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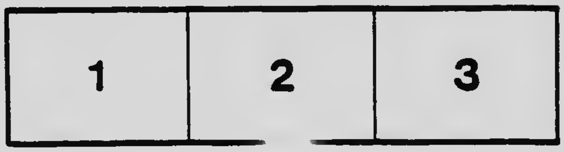
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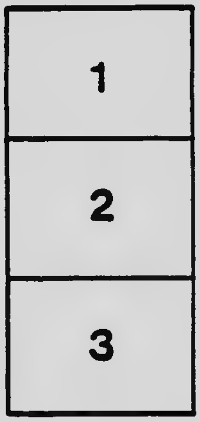
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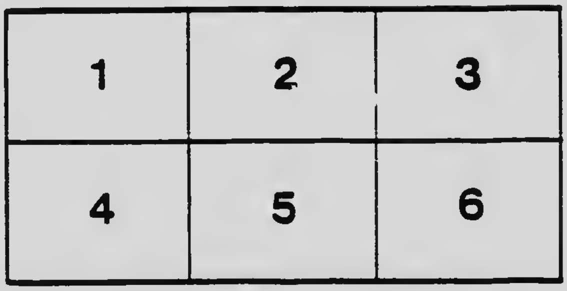
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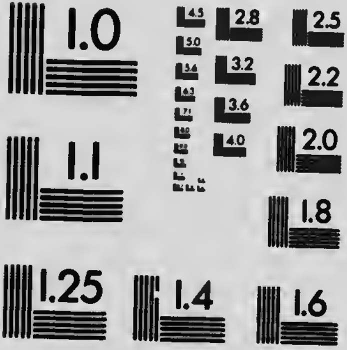

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GEOLOGICAL SURVEY OF CANADA
ROBERT BELL, M.D., D.Sc. (CANTAB.), LL.D., F.R.S., I.S.O.

REPORT

ON THE

ORIGIN, GEOLOGICAL RELATIONS AND COMPOSITION

OF THE

NICKEL AND COPPER DEPOSITS

OF THE

SUDBURY MINING DISTRICT

ONTARIO, CANADA

BY

ALFRED ERNEST BARLOW, M.A., D Sc.

OTTAWA
PRINTED BY S. E. DAWSON, PRINTER TO THE KING'S MOST
EXCELLENT MAJESTY
1904

No. 873

To Robert Bell, M.D., LL.D., D.Sc. (Cantab), F.R.S., I.S.O.
Acting Director, Geological Survey of Canada.

Sir,—I beg to transmit, herewith, my report on the Origin, Geological Relations and Composition of the Nickel and Copper Deposits of Sudbury, Ontario. The report also includes brief references to the character and extent of all the more important nickel deposits of the world, with a general statement of their production and methods of smelting and refining. Details of the mining, smelting and refining operations of the Sudbury ores are furnished, as well as complete statistical tables of production, prices, uses and composition of the nickel of commerce. It is believed that the report will serve to bring together in one volume, all of the more valuable and critical original investigations in regard to these immense and apparently inexhaustible deposits.

Canada has at last realized the true importance and value of these mines and has, within the last year, taken her position, from which she will not recede, of being the largest producer of nickel in the world. Hoping the present report will satisfy the demand which has existed for some time, for detailed and accurate information in regard to these ore bodies,

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

ALFRED ERNEST BARLOW.

Geological survey office,
Ottawa, July 4th 1904.

THE NICKEL AND COPPER DEPOSITS OF SUDBURY, ONTARIO.

BY

ALFRED ERNEST BARLOW, M.A., D. Sc.

INTRODUCTION

Reasons for undertaking present work.

Ten years having elapsed since the appearance of the first official and detailed account of these famous ore bodies, (1) coupled with the fact of a renewed and even increased interest and activity in the mining of nickel, marked the time as most opportune, when another attempt should be made to arrive at a more accurate and complete understanding of the true nature and extent of these deposits which have proved such a valuable asset to Canada. Besides, the first edition of the map of the Sudbury Mining District, published in 1891, to accompany a report by Dr. Robert Bell on the geology of this area (2) had nearly all been distributed, and this in spite of the fact that the Bureau of Mines of Ontario had on several occasions issued special editions of practically the same geological map, to accompany the Annual Reports of their department, as, for instance, in the years 1892 and 1900. In addition, it was felt that although the general accuracy and usefulness of this map had never been questioned, it was lacking in certain details which are now known to be of the first importance and which are most essential for a proper interpretation and judgment of these deposits. Thus, on the first map, the intrusive mass with which the Chicago and Victoria Mines occur, is entirely separated from a band of similar rock along the southern borders of which the Gertrude, Creighton and North Star deposits are situated, whereas, it has now been ascertained that all of these properties are developed along the southern boundary of one large and [illegible] band, constituting the southern or principal belt of the nickel-bearing eruptive. Again, on this first map, no distinction is drawn between the masses or belts of nickel bearing norite, and certain older hornblende porphyrites, diorites and green schists, which, although closely related to, and often resembling

Continuity of main mass of norite.

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(1) Ann. Rep. Geol. Sur. Can., Vol. V, part [illegible] 1890-91, pp. 122-138.

(2) Ann. Rep. Geol. Sur. Can., Vol. V, part [illegible] 1890-91, pp. 1-95.

the norite, are altogether barren of deposits of the valuable sulphide material. This resemblance is particularly striking when, as is frequently the case, both have undergone more or less pronounced metamorphism. It is, therefore, not surprising that in the first instance they were confounded and mapped together. Moreover, the presence of the norite as a distinct geological unit was not suspected until long after this first work was completed, the associated greenstones being considered as portions of the norite, which had been metamorphosed by the intrusion of the younger granite masses. Even the Bureau of Mines' map of 1902, which should have furnished the latest information in regard to this area, made no attempt whatever, either to correct the more glaring inaccuracies in the geological boundaries, or to trace out the important line of separation between the nickel bearing eruptive proper and the closely related, though barren greenstones.

The norite a distinct geological unit.

Limit of new work.

In undertaking this new work, it was felt that by confining operations as closely as possible to the area characterized by the presence of the sulphide bearing norite and other kindred eruptives, a more accurate knowledge would be obtained of the mineralogical composition, structure and age relations of the various rock masses, while at the same time the boundaries between the several formations could be drawn with a much greater degree of precision.

Victoria Mines and Sudbury maps.

Two map sheets have been prepared to accompany this report, called respectively the "Victoria Mines" and "Sudbury" maps, each on a scale of one mile to an inch. The former covers an area of 220 and the latter 210 square miles, making a total of 430 square miles. The principal new work on the Victoria mines map has been the outlining of the two smaller bands of norite south of the Canadian Pacific Railway. One of these, crossing the southeast corner of Drury, extends completely across the southern part of the township of Denison. This band, which comes to an end east of the Vermilion river, contains the Worthington, Mitchener and Totten mines. The first mentioned of these mines is famous as having produced the richest nickel ore in the district. On the other band, which forms the prominent ridge to the south of McCharles and Simon lakes on the Whitefish Indian Reserve, no deposit of any economic importance has been found. The boundaries of the intrusive mass of younger granite which extends across the northern and central parts of Graham township, and thence into Snider and Waters townships, have also been outlined with considerable care. It is to be regretted that time did not permit the separation of the norite and the older greenstones and schists, but the geological work done in 1901 was intended to cover the

Minor band of norite.

whole of the southern belt in one season, and at the time it was considered more important to ascertain definitely the continuity or otherwise of the southern or main nickel range. The main mass of the norite, therefore, which runs northeast from the Victoria mines, was followed through the northern part of the township of Denison, and thence across the Vermilion river into the southern part of the township of Creighton, thus making connection with the other mass of similar basic intrusive rocks, which had been shown on geological maps previously issued. With the exception of a somewhat critical examination of some of the outcrops of the peculiar differentiation product, or "micropegmatite" phase of the norite, exposed on the shores of Skill and Fairbank lakes, no new work has been done in the northwestern and western parts of this area, and the outlines of the formations are reproduced from the old geological map.

Revision of geology of Sudbury area.

Mining geological plans.

Area of Copper Cliff maps.

Murray and Elsie mines map.

The geology of the region comprised in the Sudbury map sheet, has all been revised, with special attention to tracing out the boundaries of the various masses of norite and separating this nickel bearing eruptive from the older greenstones. This map will serve to show in a very emphatic manner, the intimate association of this peculiar eruptive, and the various nickel deposits, and the invariable development of the latter along the line of junction between this and the neighboring rocks. In addition to these two map sheets, which exhibit on an adequate scale not only the general geological features, but also the relative position of all the more important mines, there are three other maps, each on a scale of 400 feet to an inch, which may be referred to as mining geological plans. These have been prepared with more care, and all details of topography, buildings, openings, etc., have been laid down as accurately as possible from surveys made by means of the transit and chain. They are expected to be of especial value to the individual companies whose properties they represent, but at the same time, they will illustrate in detail many of the characteristic features of association, which most of these deposits possess in common with one another. The two sheets showing the district in the vicinity of the International Nickel Company's mines at Copper Cliff, and extending from Kelley lake on the south to the Lady Violet mine on the north, cover an area of about 9 square miles. The third map sheet, which shows the geology in the neighbourhood of the Murray and Elsie Mines as well as the position of the various mining buildings, covers an area of nearly two square miles. The following bulletin is based mainly on the field work carried on during the seasons of 1901 and 1902. A short account of what was accomplished each year has already appeared in the Summary Reports of the Geological Survey

Department, (¹) In addition to this and other information which has appeared from time to time in the official publications of the Geological Survey Department and the Bureau of Mines of Ontario, certain details of original investigation, which throw much additional light on the origin and association of these deposits, have appeared in various scientific periodicals, many of which are not very easy of access to the ordinary reader. It has been the purpose of the writer, in the preparation of the following report, to bring together and make use of much of this widely scattered information, and by thus supplementing his own, render the present publication of wider application and greater service to the public.

Other information included.

In carrying out the field work, the author was materially aided by Dr. Ludwig Mond of London, England, under an agreement by which he was partially relieved from his duties on the Survey, during the six months from July 1 to December 31, 1901.

Work of Mr. James White.

Much of the accuracy which the accompanying maps are believed to possess, is due to the efforts of Mr. James White, Dominion Geographer, who kindly undertook the direction of the surveys necessary for a detailed mapping on a large scale of the area examined. This included in 1901, a traverse by means of transit and steel band chain, of the main line of theCanadian Pacific Railway, from Wanapitei station to the northern boundary of the township of Dowling, a short distance northwest of Onaping station. The "Sault" branch was similarly surveyed from Sudbury Junction as far west as Worthington station. Connection was made with the observatory at Rayside, occupied by Astronomer O. J. Klotz. The position of this temporary observatory, in the township of Rayside is stated by Mr. Klotz to be 606 feet west of the line between lots 2 and 3, in con. 1, and 441 feet north of the centre line of the Canadian Pacific Railway. Its astronomical position, as determined by Mr. Klotz is Long. 81°, 05′, 38″ W. and Lat. 46°, 32′, 47″ N. This position was accepted and the projection of the map framed in accordance therewith. In 1902, Mr. White carried on similar detailed surveying necessary for the preparation of the two large scale map sheets of the area in the vicinity of the International Nickel Company's mines at Copper Cliff.

Work by Ast. O. J. Klotz.

Work by O. E. Leroy.

In the whole of this work, the author had the advantage of the zealous and able assistance of Mr. O. E. Leroy, M. A. Sc., formerly Demonstrator in Geology at McGill University, Montreal, and this opportunity is taken to express his keen appreciation of Mr. Leroy's untiring efforts to promote in every way, the objects of the work.

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(1) Sum. Rep. Geol. Sur. Can. (1901) pp. 141-145, (1902) pp. 252-267.

Work by W. M. Ogilvie.

By kind permission of Dr. J. B. Porter, and with the approval of the University authorities, the magnetic separation of these ores was carried on in the mining laboratories of McGill University by Mr. W. M. Ogilvie, B.A. Sc.

Work by Donald Locke.

Most of the assays and analyses are the work of Mr. Donald Locke, a graduate of the School of Mines, Freiberg, Germany, who for a short time was attached to this department as metallurgist and assayer.

Acknowledgments.

The author desires to express thanks for information and assistance to Dr. Ludwig Mond, Dr. Bernhard Mohr and other officials of the Mond Nickel Company; to President A. P. Turner, Captain Lawson and other officers of the International Nickel Company, resident at Copper Cliff, Ont.; to the representatives of the Lake Superior Power Company, Great Lakes Copper Company and H. H. Vivian and Company, who were stationed in the district. It would be difficult to mention by name, all those who, either with information or otherwise, have assisted in the object of these investigations, but the author would like in this connection to express his deep gratitude to the residents of Sudbury, Copper Cliff and Victoria Mines, who showed him the greatest kindness and consideration during his sojourn in their midst.

Previous Examinations and Descriptions.

Deposits of scientific and economic interest.

The literature in regard to the nickel and copper deposits of the Sudbury mining district, has already reached such large proportions, that it seems advisable in passing to make brief mention of some of the principal publications, which show evidence of original research, the results of which have added materially to our knowledge of the nature of the occurrences of these immense ore bodies. These deposits of pyrrhotite, with their unusually high content of nickel, and intimately associated chalcopyrite, are of importance, not only from the economic standpoint, but also from the point of view of science, as having furnished such strong presumptive evidence for regarding these, and similarly related deposits as of igneous origin, and due to processes of differentiation in the original magma, from which they and the associated eruptive rocks have solidified.

Discovery of nickel at Wallace mine.

The discovery of nickel at the Wallace mine in 1846, (1) although creating some excitement at the time, was soon forgotten, as well as the prediction which has since been amply verified, that deposits of both nickel and cobalt of economic importance would yet be located

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(1) Rep. of Progress, Geol. Sur. Can., 1848-49. pp. 61 63; Geol. of Can. 1863, p. 506.

Early discovery of nickel near Creighton mine.

Inaccessible nature of country before constructon of C. P. Ry.

in this region. Attention was again drawn to the subject by the finding in 1856 (1) of nickel and copper on Salter's meridian line, a little over six miles north of Whitefish lake, and less than half a mile southwest of the main pit of the present celebrated Creighton mine, probably the largest deposit of nickeliferous pyrrhotite in the world. This was again lost sight of or the discovery considered of no importance, perhaps because of the meagre information in regard to its occurrence, but more likely on account of the wild and inaccessible nature of the district, in which the deposit had been found. The opening of the Canadian Pacific Railway quickly changed these conditions, and in less than ten years from the first opening of this means of access to the district, all the mines which are at present working had been located.

First statistics.

The first statistics concerning these deposits which were published, related to the export of copper ore in 1886, amounting to 3,307 tons, with a declared customs value of $16, 404 (2). In 1887, this quantity had decreased to 567 tons, valued at $3,416 (3). The discovery of nickel in the ore about this time, decided the Canadian Copper Company to instal the necessary plant for the production of nickel and copper matte, and in the preparation for this and other mining development work, no exports are recorded from this district in 1888.

Descriptions by J. H. Collins.

Mr. Attwood's opinion.

In October, 1887, Mr. J. H. Collins visited the Sudbury region to examine into the extent and economic possibilities of the so-called copper mines. On June 6th, 1888, he read a paper before the Geological Society of London, 'On the Sudbury Copper Deposits,' in which he embodied the results of these examinations, which, however, seem to have been restricted mainly to the area in the immediate vicinity of the Copper Cliff and Stobie mines. An abstract of this paper, was afterwards published,(4) accompanied by two cross sections of the mines above mentioned, showing the geological association and position of these deposits. The author considers the main ore bodies to have been the result of secondary action, the sulphides occupying fissures along certain lines of weakness, produced by the intrusion of igneous material. In the discussion that followed, Mr. Attwood stated his conviction that the diorites had brought up the metals. At the end of the paper, a note is added bearing the date of October 22nd 1888, that the ore of the Evans mine contains Copper 3%, Nickel 3.5%, Iron 40%, Sulphur 24%, Rock 29.5 %.

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(1) Rep. of Progress, Geol. Sur. Can., 1853-56, pp. 180-181.

(2) Ann. Rep. Geo. Sur. Can. 1886, Part S. p. 25.

(3) " " " " " 1887-88, Part S, p. 21.

(4) Quart. Jour. Geol. Soc. Lon., Vol. XLIV, 1888, pp. 834-838.

Discovery of sperrylite by F. L. Sperry.

In October, 1888, Mr. Francis L. Sperry, then chemist to the Canadian Copper Company, sent a small quantity of what seemed a remarkable mineral to Professor H. L. Wells, of the Sheffield Scientific School at New Haven, Conn. A few tests sufficed to show that the substance was essentially an arsenide of platinum. Several ounces of this mineral had been obtained in milling certain loose material (gossan), associated with the sulphides at the Vermilion mine in the township of Denison. A complete statement of facts relative to its composition, physical characters and crystallographic behaviour, was prepared by Profs. Wells and Penfield, who proposed the name 'sperrylite' for this new mineral in honour of its discoverer. (¹)

Description of mineral by Profs. Wells and Penfield.

Discovery of polydymite by Profs. Clarke and Catlett.

About the same time, Profs. Clarke and Catlett (²) of Washington, obtained through two different channels, certain samples of nickel ores taken from the Vermilion mine, belonging to the Canadian Copper Company. From one source, they obtained two masses of sulphides to be examined for nickel and copper, from the other came similar sulphides, together with a series of soil and gravel-like material (gossan), seven samples in all. In the latter case, an examination for platinum was requested, and in five of the samples above mentioned, it was found the gravel yielded 74·85 ozs. of metals of the platinum group to the ton of 2,000 lbs. The sulphide ores were all of a similar character. They consisted of mixed masses, in which a gray, readily tarnishing substance was predominant, with some chalcopyrite, possibly some pyrite, and a very little quartz. An analysis of carefully selected material of the nickel mineral, showed its formula to conform in general with that of polydymite, which had previously been described by Laspeyres from Grünau, Westphalia, of which it is evidently a ferriferous variety.

Paper by W. H. Merritt.

At the Buffalo meeting of the American Institute of Mining Engineers, W. H. Merritt, Toronto, contributed a paper on 'The Minerals of Ontario and their Development', in which he includes a brief description of the Sudbury deposits. (³)

Examinations and descriptions by Dr. Bell in 1888.

In the Summary Report of the Geological Survey for 1888, Dr. Bell (⁴) mentions that 'the modes of occurrence and the geological relations of the economic minerals of the districts examined (between Lake Huron and Montreal river) were carefully studied. The metals

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(1) Amer. Jour. Sc., Vol. XXXVII, 1889, pp. 67-73; also Zeit. für Kryst. Vol. XV, pp. 285 and 290-291.

(2) Amer. Jour. Sc. Vol. XXXVII, 1889, pp. 372-374.

(3) Trans. Amer. Inst. Min. Eng., Vol. XVII, 1888-89, pp. 293-300.

(4) Ann. Rep. Geol. Sur. Can. 1887-88, p. 79 A.

which give most promise are the copper and nickel deposits which have been worked for the last three years near Sudbury'. Again, in the report for 1889, Dr. Bell, (1) after a brief sketch of the geology of the area included in the Sudbury map sheet, gives a few notes on the character and mode of occurrence of these deposits, as also the progress of the mining and metallurgy which were then in vigorous operation. He viewed the pyrrhotite a sa true nickeliferous variety, in which some of the iron is replaced by nickel. The deposits are described as 'stockworks' in which the vein structure is very obscure. The ore bodies are regarded as usually occurring in some form of diorite, the concentration of the ore being perhaps connected in some way with certain diabase dykes which were in some cases seen near the deposits.

Account by Dr. E. D. Peters.

At the Ottawa meeting of the American Institute of Mining Engineers, held in October, 1889, Dr. E. D. Peters, who had charge of the operations at the Canadian Copper Company's mines near Sudbury, read a paper On the Sudbury Ore Deposits'. (2) He opens with a short and very general statement of the geological conditions, makes a passing mention of the two principal sulphides which constitute these deposits, and devotes the rest of his paper to a description of the equipment and methods of mining and metallurgy pursued by the company of which he was the manager.

Reference by Dr. Bell in 1890.

In 1890, as one of the Royal Commissioners to inquire into the mineral resources of Ontario, Dr. Robert Bell of the Geological Survey of Canada, in the treating of the "Geology of Ontario with special reference to economic minerals," devotes some attention to the nickel and copper deposits of the area in the vicinity of Sudbury. (3)

Report by Dr. Bell in 1891 on 'Sudbury Mining District.'

First geological map.

In 1891 (4), Dr. Bell described in greater detail the nature and extent of these deposits and also their geological relations, giving the results of the field work of the Geological Survey in this area during the three years 1888-90. Accompanying the same volume, the first geological map of the district appeared, showing in this graphic way, the limits of the different formations or subdivisions of these old rocks, over an area of 3456 square miles. This map, although faulty and inaccurate in places, has been the basis of all subsequent geological work undertaken in this district, although it is now superseded in

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(1) Ann. Rep. Geol. Surv. Can. 1888-89, pp. 29-32 A.

(2) Trans. Am. Inst. Min. Eng., Vol. XVIII (1889) pp. 278-289.

(3) Min. Res. of Ont. 1890, p. 24; also pp. 433-435, also Ann. Rep. Bur. of Mines, Ont. 1891. pp. 88-90.

(4) Ann. Rep. Geol. Sur. Can., Vol. V, 1890-91, Part F, pp. 1-95; also Bull. Geo. Soc. Am., Vol. II, 1891, pp. 125-137.

certain areas, by the maps lately published by the Bureau of Mines of Ontario, and those issued to accompany the present bulletin. The imperfections of these latest maps will also in turn become apparent as the region is cleared and opened up and more detailed information in regard to the distribution of the various rock masses is thus possible.

Description by A. E. Barlow.

On March 6th, 1891, (1) the author of the present bulletin read a paper before the Logan Club of Ottawa 'On the Nickel and Copper Deposits of Sudbury,' which was published in June of the same year, in which appears a very definite statement affirming an igneous origin (2) for these masses of sulphide material, in the following words :

Origin of ore bodies.

Nickel does not replace iron.

First recognition of pentlandite.

'The ores and the associated diabase, were, therefore, in all probability simultaneously introduced in a molten condition, the particles of pyritous matter aggregating themselves together in obedience to the law of mutual attraction.' In the same paper, the author makes the following significant statement which has since been proved by means of the magnetic separation of the ore : 'The nickel is usually spoken of as replacing an equal quantity of iron in the pyrrhotite, but the discovery of undoubted crystals of millerite or sulphide of nickel, 150 feet below the surface at Copper Cliff mine, as well as the more recent recognition of polydymite, a ferriferous sulphide of nickel at the Vermilion mine, in the township of Denison, seem to justify the assumption that in the more highly nickeliferous deposits of the region at least, the nickel is also present as a sulphide, disseminated through the ore masses like the iron and copper.' In 1891, Mr. T. L. Walker, then chemist at the Murray mine, obtained 30 per cent of nickel in some bright cleavable fragments of a mineral which occurred in the form of more or less rounded patches in the ordinary nickeliferous pyrrhotite at the Worthington mine. The writer, who had provided Mr. Walker with these samples, suggested the advisability of a complete analysis of as pure material as could be selected. It is to be regretted for Walker's sake, so far as priority in the first recognition of pentlandite in this district is concerned, that the present writer, in publishing the results of this first analysis (3), merely stated his own belief, that these peculiar nodular masses probably represented a mixture in which millerite was the most prominent constituent, omitting to make mention of the fact that, the chemist had stated his belief, that the material was almost pure "Eisennickelkies" the German synonym for pentlandite. At this time, it was considered of more importance to empha-

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(1) Ottawa Naturalist, June 1891, pp. 1-20 ; also Ann. Rep. Geol. Sur. Can., Vol. V, Part S, 1890-91, pp. 122-138.

(2) See also a paper by Dr. Robert Bell on 'The Nickel and Copper Deposits of Sudbury District, Canada.' Bull. Geol. Socy. of Am., Vol. II, 1891. page 135-36.

(3) Ann. Rep. Geol. Sur. Can. 1890-91, Part SS, pp. 116-117.

zise the fact which had grown beyond a conviction, that the nickel was undoubtedly present in these ore bodies as a distinct sulphide, mechanically intermixed and probably separable and not as replacing a portion of the iron in the pyrrhotite. It was even considered probable that several nickel sulphides, and not one alone, contributed to the unusual enrichment of these ores.

First detailed statistics of nickel.

The report of the Division of Mineral Statistics and Mines of the Geological Survey for 1890, although not published until the following year, contained the first statistics showing the production and export of nickel and copper matte from the Sudbury district. This was likewise accompanied by a somewhat detailed description of the deposits, to which attention has already been drawn (¹). Previous to this, however, in the report (²) of the same department for 1889, mention is made of the production of nickel in Canada, but the figures of production then supplied were only used in the summary of production. This course was necessary at the time, as the figures then available represented the production of only one company, who gave the figures on the understanding that they were only to be used in the compilation of totals.

Descriptions by Bureau of Mines of Ontario in 1891.

In the first report of the Ontario Bureau of Mines for 1891, then just organized, considerable space is devoted not only to the statistics of production of nickel and copper matte, but also to various details regarding the geological relationship of the ores, the methods of mining and metallurgy, as well as the use and value of nickel. It also contains the first of the annual reports of the inspector of mines, which each year since has contained an epitomized statement of the progress of mining and smelting in this area.

Paper by J. Garnier.

In 1891, Mons. J. Garnier, (³) who had become famous as the discoverer of the New Caledonia nickel deposits, visited Canada, and on his return to Paris, furnished an account of his examination in a paper entitled, 'Mines de Nickel, Cuivre et Platine du District de Sudbury, Canada.

