated with native silver and carrying cobalt and nickel, have been found in small quantities at Silver Cliff, Colorado, and Bullards Peak, New Mexico. Many years ago there was a small production of arsenical cobalt-nickel ores in Connecticut. Pyrrhotite-chalcopyrite deposits in which nickel occurs in economic quantity are represented by the Gap mine, Lancaster, Pa., and Friday claim, Julian, Cal., and others. The Gap mine has been referred to on a preceding page. At one time it was an important producer, but, since the discovery of the New Caledonia and Sudbury deposits, ore bodies of its size and character have become of little economic interest.

Imports and Exports.

Nickel ores and nickel matte are specifically exempted from duty,[2] but imported "nickel, nickel oxide, alloy of any kind in which nickel is a component material of chief value, in pigs, ingots, bars, rods, or plates," must pay a duty of 10 per centum *ad valorem;* sheets of strips 20 per centum.[3]

Large quantities of nickel matte are imported into the United States, as shown by the following table:

Origin of Nickel Matte Imported in 1915.

	Quantity.	Nickel Content.
	Short Tons.	Pounds.
Matte from Sudbury, Ontario, ores	43,123	53,638,101[4]
Matte from New Caledonia ores	2,674	2,714,363
Total	45,797	56,352,464

Of the New Caledonia product 443 tons of high-grade matte, averaging 78 per cent. of nickel, came from France, 1,138 tons of low-grade matte, with 45.7 per cent. of nickel, direct from New Caledonia, and 1,093 tons, averaging 44.8 per cent. of nickel, were imported from New Caledonia via Australia. The only other

[1] Min. Res. U. S., 1915, Part I, pp. 743-766, published January, 1917.
[2] Tariff Act of Oct. 3, 1913, sec. 565. [3] Ibid, sec. 155.
[4] This quantity of nickel appears to be incorrect, but it is given in Min. Res. U. S., Part I, 1915, p. 759. Compare with figures in Chapter XII of this Report.

country from which unrefined nickel was obtained was Peru, 1 ton of ore containing 118 pounds of the metal being imported from that southern country.

Nickel alloys, pigs, bars, etc., were imported to the extent of 31,990 pounds, and the quantity of nickel oxide was 497 pounds.

The United States refines much more nickel than it can use, so that, though not a large producer, it is a large exporter. No nickel matte is known to be exported.

Exports of Nickel and Nickel Oxide.

Year.	Quantity.	Value.
1913	29,173,088	$9,686,794
1914	27,595,152	9,455,528
1915	26,418,550	10,128,514

The nickel content of salts and metallic nickel produced in the electrolytic refining of copper is given as 822 tons in 1915, of which between one-half and two-thirds is estimated to have come from United States ores. This quantity appears to be too low. Accurate statistics of such productions are difficult to obtain.

The American Smelting and Refining Company produced 560 tons of refined nickel in 1915, and 612 tons in 1916.[1]

[1] Eng. and Min. Jr., March 17th, 1917, p. 471.

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