Analyses and magnetic separation of Sudbury ores by Dr. Emmens.

In 1892, Dr. S. H. Emmens of Youngwood, Penn., and President' of the Emmens Metal Company, announced the discovery of three new nickel minerals from the Sudbury district, for which he proposed the names Folgerite, Blueite and Whartonite. (⁴) The substances thus named, were stated to be sulphides of iron and nickel, the proportion of the latter metal varying from 3·76 per cent in blueite to 35·20

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(1) Ann. Rep. Geol. Surv. Can., 1890-91, Part. S, pp. 121-143.

(2) Ann. Rep. Geol. Surv. Can., 1888-89, Part. S, 1889, pp. 5 and 123.

(3) Mem. Soc. des Ing. Civils, Paris, 1891.

(4) Jour. Am. Chem. Soc., Vol. XIV, No. 7; also Ann. Rep. Bur. of Mines, Ont., 1892, pp. 167-170.

cent in folgerite. All authorities are, however, agreed that none of these are definite mineral species, being mixtures of different sulphides. Thus folgerite is regarded as impure pentlandite, blueite is a nickeliferous pyrite, and whartonite a mixture. A persual of Dr. Emmens' methods of analysis, and the variability of his results are sufficient proofs, that none of these names which he proposes, should receive a place in mineralogical literature. About the same time, Dr. Emmens conducted some rather crude and evidently hurried experiments in regard to the separation of the components of the pyrrhotite by means of magnetism, but the results are far from satisfactory. (1) The material on which the trials were made came from both the Gap mine, Pa., and Sudbury, Ont.

Folgerite whartonite and blueite not true mineral species.

Memoir on nickel by Mons. David Levat.

In 1892 Mons. David Levat, formerly Director-General of the Société le Nickel, prepared a memoir on the production and uses of nickel and its alloys, entitled 'Progrès de la Métallurgie du Nickel,' (2) an abstract from which is translated and printed in the report of the Bureau of Mines of Ontario. (3) Besides a description of the metallurgical treatment of the Sudbury ores, he institutes a comparison between these and the New Caledonia ores, giving all necessary details in regard to these latter, their composition, metallurgy, transportation, mining operations, and concludes with certain particulars relating to the composition of the nickel of commerce, its alloys and statistics of production.

Work by Baron von Foullon.

During the summer of 1890, the late Baron von Foullon of the Geological Survey of Austria, spent a few weeks in the district, directing his attention chiefly to the determination of the relative ages of the different rocks. His collection of rocks for future study, contained a specimen obtained from one of the detached blocks of material, which had been blasted out to make room for the the foundations of the smelter at the Murray mines. Examination of thin sections of this specimen under the microscope, revealed for the first time the identity of what was evidently a typical and unaltered representative of the nickel bearing eruptive, showing it to contain besides the plagioclase, strongly pleochroic hypidiomorphic individuals of hypersthene, together with a smaller amount of diallage, both these last mentioned minerals being often bordered with hornblende. The rock thus evidently belonged to the general type of gabbros, which by the abundance of the hypers-

First recognition of nickel bearing eruptive.

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(1) Jour. Am. Chem. Soc., Vol. XIV, No. 10; also Ann. Rep. Bur. of Mines, Ont., 1892, pp. 163-166.

(2) Ann. des Mines, Paris, 1892, pp. 141-224.

(3) Ann. Rep. Bur. of Mines. Ont., 1892, pp. 149-162.

Description of gabbro by G. H. Williams.

Coleman's description of norite and related rocks from North Nickel Range.

thene is related to the norites. (1) This was the first recognition of the true character of the eruptive with which the nickel deposits are so intimately associated, although the late Professor G. H. Williams had in 1891 described (2) a very similar rock from the vicinity of the Blezard mine, but which in the description of the field relations furnished him, had been reported as occurring in a later dyke. In 1893, Dr. A. P. Coleman, (3) showed that the country rock of the nickel deposits south of Clear Lake, on the Northern Nickel Range, was a gabbro containing both diallage and enstatite. In the same publication, he gives a description of the petrographical characters of the peculiar type of rock to which Williams first gave the name "micropegmatite," and which occurs here as elsewhere, throughout the district, in intimate association with the sulphide bearing eruptive.

Recognition of pentlandite by Prof. Penfield.

In 1893, Prof. S. L. Penfield, recognized and described for the first time, the mineral pentlandite, from the Sudbury district, found in some sulphide material sent to him some years previously by Mr. F. L. Sperry. (4) Immediately following this article, in the same publication, he criticizes rather severely the methods of analysis, adopted by Dr. Emmens, in his attempt to establish the claims of folgerite, blueite and whartonite, to be recognized as new mineral species (5).

Magnetic separation by David H. Browne.

In the same year David H. Browne, (6) chemist of the Canadian Copper Company, challenged the accuracy of Dr. Emmens' magnetic work, as also the conclusions based thereon, so far at least as the material from Sudbury is concerned At the same time, he published the details of certain personal experiments in connection with the magnetic separation of the ores from the Copper Cliff, Evans and Stobie mines. The ore was first handpicked and then crushed to various degrees of fineness. By means of these trials, he succeeded in dividing the material thus prepared into a magnetic and non-magnetic product, the analysis of the latter showing a close resemblance to the pentlandite described by Penfield.

Examination of sperrylite. by T. L. Walker.

In June 1893, T. L. Walker (7) visited the Vermilion mine and procured some additional material similar to that in which Wells and

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(1) "Ueber einige Nickelerzvorkommen," Jahr. d. k-k. geol. Reichsanstalt, Vol. XLII. pp. 223-310, Vienna, 1892.

(2) Ann. Rep. Geol. Surv. Can., 1890-91, Part F, p. 77.

(3) "The Rocks of Clear Lake near Sudbury." Can. Rec. Sc., Vol. V, 1892-93, pp. 343-346.

(4) Am. Jour. Sc., Vol. XLV, 1893, pp. 493-494.

(5) " " " pp. 494-497.

(6) Eng. & Min. Jour., Dec. 2nd, 1893, Vol. LVI, pp. 565-566.

(7) Am. Jour. Sc., Vol. I, 1896, pp. 110-112.

Penfield had first discovered sperrylite. The evidence of these new specimens of this comparatively rare mineral, enabled him to publish further details in regard to its crystallographic behaviour. After critical examination of the associated sulphides, he concludes that this sperrylite is associated with the chalcopyrite, and not with the pyrrhotite, and that accordingly nickel mattes from mines low in copper contain very little platinum, while those richer in copper afford a matte proportionately richer in platinum. He mentions the fact, however, that the polydymite of Clarke and Catlett contains from 0·006 per cent to 0·024 per cent of platinum (1).

Discovery of nickeliferous pyrite by Prof. W. L. Goodwin and T. L. Walker

In April, 1893, Prof. W. L. Goodwin (2) announced the discovery of a highly nickeliferous pyrite, occurring at the Murray mine, and published an analysis of this somewhat unusual association. The material, however, on which the examination was conducted, was massive and somewhat decomposed. A little latter, however, T. L. Walker secured several specimens showing druses of small bright cubic crystals. These were found associated with marcasite, (containing no nickel or cobalt) magnetite, galena, chalcopyrite and nickeliferous pyrrhotite. An analysis of this new and fresh material was made, and the conclusion reached that the specimens represented true nickeliferous pyrite. in which the isomorphus elements, iron and nickel, replaced each other in varying proportions. (3)

Description by E. Renshaw Bush.

During the summer and fall of 1893, E. Renshaw Bush, while pursuing professional work, visited some of the more important deposits, afterwards publishing his observations in a paper called 'The Sudbury Nickel Region.' (4)

Paper by Philip Argall.

On December 4th, 1893, Philip Argall of Denver, Col., presented a paper to the Colorado Scientific Society, on 'Nickel, the Occurrence, Geological Distribution and Genesis of its Ore Deposits.' This author gives a short but rather complete statement of the character, composition and distribution of the three groups of the ores of nickel—arsenides, sulphides and silicates—and makes special mention of the main features and importance of the Sudbury Ore Deposits.(5)

Opinions by Dr. F. D. Adams.

On January 12th, 1894, Dr. Frank D. Adams of Montreal, submitted a paper to the General Mining Association of the Province of

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(1) Bull. U. S. G. S., No. 64, p. 21.

(2.) Can. Rec. Sc. Vol. V, 1892-93, pp. 346-347.

(3.) Am. Jour. Sc. Vol. XLVII, April, 1894, pp. 312-314.

(4.) Eng. & Min. Jour., March 17, 1894, Vol. LVII, pp. 245-246.

(5.) Proc. Col. Sc. Soc., Vol. IV, 1891-92-93, pp. 395-421.

Quebec, 'On the Igneous Origin of certain Ore Deposits.' In this paper, he gives a synopsis of the main conclusions reached by Prof. J. H. L. Vogt of Christlania, from his examinations and study of the nickeliferous sulphides of Norway, and agreeably with these, Dr. Adams claims an igneous origin for the various Sudbury occurrences, the concentration of the ore being the direct result of magmatic differentiation of the peculiar type of eruptive with which the deposits of both countries are always associated. (¹)

Views by Prof. J. F. Kemp.

In 1895, Prof. J. F. Kemp of Columbia University, New York, gives 'An Outline of the Views held today on the Origin of Ores' offering an explanation, based on the laws of thermo-chemistry, to explain the concentration of these sulphides of iron, copper and nickel. (²)

Detailed description by Dr. T. L. Walker.

In 1897, Dr. T. L. Walker presented his inaugural dissertation to obtain the degree of Doctor of Philosophy, to the University of Leipzig, taking as his subject 'Geological and Petrographical Studies of the Sudbury Nickel District, Canada.' This thesis was afterwards communicated to the Geological Society of London, by Prof. J. J. H. Teall and subsequently published in an abridged form. (³) This publication contains an epitome of Dr. Walker's studies of the rocks which are most intimately associated with the nickel deposits. The author is in full agreement with Vogt, Adams and others, regarding these ore bodies as of igneous origin, owing their present position and dimensions to magmatic differentiation. He furnishes very complete details of the petrographical character, not only of the nickel bearing eruptive, but also of the associated greenstones and the clastic rocks of the Huronian, making brief mention of the mineralogical composition of the Laurentian gneisses exposed near Wanapitei station. Dr. Walker was the first to recognize that the 'micropegmatite', classed on previous geological maps, as belonging to the Laurentian, which it resembles, is really a differentiation phase of the prevailing norite. The later dykes of olivine diabase are also described in considerable detail. The whole publication may be characterized, in brief, as the most complete statement in regard to the geology and petrography of the district, which had yet appeared.

Dr. Walker first to recognize the micropegmatite as differentiate of norite.

Paper by J. W. Bain.

In 1900, J. Watson Bain prepared 'A Sketch of the Nickel Industry,' which treats of the source and production of nickel ores, the me-

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(1.) Can. Min. Review, February, 1894.

(2.) Min. Industry, Vol. IV, 1895, pp. 755-766.

(3) Quart. Jour. Geol. Soc. Lon., Vol. LVIII, (1897) pp. 40-66.

tallurgy of both the New Caledonia and Sudbury products, concluding with a brief statement of the composition and uses of nickel. (1)

Description by Dr. Coleman in 1901.

In 1901, Dr. A. P. Coleman gives certain petrographical details of the nickel bearing eruptive and the associated greenstones, with special reference to occurrences of these rocks, between the Stobie and Nickel Mountain mines. He also furnishes an account of the mineralogical composition and character, as revealed by the microscope, of some of the sedimentary rocks classified as Huronian in this district. (2)

Work by A. E. Barlow in 1901 and 1902.

In 1901, (3) and again in 1902, (4) the writer gives certain preliminary information in regard to the geology and petrography of the Sudbury district.

[illegible]errylite by [illegible]ldschmidt [illegible] Nicol.

In the summer of 1902, Profs. Victor Golds[illegible]nd William Nicol prepared a very complete statement of th[illegible]tography of sperrylite, the material being obtained from the ori[illegible]ality at the Vermilion mine. (5)

Sep[illegible]ation of sperr[illegible]lite from [illegible]alcopyrite by Dickson.

In 1902, C. W. Dickson, (1851 Exhibition S[illegible]om Queen's University, Kingston, and doing post-graduate wor[illegible] School of Mines, Columbia University, New York) succe[illegible] separating sperrylite from the unaltered chalcopyrite, obtai[illegible] at the Victoria mines, and thus proved definitely that the platinum was associated with the copper sulphide. (6) This is in agreement with the result[illegible] by Walker, some years previously, to which reference has al[illegible] made, and also accords with the views of Prof. Vogt, from an[illegible] of the various ores from the Norwegian nickeliferous pyrrhotite deposits. (7)

Paper by C. W. Dickson.

At the meeting of the American Institute of Mining Eng[illegible]eld in Albany in February, 1903, Mr. Chas. W. Dickson to [illegible]ference has already been made, submitted a paper entit[illegible] The Ore Deposits of Sudbury, Ontario.' The information thus [illegible] was also presented in the form of a thesis ,to obtain the degr[illegible] D at Columbia University, New York city. (8)

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(1) Ann. Rep. Bur. of Mines, Ont., 1900, pp. 213-224.

(2) Ann. Rep. Bur. of Mines, Ont., 1901, pp. 206-208.

(3) Sum. Rep. Geol. Surv. Can., 1901, pp. 141-145.

(4) " " " 1902, pp. 252-267.

(5) Amer. Jour. Sc., Vol. XV, 1903, pp. 450-458.

(6) " " " " 137-139.

(7) Zeit für Prak. Geol. Aug., 1903, pp. 258-260.

(8) Trans. Am. Inst. Min. Eng. (Albany Melting) February, 1903, 65 pp.

New methods of research.

This publication marks a decidedly new departure, not only in the
methods of research adopted, but also in the results sought to be
obtained, and if the conclusions reached, seem new and startling, and
at variance with many of the preconceived notions entertained in
regard to the composition and origin of these ore bodies, the author
must be given the credit for having weighed all the evidence and
exhausted every means to prove the validity of his conclusions.

Mr. Dickson mentions that one of the purposes of his investigatio
has been to ascertain whether the nickel and cobalt replace the iro
isomorphously in the Sudbury pyrrhotite. Another purpose has bee
to try to find a definite formula for the sulphide of this district, wit
the idea of comparing it with similar minerals from other localitie
The thesis is divided into two main portions, as follows: I. The rela
tion of nickel to pyrrhotite and II. Genesis of the Sudbury ores.

Analyses of Sudbury ores & pyrrhotites.

The first of these two parts of Mr. Dickson's paper deals, in the fir
place, with a general statement of the Sudbury nickel region. Th
is followed by a summary of the composition and origin of pyrrhotit
to which is added a table, showing the percentage of nickel and coba
in this mineral. Then succeeds a brief description of the Sudbu
pyrrhotites, with tables indicating the percentages of nickel, cobalt a
copper, not only in the ore of the principal mines, but also the avera
composition of some of the resulting mattes.

Magnetic separation of pyrrhotite.

Nickel does not replace iron in pyrrhotite.

Mr. Dickson then discusses the methods pursued, and the results
his investigation into the magnetic separation of the pyrrhotite, and
a result of these experiments, he concludes that all of the nickel, in t
Sudbury ores at least, occurs as a separate mineral, and, that in t
district there does not exist a true nickeliferous pyrrhotite, in the se
that the nickel isomorphously replaces part of the iron in that mine
In the second part of the paper, he adduces strong evidence in supp
of his opinion that all of the Sudbury ore deposits are of essentia
and predominantly secondary origin. The evidence adduced, is deri
not only from a study of the larger field occurrences of the depo
and associated rocks, but also finds abundant support in the relati
between the ores and rock minerals, as seen under the microscope.

Comparisons.

A comparison is made of these Sudbury deposits with those of R
land, B. C., and Ducktown, Tenn., which are stated to show m
remarkable and essential points of similarity, and concerning wh
secondary origin, there can be no doubt.

Dr. Coleman's examinations and descriptions in 1903.

In 1903, Dr. A. P. Coleman published his account of 'The Sudb
Nickel Deposits', (1) giving the results of the field operations un

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(1) Ann. Rep. Bur. of Mines, Ont., 1903, pp. 235-299.

taken at the instance of the Bureau of Mines of Ontario, in the summer of 1902. This is, doubtless, the most comprehensive and satisfactory description of these deposits which has yet appeared. This work is copiously illustrated with photographs of the different mines and buildings, together with several small maps showing the progress of the surface work, and the disposition of the various openings and mining buildings. It is also accompanied by two coloured geological maps, representative of the area in the vicinity of the Copper Cliff and Stobie mines. It is not considered necessary in this connection, to summarize the results of this work, as the publication is of such recent date, and readily available to any one who desires to take advantage of this information; and no one interested in the geological and petrographical problems involved, should be without it. In 1903, Dr. Coleman continued this work, directing his attention to the mapping out in detail of the outline of the northern nickel range, in order to determine its connection or otherwise with the Southern or Main Range.

Geological maps of Copper Cliff and Stobie mines.

It is proposed, that during the coming season, Dr. Coleman will again continue this work, with the intention of ultimately publishing a monograph which will contain, in succinct form, all essential information in regard to these deposits, which have figured so largely in the mining industrial development of Canada.

Further detailed work by Dr. Coleman.

HISTORY OF DEVELOPMENT.

The presence of large deposits of nickel and copper, in the vicinity of the town of Sudbury, and close to the boundary between the Districts of Algoma and Nipissing, in Northern Ontario, has, for many years, attracted world wide attention, in the first place, on account of their immense and apparently inexhaustible character, but latterly, because of the much more extended use of nickel, especially as an alloy with steel, to improve the qualities of the latter. The recent agitation for the imposition of an export duty on nickel ore and matte, has, at least, resulted in drawing public attention to the fact, that Canada has for some time past, been one of the two great sources of nickel in the world, and at the present day, produces more than half of the world's consumption of this metal. The history of the development of nickel mining in this region is inseparably bound up with that of copper, for the two minerals are always present in such intimate association with one another, that, in abstracting their metallic contents, they are subjected to the same metallurgical processes.

Public attention attracted to these nickel and copper deposits.

Knowledge of existence of copper in 1770.

Work started at Bruce Mines.

Mining work at Wallace mine.

The existence of workable deposits of copper in this region, was a fact that had long been known, and as far back as 1770, a company had been formed and attempts made to mine this metal, but the difficulty of procuring and maintaining miners, at so great a distance from any centre of civilization, the remoteness of any market for the ore, as well as the absence of facilities for transportation, were in themselves amply sufficient causes, if none other existed, to render these first attempts abortive. However, in 1846, owing to the activity in prospecting and locating mineral lands, on the southern shore of Lake Superior, and a favourable report by Mr. W. E. Logan, then newly appointed Provincial Geologist, some enterprising Canadians banded themselves together into two associations called 'The Montreal Mining Company', and 'The Upper Canada Mining Company.' The former company purchased, amongst others, what was then known as 'The Bruce Mines Location', and, on account of the apparent richness of the deposit, decided to commence active work at this locality, while the Upper Canada Company proceeded to develop and work what was known as the 'Wallace Mine', near the mouth of the Whitefish river, on Lake Huron. The Wallace mine was the choice of a number of locations, owned by the same company, on the north shore of Lake Huron, and was selected on account of its promising character and proximity to civilization. It is chiefly remarkable as having been the first place in Canada, in which the presence of nickel was detected. After sinking a shaft to the depth of between 60 and 90 feet, and the opening up of a few pits to test the size of the deposit, all work was abandoned, and has not been resumed since, as the quantity of ore encountered in these operations did not seem to warrant any further expenditure.

Murray's description of southwestern extension of Creighton mine in 1856.

In his report for 1856, Mr. Alex. Murray,(1) thus refers to certain outcrops of sulphide bearing rocks, which were long afterwards shown to be the southwestern extension of the now famous Creighton Nickel mine. 'At the fifth mile a dingy green magnetic trap, with a large amount of iron pyrites, forms a ridge, and that rock with syenite, continues in a succession of ridges to the seventh mile, beyond which the country becomes low and marshy. Previous to my visit to Whitefish lake, I had been informed by Mr. Salter that local attraction of the magnet had been observed by himself, while he was engaged in running the meridian line, and he expressed it to be his opinion that the presence of a large body of iron ore was the immediate cause. When, therefore, I came to the part indicated by Mr. Salter, I made

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(1) Rep. Geol. Surv. Can. 1853-56, pp. 180-181.

a very careful examination, not only in the direction of the meridian line, but for a considerable distance on each side of it, and the result of my examination was that the local attraction, which I found exactly as described by Mr. Salter, was owing to the presence of an immense mass of magnetic trap.

Variation of compass and supposed cause.

The compass was found while traversing these trap ridges, to be deflected from its true bearing upwards of ten degrees at several parts, and in one place it showed a variation of fifteen degrees west of the true meridian, or about twelve degrees from the true magnetic north. Specimens of this trap have been given to Mr Hunt for analysis, and the result of his investigations shows that it contains magnetic iron ore and magnetic iron pyrites, generally disseminated through the rock, the former in very small grains; titaniferous iron was found in association with the magnetic ore, and a small quantity of nickel and copper with the pyrites. It was remarked that notwithstanding the powerful influence of this magnetic mass in causing a general local attraction, the contact of fragments of it with the compass, although producing a slight effect, rarely occasioned any remarkable agitation of the needle.'

Position of deposit.

The line referred to in the above description, was what was once known as 'Salter's Meridian line', and the exact position of these outcrops of mineralized 'trap', on the line, is in the first concession, on the boundary between Snider and Creighton townships. It can thus be seen, that even at this early period of its history, the officers of the Geological Survey were aware of the existence of nickel in this region, and had pointed out the probability, that workable deposits would be found. (1)

Inaccessible nature of country before passage of C. P. Ry.

Years passed by, and the inaccessible nature of the country deterred prospectors from making any very detailed exploration or examination, so that it was not until 1883, when the Canadian Pacific Railway was in course of construction, that the first discoveries of any consequence were made, since which time, the whole belt characterized by the presence of the Huronian rocks in the Sudbury district, has been overrun with eager prospectors and miners.

Discovery of Murray mine by Dr. Howey.

A not infrequent accident in newly settled districts, led to the first important discovery. Judge McNaughton, late Stipendiary Magistrate at Sudbury, had been lost in the woods to the west of the town, and a diligent search was at once instituted for him. A party, consisting of Dr. Howey and two others, found the judge seated on the

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(1.) Rep. Geo. Sur. Can. 1848-49, p. 63.

small eminence which then marked the site of what is now known as the Murray mine. Dr. Howey's natural curiosity and geological turn of mind are well known to all his friends, and it is not surprising, therefore, that having overcome his anxiety on the Judge's account, he should turn his attention to the neighbouring rocks. Looking down at the knoll, which had served as a resting place for the tired wanderer, he noticed that the rock composing it contained abundant impregnations of what appeared to be a valuable ore of copper. More critical examination still, convinced him, that he had discovered a mine and hastily securing some representative samples, he exhibited them to Drs. Girdwood and Selwyn, who happened to be in the neighbourhood, and either of whom he considered fully competent to pronounce with authority as to the economic value or possibilities of his find. Dr. Girdwood, it may be remarked, was, at the time, one of the chief medical advisers of the Canadian Pacific Railway, and a well known authority on chemistry and mineralogy. Dr. Selwyn, then Director of the Geological Survey, accompanied Dr. Girdwood, in order to obtain the necessary transportation facilities, enabling him to make a geological reconnaissance of the area in the vicinity of the railway. To Dr. Howey's surprise, they informed him that the pyrrhotite which formed such a large proportion of his samples, was practically valueless, that the only metal of importance which might be present in such a mineral was nickel, and that past experience with similar ores in Canada and elsewhere, had taught them, that this was always present in such small amount as not to permit of its profitable extraction. Turning their attention to the chalcopyrite, which was also represented in his samples, both these gentlemen agreed, that although it was a valuable ore of copper, the mineral was not present in sufficient quantity to pay for working. Thoroughly convinced of the soundness of their advice, but disappointed at the unexpected result, Dr. Howey took no further action in the matter, ridiculing in a quiet way the earnest and persistent efforts of others to interest capital in the immense economic possibilities of this and similar deposits afterwards found. One can imagine his chagrin, therefore, and sympathize with his mortification, when subsequent development demonstrated that both these gentlemen, whose scientific attainments could not be called in question, had been rather hasty in their judgment, although from a wide experience with the composition of pyrrhotites in general, they had been right in thus expressing their opinion.

Opinions by Drs. Selwyn and Girdwood.

Dr. Howey's disappointment.

Discovery of Murray mine

Early in 1884, the Canadian Pacific Railway made a cutting for their main line through this small hill (Murray mine), about 3½ miles northwest of Sudbury, and on July 12th of the same year, Dr. Selwyn

Dr. Selwyn's opinion.

made a careful examination of the location, and, stated to the writer, some years afterwards, that he had pronounced the lode to be one of the most promising he had yet seen in Canada. No such opinion, however, was ever published, although it is quite possible that the greater facility of examination caused by the cutting for the railway, and the massiveness of the deposit thus exposed, reversed his previous judgment of the ore body in question. (1)

Other mines found.

First reports greatly exaggerated.

Form of nickel bearing eruptive.

Other discoveries soon followed, and the McConnell, Lady Macdonald, Stobie, Blezard, Copper Cliff and Evans mines were all located. At first, the wildest notions were entertained as to the extent of these deposits, and the most exaggerated reports circulated as to their value. It was even confidently asserted that these were immensely important discoveries, and would revolutionize the whole copper trade, and render other mines then in operation quite unremunerative. Rounded hills of gossan, indicating the presence of the more solid and unaltered ore beneath, occur at intervals for miles in a southwesterly direction, conforming rudely to the strike of the stratified or foliated rocks, in the vicinity. This circumstance is all that seems to have justified the early discoverers in describing the deposits as veritable mountains of solid ore, many miles in extent and hundreds of feet thick. During the interval which has elapsed since the first discovery was made, prospectors have not been idle, and their efforts have been rewarded by the location of three large belts or masses of the sulphide bearing norite. Until lately, these have been considered as entirely separate and distinct from one another, but the later geological work is tending to prove their connection as one continuous ellipsoidal band, the central portion of which is now occupied by tufaceous slates and sandstones, coloured provisionally as of Cambrian age.

History of development.

The history of the development of mining in the Sudbury district is, in the main, that of the Canadian Copper Company, for it was the

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1. A specimen collected at the time by Dr. Selwyn from the cutting on the railway at the Murray mine, was examined by Dr. Hoffmann, who says 'It consisted of magnetic-pyrites and copper-pyrites, in association with a dark gray fine-grained diorite and a grayish green chloritic schist; a few of the fragments were in parts, coated with hydrated peroxide of iron. Some specimens of the magnetic-pyrites from this deposit contained numerous flakes of molybdenite. It was found to contain after drying at 100° C., (Hygroscopic water = 0·085 per cent.)

Iron	27·35
Copper	9·08
Sulphur	18·69
Insoluble matter (gangue)	36·63
Gold	mere traces.
Silver	2·187 oz. to the ton of 2,000 lbs.

(Ann. Rep. Geol. Surv. Can. Vol. I, 1885, Part M, pp. 19-21.

first combination of capital which seriously undertook the business of mining in this area, while, at the same time, having the distinction of being the only corporation, which has continued its operations without serious interruption, from the commencement until the present time.

Canadian Copper Co. organized.

The McAllister mine, later called the Lady Macdonald mine, (now No. 4 mine of the Canadian Copper Company's group), situated on the north side of the lake of the same name, on lot I, con. III., of the township of Snider, was the first property on which any work was done in the summer of 1885, although later in the fall, the Evans mine, about two and a half miles farther south in the same township, was opened up and some preliminary tests made. On January 5, 1886, the Canadian Copper Company was formed, with a subscribed and paid up capital of $2,000,000, which was afterwards increased to $2,500,000, to operate the Copper Cliff, Stobie and Evans mines.

Mining started at Copper Cliff.

First blast furnace.

No. 2 mine started.

Evans mine closed down.

On May 1st, 1886, work was started in earnest at the Copper Cliff mine, near the north end of lot 12, con. II., of McKim township, and the first shipments of ore made from the district, were obtained from the surface openings of the original Copper Cliff mine. Later on in the same year, both the Stobie and Evans mines were opened up, and these three mines together produced all the ore treated in the smelters at Copper Cliff, until the year 1898. The first blast furnace installed at the old or East Smelter was blown in on December 24, 1888, this being augmented under the same roof by a second blast furnace, which was started on September 4, 1889. During 1896, and 1897, diamond drill exploratory work was undertaken in connection with the deposits afterwards known as the No. 1 and No. 2 mines with their extensions, and in 1898, many of these openings produced a considerable quantity of high grade ore, but, with the exception of the deposit at No. 2, there was apparently no very large or continuous body encountered, for they were soon abandoned and are now completely dismantled. About the same time, what is now the largest open pit of the whole group of the Copper Cliff mines (No. 2), was started in earnest, soon supplying a very large quantity of ore, which, however, contains a considerable admixture of rocky matter. The Evans mine, although with some rather serious interruptions, continued to furnish ore until late in the fall of 1899, when it closed down, and to all appearances has been permanently abandoned. The engines, boilers and other machinery have been removed, and the rails of the spur connecting the mines with the main line of railway, have all been torn up and carried off to be used elsewhere. In the fall of 1899, preparations were made for opening up the Frood mine (No. 3), situated

Frood mine opened.

Clarabelle mines.

Opening of Creighton mine.

Stobie mine.

Closed down in 1901.

Very large supply of ore from Creighton mine.

a little over a mile southwest of the Stobie mine, on lot 6, con. VI., of the township of McKim, and early in 1900, this was added to the list of producing mines. During 1899, and succeeding seasons, many of the openings northwest of No. 2 mine, as well as some of the pits and shafts known as the Clarabelle group of mines, were being operated at one time or another, and added materially to the reserves of ore, but all of these were shut down in the spring of 1902, when the business of the company was being curtailed, pending reorganization and consolidation of the various interests. In July, 1900, the work of stripping at the Creighton mine was begun, and in August of the following year, ore was shipped for the first time to the roast yards at Copper Cliff. The Creighton mine is undoubtedly the largest mine in the district of which we at present have knowledge, and from the very beginning of operations, has produced very large quantities of the almost pure sulphides, with little or no rocky admixture. It is especially valuable as carrying a high percentage of nickel, with a very much smaller proportion of copper. The mine is situated on the north half of lot 10, concession I., of the township of Snider, about six miles in a straight line west of Copper Cliff station. The ore, when mined, is carried on cars over the Manitoulin and North Shore Railway, on the north side of which the mine is located, to Clarabelle junction where connection is made with the railway owned by the Canadian Copper Company. Before the opening of the Creighton mine, the [illegible] had the distinction of having supplied the largest quantity of ore of all the Canadian Copper Company's mines, and with the exception of some minor stoppages, this mine was in continuous operation from the date of its opening in 1886, until November, 1901, when it closed down and has remained so ever since. The reason for this cessation of operations does not appear to be that the end of the deposit has been reached, but because the quality of ore which it supplies is not needed in the present smelting operations. The Creighton mine is at present the main source of supply, and this mine with its equipment allows for a production of between 500 and 600 tons of ore per day, and Dr. Coleman is authority for the statement that for some time in 1902, the output from this mine alone reached 17,000 tons per month. The old or original Copper Cliff still continues to supply about 1,000 tons of ore per month, obtained mainly from the 13th and 14th levels, the latter workings being 1,052 feet below the surface; but even at this depth the ore body shows no serious diminution, either in size or richness. No. 2 mine and the Frood (No. 3), complete the list of mines from which at present the supply of ore is drawn. The mines of this company, not in use at present, must not all be considered as having been permanently abandoned, but the openings now utilized produce an ample supply of the sulphide material of the various grades suitable for smelting.

Increase in smelting equipment at Copper Cliff.

This activity in mining at Copper Cliff, and the steady increase in the production of ore, necessitated constant additions to the smelting equipment, as well as the erection of new and suitable buildings for the accommodation of the new blast furnaces. We thus find, that, besides the enlargement of the old or East Smelter, where three new furnaces were installed in addition to the two already mentioned, an entirely new structure known as the West Smelter, was built in 1899. At first, this building had room for only 4 furnaces, but this was quickly enlarged, and the furnace capacity doubled. The site chosen for this new building, was on the slope of the hill about 300 feet southeast of the No. 2 mine rock house, the deep valley to the south providing a convenient and ample dumping ground for the slag.

East Smelter abandoned.

Since the inauguration of this smelter, the one at the east end of the works is being gradually abandoned, and much of the old plant has already been removed to the site of the new building. The work done at this place, since the suspension of operations in the beginning of 1902, has been rather spasmodic, and has consisted mainly in the production of a low grade matte known as 'spilt matte.'

Pyritic smelting.

Thus, several of the furnaces at this smelter were being employed in producing this matte from June, 1902, until the end of the year. In addition, two of the furnaces have been engaged from time to time, making experiments in the way of smelting the ore pyritically. It is hoped, by this method, to reduce the coke to 3 or 4 per cent of the charge, by using a hot blast and an oxidizing atmosphere in the blast furnace, and utilizing the heat developed by the burning of the sulphur and iron of the ore, for the smelting. In the fall of 1900, the plant of the Ontario Smelting Works was installed by the Orford Copper Company, an organization closely related to the Canadian Copper Company. The works, as completed, are designed to further refine the first or lower grade matte, produced by the blast furnaces of the Canadian Copper Company, using as a flux, the silicious ore from the Massey Copper mine.

Installation of Ontario Smelting Works in 1900.

Formation of International Nickel Co.

Perhaps, the most important event in the development of the nickel industry, either in this district or elsewhere, occurred in April, 1902, when after negotiations, covering a period of several months, the International Nickel Company was organized under the laws of the State of New Jersey, to consolidate and control the nickel production of the world. The following properties were included in the new organization:—The Canadian Copper Company; the Orford Copper Company, with reduction works at Bayonne, N.J.; the Anglo-American Iron Company, and the Vermilion Mining Company, in Canada; the American Nickel Works, in Camden, N.J.; the Nickel Corporation, Limited, and the Société Minière Caledonienne, in New Caledonia. During 1902, and 1903, mining operations were considerably curtailed, except in the case of the Creighton mine, where the production has been brisk ever since it was first opened. This has permitted certain very necessary explorations of many of the ore deposits, by diamond drilling and testing shafts. The results of these experiments, have added very largely to the detailed knowledge, not only in regard to the size and shape of the deposits already known, but has succeeded in revealing the presence of considerable bodies of ore, whose presence had not been suspected.

Mining operations curtailed.

Such, in brief, is the record of the principal events in the development of the mining and metallurgical operations of this pioneer company, in the nickel industry in Canada. From the start, their work has always been characterized by energetic and business-like methods, and if at the present time, they seem to have gained control of more than their fair share of the available nickel bearing area, which likewise includes many of the mines producing the largest supplies of high grade nickel ore, the result must not be attributed to chance or a series of fortunate circumstances, but is rather the strongest evidence of the keen business foresight of the originators of the enterprise, and an abiding faith in the permanence of the nickel mining in this district.

Business-like methods of Canadian Copper Co.

It must not, however, be assumed that all of the available or even important deposits of nickel-copper sulphides, have passed under the control of the International Nickel Company, for besides the Victoria mines of the Mond Nickel Company, which still contain a very large reserve of high grade ore, there are many others throughout the district which are capable of economic development as more or less permanent mines. Suspension of operations, so often recorded in the history of the mining development of the district, does not in all or even a majority of cases, imply a failure in the ore supply, but is oftener to be attributed to a waste of capital, owing to lack of business judgment, and the need of a technical knowledge of the difficulties to be encountered in both the mining and smelting departments. Moreover, many of the deposits have been condemned, because they failed to give a proper return for the capital invested, when all that was available of the latter was utilized in costly experiments, to discover new methods of smelting or refining. Past experience in this district has shown that

All important deposits do not belong to International Nickel Co.

Reasons for suspension of operations.

Necessity for large reserves of ore.

success and permanency in the mining and smelting operations of any company, can only be secured by the possession of large reserves of ore, preferably obtained from different mines or deposits. In this way, not only is a constant supply of ore assured, but diversity in composition is possible thus enabling a judicious selection of the different grades, whose mixture in the proper proportions, promotes successful and economic smelting.

Important deposits on Levack and North Nickel Range.

In addition to the deposits which are still available along the Southern Range, most of which are in various stages of development, there are other apparently very large and important ore bodies, situated along the Middle range (in Levack township); and others again on the Northern Nickel Range which are certainly worthy of close attention and which seem destined, in the near future, to be worked as mines. The lack of transportation facilities has, up to the present, prevented any deep mining work being done, but the surface indications and geological conditions are entirely favourable to the existence of large ore bodies, which, although perhaps not attaining the phenomenal dimensions of the Creighton mine, will nevertheless prove of sufficient magnitude to form valuable mines.

Henry H. Vivian & Co.

Beginning of operations at Murray mine.

The incidents attending the discovery of the deposit which was afterwards known as the Murray mine, have already been related, as also the fact that it was located over a year previous to either the Copper Cliff or Stobie mines. In spite of this circumstance, however, and its advantageous situation on the main line of the Canadian Pacific Railway, no mining of any importance was done in connection with this property until early in the year 1889. During the whole of this season, however, it was prospected under bond by H. H. Vivian & Co., of Swansea, Wales, and in October, of the same year, it was sold outright to this company by the original owners. The mine is situated on the north half of lot 11, con. V., of McKim township. All the necessary machinery, buildings and other adjuncts were installed, and preparations made for carrying on the business of mining on an extensive scale.

Smelting at Murray mine.

The first blast furnace at the Murray mine was blown in about the end of September, 1890, and put to work on some ore which had been previously roasted. The general practice followed by this company in their smelting operations, consisted in the production of a comparatively low grade blast furnace matte (averaging 9.4 per cent nickel and

4.7 per cent copper), thus preventing an undue loss of the metals in the slag; and subsequently bessemerizing this into a second or higher grade matte (averaging nearly 75 per cent of the combined metals or about 49 per cent nickel and 26 per cent copper). For this second concentration of the metallic contents, the Vivians were the first to make use of the Manhès furnace or converter in 1891. Mining and smelting operations were continued, although with some minor interruptions, from 1889 until 1894, when the works were finally closed down. Between August, 1896, and January, 1897, however, the smelter was engaged in producing matte from about 6,000 tons of ore which had been roasted by the Vivians. This product was shipped to Mr. Joseph Wharton, of Camden, N. J., to whom it had been sold.

Cessation of operations.

Purchase of Murray mine by Vivians of great promise to whole district.

The purchase of the Murray mine by this old established and well known firm of Welsh smelters, was regarded by all as marking a distinct epoch in the history of nickel mining in Canada. Their wide experience in all branches of metallurgical industry, seemed to augur well for the success, not only of their own individual enterprise, but their presence in the district, promised to be of immense assistance to others similarly engaged in the mining and smelting of these nickel and copper sulphides. The difficulties which always attend the initiation of a new undertaking, were in evidence from the very beginning of the business of nickel mining, and were of that nature, which required the exercise of just such ripe technical knowledge as the Vivians were sure to possess. Moreover, such a significant acknowledgment of the success and permanence of nickel mining in Canada, on the part of a firm whose sphere of activity in mining and smelting had extended to all parts of the known world, could not fail to have a most marked influence on all subsequent mining operations in the district. It was, therefore, to say the least, bitterly disappointing, that from the very outset, a seeming lack of energy, and often even of ordinary business ability, on the part of those who had control of the work, was a subject of common remark, being in marked contrast to the alert methods characterizing the operations of the rival corporation, the Canadian Copper Company. This was evident in almost every department of the work, and the apparent lack of technical knowledge and business capacity on the part of this firm, from whom so much had been expected, could not be very well understood by the ordinary observer. On the other hand, the management entrusted with the conduct of affairs at the mine, complained of want of interest and attention on the part of the authorities in England, but, whatever the real cause or combination of causes, the enterprise was not attended with the success anticipated, and which should have been reasonably

Cause of failure.

Apathy of management.

expected. The final decision of the company to close down and withdraw from the business of mining in Canada, came as a distinct shock to all those who were interested in seeing the permanency of the nickel mining established. The failure of these operations must not, therefore, be attributed, as some have supposed, to the diminution in depth of the ore body or to abundant rocky admixture, although these, no doubt, contributed to a certain extent to bring about the undesirable result. It seems altogether reasonable to suppose that a considerable quantity of ore is still present, both in the lower levels of the mine, as well as below these workings at depths which have not yet been reached by the mining explorations so far undertaken, which could be profitably mined in conjunction with other deposits. In this respect, the Vivians were at a manifest desadvantage as compared with the Canadian Copper Company, the varied composition and character of the ores from whose different mines permitted, and even favoured, the mixtures which are seemingly so essential for the successful and economical smelting of these sulphide ores. In addition to the Murray mine, the Vivians owned the nickel and copper deposit known as the Lady Violet mine, situated on the north half of Lot 1, con. IV., of the township of Snider, about 1½ miles southwest of the Murray mine. The mining, however, undertaken at this locality consisted chiefly of stripping, the sinking of trial shafts, and other preliminary development work. A blacksmith's shop and some temporary residences were the only buildings erected.

Ore still present in lower levels of mine.

Necessity for various grades of ore.

Lady Violet mine.

Some rather extensive diamond drill exploration work was subsequently undertaken by order of the Board of Directors in England, at both the Murray and Lady Violet mines, but unfortunately, the different sites for the drill, as well as the angles of inclination and direction of the bore holes, were determined by some of these same directors in England, whose only means of guidance in this selection, seems to have been maps of the two properties in question, but without any very extended personal knowledge of the actual geological conditions prevailing at these places. As might have been expected, from operations carried on under such adverse conditions, no important ore bodies were encountered, nor was any information of material value obtained, which might be of assistance either to the owners or to any prospective buyer. The diamond drill used belonged to the Ontario government, and was loaned to the Vivians under the usual conditions of working in 1898. Boring was begun on the 2nd of December, 1898, and the work continued until the 16th of June, 1899, the number of days of actual boring being 212, of 10 hours each. In all, eight holes

Diamond drill exploration at Murray and Lady Violet mines.

Cost of diamond drilling.

were put down, having an aggregate depth of 1,146 feet, which cost on an average $2.65 per foot. (1)

Caretaker at Murray mine

Since the abandonment of active mining, the property has been under the charge of Mr. G. H. Behenna, who has been continuously employed looking after the various buildings and machinery, while a pump has kept most of the levels comparatively free from water.

Dominion Mineral Company.

Location of Blezard mine.

Erection of smelter.

Composition of ore.

Cessation of operations.

Production.

Discovery and location of Worthington mine.

Depth of mining.

The Dominion Mineral Company commenced mining operations in the summer of 1889, on a deposit of nickel and copper ore known as the Blezard mine, occurring on lot 4, con. II., of Blezard township, about 1¼ miles north of the Stobie mine, at the southern edge of the Main or Southern Range of norite, which here comes in contact with the older diorites and hornblende schists. A smelter was soon built, with a furnace capacity of 120 to 150 tons daily. Four shafts were sunk at this mine, the deepest of which seems to have reached a point 172 feet below the surface. Most of the ore secured, however, was by means of a series of large open pits which are at present filled with water. The "kies" or metallic portion of the ore thus obtained is said to have averaged about 4 per cent nickel and 2 per cent copper. For reasons which have been differently stated, mining operations were discontinued in the summer of 1893, and have not been resumed since The smelter, however, at this mine, was kept running until July, 1895, on ore brought chiefly from the Worthington mine. The total production of ore cannot be accurately given, but the figure of 100,000 tons is certainly somewhat below the actual output. The Worthington mine, also worked by the same company, is situated at a station of the same name, on the Sault branch of the Canadian Pacific railway, twenty-five miles west of Sudbury. The mine itself, consisting of two shafts, lies close to the line between lots 1 and 2, con. II., of the township of Drury. It was discovered at the time of the construction of this branch by Mr. James Worthington, one of the railway contractors. Actual mining was started on this property in the summer of 1890, and continued without much interruption until the middle of September, 1894, when operations ceased, and with the exception of a short time in 1902, when the mine was pumped out for [illegible] poses of inspection, no work of any consequence has since been [illegible] From the two shafts, one of which reached a depth of 100 feet, and the other 175 feet below the surface, as well as from two adjoining

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(1) Ann. Rep. Bur. of Mines, Ont., 1901, pp. 53 & 56.

Production of Worthington mine.

Character and composition of ore at Worthington mine.

stopes and connecting levels, a considerable amount of unusually high grade ore was obtained, which has been estimated by Dr. Coleman at 25,000 tons. The pyrrhotite occurring at this mine is often phenomenally high in nickel, chiefly owing to abundantly disseminated pentlandite, and the first recognition of this mineral in the district was by Dr. T. L. Walker, in the ore procured from this mine by the writer in 1891, and to which reference has already been made. The analysis of this pentlandite by Walker showed 30 per cent nickel, but an examination of some large masses of ore obtained at a depth of 85 feet below the surface, and consisting of pyrrhotite with a considerable proportion of pentlandite, which could be readily discerned, showed 17·48 per cent of nickel. In 1891, a shipment of raw ore was made from this mine of 123 tons, which contained 10 per cent nickel and 3 per cent copper. Large masses of practically pure chalcopyrite were also obtained, and a considerable quantity of such ore is stated by Manager Attwood to have been shipped, assaying 18 per cent copper and 2·5 per cent nickel.

Work at Cameron mine.

Reasons for cessation of mining.

In the fall of 1895, some development work was done by this same company, at the Cameron mine, on lot 7, con. 1, of Blezard township, nearly two miles southwest of the Blezard mine. A shaft was sunk a distance of 65 feet with a drift 66 feet in length. The real reason for the cessation of work at both the Worthington and Blezard mines is very difficult to ascertain, but bad business management was responsible in large part for many of their difficulties during these mining operations. Individual members of the company state that the present idleness of these properties is because no decision satisfactory to all parties can be reached by the board of directors, so that working under these conditions is impossible, and they would be inclined to sell.

Some of the other companies who carried on mining and in some cases smelting operations for a time, shortly after the recognition of this area as a mining district deserve a passing mention in this connection.

Work by Algoma Nickel Co.

One of these, the Algoma Nickel Company, in 1891, under an option secured from the owners of the property, sank four shafts varying in depths from 12 to 35 feet and aggregating 84 feet in all, besides some smaller openings or test pits on lot 11, con. V., of the township of Lorne. No large body of ore was, however, met with as a result of this development work, the sulphides apparently occurring as unusually rich impregnations, which, if continuous, might prove an economic possibility. These sulphides occur in connection with what is seemingly the southwestern extension of the same mass or band of norite on which the Worthington and Mitchener mines are situated. Work was abandoned, leaving ore piles aggregating about 500 tons in weight. Assays of an average sample in the laboratory of the Survey showed 1·95 per cent nickel, with traces of cobalt.

The Drury Nickel Company purchased the deposit known as the Chicago or Travers mine in 1890, and began active mining in February, 1891. This mine is situated on lot 3, con. V, of the township of Drury, about 5 miles north of Worthington station, on the Sault branch of the Canadian Pacific railway. Most of the ore was mined by means of open cuts, one of which had a depth of 30 feet, length 60 feet and width 30 feet, from the bottom of which a shaft 8 by 12 feet was sunk to a depth of 60 feet. Another open pit measured 40 feet in length, 80 feet in width and 30 feet in depth. From these openings 3,500 tons of ore were obtained, and reduced to matte in a water-jacketed furnace capable of treating 60 tons in 24 hours. A roast-yard was prepared, suitable buildings erected, and the plant installed necessary for permanent mining, but in spite of all this, the mine closed down in 1892. In 1893, after lying idle for nearly a year, some additional mining and smelting was undertaken, but this was also soon abandoned. On May 20, 1896, work was again resumed, the company being reorganized under the name of the Trill Nickel Mining and Manufacturing Company, and the deposit itself was rechristened the Inez mine. An elevated tramway, 4½ miles long, was built from Worthington station, for conveying supplies to the mine, and the product of the mine, in turn, to the station. It was possible, by means of this tramway, for a single horse to haul two cars, each containing two tons, and to make two round trips, each way, daily. Mining and smelting continued briskly again, for a while, but before August, 1897, work was again stopped and has not since been resumed.

Drury Nickel Company.

Mining at Chicago or Travers mine.

Smelting.

Trill Nickel Mining and Man'fg. Co.

Inez mine.

From time to time, mention is made of the 'Big Levack properties,' thus referring to certain deposits of nickeliferous pyrrhotite, which were discovered early in the history of the district in the township of Levack, but none of which have been sufficiently developed to be dignified by the name of "mine." From time to time, however, considerable work has been done and examinations made, with a view to possible purchase, but for various reasons, the properties are at present lying idle and without any present prospect of being opened up in the near future. The deposits in question are situated along the northern junction of what has sometimes been called the Windy lake eruptive or Middle Belt of the nickel-bearing norite, although it is possible that this is a portion of the huge ellipsoidal band, and the south-

Levack mines.

Windy lake eruptive.

Surface indications among the best in the district.

Character of ore body.

Examination and work by Alfred Merry.

Composition of Levack ores.

Exploration by Mond Nickel Co.

Diamond drilling not always satisfactory.

Probability of large ore bodies in Levack.

western continuation of the Northern Nickel Range. The surface indications are undoubtedly among the best in the district, and the development work so far undertaken has exposed a very large amount of almost pure nickeliferous pyrrhotite, with little or no rocky admixture. The ore-body has the additional advantage that chalcopyrite forms only a comparatively small proportion of the whole. The first, and probably the most extensive mining exploration work in connection with these properties, was undertaken in 1887, and a report made by Mr. A. Merry, of H. H. Vivian and Company, for the owners of the property. This work consisted of extensive stripping, and the removal of portions of the overlying drift material, the opening up of numerous cross cuts, trenches and test pits. The average assay of a number of typical samples, made by Mr. Merry, showed the presence of 3.86 per cent of nickel in the pyrrhotite, with 0.81 per cent of copper. Assays made in the laboratory of the Survey show the nickel to vary from 1.96 to 4.13 per cent, the lower figure containing considerable gangue, while the higher results were obtained from the solid, coarse-grained pyrrhotite. Early in 1901, some of these locations were examined by means of diamond drill exploration, under option by the Mond Nickel Company, but to the disappointment of all who were concerned in the welfare of the district, this company decided to abandon their option, and the property was again thrown on the market. It is manifestly unwise, as a rule, to condemn as worthless the testimony afforded by diamond drill exploration, especially when such work is under the superintendence of men thoroughly experienced in the mode of occurrence of the class of deposit to be tested, but an inspection of the work performed at this time, seems thoroughly convincing, that much of what was done added very little, if any, information to what we already possessed in regard to these deposits, or than can be secured without such costly assistance. We are, therefore, still in the dark as to whether or not there are any large or continuous bodies of ore at these places, and if the former, as to their most likely disposition. All geologists who have visited these deposits, and especially those who have had wide experience in the district, are agreed that large and valuable ore-bodies are likely to occur at this place. The rock is the usual norite, with which all the other mines of the district are associated, while the contact is well and sharply defined, and the differentiation pronounced. The area covered by the nickel-bearing norite is very large, and no other deposits have been found in connection with this eruptive. The angle of dip to the southeast is unusually low for the district, and this fact has to a large extent prevented its successful exploration. The development work, as well as the borings undertaken by the diamond drill, seem to incline the casual observer to the conclusion that the deposit is a 'pancake' and has no great depth or permanence. A careful study of the attitude of the outcrops of rock, as well as their surface outline in the immediate vicinity of the sites chosen for drilling purposes, is convincing that no deep deposit need be expected in their vicinity, while on the other hand, it seems reasonable that the main body of the sulphides is concealed beneath the drift, at the base of the hill, where no trials whatever have been made. A shaft sunk here and continued with the granite-gneiss as a foot-wall, with drifts outward towards the main mass of the norite, would show definitely and finally not only if any large and continuous ore body is present along this line of junction, but at the same time would secure a considerable amount of ore, which could afterwards be used.

Suggestions for mining exploration work.

Location and work at Beatrice or Sheppard mine.

In 1891, a shaft was started on the Davis property, known as the Sheppard or Beatrice mine. This deposit is situated along the north-eastern extension of the same line of junction as the Blezard mine, between the norite and greenstone. It is on lot 1, con. III., of Blezard Township, nearly two miles north-east of the Blezard mine, with which it is connected by wagon road. The shaft, 10 by 12 feet, was sunk to the depth of 100 feet, with three small drifts, aggregating 34 feet. Work, however, was not continued after April, 1893.

Operations by Emmens Metal Co. at Gersdorffite or Macdonell mine.

In the same year, (1891), a shaft was sunk and considerable development work done by the Emmens Metal Company, on the property afterwards known as the Macdonell or Gersdorffite mine, situated in the southeast corner of lot 12, con. III., of the township of Denison, and about one mile and a half northeast of Worthington station. This locality is remarkable as having furnished the first specimens of the rich nickel minerals, niccolite and gersdorffite in the district, but as no large body of ore was discovered, mining operations soon came to an end.

Trillabelle mine.

In 1894, the deposit known as the Trillabelle mine was opened, and a shaft 60 feet in depth sunk on the deposit. This mine is situated on lots 10 and 11, con. III., of the township of Trill, and is connected by wagon road, by way of the Inez or Travers mine, with Worthington station, which is about 13 miles distant.

Mining at Kirkwood mine.

In 1898, the deposit which was named the Kirkwood mine, situated on lot 8, con. III., of the township of Garson, at the southern edge of the main or southern belt of norite, along the same line of junction as the Blezard and Beatrice mines, was opened. Three shafts were sunk, the deepest of which was rather less than 50 feet. A substantial rock house and other suitable mining buildings were erected, but for lack of sufficient capital the work has not proceeded further.

Great Lakes Copper Co. purchase of and work at Mount Nickel mine.

On October 5, 1899, the Great Lakes Copper Company was organized, and purchased the property known as the Mount Nickel mine, comprising lots 5 and 6, con, II., of the township of Blezard. They also purchased what was known as the "Trill Property," consisting of lots 9 and 10, in cons. III., and IV., of the township of Trill in the district of Algoma. The Mount Nickel mine was chosen as the scene of the first mining operations, and this deposit was developed by means of two open cuts and a shaft, which eventually reached a depth of about 165 feet, with certain levels and drifts, from all of which considerable ore was obtained. It is also stated that diamond drill explorations subsequently undertaken revealed the presence of a good supply of ore. The mine was equipped with all the machinery and other appliances for carrying on extensive mining operations. The smelting works were built from original designs, by Anton Graf, of Vienna, and it was proposed to produce high grade matte at one operation, from ores which had received no previous roasting. This method of smelting failed, and in May, 1901, all operations ceased, and have not been resumed since.

Equipment and smelting at Mount Nickel.

Work by Hoepfner Refining Co. and the Nickel Copper Co.

In the latter part of 1899, it was announced that a strong company, under the title of the Hoepfner Refining Company, with a capital of $10,000,000, had been formed in Hamilton, to refine nickel-copper mattes and zinc ores. These metals were to be recovered by electrolytic methods discovered by Dr. Carl Hoepfner. The Nickel Copper Company, of Hamilton, also organized about the same time, were to furnish the necessary supply of nickel-copper matte. Unfortunately, however, Dr. Hoep[illegible]as unable to so perfect his methods as to permit of its econo[illegible]ication on a large scale, and the Nickel Copper Company too[illegible] matter of experimenting into their own hands. The services of Mr. Hans A. Frasch were obtained, who devised what is known as the "Frasch Process." This method likewise, although possible under ordinary conditions of laboratory practice, as was demonstrated at a public exhibition held on September 3, 1900, was not capable of commercial application. The operations of the Nickel Copper Company came to an end in 1901, owing to the complete failure of the new self roasting plant erected near Worthington station.

Operations ceased in 1901.

Lake Superior Power Company.

Proposals for work by Lake Superior Power Co.

For some time after the opening of the pulp mills at Sault Ste. Marie, the Lake Superior Power Company were content to manufacture mechanical pulp, but discovering that there was a large and growing demand for sulphite pulp, it was decided to at once enter upon its manufacture. The proximity of the sulphide deposits at Sudbury, suggested that the sulphur which was necessary for the production of this pulp might be most profitably extracted from these ores, and at the same time yield a by-product of very great value. The preliminary experiments with the nickeliferous pyrrhotite were convincing that sufficient sulphur dioxide could be procured from this mineral by roasting, while at the same time the roasted ore or residue, consisting essentially of a mixture of iron and nickel with only a comparatively small percentage of sulphur, could be mixed with lime and charcoal and smelted in electric furnaces to ferro-nickel. It was intended at the time to employ this alloy in the production of steel rails, which it was proposed to manufacture in large quantities. An inspection of all the available deposits of nickeliferous pyrrhotite seemed to indicate that the property afterwards known as the Gertrude mine was peculiarly adapted to meet the necessities of the case in hand. In 1899, therefore, the Lake Superior Power Company purchased this mine, and immediately proceeded to develop the deposits which were situated on the S. ½ of lots 3, 4 and 5, of concession I, of the township of Creighton, a little over twelve miles west of Sudbury. The preliminary examinations and first development work showed an unusual predominance of a high grade nickeliferous pyrrhotite, with comparatively little of the objectionable copper in the form of intermixed chalcopyrite. As mining operations proceeded, however, more chalcopyrite was encountered, and the deposit gradually assumed the usual characteristics of those elsewhere in the district, and the copper contents assumed too large a proportion to permit of the successful carrying on of the first proposal. Repeated experiments were made with many car loads of raw material shipped to the works at the Sault for this purpose, but it was finally decided to adopt the ordinary processes of smelting in use elsewhere throughout the district, producing a blast furnace matte averaging about 29 per cent of the combined metals, the proportion of nickel being about double that of the copper.

Manufacture of ferro-nickel.

Purchase and beginning of operations at Gertrude mine.

Large experiments at "Sault."

Ordinary smelting method adopted.

In 1900, the development of the Gertrude mine was continued, but the necessity of transportation facilities greatly hampered these operations. Two shafts were sunk, one attaining a depth of 120 feet, and the other of 80 feet, with several levels and drifts. In the spring of 1901, the Manitoulin and North Shore railway reached his mine, and work was conducted much more energetically. Roast yards were prepared, and the erection of a smelter commenced. In July of that year, the Elsie mine on the S. ½ of lot 12, concession V., of McKim, and about half a mile southwest of the Murray mine, was open-

Mining development at Gertrude Mine.

Opening of Elsie mine.

Smelting at Gertrude mine.

Cessation of operations.

ed up. The ore was shipped in 50 ton steel cars to the roast yards at the Gertrude mine, and the first shipment of ore was made to this place on the 26th of October 1901, on the completion of the switch, which connects the deposit with the main line of the Manitoulin and North Shore railway. The smelter at the Gertrude mine was finished in June, 1902, and afterwards ran steadily throughout the year, converting 100 to 160 tons daily into standard matte. In November, 1902, all work was suspended at the Elsie mine. to permit of the needed removal of some of the mining buildings, whose safety was threatened, by a continuance of the mining work. Later, in 1903, the whole of the mining operations in the Sudbury district shared the same fate in common with the other industries, operated by the same company, at the time of their failure.

Mond Nickel Company.

Discovery of carbon monoxide process.

Perfection of method and erection of refineries.

In 1889, Dr. Ludwig Mond, F. R. S., in collaboration with Dr. Carl Langer, while carrying on certain experiments for determining a suitable method for eliminating the carbon monoxide gases containing hydrogen, made certain observations, which eventually resulted in the discovery of what has since been known as the Mond or carbon-monoxide process, for separating metallic nickel from copper, etc. In this process, there were many technical difficulties to be overcome, so that although a patent was applied for on the 12th of August, 1890, it was some years before it had reached such a stage as demonstrated its possibilities of commercial success. In 1892, an experimental plant, on a large scale, was erected at Smethwick, near Birmingham, England, and after several years of patient work, during which time the plant had to be several times remodelled, in order to meet all the requirements of this somewhat delicate process, it gradually assumed its present shape. In 1898, it had reached such a state of perfection, as to afford the most convincing proof, that the process was able, not only to compete successfully in regard to cost of operation, but at the same time, the metallic nickel produced, showed on analysis, a higher degree of purity than had yet been possible by any other known process.

rchase of ictoria mine.

The success of the method being thus assured, Dr. Mond began at once to make inquiries, with a view to obtaining an unfailing supply of nickel ore. Experiments conducted on the nickel and copper sulphide ores, seemed convincing, that such were peculiarly suited to treatment by the Mond process, so that it was decided to buy one or more of the best locations which were then available in the Sudbury Mining District. At this time, and for some years previously, it was a matter of common gossip throughout this area, that the McConnell mine or property, in the township of Denison, was one of the largest deposits of high grade ore which had yet been found, and attention was, therefore, directed to it with a view to possible purchase. After some negotiations, and a thorough investigation of the merits of these deposits, Dr. Mond decided to acquire these properties, and accordingly, in the summer of 1899, the necessary transfer was made. These mining locations had been under development for some time by their former owner, Mr. Rinaldo McConnell, and at the time they were sold to Dr. Mond, explorations were being carried on by means of the Ontario government diamond drill, with a view to determining more definitely the position and extent of the various ore-bodies. The change in ownership, however, did not affect the progress of the work, which began on July 10, and finished on November 21, 1899. In this time, seven holes were bored, the aggregate number of feet being 994, at an average cost of $1.75 per foot. In addition, two other drills owned by Dr. Mond were engaged more or less continuously during this and the two succeeding years, investigating these and other mining locations, in which Dr. Mond was interested. The main shaft and mining buildings of what was henceforth to be known as the Victoria mines, are situated on the north half of lot 8, con. IV., of the township of Denison, while the smelter, offices and official residences, were built on the north half of lot 8, con. II., of the same township, close to the "Sault" branch of the Canadian Pacific railway, and a little over two miles south of the main openings.

Diamond drill exploration.

Cost of diamond drilling.

Location of mine and smelter.

Opening up of deposits.

Beginning in 1899, the work of opening up these deposits proceeded as rapidly as circumstances permitted. Extensive stripping of the deposits and other preliminary development work was undertaken; roads were opened up; a roast [illegible] was levelled and otherwise prepared, and the necessary timbers [illegible] for the numerous extensive structures contemplated.

Erection of smelter.

During 1900, this work was continued, special attention being given to equipping the mines and smelter, the site of the latter being chosen close to Fairbank creek, on the Sault branch, 22 miles west of Sudbury. An aerial tramway, 11,000 feet in length, was installed by the Trenton Iron Co., of Trenton, N. J., to convey the ore from the rock house at the mines to the roast yard, which was first located close to the smelter.

Aerial tramway.

Incorporation of Mond Nickel Co.

On the 16th of October, 1900, the Mond Nickel Company, Limited, of London, Eng., was authorized, by license of the Lieutenant-Governor, to carry on business in Ontario. The incorporation of this company, with a capital of £600,000, was for the purpose of acquiring all the above property, plants, patents, and smelters belonging to Dr. Ludwig Mond in the Sudbury district.

Building up of Victoria Mines.

Plant of the most modern type, for roasting, smelting, and bessemerizing the ore, was erected at Victoria Mines, under the direction of Mr. Hiram W. Hixon, formerly of the Anaconda Company, this equipment being the most complete and conveniently arranged, which had, up to that time, been installed in the district. In addition, substantial offices and tasteful dwellings, with all modern conveniences, such as water and electric light, have been erected for the accommodation of the staff and their families, and the site of pre-existing swamps and rocky hummocks was quickly filled in, levelled and transformed into an important village and business centre.

Beginning of mining and smelting operations.

Breakdown caused by lightning.

Removal of roast yards.

Early in 1901, the mine was in complete working order, and beginning with February, ore was regularly raised and transported by means of the aerial tramway, to the roast yard. The smelter shortly afterwards commenced to turn out matte, by the Bessemer process, this product averaging about 80 per cent of combined nickel and copper, the former metal being usually present a little in excess. On 1st July, 1901, the head house or landing station at the roast yard was struck by lightning, and before adequate assistance could arrive, was burned to the ground. This temporary breakdown of the cable system, although greatly retarding mining operations at the time, was really a blessing in disguise, as it resulted in a decision to abandon this roast yard, the position of which on the immediate outskirts of the village, had been a source of annoyance and inconvenience to the residents, who during certain conditions of wind and weather, suffered greatly from the sulphurous fumes given off by the burning piles. The new site chosen, consisted of a flat about half way between the smelter and the mine, which could be easily levelled, drained and otherwise prepared, this location being much more spacious and suitable in every way, than the roast yard it was proposed to abandon.

Temporary curtailment of operations.

Operations at North Star and Little Stobie mines.

During the winter of 1901 and 1902, the operations of this company, at the Victoria mines, were greatly curtailed, but the completion of the refining works in England, and the beginning of operations on a large scale at these works in April, 1902, gave a fresh impetus to all departments of mining activity. During the summer of 1902, the North Star mine, situated on lot 9, cons. II and III., of the township of Snider, and the Little Stobie mine, on the north half of lot 6, con. I., of the township of Blezard, were worked by this company. The ore, amounting to 4,724 tons, obtained from the North Star, and 1,584 tons from the Little Stobie, was shipped to the Victoria mines for treatment. The bessemerized matte, as quickly as produced by the smelting works at Victoria mines, was shipped to Clydach, near Swansea, in Wales, where extensive works had been built for its treatment, calculated for an annual production of from 1,000 to 1,500 tons of metallic nickel, and 4,000 to 6,000 tons of copper sulphate. These works have been so designed as to render future extension easy and economical. The property at Clydach, including about 33 acres, on which the works are erected, has a frontage on the Swansea Valley canal, giving easy access to the port of Swansea, and is connected by a siding to the Midland railway. After a year's steady production from both mines and smelter, all activity ceased in December, 1902, and although most of the higher officials were retained in office, no mining work of any consequence was undertaken until early in the spring of 1903, when work was again resumed and continued until November of the same year, when operations were again discontinued. It is currently reported that the real reason for these frequent interruptions in the mining operations, was due to certain defects in the plant at the Clydach refining works, and it is also rumored that after a recent breakdown in the plant, there were over twenty cases of poisoning from the escaping gas, which resulted in several fatalities. It is confidently expected that a remedy will soon be found for this serious condition of affairs, and that the necessary alterations in the plant will again permit of its operation on an extensive scale, thus insuring a resumption of work at the Victoria mines.

Capacity of refinery at Clydach, Wales.

Location of refinery.

Causes of cessation of mining.

The history of the development of mining in the Sudbury district, has not, therefore, been an unbroken record of brilliant successes, but often quite the reverse has been the rule, and as may be noticed in the preceding pages, the number of companies who for different lengths of time have operated in this area, already constitute a formidable list. These failures, and the causes which have operated to bring about this untoward result, serve however to bring into strong relief, the gallant and successful struggles of the only company, which has been able to surmount the various difficulties to which the other organizations have successively succumbed; at the same time, strengthening the belief, that the crisis has been passed, and the industry has at last been established on a firm and permanent basis. It is true that certain details in regard to the extraction of the nickel are still in the experimental stage in order to determine, if possible, a more economical method, but there is no doubt whatever, that the business of the mining and smelting of nickel, is not only in a satisfactory condition, but has reached such phenomenal dimensions, that operations in other countries have, in consequence, been either greatly

History of development not a series of successes.

Credit to Canadian Copper Co.

Sudbury District greatest producer of nickel in the world.

curtailed, or have ceased altogether, so that at the present time the supremacy of the Sudbury mining district as the world's greatest producer of nickel is unquestioned.

Reasons for fir failures.

It may be well, in passing, to state some of the reasons which have contributed to the failures, which have been so frequently recorded in connection with the establishment of the Sudbury nickel industry. For some time after the beginning of mining work in this region, the world's annual consumption of nickel did not exceed 700 or 800 tons of the pure metal, which amount could readily be produced by any one of the three companies then operating in the district. The demand for nickel was, therefore, so small and uncertain, that before the discovery was made of [illegible] advantageous employment as an alloy with steel, especially in the manufacture of armour plate, no great future seemed assured for the nickel industry, and even with this distinction in its favour, no very marked increase in the demand for nickel could be noticed, and it took a number of years more before the consumption [illegible] increased to 1500 tons per annum. By the time, however, this latter figure had been reached, it was certain that a constant and ever increasing demand for nickel was assured, on account of its general use in all kinds of steel, where strength combined with lightness, were the important factors. At the present time the consumption of nickel exceeds 10,000 tons per annum, and exhaustive experiments now being undertaken under the auspices of the International Nickel Company, are stated on the best authority, to give strong evidence of the superiority of nickel steel in bridge building, so that a much larger demand for nickel can be looked for in the immediate future. In addition, the recent decision of the Pennsylvania railway, to use nickel steel rails, and the award of a contract for 9000 tons of the same to carry 3·50 per cent nickel, by this vast and progressive corporation, will no doubt give a fresh stimulus to the demand. The only anxiety which now exists, and which has often been urged against any large employment of nickel steel, relates to the sources of supply, and to the possible exhaustion of the nickel deposits now known to exist. All authorities are, however, in substantial agreement, that the supply of high grade nickel ore, contained in the Canadian deposits is practically unlimited, and at least amply sufficient for many years to come, to supply the requirements of even much more extensive smelting operations than are now carried on in the Sudbury district. Besides, a demand for larger quantities of nickel will stimulate prospecting, not only in this region, but also in areas of similar crystalline rocks, to be opened up in a very short time by the Grand Trunk Pacific and its branches, as well as by the Temiscaming and Northern Ontario railway, with the probable result that many more new deposits will be discovered.

Small consumption and demand.

More extended use in alloy with steel.

Nickel steel experiments.

Contract for nickel steel rails awarded.

Deposits practically unlimited.

New deposits likely to be found.

The assumption that all mines possess unlimited supplies of ore another reason for failures.

Another fact, which has contributed to a considerable extent to bring about the failure of some of the Sudbury mining concerns, was the assumption by interested parties, that each individual deposit, of which they had the good fortune to obtain possession, was a mine, capable of producing a permanent and unlimited supply of nickel ore of the desired grade, the ore-body extending to unknown depths, and increasing both in quality and quantity with its downward extension. With such confidence in the size, permanency and suitability for smelting operations of the ore-bodies, it is not surprising that very often no special effort was made to obtain control of other available sources of supply, which were sure to be needed when extensive and long continued refining operations were in progress.

The need of technical experience has caused most failures.

A third cause, which perhaps assisted more than any other to bring about the frequent suspension in mining and smelting operations already recorded, was the lack of the necessary technical knowledge and experience on the part of those who had the management of many of the organizations. The strong necessity of such information, in every department of mining and smelting, needs no special explanation or emphasis, but it was more than ever required for the successful treatment of these particular sulphide ores. Thus, some of the companies engaged in mining in the vicinity of Sudbury, succeeded in reaching the stage of producing matte, but even these were obliged to sell this unfinished product to the various refiners, at prices which usually came far from realizing their expectations in this respect. The refiners were accused of reaping all the profits, which should have been shared with the producers, so that very early in the history of the region, it was patent to everyone, that to share in the full benefits of the industry, the same individuals or company must control the whole of the operations necessary to manufacture the finished product. Acting on this knowledge, therefore, many of the corporations engaged what was considered the most expert metallurgical advice, and numerous experiments were undertaken, to determine an effective and economic process, by which the nickel and copper could be extracted from these ores, and afterwards separated from one another. In this manner, the too often very limited resources of these companies, were taxed to the utmost, and any failure, even in the preliminary trials, to yield the decisive and satisfactory results looked for, often resulted in the closing down and practical abandonment of the mines and works concerned. Finally, in more than one instance, the absence of sound business methods, assisted very materially to bring about some of the disastrous failures, which have been recorded in the foregoing pages.

Refiners said to reap most of the profits.

Companies should produce finished article to enjoy the full benefit.

Unsound business judgment caused some failures.

General Physical Featur..

"Sudbury Mining District" not an electoral subdivision.

The expression "Sudbury Mining District," was applied as a term of convenient reference, soon after the discovery of these valuable mineral deposits, to designate that particular tract of country, immediately surrounding, and tributary to the town of Sudbury. It must not, therefore, be confounded with other areas in Northern Ontario, to which the term "district" has been applied, and which have been thus set apart, with definite boundaries, for electoral and other purposes. Roughly speaking, it may be described as extending from Wanapitei lake and river on the east, to Onaping and Worthington stations on the west. On the north, it may be considered as embracing the recently discovered iron deposits in Hutton township, while southward, the commencement of the Laurentian gneiss, is believed to limit important mineral discoveries in that direction.

Definition of limits of Sudbury District.

Location of the town of Sudbury.

The town of Sudbury is a creation of the Canadian Pacific railway, coming into existence, at the time of its construction in 1882, and increasing in importance, by reason of its being chosen as the junction point for the branch line to Sault Ste. Marie. It is distant on the main or transcontinental line of this railway, 442.7 miles from Montreal, and 322.4 miles from Ottawa, the capital of the Dominion of Canada.

Outlines of areas of nickel bearing eruptive.

The area in which workable deposits of nickel and copper are now known to occur, extends from the southeast corner of Snider township (Evans mine), northwest to the central part of the township of Levack, a distance of about 20 miles; in a northeasterly direction, it reaches from the township of Drury, to Wanapitei lake, a distance of about 40 miles. The mines which have actually produced ore for smelting or shipping purposes are, with the exception of the Worthington mine, all connected with that portion of the main mass or belt of norite, which stretches from the old Inez or Chicago mine, in the township of Drury, to the Blezard mine, a distance of abut 26 miles.

Description of township and method of survey and sub-division.

The area contained in the two accompanying map-sheets (Victoria mines and Sudbury), and comprising portions of the district of Algoma and Nipissing, has all been subdivided into townships and lots of the more recent form adopted by the Crown Lands Department of Ontario. With few exceptions, each of these townships measures six miles square, the area thus embraced being thirty-six square miles. Each township is divided into six concessions, by east and west lines, run astronomically, which are designated by the Roman numerals, the order of numbering being from south to north; while the concessions themselves are subdivided into twelve lots, by true north and south lines, which carry the ordinary Arabic figures, numbered from east to west. Each lot, therefore, measures one mile from north to south, and half a mile from east to west, thus containing an area of 320 acres. Only every alternate lot line is cut out through the woods, the intervening boundary being marked by posts on the concession lines. The lines are all supposed to be run astronomically, although in some cases, no allowance having been made for the convergence of meridians, considerable error and confusion have resulted. Sometimes the surveys of these townships have not been done as carefully or accurately as might be desired, and in more than one instance, two, or even more approximately parallel lines were found, within short distances of one another, evidently intended for a single boundary, each connecting with separate posts, designed to mark the same point. Over the larger part of the district, repeated forest fires have destroyed all traces of many of these lines, and the limiting posts, except where an occasional one happened to be located in a swamp, have been burnt, so that it is usually exceedingly difficult, and sometimes impossible, to locate these original boundaries.

Lines not always astronomical.

Careless surveying.

Destruction of boundaries by forest fires.

The general character of the country may, perhaps, be best described as that of an uneven or undulating rocky plain, with a gentle slope towards the south and southwest. In detail, the surface of the plain is far from uniform, consisting of a rapid succession of more or less parallel and disconnected rocky ridges, with a prevailing northeast and southwest trend, the intervening valleys being usually occupied by swamps, lakes or river courses. The average general elevation of the district as a whole, varies from 800 to 1,100 feet above the sea. The present topography has been the result of prolonged denudation and erosion, assisted to a considerable extent by subsequent glacial action, which removed the softer decomposed material from the higher levels, to be deposited elsewhere in the neighbouring valleys, or in areas considerably removed to the southwest. The scouring action of the vast glacier is everywhere apparent, in the smooth well-rounded hills, while in most cases, the exposed rock surfaces still preserve the glacial grooves and striæ. Although the country is exceedingly rocky and uneven, there are no very prominent hill features, the highest seldom attaining a greater altitude than 150 feet above the neighbouring valleys, while elevations of 25 to 100 feet are far more common. The highest land in the district comprises a strip varying in width from 3 to 5 miles, and extending in a northeasterly direction from Denison to Garson townships, a distance of over 30 miles. This is underlaid for the most part by the nickel-bearing and associated eruptives, although some areas of highly altered quartzites contribute to this unusual

General physical features of district.

Average elevation.

Glacial action.

No very pronounced hill features.

Location of highest land.

Character of underlying rock.

Location of highest hill.

Elevations on Canadian Pacific railway.

Elevations on Manitoulin and North Shore Ry.

Flat belt of country between Vermilion and Wanapitei lakes.

elevation. One of the highest hills in this rocky belt is situated immediately south of the Elsie mine. Barometrical observations correlated with the known elevation at the intersection of the Elsie mine branch with the M. & N. S. railway, show this to have an altitude of 1,120 feet above the sea. Starting from Sudbury, which has an elevation of 850 feet, the Canadian Pacific railway ascends a series of steep grades for a distance of 3½ miles before the summit is reached, at an altitude of 992 feet; while an equal distance further, at Azilda station, this elevation is decreased to 881 feet above the sea. The Manitoulin and North Shore Railway Company, on the other hand, have built a portion of this road, a little over twelve miles in length, and have located it to Victoria mines and beyond, the line running through this hilly district for the whole distance. Starting from Sudbury, which as stated, has an elevation of 850 feet, the grade rises to 919 feet at Clarabelle junction, and further to 959 feet at Elsie junction. The summit is reached about 8 miles west of Sudbury, where the level of the rail is 986 feet, falling again to 965 feet above the sea, at the end of the profile 12·7 miles from Sudbury, close to the Gertrude mine. To the northwest of this hilly tract, the land becomes tolerably level, forming a plain with an average elevation of nearly 880 feet above the sea. This flat belt of country has an general width of about six miles, and stretches from the vicinity of Vermilion lake, in Fairbank township, almost to Wanapitei lake, a distance of over 30 miles. The whole of this area is evidently underlaid by the slates and felspathic sandstones coloured provisionally as of possible Cambrian age, but this rocky floor is largely concealed by a thick mantle of drift, through which protrude occasional low, rounded hummocks, which alone give evidence of the underlying material.

Character of drift of the Chelmsford flat.

This drift is composed of a well stratified gray clay, unencumbered for the most part by boulders, and is seemingly well adapted for all purposes of agriculture. Roads have been opened, and large clearances made over most of this level district, the various barns and buildings erected, giving strong evidence of the prosperity of this farming community.

Another irregular flat.

To the south, and southeast of the hilly stretch already mentioned, a somewhat irregular shaped, and comparatively narrow valley, extends from the vicinity of the Worthington mine, almost to Wanapitei lake, where it connects to the north and west with the extensive plain just described. The continuity of this comparatively level tract of country is broken, at certain intervals, as for instance, near the crossing of the Whitefish river, but the whole flat may be considered as belonging to one valley, with a gentle though perceptible slope towards the southwest. In the township of McKim, this flat has an average general elevation of about 845 feet above the sea. From Sudbury, in a southwesterly direction, this comparatively level belt has been utilized in the location of the 'Sault Branch' of the Canadian Pacific railway, while, in addition, advantage has been taken of the even surface in erecting most of the buildings included in the towns of Sudbury and Copper Cliff. In the township of McKim, the surface of this flat is sometimes broken by small rocky hills, and the considerable areas, that are available, have been cleared, and are now under cultivation, with gratifying results, especially during those years when the roasting of the ores at the mines is not proceeding too briskly.

Flat in the township of McKim.

Farming good in places.

Flat north-east of Sudbury.

Throughout McKim, and the area to the southwest of this township the soil is a fine silty clay, well stratified; but to the northwest, in the township of Garson and beyond the limits of the Sudbury sheet, in the township of Falconbridge, this is replaced by a coarse yellow sand, with gravel in certain places, the whole forming a light and rather poor soil, although some portions of it are now being used for farming purposes.

Rough area east and southeast of Sudbury.

To the east and southeast of Sudbury, the district is, for the most part, exceedingly rough and hilly, this area being characterized by the presence of quartzite, with large and irregular intrusive masses of norite and diorite, and only occasional limited flats are available for agriculture.

Valleys caused by erosion of olivine-diabase dykes.

Perhaps one of the most interesting physical features presented by this district, is the narrow valley formed by the weathering of the large diabase dyke, near the Murray mine. This dyke, which is about 150 feet wide at this point, and intruded through a mass of granite, has been decomposed and considerably eroded, leaving a valley the whole width of the dyke, with perpendicular walls of granite. This very conspicuous feature in the landscape has been used in locating the wagon road between Sudbury and Azilda (formerly Rayside).

Influence of underlying rocks on surface contour.

The influence exerted by the underlying rock on the general contour of the ground is everywhere well exemplified throughout this district. The harder igneous and quartzite rocks, owing to their greater resistance to processes of weathering and erosion, form the higher ridges, while the more fragile slates, sandstones and schists, make up most of the intervening lower ground, occupied chiefly by the river valleys, swamps and lake basins. The area covered by the main mass or belt of norite is likewise one of low relief, in contrast with the other igneous

District not so abundantly supplied with lakes as other Archæan areas.

Elevations of lakes.

rocks with very small gently rounded hills, this variety of rock evidently offering no very effectual resistance to decomposition. The district, as a whole, is not as abundantly supplied with lakes as many other areas of similar Archæan rocks, but several fairly large and beautiful lakes occur, and nearly all are supplied with good clear water. The shores and islands of Ramsay or Lost lake, are occupied by the summer residences of many of the inhabitants of Sudbury, while its pure clear water is used to supply the large water tank, erected for the water works, on one of the rocky hills east of the town. The highest lake in the area is Garson lake, which is 923 feet above the sea; while the lowest is McCharles lake, an expansion of the Vermilion river, which has an altitude above the sea of 760 feet.

The drainage of the district by Wanapitei, Spanish and Vermilion rivers.

The drainage of this district is effected through three important and well known streams, the Wanapitei, Spanish and Vermilion rivers, the whole of the water eventually reaching Georgian bay and Lake Huron through these channels. The Vermilion river with its tributaries the Whitefish branch, Levey river, and Whitson and Fairbank creeks empties the water of nearly the whole of the area included in the two map sheets. The Vermilion river is itself a branch of the Spanish river, joining this stream near the boundary between Merritt and Foster townships, about 10 miles southeast of the corner of the Victoria mines map. A portion of the Spanish river, known as the 'Great Bend', crosses the corner of this map sheet, receiving in this distance, the whole of the drainage of the township of Drury, and the western part of Denison township. The branches of the Wanapitei river are limited to the eastern parts of Garson and Neelon townships.

District once covered by a dense forest.

Havoc wrought by fire.

Character of forest growth.

The whole area was once covered with a dense forest, but repeated fires have destroyed nearly the whole of this original growth, and even the tall rampikes which often alone remained as the silent witnesses of the havoc wrought by the fire fiend, have themselves been gradually cut down to aid in kindling the heaps of roasted ore. Occasional small areas, as for instance, in the northern part of Garson, the western part of Snider and Creighton townships, are still covered by green bush, but the lumberman's axe is quickly clearing out all the valuable timber that remains, while the constant demand for cordwood as fuel for the roast heaps, will still further limit the forest area. Hardwood is scarce, and can only be found in valleys, chiefly in the vicinity of certain streams. Occasional dwarf oaks were noticed in some of the hollows between the higher ridges. The second growth usually consists of poplar and birch, these small trees being so closely packed together in some of the valleys as to form almost impenetrable thickets.

District as a whole not suited to agriculture.

The district, as a whole, cannot be said to be suitable for agriculture, and must rely for its ultimate importance on the development of its mineral resources. The proximity of the mines furnishes a good market, so that every flat is being utilized for purposes of farming.

Geology.

Geological subdivision of rocks.

The rocks of the Sudbury Mining District, arranged in the probable order of their geological age, may be stated as follows, in ascending order.

General character of Lower Huronian.

1. *Lower Huronian.* No rocks of this age are at present known in the nickel bearing area, but this period is represented, in part, by the banded silicious magnetites and associated rocks of the townships of Hutton and Wissner.

Subdivisions of Upper Huronian.

2. *Upper Huronian.* (*A*) Diorites, hornblende-porphyrites and green schiste, (*B*) Conglomerates, greywackes and quartzites (*C*) norite and diorite (Worthington mine belt, and areas southeast of Evans mine and east of Sudbury).

Laurentian gneiss.

3. *Laurentian.* Granite and diorite-gneiss near Wanapitei station.

Character of Upper Huronian or Cambrian.

4. *Upper Huronian?* Tuffs, felspathic sandstones and slates classified provisionally on previous geological maps as of Cambrian age.

Post Huronian eruptive.

5. *Post Huronian. A.* Granites. *B.* Nickel bearing eruptive of the main belt (quartz-hypersthene-gabbro or norite, diorite, with their peculiar differentiation product, micropegmatite). *C.* Dykes of olivine diabase.

Pleistocene.

6. *Pleistocene.* Clays and sands.

General geological history of district.

Abundant evidence of unexampled volcanic activity.

The geological history of the nickel mining area proper, or that portion of the Sudbury district which is included in the accompanying map sheets, began in very ancient times, and most of the rocks now exposed are regarded as representative of what is known as the Huronian period, being thus the oldest with which geologists are at present familiar. The detailed examination and study of these rocks have furnished abundant evidence of the almost unexampled volcanic activity then prevailing, caused largely, no doubt, by the instability of the earth's crust at this early period of its history. These rocks are esssentially of pyroclastic origin, consisting mainly of tuffs of both acid and basic types, intimately associated with more or less altered basic eruptives, some of which still retain much of their original massive character, although by far the larger proportion have undergone such profound deformation and metamorphism, that it is exceedingly difficult, if not impossible, even with the assistance of the microscope, to make any very definite or accurate statement in regard to their original composition and structure. Some of these eruptives are, however, probably of laccolitic origin, and intruded along the planes of bedding of the enclosing clastic rocks, while many of the porphyrites and obscurely amygdaloidal forms, doubtless represent surface flows of lava which have been very much altered and decomposed.

General types of eruptive rocks.

With the establishment of conditions of more stable equilibrium, came a time when the higher elevations were being subjected to the usual processes of degradation and erosion, with the transportation of the material thus detached to be deposited at the lower levels, forming the conglomerates, felspathic sandstones and quartzites, included in the above table as Upper Huronian. Even this period of comparative quiet was probably interrupted at intervals by a return of the volcanic activity, and some of the breccia-like material, and certain of the interbedded greywackes, may be the direct results of explosive action. Subsequent to the formation of these rocks, the huge bathyliths of granite and diorite-gneiss classified as Laurentian, and occurring in the vicinity of Wanapitei station, were intruded into the highest or quartzite member of the Upper Huronian. Later than these quartzites, and possibly also later than the Laurentian gneiss, certain masses of norite and diorite, among which may be mentioned the belt on which the Worthington mine is located, were intruded. This Worthington mine band of norite, as may be seen by a reference to the map, extends across the southern part of the township of Denison, forming a conspicuous range of hills, a short distance south of the Canadian Pacific railway. The band of similar igneous material, which forms the high lands to the south of McCharles lake, is of the same age, as also its probable continuation, in the large belt of norite and diorite, which crosses the country to the southeast of the Evans mine. This same band of intrusive rock continues with unbroken continuity northeast, forming a considerable area of exceedingly rough country east of Sudbury, and north of the Canadian Pacific railway, besides covering a considerable portion of the northern and central parts of Neelon township.

First clastic rocks formed.

Volcanic interruptions.

Correlation in age of the various rock masses.

The age of the tuffs, felspathic sandstones and slates hitherto classified provisionally as of Cambrian age, and so coloured on all previous geological maps, is still a matter of considerable doubt, and much more detailed work and critical examination of the area, characterized by the presence of these rocks, will be necessary, before this can be

Age of so-called Cambrian, still a matter of doubt.

satisfactorily settled. They apparently form a synclinal basin, resting against the micropegmatite phase of the nickel bearing cruptive, and a study of several of the localities where the junction between these rocks is exposed, lends some support to the belief that the micropegmatite is intrusive through the tuff or breccia. On the other hand, it seems reasonable to suppose, that all of these rocks are very intimately associated in regard to their time and manner of genesis.

Age of granites.

The granites, usually referred to as 'younger', are decidedly so, in reference to the older diorites, porphyrites and green schists and a rock which may be called a breccia, formed by an exceedingly intricate intrusion of dykes and masses of granitic material through these basic rocks, covers considerable areas throughout this district; while even the main mass of the granite bathylith, frequently contains embedded fragments and masses of all sizes and shapes of these older greenstones.

Relative age of nickel bearing eruptive.

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 is 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 dykes 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

Anomalous behavior of norite.

Intrusive nature of contact north of Clarabelle lake.

Character of contact near Creighton mine.

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.

Age of olivine diabase dykes

The olivine-diabase dykes cut through, and are, therefore, later than all the rocks with which they have been noticed in contact. Their mineralogical composition is essentially the same as the dykes of diabase-porphyrite in the Lake Superior district, which latter have been regarded as the channels by which the Keweenawan lavas reached the surface.

(2.) UPPER HURONIAN.

(A.) GREENSTONE SCHISTS.

Use of the term 'greenstone.'

Greenstones oldest rocks in area

Early misconceptions.

Greenstones not deformed portions of nickel bearing norite.

It has been the general practice in previous reports of this and other Archæan areas, to employ the somewhat vague and indefinite term 'greenstone', the common field name for certain basic eruptive rocks, often more or less altered and deformed. In the present report, this term has been retained as the most appropriate and convenient designation for certain very ancient basic intrusives, presenting every possible phase of metamorphism and deformation. Under the general heading, 'greenstone schists,' are included several varieties of diorite, porphyrite, hornblende and chlorite schists. They are undoubtedly the oldest rocks with which we have at present any acquaintance in the district. Their usual occurrence in intimate association with the more massive and uniform norite, in addition to their general lithological appearance and behaviour, especially the more massive types, were the main reasons for grouping these rocks together, under the same colour designation, on al[illegible] earlier geological maps. In these first examinations, such roc[illegible]garded as the sheared and altered representatives of the more mass[illegible] norites, the latter, by some fortunate circumstance or series of circumstances, having escaped this extreme of deformation and metamorphism. Later examinations have, however, revealed the fact, that in most cases, at least, these more or less foliated and schistose basic eruptive rocks, are distinctly older in age, and were upturned, faulted, folded and considerably metamorphosed, at some time prior to the intrusion of the nickel bearing eruptive proper. Careful and detailed work never fails to reveal the presence of a distinct line of separation between these two classes of igneous rocks, and the importance of accurately tracing out and mapping such a boundary, from an economic point of view, is especially emphasized, when it is remembered that all the deposits of nickel and copper ores, which are commercially valuable, are located either in the imme

Mapping of lines of junction of norite very important diate neighbourhood, or at various points directly on the line of junction between the norite and the associated rocks.

Character and derivation of older diorites and greenstones.

The least altered representatives of these older diorites, or more massive varieties of the older greenstones, can with difficulty be distinguished from the prevailing type of diorite (altered norite), with which the nickel and copper deposits occur, and it is impossible to resist the conclusion that both rocks have originated from precisely similar types. Their difference in age, however, is quite evident from their field relations, and although both pyrrhotite and chalcopyrite occur in these earlier basic rocks, no deposits of economic importance have been found in association with them at any great distance from the line of junction with the younger norite or diorite.

No deposits of economic importance in older greenstones.

Colour of older green stones.

Most of the hand specimens examined of the more massive types of these older rocks, are considerably finer grained than the neighbouring norite, and in contrast to this rock, are decidedly greenish rather than greyish or blackish in color. Most of the outcrops may be referred to as 'gabbro diorite', a name proposed by the late Prof. G. H. Williams, for a diorite which gives unmistakeable evidence in the hornblende, of its derivation from pyroxene, originally present. Some exposures exhibit the ophitic or interlacing structure characteristic of diabase, which is often discernible either to the unaided eye, or with the assistance of an ordinary pocket lens ,and the rock in which the structure is developed would be referred to as a uralitic diabase.

Gabbro-diorite or uralitic diabase the prevailing massive type.

Petrographical characters of older diorite.

Mineralogically, as represented by the thin sections, examined under the microscope, the rock is now composed essentially of plagioclase and hornblende, and no portion of the original pyroxene has yet been detected. The plagioclase, in all cases where the rock is sufficiently fresh for its identification, is labradorite, and in those specimens, which have suffered least from metamorphism, this mineral occasionally has a pale brownish tint, the colouring matter (presumably very finely disseminated ilmenite), being rather unevenly distributed through the various individuals, with cloud-like effect. Pressure and advancing decomposition, however, seem to quickly destroy or remove all traces of this colouring matter, so that, with few exceptions, the felspar is nearly, if not quite, colourless. As a rule, the plagioclase has undergone more or less advanced saussuritization, but some individuals are still sufficiently fresh to permit of their recognition by means of the extinction angles. All stages in this characteristic alteration of the basic plagioclase are represented in the specimens collected and examined, but this has been so fully described in previous publications, that only a brief mention is necessary in this connection. The first

Alteration of plagioclase.

General characters of saussuritic and its composing minerals.

Another form of alteration.

step in the decomposition of the original felspar, consists in the development of minute scales of sericite, and fine needle-like forms of epidote and zoisite, in the midst of the plagioclase substance. Another, and very frequent form of development of these secondary minerals, consists of grape-like bunches of finely granular saussuritic material, chiefly zoisite or epidote, whose coalescence ultimately produces a single larger individual, or aggregate of several individuals of these minerals. One of the more advanced stages in this process of decomposition of the felspar, consists in the complete obliteration of the twinning lamellæ, and the replacement, either wholly or in part, of the plagioclase substance, by a brilliantly polarizing aggregate, made up chiefly of sericite, epidote and zoisite. In occasional instances, the place of the felspar is taken by a colourless or pale yellowish saussurite, which polarizes in dull bluish tints. This substance is usually so fine-grained that it cannot with certainty be resolved into its component minerals, even with the assistance of the higher powers of the microscope. Some of the coarser portions of this substance were examined rather critically, with the result that zoisite, sericite, a little calcite and a secondary plagioclase, possibly albite, were recognized as contributing to the aggregate. Still another form of alteration of the original felspar, and one often accompanying the more usual saussuritization, consists in the replacement of part of the original felspar by a fine interlocking mosaic of a clear, sharply extinguishing, secondary felspar (albite) and quartz.

Microscopic character of bisilicate minerals.

Hornblende.

Biotite.

'Bleaching' of biotite.

The hornblende, is as a rule, the usual deep green, strongly pleochroic, compact variety, occurring in long, imperfectly developed, prismatic forms. Occasionally the fibrous or actinolitic variety is represented, much paler in colour, and with less pronounced pleochroism. Many of the individuals of this mineral show the pale coloured, more or less non-pleochroic interiors, with deep coloured, much more compact, and strongly absorptive borders characteristic of uralite. Portions of occasional crystals show a brownish colour, but even these have a decided greenish tinge. Biotite is almost invariably present, and usually in large amount. It is of the usual deep brown colour, showing strong differences in the absorption of light when rotated between crossed nicols. It occurs in plates and scales, frequently embedded in, and sometimes forming intricate parallel intergrowths with the hornblende. It has often undergone considerable 'bleaching', and is then somewhat paler in colour than usual, besides showing brilliant chromatic polarization between crossed nicols. In spite of the elimination of a considerable portion of the iron, the pleochroism as stated is still very pronounced. It often contains irregular grains of

Decomposition of hornblende and biotite.

Epidote and zoisite.

Quartz, a primary constituent.

Ilmenite and titaniferous magnetite.

Apatite.

Sulphides.

magnetite. Both the hornblende and biotite show frequent decomposition to chlorite. 'Pleochroic halos', surrounding embedded small grains or crystals, chiefly of sphene, are frequent in both the hornblende and biotite, as well as in the chlorite derived from them. Comparatively large and sharply defined crystals of epidote and zoisite occur, some of which may be of primary origin, although by far the larger proportion are undoubtedly the secondary products of decomposition. Quartz is almost invariably present, occasionally forming the characteristic granophyric intergrowth with the felspar. In most cases it is not of secondary origin, but an integral part of the same magma out of which the other minerals have been formed. It was as usual the last mineral to form, filling up the irregular interspaces left by the crystallization of the other constituents. Ilmenite and highly titaniferous magnetite are the prevailing iron ores, and these are present often in comparatively large amount. Most of the individuals are surrounded by opaque grayish leucoxene, or the more normal sphene, resulting from the alteration of the titaniferous iron ore. Apatite is usually present in small amount, occurring in the characteristic long, acicular, prismatic forms, which pierce all the other constituents of the rock. Pyrrhotite, chalcopyrite and pyrite, frequently occur disseminated through the rock, and under the microscope are seen to form curious irregular skeleton or sponge-like masses, intimately associated with, and frequently embedded in the coloured constituents.

Altered diorite.

Decomposed diabasic rock from "Lake Hill" Denison.

Mineralogical composition.

Porphyritic diorite of roast yard at Victoria mine.

These diorites occur in all stages of decomposition, while still retaining much of their original massive character. A type illustrative of perhaps the extreme of this alteration is well represented by a hand specimen obtained from the tunnel in 'Lake Hill', lot 8, con. IV., of Denison. This rock is a fine-grained, comparatively light greenish-gray, diabasic rock, with occasional fine disseminations of pyrrhotite and chalcopyrite. The thin section shows that all of the hornblende and part of the biotite have been altered into green chlorite, which retains much of the strong pleochroism characteristic of the original minerals from which it has been derived. The ilmenite has been almost wholly converted to sphene, which occurs in irregular grains and crystals. Calcite is very abundant, and portions of the slide are made up of a rather coarse mosaic of quartz and calcite, with a smaller proportion of chlorite. As a rule, these old diorites are comparatively uniform in grain, but porphyritic varieties occur, and a good example of this phase, was collected from certain small rounded hummocks, on the west side of the upper or new roast yard of the Victoria mines, (N. ½ lot 8, Con. III, Denison). The hand specimen, shows, a comparatively coarse-grained rock, made up of indefinite or irregular phenocrysts of

Mineralogical composition.

dark green, almost black hornblende, embedded in a proportionately smaller amount of a comparatively fine-grained matrix, which is rather paler in colour. The microscope shows the rock to be a porphyritic diorite, made up very largely of a green, feebly pleochroic hornblende. Much of the hornblende is compact, but in the finer-grained portions of the rock, as well as in the terminations of the larger crystals, the mineral shows a marked tendency to assume the actinolite habit. The interspaces between the larger porphyritic individuals are made up of saussuritized plagioclase, actinolite and ilmenite, the latter mineral in various stages of alteration to leucoxene. Occasional small scales of biotite may be noticed embedded in the hornblende.

Hornblende-porphyrite from Murray and Elsie mines.

Another closely related rock is that which is usually referred to as 'hornblende-porphyrite.' This type of rock is perhaps best illustrated by outcrops occurring to the southeast of the Elsie mine, while the steep and prominent hill southeast of the office at the Murray mine, is almost wholly made up of this material. The groundmass is much finer in grain than in the porphyritic diorite just described, but the phenocrysts are usually considerably larger and more conspicuous, their deep green, almost black colour, with glistening cleavage planes, contrasting well with the fine-grained and lighter coloured matrix made up largely of hypersthene with some felspar. Still another closely related form, and one which may be included in the general class of the older and more massive greenstones, may perhaps be best described as a 'diorite porphyrite'. The best examples of this type of rock were obtained from exposures outcropping a little north of the boundary between Graham and Creighton townships, on lot 2, con. I of Creighton township. The hand specimen shows a dark-green, rather schistose, dioritic rock, with ill defined phenocrysts of plagioclase, some portions of which are of a paler yellowish-green colour, while other parts of the same crystal are reddish. Under the microscope, the thin section shows that these large irregular phenocrysts are labradorite, which have undergone more or less advanced alteration to saussurite or huronite, with the development of zoisite, epidote and sericite. The reddish portions of the crystals are comparatively unaltered and still show the twinning lamellæ. The finer interstitial matter is made up essentially of green hornblende and plagioclase. Some of these individuals show the pale interiors and comparatively dark-green borders usually considered as characteristic of uralite. Most of the plagioclase has undergone more or less advanced saussuritization. The iron ore present is mainly, at least, ilmenite, for it may be seen undergoing alteration to leucoxene. A little quartz is present, and also an occasional scale of biotite.

Diorite-porphyrite between Gertrude and Creighton mines.

Mineralogical composition of diorite-porphyrite.

Formation of different types of greenstone schists.

Mineralogical composition of amphibolite.

Amphibolite from Cryderman mine.

Decomposition of amphibolite.

Very frequently these more massive types pass into foliated schistose varieties, the structures being the direct result of pressure and stretching, and all gradations may frequently be observed in the same rock exposure, from the massive gabbro-diorite, through diorite schist, hornblende schist or amphibolite, to actinolite and chlorite schist. The prevailing type of hornblende schist or amphibolite, is a dark-green to almost black, usually glistening and very fissile rock. It is made up largely of slender prisms of the common green hornblende, usually compact and strongly pleochroic, but sometimes actinolitic, a varying but usually small amount of plagioclase and quartz occupying interspaces between the rudely parallel individuals. In the less altered varieties the original plagioclase still remains, although usually more or less saussuritized, but some specimens examined are seen to have undergone more or less complete recrystallization, with the formation of an interlocking mosaic of water-clear, usually unstriated plagioclase (albite ?) and quartz. Biotite is almost invariably present, and the iron ore is sometimes ilmenite, or highly titaniferous magnetite, the grains of this mineral being bordered with sphene. In other instances, the iron ore is simply magnetite, showing no traces of alteration and this mineral is often present in large quantity. Pyrrhotite, chalcopyrite and pyrite, are sometimes disseminated through the rock in small grains, and in the vicinity of the ore bodies, these sulphides are often abundantly present in this type of rock. Some exposures of these rocks are made up almost entirely of hornblende. The thin section of a specimen, secured from Cryderman mine, (lot 5, con. III., Garson) showed this rock to be made up of hornblende individuals closely compacted together, with no intervening felspar or quartz. Magnetite is abundant, while pyrrhotite and chalcopyrite are thickly disseminated through the rock. Some phases of these hornblende schists are sometimes so badly decomposed that only occasional cores of the hornblende crystals have survived, the remainder having been converted into chlorite. The plagioclase and quartz present in these rocks, are often indistinguishable from one another, the former being the clear, often unstriated variety (albite), so characteristic of these recrystallized eruptives. Biotite is present in much smaller amount, and has likewise contributed by its alteration to the formation of the abundant chlorite. Epidote and calcite are also present in comparatively large amount, as secondary products of decomposition. Magnetite is plentiful, and much of it is undoubtedly of secondary origin. These rocks are usually much paler in colour than the prevailing and less decomposed varieties of amphibolite.

'Augen' amphibolite.

In certain localities these hornblende schists were noticed to contain numerous small, irregularly oval, light-coloured patches or 'augen', sometimes made up almost entirely of plagioclase, or this mineral in association with an equal or even greater quantity of quartz, while in certain instances, quartz alone is present. These are of various sizes and shapes, but they are usually less than a quarter of an inch in diameter, and most of them are about the size of an ordinary pea. In certain instances, some of the larger of these areas seemed to be made up of a single imperfect phenocryst of plagioclase, but a study of the slides usually shows, a mosaic made of several distinct interlocking grains of this mineral, together with a varying amount of quartz. The rock, at first sight, suggests, an amygdaloid, with the amygdules or vesicles filled with this quartzo-felspathic material, but a more reasonable explanation suggests their probable origin as small, more or less continuous veins, of pegmatite which have become thus deformed and separated as a result of stretching. The structure is of rather frequent occurrence and characteristic of comparatively large areas of the amphibolite. Similar rocks have been noticed by Dr. Coleman as occurring in the vicinity of the Frood mine, while in the central part of the township of Graham, the writer has collected several specimens from the N. ½ lot 8, con. III., and the N. ½ lot 1, con. IV., of this township. The matrix in which these small eye-like forms are developed, shows a fine-grained hornblende schist made up, in great part, of compact, dark-green, strongly pleochroic hornblende, together with a little biotite. In the specimen from the N. ½ lot 1, con. IV., of Graham, the quartz and felspar of many of the 'augen' contain small scattered individuals of hornblende, zoisite and biotite.

Origin of 'Augen.'

Augen amphibolite from Frood mine and Graham township.

Biotite schist from Denison.

Another type of rock, which was noticed at two widely separated localities, intimately associated with these amphibolites, is a dark-gray, almost black, faintly glistening schistose rock. The thin section of a specimen obtained near the openings on lot 12, con. IV., of Denison, shows a fine-grained aggregate of pale coloured or 'bleached' biotite, with a much smaller amount of plagioclase. Small grains of sphene are abundant, and also irregular fragments of calcite.

Biotite schist from Graham.

Another variety of the same rock is represented by a specimen obtained near the Century Copper mine, on the N. ½ lot 4, con. IV., of Graham. It contains frequent disseminations of pyrrhotite, pyrite and chalcopyrite, and in addition to the plagioclase, contains a considerable amount of quartz. The biotite, which is in fairly large plates, is 'bleached' with frequent pleochroic halos, surrounding certain of the smaller inclusions, which are abundant, and include sphene, epidote and zoisite.

Garnetiferous amphibolite from Vermilion mine.

Microscopical determination of minerals.

Occasionally these amphibolites contain garnet, which is sometimes abundant, and often in large, ill-defined or rounded crystals. The most striking example of such a rock is, doubtless, that occurring in the vicinity of the Vermilion mine, (lots 5 and 6, con. IV., of Denison). The matrix shows the prevailing fine-grained, dark-green schist, in which rounded crystals of reddish garnet, sometimes two inches in diameter, are developed. The matrix is made up principally of hornblende and quartz. The garnet is quite normal, but is much cracked and slightly seamed with green chlorite, which has resulted from its incipient alteration. It was also noticed to contain inclusions of magnetite and quartz.

Origin of greenstones.

Deformed eruptives.

Squeezed lava flows.

Altered volcanic ash rocks.

Altered clastic rocks included with greenstone.

There can be little doubt in regard to the origin of most of these older greenstones, that they represent greatly decomposed, sheared, and, at times, completely recrystallized, basic eruptives, but there is still considerable doubt regarding the exact conditions attending the genesis of certain other types of rocks, which are intimately associated with, and usually included in these greenstones. Some of these show, though somewhat indistinctly, the ellipsoidal and amygdaloidal structures, characteristic of lava flows, while others, again, are almost certainly of a pyroclastic nature, representing consolidated beds of volcanic ashes and fine agglomerates, but all of these have been so greatly squeezed and stretched that their precise identification is extremely difficult, if not impossible. Some portions of the sedimentary rocks, chiefly quartzites and greywackes, are included in these areas of greenstones. In some instances, these clastic rocks, which have been thus caught up in the greenstone, are sufficiently large to permit of being separated on the map, but, for the most part, they are comparatively small, and have been included under the same colour as the greenstone. All of these clastic rocks are greatly metamorphosed. The tuffs or greywackes are now made up chiefly of clear felspar, with a smaller proportion of quartz, the former mineral being largely altered to sericite; biotite, chlorite and magnetite or ilmenite, are the most abundant minerals represented. Often recrystallization has been so advanced that no traces of their detrital origin remain. The quartzites are of the usual felspathic variety, the component grains only occasionally revealing traces of water action, the structure, for the most part, being eminently interlocking.

(2.) UPPER HURONIAN.

B. CONGLOMERATES, FELSPATHIC SANDSTONES AND QUARTZITES.

General characters of rocks of Upper Huronian.

Although a large proportion of the rocks included as Huronian, in the Sudbury District, are the direct result of igneous action, considerable

Stratigraphical position not satisfactorily determined.

Difficulties of determining true succession.

Rocks greatly disturbed and altered.

Schistose structures mistaken for bedding.

Succession interrupted and complicated by intrusive masses.

Present scheme offered with some hesitation but essentially the same as Dr. Coleman's.

areas are underlaid by others of undoubtedly sedimentary origin. While, however, the various types of these rocks have been studied in considerable detail, so that their precise mineralogical composition is well understood, their stratigraphical position has not been determined as satisfactorily as might be desired, as only a comparatively limited time could be spared from the work of examining and delimiting the more important eruptives, directly associated with the ore bodies. The geological succession therefore, advocated in this report, is not based on an extended or critical study of the field relations of these rocks, and much more exhaustive work will be necessary before a final and authoritative utterance is possible on this point. Some difficulties which presented themselves during even the preliminary investigations undertaken by the writer, may be mentioned briefly. In the first place all the rocks of the district have been greatly disturbed, so that, the originally horizontal strata are now tilted at very high angles, in some instances, having assumed a vertical attitude, and occasionally, have even been overturned as a result of the mechanical stresses, to which they have been subjected. In some cases, and over extended areas, the rocks have been so metamorphosed, that the planes of original sedimentation are more or less completely masked, or even destroyed altogether, thus rendering it very difficult, if not impossible to interpret the true structure or succession. In addition, the situation is further complicated, and a satisfactory explanation delayed, by reason of the frequent development of certain secondary structures due to intense and prolonged pressure and stretching. The foliated, schistose or slaty structures, thus induced, are frequently mistaken for bedding planes, although usually forming considerable angles with them. Besides the continuity of the areas of the clastic rocks is frequently broken by the intrusion of irregular masses of igneous material which not only greatly disturbed and obscured the original order of deposition, but divide these sedimentaries into a number of separate basins, whose satisfactory correlation can only be unravelled by much more detailed study than the present opportunity afforded the writer. At this stage, therefore, the succession favoured in this report, is not offered without a certain degree of hesitation, although it is without doubt, a much more complete and satisfactory classification than any which has yet been attempted. With the exception of one or two minor points, it differs in no essential particular from the scheme offered by Dr. Coleman in his last report. (1) and we both agree, in advancing the opinion, that the intrusion of the nickel bearing norite, took place at a much later date, than formerly supposed.

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(1). Ann. Rep. Bur. of Mines, Ont. 1903, p. 298.

It is confidently expected, however, that Dr. Coleman, as a result of the later work he is now conducting in the district, will decide many of the questions which are still a matter of opinion and conjecture, and the appearance of his monograph is accordingly awaited, with the expectation that this question, of succession especially, will receive full and satisfactory treatment.

Expected Dr. Coleman's later work will determine true succession

The oldest clastic rocks exposed in the vicinity of Sudbury, are certain felspathic sandstones or greywackes, frequently interbedded with, and passing by insensible gradations, into felspathic quartzites or arkoses, the latter, for the most part, being the later rocks, and usually forming the summit of the series. These rocks are evidently closely related, the main point of difference noticed, consisting in the relatively coarse grain and large amount of quartz in the quartzites, with less of the finer-grained interstitial material, this being made up, for the most part, of the lighter coloured decomposition product sericite, while in the greywacke, the texture is finer, and felspar, not quartz is the predominant constituent. Chlorite, with innumerable fine, disseminated particles of opaque matter, gives the prevailing dark colour to the rock. The quartzites, for the most part, occur in thick, massive beds, which are very uniform in mineralogical composition, while the greywackes are much more distinctly and evenly stratified, and certain shales and slates exposed in the district, are evidently thinly bedded varieties of this rock. All intermediate stages, both in composition and structure, may be noticed between these two types of rock, which at the two extremes, are quite distinct and recognizable. Comparatively large areas are characterized by the prevalence of one or other of these rocks.

Oldest clastic rocks of Sudbury.

Mineralogical composition of greywacke

Transition between greywacke and quartzite.

Some of the greywackes are evidently of the nature of muddy sediments, deposited in water, as a result of ordinary conditions of degradation and deposition, but tuffs constitute, by far, the larger part, representing the consolidation of what was originally volcanic ashes, being one of the results of the explosive action to which is due the presence, at the surface, of the great belts of greenstone. These have, in most cases, been sorted and re-arranged by the action of water, but, in other instances, little or no trace of rounding action can be detected in the component grains, even in those types which have suffered little or no alteration. These rocks are usually of a dark-gray, purplish-brown, or greenish-gray colour. They are often evenly and very distinctly banded, in varying shades of gray. Jointing is frequent and also slaty cleavage. They are often faulted and shattered, and in the vicinity of the various greenstone masses, are penetrated and altered by irregular tongues and masses of the basic ig[illegible] [illegible] [illegible]

Origin of greywacke.

Microscopic structures of greywacke.

Porphyritic greywacke or 'rice rock.'

Phenocrysts of andalusite staurolite and hornblende.

Composition of greywacke.

Alteration of greywacke.

Quartzites

Mineralogical composition of quartzite.

porphyritic, and usually the phenocrysts are small, very thickly disseminated, and of a very pale-grayish or whitish colour. For this reason, the rock has been referred to, in the field, as 'rice rock.' These phenocrysts were probably andalusite or staurolite, but the skeleton-forms are now occupied by a confused aggregate of minute sericite scales and quartz. Other exposures show small yellowish-brown spots made up of rutile, while others again, exhibit irregular phenocrysts of hornblende, now wholly replaced by chlorite. Thin sections, examined under the microscope, reveal a rock which has undergone rather extensive decomposition. It is usually made up very largely of felspar, with a smaller proportion of quartz, in small, angular or slightly rounded fragments. These are surrounded by a net-work of sericite and chlorite scales, together with a considerable amount of opaque iron ore. The larger individuals, at least, have evidently been ilmenite, but are now almost completely altered to leucoxene. The darker bands are made up of more thickly disseminated, dust-like particles of iron ore, much of which at least, is ilmenite. In the vicinity of the various eruptive masses, as well as in those masses which have been caught up in the greenstone, these rocks are very much altered, the various types having been described as mica schists, felsites and phyllites. The rocks referred to as quartzites are massive, though usually distinctly stratified, of a pale-gray reddish, yellowish-gray, or greenish-gray colour. They are intimately associated and often interbedded with the tuffs or greywackes, so that it is frequently impossible to separate the two for purposes of mapping. Under the microscope the thin section exhibits a rock made up chiefly of quartz, with a somewhat smaller proportion of felspar, most of which is unstriated, and therefore presumably orthoclase. Occasional grains of microcline were noticed, showing the various stages in the development of the characteristic fine, cross-hatched, twinning structure. Much of the felspar is decomposed into a hydrous form of muscovite (sericite), occurring in irregular, pale-yellowish or colourless scales and plates, which together with fragments of undecomposed felspar, make up a groundmass, in which the larger individuals of quartz, and more rarely of felspar, are embedded.

Microscopical structure.

The structure of the rock is for the most part interlocking, but some specimens show distinctly clastic structure, while, in most, the resemblance to well authenticated, recrystallized clastics is such as can hardly be mistaken.

Altered quartzite band northwest of Sudbury.

A little over a mile northwest of Sudbury, the Canadian Pacific railway crosses a belt of very highly altered felspathic quartzite, the outcrops of this rock, forming a series of comparatively high and conspicuous ridges. This band averages about half a mile in width, and extends with unbroken continuity, from the vicinity of the Frood mine to Copper Cliff. Here, denudation has removed a considerable portion of these rocks, leaving only small areas such as that which outcrops immediately north of the old Copper Cliff mine. These rocks are again exposed to the west of the Ontario Smelting Works at Copper Cliff forming the high ridges, which with some minor breaks, extend in a southeasterly direction, a little beyond the boundary between Waters and Graham townships. Areas of very similar rocks are shown on the map, as occurring in the township of Denison, the largest mass covering a considerable tract north of the Vermilion mine. The microscopical examination of most of the thin sections, representative of this rock, throws little or no light on its origin, and the exposures might very readily be mapped as belonging to a biotite or hornblende granite, while the presence of a breccia of autoclastic character at the junction between this and the greywackes to the southeast, might easily be interpreted as indicating the intrusion of a granitic rock through the greywacke.

Altered quartzite in Denison, Graham and Waters townships.

Autoclastic rocks.

These small, usually parallel, and seemingly dyke-like forms of quartzo-felspathic material, are in reality thin beds of arkose material, which, originally continuous, have been drawn out, broken and separated during the processes of stretching, while the enclosing rocks, having yielded more readily to deformation, give no evidence of autoclastic action. This quartzite is frequently 'blotched' in the vicinity of the railway line, the spots or blotches of a pale-reddish or pinkish colour, being embedded in a network of grayish material, without however, any sharp or well-defined boundary between these two portions of the rock. It is made up principally of quartz, felspar, biotite, muscovite and sometimes hornblende, the last mentioned mineral being especially conspicuous in those exposures of the rock crossed by the railway and wagon road to Azilda. This mineral occurs usually in long, slender prisms, of a dark green colour, disposed at various angles to one another, and very evidently the product of secondary action.

'Blotched' quartzite northwest of Sudbury.

The component minerals possess the irregular, interlocking outlines, with usually no suggestion of the rounding action of water and at first sight, has every resemblance to a granite or gneiss. An examination of the field occurrences of this rock is, however, much more satisfactory than that of the thin section under the microscope. At times, a series of beds can be traced out, differing considerably in composition and texture, the whole occurring in the form of a synclinal basin, resting upon the greywackes. This quartzite represents the most advanced

Mineralogical composition of altered quartzite.

'Regenerated granite.'

type of a recrystallized arkose for which the term 'regenerated granite' has been proposed (¹). In the Huronian, there are no very large areas of conglomerate, and the exact position of these rocks is still a matter of doubt, but it is hoped that future investigation will, at an early date, enable a precise statement of their stratigraphical position to be made.

Stratigraphical succession.

From the investigations undertaken by the writer, these conglomerates would appear to lie at the base of a series, which passing upwards into darker coloured felpathic sandstones or greywackes, are in turn overlaid by felspathic quartzites or arkoses which cover the larger portion of the southeastern part of the Sudbury map.

Character of conglomerates

Mineralogical composition of conglomerates.

Such rocks are, as a rule, of a dark-gray colour, with disseminated, angular, subangular, or rounded fragments, chiefly of quartz, granite, diorite, etc. Thin sections exhibit a rock made up of fragments, chiefly of quartz, but also of orthoclase, plagioclase and microperthite. The most abundant composite fragments are granitite, composed mainly of microperthite and quartz, together with a little biotite. All of the larger individuals are embedded in a matrix, made up of much finer pieces of quartz and felspar, together with biotite, sericite and a pale-green chlorite. Occasional grains of pyrite and also some of ilmenite occur.

Ramsay lake conglomerate.

Excellent exposures of the last mentioned conglomerate may be seen along the line of the Canadian Pacific railway, immediately east of Sudbury, and in the vicinity of the north shore of Ramsay lake. As usual, these conglomerates are extremely local in their development, covering no very large extent of country, and the area to the east of Sudbury is, by far, the largest covered by such coarse, detrital rocks.

Conglomerate in Denison.

Exposures of a very similar rock occur on lot 7, con. I., of the township of Denison, to the south of a small lake, the conglomerate at this place underlying the quartzite.

Conglomerate near Stobie mine.

Dr. Coleman mentions that, 'the most typical conglomerate in the region, however, extends as a much broken band from northeast to southwest, near Stobie mine, showing crowded pebbles and small boulders of more than half a dozen kinds, including granite, quartzite and several sorts of green schist, as well as greenstone.' (²) The occurrence of these conglomerates and the character of their pebbles, indicate a probable lack of conformity in the Huronian, and it is quite possible

Probable unconformity in Huronian.

that there is a lower and an upper series, the former made up of greenstones, schists, greywackes and highly altered quartzites (regenerated granites), overlaid unconformably by the conglomerates just mentioned, together with the overlying greywackes and felspathic sandstones

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(1.) Quart. Journ. Geol. Lon. Vol. LIII (1897) p. 44.

(2) Ann. Rep. Bur. of Mines Ont., 1903, pp. 239 and 290.

Pseudo-conglometates or autoclastic rocks.

Autoclastic greenstone and granite breccia.

exposed in the southern part of the Victoria mines map, and the south-eastern part of the Sudbury map. Besides these coarse detrital rocks, which are evidently consolidated shore deposits, there are certain pseudo-conglomerates or autoclastic rocks, formed, as already stated, as a result of pressure and deformation. These 'crush' conglomerates are especially abundant where the harder and more brittle quartzites come in contact with the schistose greywackes. Certain portions of the green schists, penetrated by granitic material, have likewise become autoclastic, through the stretching and rolling out of the rocks, while large portions of the greywackes themselves, have been broken, the fragments separated and recemented together, by similar, though somewhat coarser material.

(2.) UPPER HURONIAN ?

(0.) OLDER ? NORITES AND DIORITES.

Peculiarties of older norite and diorite.

Older norites are younger than clastic rocks.

Relation with main mass of norite uncertain.

Certain areas of gabbro and norite, with their derivative diorite, occur, which have no direct or visible connection with the main mass of the nickel bearing norite. Most of these intrusive masses exhibit certain peculiarities of composition and structure, which all seem to possess in common, and by means of which, they may usually be distinguished from the ordinary norite. The possession of these characteristics, as well as their prevailingly greater alteration, suggests a probable difference in age, and the position assigned to them in the table of the geological formations exposed in this district, is believed to be a very close approximation to the truth. Most of these masses, at least, are distinctly younger than any of the clastic rocks with which they come in contact, as they pierce and alter the highest beds of the quartzites, which occur in the region covered by the southern and south-eastern portions of both the accompanying map sheets. Their age, with regard to the granite or main mass of norite, is not known, as they nowhere occur in conjunction with these rocks. They are, however, older than the olivine-diabase, for dykes of this latest rock in the area, are seen to cut them in many places.

Worthington mine only large deposit of older norite.

Other deposits.

With the exception of the Worthington mine, no large or economically valuable deposits of nickel or copper have been found in connection with them, although the Mitchener and Totten mines, situated in the township of Drury, were opened on masses of these minerals which were directly connected with the Worthington mine intrusive. Other deposits of these sulphides are known to occur at several points, as for instance on lot 12 con. III., of Neelon township, where the pyrrhotite was found to contain 3.10 per cent of nickel, and on the north half of lot 4, con. VI., of Neelon township, but, so far as known, none of these are of sufficient dimensions to form working mines under present conditions.

Outline of band of older norite.

Older norite east of Sudbury.

Older norite in Neelon township.

Smaller areas of older norite.

Older norite in Denison.

Older norite in Graham.

One of these belts of norite starts in the township of Drury, to the south of the Canadian Pacific railway, and extends across the southern part of the township of Denison, ending a short distance east of the Vermilion river. The small areas shown on the map, as occurring on lot 12, con. II and III., of Denison, are of the same rock. Another band forms the high land between Trout, Clear and Whit fish lakes on the southeast, and McCharles and Simon lakes on the northwest. The highest portion of the ridge rises 220 feet above McCharles lake. The probable continuation of this band forms the higher hills northwest of Kelley lake, and with some minor breaks, the ridges formed by the outcropping of these hard rocks, extends to the eastern end of Ramsay lake. To the north of the Canadian Pacific railway, and to the east of the town of Sudbury, the rock forms a series of exceedingly rugged and comparatively high hills, the highest of which rises over 1000 feet above the sea. This mass of norite and diorite covers an area of about four square miles in this part of McKim and Neelon townships, sending off a long narrow arm, which crosses the sixth concession of the township of Neelon. The large irregular mass of similar igneous material, occurring in the eastern part of Neelon, and shown on the map as covering portions of the third, fourth and fifth concessions, is known to be directly connected with the same mass. With the exception of the smaller separated masses, with which the Frood and Stobie mines are connected, and which undoubtedly belong to the main mass of the norite, all of the smaller areas of massive, basic, igneous rocks, shown on the map, are made up of this or a closely related type of rock. In addition to these, considerable areas of massive diorite occur in intimate association with, and probably intrusive through, the older greenstones and tuffs, which make up the larger portion of the area covered by the third and fourth concessions of Denison. These rocks are quite distinct from that which forms the main mass of norite, and are seemingly more closely related to this older norite intrusive. Similar areas of diorite rocks occur in the belt of older hornblende and tufaceous rocks, which crosses the third and fourth concessions of Graham, to the south of the granite mass. Deposits of pyrrhotite, chalcopyrite, pyrite and cobaltiferous arsenopyrite are known to occur in connection with these rocks, but they are not at present of economic importance.

Field character of older norite.

In the field, outcrops of these older norites, are pale-greenish, in contrast to the dark-grayish or black tones of the main mass of norite. They are, as a rule, finer in grain, eminently diabasic in texture and frequently show considerable masses of diorite pegmatite, or malchite, in this last respect, differing from the ordinary norite, which is remarkably uniform in grain over the whole area. Under the microscope, they contain less quartz, and the hornblende is always actinolite, and not the compact variety common in the diorite derived from the norite of the main mass.

Fresh representatives of older norites very rare.

Fresh representatives of this apparently older norite are comparatively rare, and the writer's specimens, selected with every care, at widely separated localities, contain only two specimens in which the pyroxenes are sufficiently fresh to permit of their identification, and even in the slides from these specimens, by far the greater portion of the original ferromagnesian constituents, are represented by the usual secondary serpentine and actinolite.

Fresh norite from between Whitefish and Simon lakes.

One of the hand specimens of the least altered phase of the diorite, collected near the eastern extremity of the band of greenstone, between Whitefish and Simon lakes, is a pale greenish, medium-textured, massive greenstone, with little or no evidence of having been subjected to dynamic metamorphism.

Microscopical character of older norite.

The thin section shows a hypersthene-gabbro or norite, the greater portion of which has undergone advanced chemical alteration or decomposition. For the most part it is now made up of plagioclase and a serpentine closely related, if not identical with bastite. The latter mineral is very evidently secondary, and occupies very approximately the same position as the original bisilicate material, from whose alteration it has resulted. Occasionally, limited areas show the original pyroxenic minerals, in various stages of the bastitic alteration. A faintly pleochroic hypersthene or enstatite and diallage are both present, and some of the individuals or grains of these minerals are, with difficulty, distinguishable from one another. Both minerals are very nearly colourless, but the double refraction of the hypersthene is weak, while the diallage, on the contrary, shows brilliant chromatic polarization. Both pyroxenes show a faint, though distinct pleochroism, that possessed by the hypersthene being more decided. The index of refraction of the hypersthene is somewhat higher than that of the diallage, while the latter mineral shows frequent polysynthetic twinning. Both pyroxenes, however, decompose to the smea pale greenish, usually fibrous, but occasionally scaly bastite, often exhibiting brilliant polarization colours. In places, this bastite is being converted into a pale greenish, feebly pleochroic, fibrous hornblende or actinolite, this uralitization being especially pronounced in the vicinity of the margins of the individuals. These bastitic areas contain

Mineralogical composition.

Enstatite and diallage.

Decomposition of pyroxenes.

Bastite.

very numerous, small, irregular scales and plates of a pale brownish, apparently secondary biotite, and, in places, are crowded with small grains of secondary magnetite. The plagioclase, which judging from the extinction angles is labradorite, has a marked poikilitic development, this mineral extinguishing simultaneously over large areas. which in the thin section, are separated either partially or wholly by intervening bisilicate material. This poikilitic effect is likewise noticeable in the hand specimen, owing to the uniform reflection of light from the plagioclase individuals. Comparatively large, irregular grains of magnetite probably titaniferous, are also distributed through the rock, while quartz occurs, filling up occasional interspaces between the tabular forms of felspar.

Poikilitic plagioclase.

Titaniferous magnetite.

Fresh norite from Neelon.

Another specimen, representing a very fresh variety of this rock, was obtained from a small hill, west of a lumber road, on lot 11, con. V., of Neelon. Dr. Coleman mentions the fact that a specimen of this rock from the hill top east of the town of Sudbury, is 'a typical norite made up essentially of faintly pleochroic enstatite or hypersthene and plagioclase, the latter somewhat lath-shaped.' (1)

Norite east of Sudbury.

Mineralogical composition of older norite southeast of Evans mine.

A thin section from a specimen obtained from the large mass of this rock, occurring to the southeast of the Evans mine, shows a greatly altered variety of this norite. The original pyroxene minerals are wholly converted into an aggregate of pale greenish, brilliantly polarizing scales and fibres of serpentine, this, in turn, being converted, in certain instances, to actinolite. Pale coloured biotite is abundant. A small amount of greenish-brown, compact hornblende is also present. The plagioclase, with the pale brownish tints so common in these rocks, occurs in rather broad, lath-shaped or tabular, well-twinned crystals, which are, as a rule, quite fresh. Quartz is not very abundant, and some grains are intergrown with plagioclase, forming the characteristic granophyre. The iron ore is ilmenite, with borders of sphene. Apatite is abundant, in the usual slender, prismatic forms.

Description of altered norite from N½ lot 10, con. V., Neelon.

Another thin section, taken from a specimen obtained on the north half of lot 10, con. V., of Neelon, is still more decomposed, the pyroxene being replaced by a very pale yellowish-green serpentine and actinolite. All the intermediate stages in the conversion of serpentine to actinolite may be studied. Much of the felspar is quite fresh and clear, with a pale brownish colour, but the areas of this mineral have been invaded, to a considerable extent, by small fibres and crystals of actinolite. A little compact, brownish hornblende is also present. A large

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(1) Ann. Rep. Bur. of Mines, Ont. 1903, p. 296.

amount of zoisite occurs as a secondary product of decomposition. Ilmenite, largely altered to sphene, and occasional grains of pyrrhotite and chalcopyrite are also present, while quartz occasionally occupies the irregular interspaces between the plagioclase laths. Another specimen, from the north half of lot 4, con. VI., of Neelon, was also examined under the microscope. The rock may be referred to, at present, as a uralitic quartz-diabase. The original pyroxene is now represented by pale greenish, feebly pleochroic bastite and actinolite, much of the plagioclase is rather clear and fresh, but some has undergone considerable saussuritization. A little brownish hornblende is present. Sphene, in irregular grains, with black opaque cores of ilmenite, epidote and zoisite, are the principal other minerals noticed.

Mineralogical composition of altered norite from N½ lot 4, con. VI., Neelon.

Other altered varieties of older norite.

The actinolite diorite and schist, with which the deposits at the Worthington, Mitchener, Totten and Macdonell or Gersdorffite mines are associated, are evidently highly altered forms of this norite. These deposits possess certain peculiarities in common with one another, which distinguish them from the other ore bodies, connected with the main mass of the norite. Some of the rock, collected at the Vermilion mine is possibly of the same type and age, but this was not definitely ascertained. As is evident from the foregoing, it is manifestly difficult, if not impossible, in all cases, to decide the question of the identity of every individual specimen of altered norite, or even the various separated masses, but in a broad way, these two norites are distinct and separate from one another, and the criteria already mentioned for distinguishing them will usually be found sufficient.

Difficult in all cases to distinguish norites.

(3.) LAURENTIAN GRANITE AND DIORITE-GNEISSES.

Laurentian rocks, where located.

The rocks usually classified as Laurentian, comprise a series of foliated, eruptive rocks, mainly of granitic and dioritic composition, crossing the southeastern corner of the Sudbury map, in the townships of Dill and Neelon, in the vicinity of the Wanapitei river. These rocks possess a well-marked foliation, this structure being determined not only by the alternation of lighter and darker coloured bands, but also by the parallel disposition and alignment of the component minerals. The lighter coloured bands are usually of the prevailing flesh-red tint, and are made up largely of quartz with orthoclase, microline and microperthite as the felspathic constituents, and these minerals, together with biotite in varying amount, make up the bulk of the rock. The darker coloured bands contain less quartz and very abundant mica, with oligoclase as the principal felspar. The biotite is often altered to

General description.

Character of foliation.

Mineralogical composition.

Almandine garnet.

Cyanite abundant in certain portions.

Sillimanite on jointing planes.

Gneisses of eruptive origin.

chlorite. Muscovite and zircon are often present in small amount. Garnet is very abundant, of the prevailing almandine variety, and usually more or less rounded, but some of the well formed individuals show the faces of the rhombic dodecahedron and icositetrahedron. Perhaps the most interesting mineral is cyanite, which is abundant in certain portions of the rock, occurring both in the micaceous and felspathic bands. This mineral occurs in flat, blade-like crystals, with the prevailing bluish and whitish colours. In the micaceous bands, the colour is especially deep, and of a beautiful azure tint, somewhat unevenly distributed or cloud-like in its effect, the colour being often deepest in the centre of the crystals, gradually becoming colourless towards the margin. These crystals are arranged, for the most part, parallel to the foliation, but some individuals are disposed at considerable angles to this structure. Sillimanite or fibrolite is also occasionally present, especially on slickensided or jointing planes, and shows abundant evidence of pressure and stretching. These gneisses are distinctly of eruptive origin, and their intrusion through the quartzites and other clastic rocks is everywhere apparent, where the line of junction is so exposed, that the relationship between the two may be examined and studied.

4. Upper Huronian (?) Clastic rocks.

Location of Upper Huronian rocks.

Rocks regarded by Dr. Bell as probably of Cambrian age.

Probable relative age.

Synclinal trough overlying norite.

The rocks, thus classified, occupy the large oval area situated immediately northwest of the main belt of the nickel bearing and kindred eruptives, and underlying the extensive clay plain, which has already been described as so eminently suitable for agricultural purposes. As a result of the first geological examination, these rocks were regarded by Dr. Bell as probably of Cambrian age, and have thus been coloured on all subsequent geological maps. Their precise geological age is still a matter of doubt, but the later work seems to indicate a close relationship both in origin and age, with the main masses of norite and micropegmatite. If, as seems probable, from the work already accomplished, these several separate ranges of nickel bearing norite are, in reality, the exposed portions of one continuous laccolite, with occasional minor irregularities or offsets, then, as illustrated by Dr. Coleman (1), these youngest clastic rocks of the district will, no doubt, be shown to occupy a synclinal trough, overlying this deep platter-shaped sheet of intrusive rock.

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(1) Ann. Rep. Bur. of Mines, Ont. 1903, (illustration 52) pp. 288-289.

These rocks extend from the southeastern part of the township of Trill, to within a few miles of Wanapitei lake, the area being thus nearly thirty-five miles in length, with an extreme width of a little over eight miles.

Succession of clastic rocks.

They comprise, at the base, certain breccias and agglomerates, most of which, at least, are of pyroclastic origin, these rocks passing upward into black bituminous shales, while they are, in turn, overlaid by a comparatively coarse greywacke or felspathic sandstone.

Identification of breccia as volcanic glass breccia by Professor Williams.

The identification of the breccia at the base of this series, as a consolidated volcanic ash, was the result of microscopical studies undertaken by the late Prof. G. H. Williams, of material furnished him by Dr. Bell. The important fact of the occurrence, in these ancient rocks, of a volcanic glass breccia, the various minute details of structure being so exceptionally preserved through silicification, as to permit of its positive recognition, has always been a matter of general interest and comment, especially amongst those geologists, who regarded these earlier periods of the earth's history as characterized by exceptional and prolonged explosive volcanic activity.

Description communicated to Geological Society of America.

A description of this comparatively rare type of rock, was carefully prepared by Prof. Williams, and communicated to a meeting of the Geological Society of America, held on December 31st, 1890. These details were embodied in an appendix to Dr. Bell's paper on the nickel and copper deposits of this district, which was also read at this meeting (¹).

Specimens from Onaping river.

The material submitted for examination, consisted of two small hand specimens, collected at the lowest falls on the Onaping river, in the township of Dowling. Prof. Williams' description (²) is so complete and satisfactory, that it may be quoted in this connection.

General description of volcanic breccia.

'In a hand specimen, this rock presents a nearly black felsitic matrix, in which are embedded sharply angular or slightly rounded fragments, varying from 1½ cm. in diameter, downwards to ultra-microscopic dimensions. These fragments are lighter in color than the matrix, but differ considerably among themselves in their tint, structure and composition. The majority resemble chalcedony in appearance, others are greenish, while some of the largest fragments are now replaced by a single calcite individual. Occasional small grains of clear vitreous quartz may also be detected, while specks of pyrrhotite are everywhere abundant. Many of the angular fragments show distinctly under the

Many angular vesiculear fragments.

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(1) Bull. Geol. Soc. Am. Vol. II. 1891, pp. 125-137.

(2) Ann. Rep. Geol. Surv. Can. Vol. V. 1890-91, Part F, pp. 74-76.

Flow structure.

Character of groundmass.

Arrangement of chlorite.

Quartz, calcite and felspar.

lens a flow or vesicular structure, which is still more apparent in a thin section of the rock when seen under the microscope. The fragments, even down to those of the smallest dimensions, have the angular form characteristic of glass sherds produced by explosive eruptions, with more or less coarsely vesicular structure. The flow structure is as perfectly marked by sinuous lines of globulites and microlites which terminate abruptly against the broken edge of the glass particle, as in the most recent vitrophyre. Minute spots of pyrrhotite are scattered throughout the section. The groundmass is of a dark colour, owing to the massing in it of minute black globulites, to whose nature the highest magnifying power gives no clue. Between crossed nicols it is seen to be made up largely of chalcedonic quartz, which has changed the easily destructible glass into a sort of jasper. Chlorite is also abundant, frequently arranged as a border of radiating scales around the edges of the fragments, so as to coat them green in the hand specimen. The larger grains are always a fine mosaic of interlocking quartz, but some of the smaller ones are composed of a unit individual of clear vitreous quartz. The only other minerals which could be identified in the section are calcite and a few grains of a glassy striated felspar. The presence of this latter mineral is very noteworthy, as we should expect it to have disappeared during the vicissitudes through which this rock has passed.'

Composite fragments also occur.

In other localities, this breccia shows a greater diversity in the character of the larger fragments, and composite rocks made up largely of quartz and felspar, either granite or recrystallized quartzite, frequently occur. Plagioclase and quartz, usually in angular or subangular pieces, are very often represented, while epidote and hornblende, also mentioned by Dr. Coleman, are likewise present in the thin sections examined by the writer.

Silica determination by Dr. Hoffmann

Chemical analysis by Dr. Walker.

No complete chemical analysis has yet been made of the individual specimens examined by Prof. Williams, but Dr. Hoffmann made a silica determination, showing it to contain 60.23 per cent. Dr. T. L. Walker however, has made an analysis of a specimen of this breccia, obtained from the north shore of Whitson lake, with the following results: (1).

SiO_2	59·93	Na_2O	3·80
Al_2O_3	12·12	K_2O	0·97
FeO	10·56	Loss by ignition	1·57
MnO	trace		
CaO	4·49	Total........	98·63
MgO	5·19		

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(1) Quart. Jour. Geol. Soc. Lon. Vol. LIII, 1897 p. 45.

Various sulphides, chiefly pyrite, but sometimes also pyrrhotite and chalcopyrite, are often abundantly disseminated through this rock, and not a few mining locations have been surveyed, intended to cover such deposits, which were regarded as possible mines. One of the most promising of these, visited by Mr. Leroy, was situated on the south half of lot 8, con. IV., of the township of Dowling, and the specimens secured were handed to Dr. Hoffmann for assay. The hand specimen shows a massive pyrrhotite, with which is associated a little chalcopyrite and a somewhat larger proportion of gangue. The pyrrhotite, when freed from the chalcopyrite and gangue, was found by Mr. F. G. Wait (1) to contain 0.26 per cent, of nickel with a trace of cobalt. Resting upon this breccia or agglomerate, are certain black bituminous shales, often with well developed slaty cleavages. This rock is made up principally of minute fragments of quartz, with intervening scales of chlorite and sericite, and abundantly disseminated, black, opaque particles of carbonaceous or bituminous matter. These slates sometimes contain fissures occupied by anthraxolite or vein anthracite, and a large outcropping of such material in the township of Balfour, occasioned considerable excitement some years ago. Samples of the surrounding rock, analyzed by Dr. Ellis, showed 6.8 per cent of carbon in the shale. (2) The highest rocks in this series are certain gray sandstones and shales, the former frequently containing concretions, which weather more rapidly than the matrix in which they are enclosed. Composite fragments can often be recognized with the naked eye, and the rock then assumes the character of a coarse grit. It is made up, principally of angular and subangular grains of quartz, embedded in a finer-grained base, composed of felspar, quartz, chlorite and mica. Zircon and tourmaline are also sometimes present. The dark colour of the rock is due to disseminations of innumerable, fine particles of opaque material, especially abundant in the felspar, and which are probably ilmenite.

Abundance of sulphides.

Deposits visited by Mr. Leroy.

Assay of pyrrhotite by F. G. Wait.

Presence of bituminous matter in shales.

Anthraxolite.

Amount of carbon in shale.

Composition of sandstones and shales.

(5.) Post Huronian.

(A.) GRANITE.

It has been customary, of late years, to speak of certain areas of acid intrusives, occurring in intimate association with the nickel bearing eruptive, as the 'younger granites.' Reference has already been made to their strange and anomalous behaviour with regard to the sulphide bearing norite, for wherever the line of junction, between these two classes of rock, has been examined, it

Younger granites.

Relation between granite and norite.

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(1) Ann. Rep. Geol. Surv. Can. Vol. XIII Part R, p. 35.

(2) Ann. Rep. Bur. of Mines, Ont. 1896 pp. 159-166.

Granitoid gneiss older than norite.

Explanation of contradictory phenomena.

Evidence of successive periods of intrusion.

Difference in rate of cooling.

Two main types of granite.

Approximately of same age.

presents a series of apparently conflicting phenomena, which, in the present state of our knowledge, cannot be satisfactorily interpreted or explained. The larger proportion of the evidence, so far available, seems decidedly in favour of regarding these granite rocks as of earlier generation than the norite or gabbro, and even in the vicinity of the Creighton mine, where the immediate junction is characterized by the presence of a narrow belt of intermediate composition between the granite or norite, Dr. Coleman states that 'on the whole, however, the impression is formed that the granitoid gneiss is older than the gabbro, the latter sometimes growing finer grained at the edge of the gneiss' (1). A reasonable explanation of the contradictory phenomena witnessed, seems to be closely connected with the manner and rate of cooling of the granite bathylith. This immense body of acid eruptive, as at present exposed at the surface by denudation, has not evidently resulted from the consolidation of a body of magma, the product of one simple act of plutonic activity, but is rather the result, locally at least, of several successive fusions and recementations, before the whole mass reached its final or present condition. The evidence of such successive periods of intrusion, is furnished by a study of the granite mass itself, for although over the larger part of the area, the granite is remarkably uniform in structure and composition, certain localities show rather sudden changes in these respects, with occasionally a sharp dividing line, thus indicating an apparent difference in age. All attempts, however, to trace out this apparent line of subdivision in detail, over any extent of country, proved futile, and the conclusion was reached, that the whole mass is very closely synchronous, and that no appreciable lapse of time in a geological sense, has occurred between the several dates, represented by these different phases of the granite. The rate of cooling, moreover, was extremely slow, much more so in fact than the norite, so that it is possible that, in certain instances, some portions may have been sufficiently consolidated to permit of the cooling against it of the norite, while in areas not far distant, some of the latest acid secretions of the granite penetrated and altered the norite or gabbro. There are two main types of these granites, the difference between the two being essentially one of structure, and although intermediate varieties between the two extremes are known to occur, such phases are relatively unimportant and may be ignored for purposes of general description. These two varieties are at present believed to be very approximately, at least, of the same age. One type of rock which occupies by far the largest area of any of these acid eruptives, is a very decided 'augen' or porphyritic granitite-gneiss. In places, this seems

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(1) Ann. Rep. Bur. of Mines, Ont., 1903, p. 245.

to pass into a finer-grained and more massive type, with ill-defined or no foliation, thus resembling the second variety, the type of which, however, forms two smaller and separated bathyliths occurring to the northeast of the main mass.

Transition between the two types of granite.

The coarser or 'augen' type presents such a strong resemblance, in every respect, to certain gneissoid rocks, occurring in the Laurentian, that it was indicated as part of this formation in the first geological map. It constitutes a well marked bathylith, intrusive through the older green schists and diorites, which it has greatly disturbed and altered, forming a belt to the south of the main mass of the sulphide bearing norite, and extending from the second lot in the township of Denison, to a point a little east of the boundary between Snider and McKim townships, near the Copper Cliff mine. The mass is thus about thirteen miles in length, with an average width varying from one to two miles. It forms a very striking and beautiful rock, eminently suitable for building or ornamental purposes. It has been used in the building of the main office at Copper Cliff, as also for mantles in the manager's house at Victoria Mines.

Resemblance of 'augen' type to Laurentian.

Outline of larger bathylith.

Suitable for building and ornamental purposes.

Under the microscope, the thin section shows the rock to be made up chiefly of microcline, orthoclase, albite, oligoclase, biotite and quartz, with epidote, sphene and apatite as accessory minerals, and calcite, epidote, zoisite, sericite and chlorite as secondary products of decomposition. The orthoclase and microcline sometimes occur free, but, for the most part, are intergrown with the albite, forming both microcline-and orthoclase-microperthite. The quartz is the usual granitic variety, frequently showing intense strain shadows and sometimes granulated into a fine interlocking mosaic. The felspars of the rock, although like the quartz, often much cracked, broken and granulated, are comparatively fresh. Reddish-brown iron oxide has passed through the cracks, giving a cloudy or stained appearance to some of the grains. Much of the oligoclase has undergone considerable alteration, the resulting products being epidote, zoisite and calcite. It is usually stained a deep reddish-brown colour. The biotite is usually 'bleached' and has often undergone more or less complete chloritization. Sphene and epidote are often embedded in the biotite. Apatite is frequently present in the usual acicular prisms, while occasionally, a little calcite was noticed in thin sections.

Microscopical determination of minerals.

The 'augen' are usually made up of a comparatively coarse-grained aggregate of microperthite or microcline, together with a much smaller proportion of quartz. More rarely, it is a single crystal of felspar, often a Carlsbad twin, rarely, however, with sharp or well defined boundaries.

Composition of 'augen'.

Reaction between granite and norites.

In the vicinity of the Creighton mine, the granite of the main bathylith comes in immediate juxtaposition with the nickel bearing norite, while to the southwest in the vicinity of the Gertrude mine, as well as to the northeast from the North Star mine and beyond, considerable areas of the peculiar granite and greenstone breccia intervene between the two rocks. As has been stated, there is the clearest evidence at the Creighton mine, of considerable reaction between the granite and norite, the former being often impregnated for a considerable distance from the contact with the nickel and copper bearing sulphides, while, in addition, certain portions of granite are unusually basic, presenting a rock of intermediate composition between the granite and norite, with deep flesh-red porphyritic individuals, often Carlsbad twins of orthoclase, microcline or microperthite, embedded in a groundmass made up principally of biotite, hornblende, epidote and sphene, the latter containing black opaque cores, presumably of ilmenite.

Two smaller areas of finer-grained granite.

The finer grained variety of granite is characteristic of two areas. The smaller one is situated immediately east of the Lady Violet mine, and extends a little north of the Manitoulin and North Shore railway, on the boundary between McKim and Snider townships. It covers a considerable portion of lot 1., Con. IV., of the township of Snider.

Location of larger area of fine-grained granite.

Microscopical determination.

Small area of coarse granite near Pump lake.

The other and larger area, extends from the main line of the Canadian Pacific railway, a little southeast of the Murray mine, northeast to within a quarter of a mile of the Little Stobie mine. It thus constitutes an oval area, measuring about three miles in length, and averaging about three quarters of a mile in width. A microscopical examination of the thin section. shows an aggregate of quartz, orthoclase, plagioclase, biotite, hornblende, magnetite and zircon. The rock has evidently been subjected to great crushing. The structure is by no means uniform, but larger fragments are embedded in a finer grained mosaic, which has resulted, in great part, from their peripheral granulation. The magnetite is highly titaniferous, as it is often surrounded by borders of leucoxene or the more normal sphene. Besides these, a very small and irregularly shaped area crosses the Manitoulin and North Shore railway, immediately east of Pump lake, on lot 1, con IV., of Snider township. It has a general resemblance to the coarse 'augen ' variety. This small mass measures about 850 feet long and from 150 to 500 feet wide.

Small intrusions of granite northwest of Murray mine.

About two miles west of the Murray mine, Walker mentions that the nickel bearing eruptive is cut by two separate intrusions of fine-grained, pinkish, biotite-granite, which send off apophyses into the surrounding greenstone. The wider of the intrusions is about 100

Breccia of green schist and granite.

Location of main masses of breccia.

Breccia at Murray and Copper Cliff mines.

yards broad, while the smaller is less than 60 yards. The microscope shows that quartz, orthoclase, plagioclase and biotite, are the chief constituents. Considerable areas, in the vicinity of the line of junction between these granites and the older greenstones, are characterized by the presence of a breccia, made up of an extremely intricate intrusion or penetration of the greenish schistose rocks by dykes and irregular masses of granitic material. The chief alteration noticed in connection with the greenstone, is the development of biotite at the expense of the original hornblende, and the replacement of the plagioclase by a fine mosaic of secondary plagioclase, quartz and epidote, the rock being thus a well formed mica or biotite schist. Subsequent differential movements have occasioned very considerable deformation, and some portions of the resultant rock mass represent very perfect and characteristic pseudo-conglomerates. Areas of these breccias are often big enough to be shown on maps of ordinarily large scale. They are especially noticeable east and southeast of the Gertrude mine, and between this and the Creighton mine, and some of the cuttings of the Manitoulin and North Shore railway, between these two mines, have been made through hills of this breccia. It seems to occupy a lenticular area, intervening between the norite and the granite, the widest part being a little over three quarters of a mile, while the length from northeast to southwest is about three miles. To the northeast, in the vicinity of the North Star mine and beyond, as far as Clarabelle lake, considerable areas are underlaid by this breccia, while in the neighbourhood of the Murray mine, they are especially noticeable and well developed. The manager's house at Copper Cliff, is located on a rocky knoll, made up of this breccia, and a comparatively narrow band of this rock extends for a short distance in a southwesterly direction.

Inclusion of greenstone in granite.

Reason for presence of greenstone fragments.

In addition, the main mass of the granite bathylith contains frequent inclusions, often of large size, of these older greenstones and schists, the reason for their presence and occasional abundance being readily explained by Dr. Daly as due to 'stoping,' as he terms the phenomenon of the detaching of portions of the original material overlying or enclosing a bathylith, and the inclusion of such fragments in the mass of the original magma. (¹)

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(1) Amer. Jour. Sc. Vol. XVI, 1903, p. 108.

(5.) Post Huronian.

(B.) NICKEL BEARING ERUPTIVE.

Early recognation of intimate connection between basic eruptives and sulphide deposits.

First microscopical descriptions.

Soon after the discovery of these nickel and copper deposits, it was remarked that all of the rich and extensive ore bodies occurred in intimate connection with certain basic eruptive rocks, of medium texture, and which for convenience of description, and in the absence of more precise information, were usually referred to under the names of greenstone and diorite. The first published microscopical descriptions were all in substantial agreement, in regarding the prevailing type of the nickel bearing eruptive as made up essentially of plagioclase and hornblende, with a smaller proportion of biotite and quartz, while ilmenite and apatite, with variable quantities of pyrrhotite and chalcopyrite, were the usual accessory constitutents. The rock was therefore regarded as an intrusive gabbro or diabase, which, owing to subsequent metamorphism, had its pyroxenic components changed to secondary hornblende or uralite. Rocks quite like these had been studied in many regions, where they could be traced with certainty into basic eruptives of normal character, and it was confidently predicted by the late Prof. G. H. Williams, who was the first to make any detailed petrographical examination of these rocks, that 'specimens might be collected at some of these localities which would establish positively both the original form, and the course of alteration of the present specimens.' (¹)

Prediction of recognition of true nature of eruptive.

Dominion mine eruptive first described as dyke.

Included in the same suite of specimens as the foregoing, all of which had been sent by Dr. Bell to Prof. Williams for identification and description, was one, which had been collected near the Dominion mine, in the township of Blezard, but which, in the hurry of a first examination, was regarded as occurring in the form of a dyke. This rock, the exceptional character of which was noted at the time by Prof. Williams, and which was described as a 'quartz-hypersthene-gabbro with accessory biotite' (²), was in reality a practically unaltered representative of the nickel bearing eruptive, although its identity as such, was not suspected until some years afterwards.

Prospector's name of diorite justified.

All of these first microscopical determinations, therefore, showed a normal type of greenstone, differing in no essential particular from others similarly altered, and with no apparent reason for the development of such unusually large and rich deposits of sulphide material. At the same time, the field and prospectors term of diorite was justified, as also the names proposed after more detailed microscopical examination, such as uralitic or gabbro-diorite, uralitic diabase, etc.

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(1) Ann. Rep. Geol. Surv. Can. Vol. V. 1890-91, Part F., pp. 60 & 62.

(2) Ann. Rep. Geol. Surv. Can. Vol. V. 1890-91, Part F. pp. 77-78.

In spite of great care exercised first specimens all greatly altered.

It is to be regretted, therefore, that although great care was exercised in the collection of these first or type specimens, attention was directed, chiefly, to the selection of material in immediate association with the ore bodies, and the rocks thus obtained, were in such advanced stages of decomposition, that no very definite or precise information was possible in regard to their original composition or true affinities. As a conseqence of this, the opinion prevails that the whole of the eruptive in the vicinity of these nickel deposits, is completely altered, whereas the very opposite appears to be the case, and most of the writer's collection of fresh and unaltered material was obtained in the immediate vicinity of the various mines. In this connection it may be remarked that some of these hand specimens, containing as much as from 5 to 10 per cent of the sulphides, have undergone so little metamorphism, as to permit of the positive identification of all the prevailing minerals, including hypersthene, enstatite, diallage, olivine and labradorite.

Many fresh specimens later secured from vicinity of mines often containing much sulphide material.

Descriptions of norite by von Foullon and Coleman.

In 1892, the late Baron von Foullon published the first determination of the nickel bearing eruptive, occurring in the vicinity of the Murray mine, showing it to be a gabbro, closely related to the norites, his descriptions being prepared after a study of material collected at this locality, in the summer of 1890. In 1893, Dr. A. P. Coleman identified the eruptive of the Northern Nickel Range as a gabbro containing both diallage and hypersthene.

Fuller descriptions by Dr. Walker

The true significance of these discoveries and isolated descriptions, was not, however, fully appreciated, until the appearance of Dr. Walker's results, the issuing of this publication marking a very signal advance in our knowledge, regarding the origin and relationship of these sulphide deposits and their associated rocks.

Two divisions of nickel bearing eruptive.

The nickel bearing eruptive, characteristic of the three main belts or ranges, may, for purposes of description, be considered under two divisions.

I. A basic portion :—Including certain gabbroid rocks, chiefly, at least, of the norite facies, with their derivative diorites, with which the nickel and copper bearing sulphides are immediately associated.

II. An acidic portion :—Comprising large areas of rock of granitic type, with well marked gneissoid structure, the prevalence and abundance of the graphic intergrowth of the quartz and felspar, known as granophyre or micropegmatite, having suggested the name 'micropegmatite,' by which this rock is now generally known.

Name for nickel bearing eruptive.

The least altered phase of the basic portion of the eruptive is represented by what may be referred to as 'norite'. The rock is sometimes called a 'quartz-hypersthene-gabbro', but for general purposes the former name is preferred.

Eruptive of exceptional interest.

The microscopical examination shows the rock to be an eruptive of rather exceptional character and interest. It belongs to the general family of gabbros, but with distinct traces, and, at times, well marked diabasic or ophitic structure. The prevalence and usual preponderance of hypersthene or enstatite, show its close affinity with the norites, while it contains, what is very exceptional for such a rock type, an abundance of original quartz. In fact, many specimens could be secured, which contain nearly as much quartz as an ordinary hornblende granite. In some instances, noticeably at the Copper Cliff mines, a large quantity of micropegmatite or granophyre is present, the felspathic constituent of this graphic intergrowth being usually plagioclase. Exposures show a massive, medium to coarse-grained, dark-grayish, greenish-gray or brownish rock, which is often almost black in color on freshly broken surfaces. Scales of deep brown biotite are usually conspicuous, while the quartz is perhaps equally so, in very characteristic sapphire-blue or purplish grains, the color which is often seen in the phenocrysts of quartz-porphyries.

Presence of original quartz and hypersthene.

Granophyre.

Biotite and quartz conspicuous.

Norite decomposes readily.

These rocks do not offer any very effectual resistance to processes of decomposition and erosion, and, as a consequence, the area characterized by their presence is, generally, one of low relief.

Spheroidal weathering.

Spheroidal weathering is characteristic, but not so pronounced as in the case of the later dykes of the olivine-diabase.

Development of hypersthene and enstatite.

The orthorhombic pyroxene, either hypersthene or enstatite, shows a distinct approach to perfection of crystallographic outline, and, in many cases was the first of the essential minerals to form. In occasional instances, the hypersthene is unaccompanied by a monoclinic pyroxene, as in some of the specimens collected in the vicinity of the Blezard mine. It is often, by far, the most abundant of the coloured constituents, as at the Murray mine, where the diallage is only occasionally represented, while almost the whole rock mass is made up of hypersthene, in various stages of decomposition, the small and infrequent interspaces being occupied by plagioclase. The hypersthene is, as a rule, rather faintly pleochroic, although specimens from the vicinity of the Blezard mine, and from a railway cutting about one mile and a half northwest of the Murray mine, are very strongly pleochroic, rose red to pale yellow fiish-green. The enstatite is also colourless in thin section, and, in contradistinction to the hypersthene, exhibits little or no pleochroism. Both the hypersthene and the enstatite are very liable to decomposition, so that, in most cases, areas of this mineral, are replaced by an aggregate

Alteration of rhombic pyroxene.

of light-green, non-pleochroic, brilliantly polarizing, fibrous or scaly serpentine (bastite). This alteration is often accompanied by the separation of minute grains of magnetite. In most cases, even the fresh individuals of hypersthene are bordered by a compact, strongly pleochroic, green hornblende which is doubtless an original constituent. This primary hornblende, likewise, forms borders on areas showing the complete bastitic alteration. In addition to this, there is undoubted secondary hornblende resulting from the alteration, first, of the bastite into actinolite, and this in turn, to the ordinary type of green hornblende.

Presence of both primary and secondary hornblende.

The monoclinic pyroxene, which is usually present in subordinate amount, is likewise frequently bordered by primary hornblende, and thus, the individuals of these two pyroxenes cannot be distinguished from one another, in specimens which have undergone any advanced decomposition. Sometimes, both pyroxenes show the presence of the characteristic, minute, tabular interpositions or schillerization products but, as a rule, these are absent.

Diallage.

The diallage is distinguished from the orthorhombic pyroxene chiefly by the absence of pleochroism, its inclined extinction, and frequent polysynthetic twinning, while it usually shows a lower index of refraction with higher double refraction. Olivine is present in small amount in the norite obtained from the Little Stobie mine, but most of it is altered to an aggregate of deep coloured scaly serpentine, talc and magnetite. Biotite is an almost invariable consituent and is usually rather abundant, in large plates and is undoubtedly of primary origin. The plagioclase is usually in broadly twinned, stout, lath-shaped or tabular crystals, whose frequent interlacing arrangement produces the characteristic, rude, ophitic structure. Separations by means of Thoulet's heavy solution, as well as the extinction angles, show that this plagioclase is labradorite. The presence of innumerable, brown, dust like inclusions, presumably of ilmenite, gives to the felspar its prevailing dark colour.

Means of distinguishing the two pyroxenes.

Olivine rarely present.

Separations by heavy solution.

Quartz and occasionally granophyre fills most of the irregular interspaces between the other constituents, although, in the norite from the Creighton mine, microcline almost invariably accompanies this interstitial quartz. Apatite, magnetite, which is usually highly titaniferous, zircon and grains of pyrite, pyrrhotite and chalcopyrite are almost always present. These sulphides are distinctly of primary origin, and were among the earliest of the minerals to crystallize from the original magma, antedating even the magnetite, in some cases, for grains of pyrrhotite were noticed completely enclosed by the iron ore. The sulphides occur, for the most part, intimately associated with, and

Quartz and granophyre.

Microcline at Creighton mine.

Primary origin of sulphides.

Sulphides intimately associated with one another.

Sulphides occur in unaltered forms of norite.

frequently embedded in the coloured constituents, in much the same way as the magnetite, from which they can only be distinguished by the difference in colour in reflected light. The pyrrhotite and chalcopyrite are often very intimately associated, so that they are extremely difficult of separation, even the smallest grains showing intimate intergrowths of these minerals with one another. These sulphides frequently occur in those portions of the norite which have suffered so little from dynamic metamorphism, that only an occasional dislocation of a plagioclase crystal is noticed, while the same exposures have been so little affected by hydrochemical agencies, that such readily alterable minerals as hypersthene, enstatite, olivine and diallage are still plainly recognizable in such specimens. The sulphide material, in such cases, is often not subordinate in amount, but is so abundantly disseminated as to characterize the rock, and justify the name of 'pyrrhotite-norite' which is sometimes applied to it.

Altered varieties of norite more abundant.

Pyroxenes mainly decomposed.

Probable identity of decomposition product of both pyroxenes.

Plagioclase usually quite fresh.

Character of other mineral constituents.

Although a considerable number of specimens were secured, representative of the comparatively unaltered norite, by far the larger proportion of the material collected consisted of a massive, usually coarse gabbro-diorite in various stages of alteration. Very few of these show even traces of dynamic metamorphism, and, as a rule, the ophitic structure, produced mainly by the interlacing arrangement of the plagioclase crystals, is quite undisturbed. The alteration is mainly due to hydrochemical agencies, and affects the pyroxenic minerals, decomposing these to a pale, yellowish-green serpentine, sometimes of the ordinary type, but usually of the bastite variety. Actinolite also results from the alteration of the pyroxenes. The compact borders of primary hornblende often surrounding the original pyroxenes, are evidently made up of much more stable material, not having been affected by any of these changes. The areas formerly occupied by the pyroxene are, therefore, replaced by bastite or actinolite, the hornblende borders remaining unaffected, the individuals thus decomposed being referred to as uralite. No distinction can be drawn between grains which represent hypersthene or diallage, as both of these minerals apparently decompose to closely related, if not identical material. The labradorite is usually quite fresh, in tabular or broad blade-like forms, with a brownish colour of varying shades, which is so prevalent in the norites. Occasionally it shows incipient decomposition to the usual saussuritic products, mainly sericite, but also epidote and zoisite. Biotite is always present and conspicuous in large plates with strong pleochroism. It is sometimes intergrown with the hornblende and has also undergone considerable 'bleaching'. It usually contains comparatively large, irregular grains of magnetite. Quartz is always present, and sometimes abundant, filling up the irregular interspaces between the other constituents. Highly titaniferous magnetite and apatite are also always present, but in small amount, while the pyrrhotite and chalcopyrite vary in amount, from occasionally disseminated grains, to such quantities as ensure the use of the mass as an ore of nickel and copper.

Acid portion of nickel bearing eruptive

Micropegmatite.

Absence of sharp line of division.

General characters of micropegmatite.

Microscopical determination of mineral constituents.

Transition type between micropegmatite and norite.

Prevalence and characteristics of granophyre.

In addition to the norite and diorite, a more acid rock of granitic composition and prevailing gneissoid structure occurs, which cannot be separated genetically from the more basic portion with which the sulphides are more directly associated. This rock has usually been referred to as 'micropegmatite' a name first suggested by the late Prof. G. H. Williams. ( ) 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. Outcrops of this rock are evenly banded or foliated, with a distinct strike and dip, usually porphyritic, weather a pale reddish or grayish colour and are frequently intersected by irregular and often intricate vein-like, masses of quartz, evidently of pegmatitic origin. On freshly exposed surfaces, the rock is usually dark coloured, with abundantly disseminated, small, reddish or yellowish phenocrysts of felspar. Orthoclase is often present in considerable amount, and, towards the outer edge of the mass, is the predominant felspathic constituent, but plagioclase (oligoclase or oligoclase-andesine) is usually more or less abundant. Microperthite and microcline are also often present, but in subordinate amount. Much of the felspar is somewhat turbid owing to decomposition. Biotite is the prevailing ferromagnesian mineral and much of it is 'bleached' and altered to chlorite. It is usually in small irregular, tattered scales and plates, arranged in narrow, approximately parallel bands, gently curving around and among the larger phenocrysts of felspar. The abundance of the biotite, and its frequent alteration to chlorite, give the prevailing dark colour to the rock on fresh surfaces. The transition type between the micropegmatite and the norite, shows a varying proportion of hornblende, which mineral, as a general rule, diminishes in amount in passing outward from the norite, although certain bands of relatively greater basicity show an appreciable amount of this mineral, even at a considerable distance from the line of junction. One of the most noteworthy points, in connection with this gneissoid rock, is the prevalence and abundant development of micropegmatite or granophyre and also the fact that plagioclase and quartz are most frequently the component minerals

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(1) Ann. Rep. Geol. Surv. Can. Vol. V, 1890-91, Part. F. p. 78.

forming this graphic intergrowth. The micropegmatite, together with the bisilicate material, chiefly biotite or chlorite, and sometimes hornblende and accessory epidote, ilmenite and sphene, form a groundmass, in which the comparatively large phenocrysts of felspar, chiefly plagioclase, but sometimes also orthoclase and microperthite, are embedded. The granophyre or micropegmatite very often stretches out, in various directions from a central portion or body, made up of well twinned and rather sharply bounded crystals of plagioclase. The effect of pressure is very noticeable in all the thin sections, not only in the strain shadows, but also in the dislocation of the felspar individuals, and the abundant development of the fine interstitial quartz and felspar.

Granophyre composed of plagioclase and quartz.

Micropegmatite formerly coloured as Laurentian.

On the first geological map, this micropegmatite was included with, and coloured as, a part of the Laurentian, the reddish colour, gneissic structure, and general behaviour, being the main factors which determined this classification.

Chemical composition of transitional types between micropegmatite and norite by Walker.

The variation in the chemical composition, marking the transition from the norite to the micropegmatite, is well illustrated by a series of analyses made by Dr. T. L. Walker (1) from specimens obtained along the Blezard mine crossing. The specimens range from south to north, from I to V. Analysis No. IV is by Mr. C. B. Fox, M. A.

	I	II	III	IV	V
SiO_2	49·90	51·52	64·85	69·27	67·76
TiO_2	1·47	1·39	.....	0·78	0·46
P_2O_5	0·17	0·10	0·24	0·06	0·19
Al_2O_3 ..	16·32	19·77	11·44	12·56	14·00
Fe_2O_3 ...	....	0·47	2·94	2·89	..
FeO	13·54	6·77	6·02	4·51	5·18
CaO	6·58	8·16	3·49	1·44	4·28
MgO	6·22	6·49	1·60	0·91	1·00
MnO ...	trace	trace	trace	trace	trace
K_2O	2·25	0·70	3·02	3·05	1·19
Na_2O ...	1·82	2·66	3·92	3·12	5·22
H_2O	0·76	1·68	0·78	0·76	1·01
Totals....	99·03	99·71	98·30	99·35	100·29
Specific gravity....	3·026	2·832	2·788	2·724	2·709

Norite is one continuous band and not separate belts as formerly supposed.

According to the present state of our knowledge, there are three main belts of norite, with which workable deposits of the various sulphides carrying nickel and copper occur. Until recently, these were believed to be entirely distinct and separated, but the later, more detailed geological examinations are tending to prove that these are

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(1) Quart. Jour. Geol. Soc. Lon. Vol. LIII, February, 1897, p. 56.

all portions of a geological unit, and all referable to one continuous mass. They have always been regarded as essentially the same in origin and mineralogical composition and approximately, at least, of the same geological age. Two of these belts are not included on the accompanying map sheets and so far, none of the deposits occurring in association with them, have ever been operated as mines, producing ore for shipping and smelting purposes.

Outlines of Northern Nickel Range.

The most northerly of these bands known as the 'Northern Nickel Range' starts from the old Ross mine (W. R. 5), near the line, between lots 5 and 6, on the line between con's. III and IV., of the township of Foy, and extends in an east-southeast direction through the township of Bowell, where on lot 6, con. II., it branches. One offset runs southeast, into the townships of Lumsden and Morgan, where its limits have not been definitely ascertained. The main band, however, runs to the east, cutting across the township of Wissner, and crosses the Vermilion river, immediately north of Bronson lake. Trending still more to the north, it connects with the large area of basic rocks, occurring to the west of Wanapitei lake. This mass extends, for the most part, in a southerly direction, and, as far as at present ascertained, is buried beneath the sand and gravel plains of the eastern part of Garson and the western portion of Falconbridge. It is, as yet, a matter of conjecture, whether this mass is continuous with the southern or main belt of the norite, which to the east of lot 3, in con. III., of Garson, is likewise covered up by the heavy mantle of drift. It is probable, however, that this main belt is continuous beneath the drift, as far, at least, as the outcrops of norite occurring on cons. IV and V., of Falconbridge. It may be possible, with the assistance of delicate magnetic instruments, to trace out this connection, but this work will be difficult and tedious, on account of the great accumulation of drift material, which is sometimes over 100 feet in depth.

Probability of continuity of norite beneath the drift east of Garson.

Difficulties of tracing belt.

Levack Nickel Range.

A second important band of norite occupies an approximately intermediate position between the other two, and so may be referred to as the 'Middle Nickel Range,' although it is likewise known as the 'Levack Nickel Range,' while Walker refers to it under the name of the 'Windy lake eruptive.' According to present information, this band starts about lot 12, con. III., of the township of Trill, extends north and northeast through this township into Cascaden, and crossing under Windy lake, goes on uninterruptedly through the northwest corner of Dowling, to lot 2, con. IV., of Levack township. Little information is available in regard to the geology of the intervening

Outlines.

Absence of information of area between Ross mine and Levack township.

Probable connection with Main Nickel Range.

stretch of country, between this point and the Ross mine, and it is possible that this gap may be filled in, by extending this norite range still further to the northeast. The area to the east and southeast is known to be occupied by the acid differentiate of the norite, (micropegmatite) so that a connection between the Levack and the Northern Nickel Range, is well within the limits of possibility. To the southwest, the Levack Range reached within two miles of the old Sultana and Trillabelle nickel mines, so that, in this direction also, a connection may be made with the southern or main belt of the norite. The celebrated Levack nickel deposits are developed along the northern contact of this band with the granitite-gneiss included as Laurentian.

Outlines of Main Nickel Range.

Width of main mass of norite.

By far the largest and most important band of norite, however is what is known as the 'Southern or Main Nickel Range', a portion of which has been described by Dr. Walker under the name of the 'Whitson lake eruptive'. Its southeastern limit, in all probability, consists of a comparatively narrow band of basic eruptive material, crossing the southern portion of Trill, and extending thence into the northeastern part of Drury township. Its possible connection in this direction with the Middle or Levack Nickel Range, has already been discussed. From Drury, the band of norite extends eastward, crossing the southern half of lot 12, con. V., of Denison. From this point, it has been traced continuously, in a northeast direction, for a distance of about thirty-five miles, as far as lot 3, con. III., of Garson, where the exposures pass under the extensive accumulation of drift material. At the Victoria mines, the basic portion of the intrusive is rather less than a mile in width, but at the crossing of the Vermilion river, this width is increased to one mile and three quarters, while in the vicinity of the Creighton mine, the norite is a little over two miles wide. Through the townships of Snider, McKim and Blezard, the width of the norite is fairly uniform, averaging about one mile and a half gradually becoming narrower until Garson township is reached, where the basic portion of the nickel bearing eruptive, is scarcely half a mile in width.

Copper Cliff mines offset.

Location of mines on this offset.

On lot 2, con. IV., of the township of Snider, this main belt of norite sends off a narrow, dyke-like extension or offset, in a southeasterly direction, on which are situated most of the mines of the Canadian Copper Company, at Copper Cliff. This band runs across the northeast end of Clarabelle lake, and crossing Lady Macdonald lake, it runs with unbroken continuity as far as No. 2 mine, where its further extension southward is covered up with drift. Mine No. 2, with its extensions to the north, mines Nos. 4, 5 and 6, are all immediately associated with this narrow, dyke-like form, while the

Lady Violet mine is located at the eastern junction of the norite with the granite, a short distance northeast of the point where it joins the main mass.

Unnecessary to give details of distribution of micropegmatite

It is unnecessary to furnish similar details of the distribution of the micropegmatite or acid portion of the nickel bearing eruptive, but the area underlaid by this rock, is considerably in excess of the basic portion, as shown on the map.

Character and location of Copper Cliff mine.

The famous old Copper Cliff mine is a veritable chimney of ore, occurring in connection with an isolated stock of norite, which comes in contact with felspathic quartzites and green schist. The openings in the vicinity of the Ontario Smelting Works belong to three separate masses of norite, which are surrounded by banded tuffs and quartzite. It is difficult to obtain specimens from the small area of norite on which the Evans mine is situated, sufficiently free from the sulphide material, for purposes of examination.

General association of the various mines.

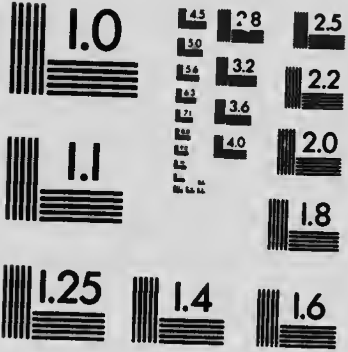
The Little Stobie mine, Dominion, Davis property, Kirkwood and Cryderman mines, are situated on the borders of the main belt of norite with green schist. The Stobie and Frood mines occur in conjunction with comparatively small stocks or areas of norite, which are separated from one another. The Elsie mine occurs at the junction between norite, on the one hand, and green schist and hornblende porphyrite, on the other. The Murray mine occurs at the junction between the granite and greenstone breccias and green schists on the one hand, and the main band of norite on the other: while the old Cameron mine, farther to the northeast, is found at the junction between the granite and the norite. The North Star and Creighton mines occur at the junction between the granite and the norite.

All deposits at or near the line of contact of the norite and older rocks.

The various openings known as the Gertrude mine, are located along the junction between the main band of norite, and a breccia made up of the granite intrusive through the older greenstone and schists. The main shaft of the Victoria mines is at the end of a small offset, connected with the main mass at the junction between the norite and the older green schists. Without exception, all of these immense bodies of sulphide material, are situated at the immediate contact between the intrusive norite and the older rocks, in such a way as to indicate in the clearest manner, their common origin.

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



(C.) LATER DYKES OF OLIVINE DIABASE.

Physical characters of olivine diabase.

The rock usually designated olivine diabase, and characteristic of what has been called the later dykes, is very uniform in mineralogical composition and structure. Hand specimens show a rock which is dark-gray, greenish-gray, to almost black, with spheroidal rusty weathering, which is very characteristic. In many instances, exposures exhibit a rude basaltic structure and are frequently porphyritic, with phenocrysts of yellowish or greenish labradorite, often an inch, or even more in diameter. The alteration of these phenocrysts produces the mineral 'huronite', so named by Thomson. These dykes possess well marked selvages of fine-grained, occasionally glassy material (tachylite), and present every gradation between basalt and diabase. The thin section of the fairly coarse rock shows a remarkably fresh olivine-diabase, made up chiefly of plagioclase, augite and olivine. The plagioclase is the principal constituent and is generally quite fresh and glassy, although occasionally somewhat turbid, as a result of incipient decomposition. Being the earliest constituent to crystallize, it is in idiomorphic, well twinned, tabular or lath-shaped crystals, which have a marked ophitic arrangement. The extinction angles clearly indicate labradorite. The twinning is according to the albite law, but a combination of the albite and pericline law, is very common. Occasional individuals exhibit twinning according to the rarer-baveno law. The augite shows a very irregular or jagged outline, with characteristic imperfect or interrupted cleavages. It is reddish-brown to violet in colour, and very distinctly pleochroic. The olivine occurs in more or less rounded, pale yellow grains, and sometimes fills in the spaces between the felspar crystals. It is remarkably fresh, but occasionally shows decomposition to a deep green, compact serpentine (antigorite).

Phenocrysts of 'huronite'

Microscopical structure and composition.

Order of generation of mineral constituents.

Apatite is very abundant, in the usual acicular prismatic forms, and the opaque constituent is probably ilmenite. Some of the thin sections are very instructive, especially as regards the order of crystallization of the various mineral constituents. Apatite was certainly the first to crystallize, as it occurs in sharp, well defined, elongated prisms which are embedded in, or pierce the other constituents. The labr dorite has, in most cases, at least, crystallized before the augite, bu its relation to the olivine is not quite so distinct. In some cases, the olivine has the rounded outline it usually assumes when its crystallization is not interfered with, but often it may be found occupying the triangular interspaces between the felspar laths, or sharply moulded upon them. It appears therefore, that the period of the crystallization of the olivine, certainly overlapped that of the labradorite, although in general, the olivine is distinctly earlier. Most of the ilmenite, likewise, is earlier than the plagioclase, but occasional individuals contain crystals of olivine and plagioclase, showing that some of the ilmenite formed after the olivine and plagioclase.

Chemical analysis of olivine-diabase of Murray mine by Dr. Walker.

A quantitative analysis of a specimen from the big dyke near Murray mine, gave Dr. Walker (¹) the following results :

SiO_2 .	47·22
Al_2O_3 ..	16·52
Fe_2O_3 ..	3·32
FeO	12·40
MnO .	0·04
CaO ..	9·61
MgO ..	3·33
K_2O ..	0·67
Na_2O ..	3·40
TiO_2 ..	3·62
P_2O_5 ..	0·33
BaO ..	0·01
CuO ..	trace
NiO ..	0·0275
CoO ..	0·0055
Loss by ignition ..	0·30
Total..........	100·803
Specific gravity..	3·01

Relative age of dykes.

These dykes of olivine diabase are distinctly later in age than the rest of the associated rocks. They cut the greenstones and associated micropegmatite, as well as the ore bodies themselves. They likewise cut the tuffs, breccias and quartzites, although one dyke was noticed, which did not reach the summit of the quartzites, but was cooled against the upper beds.

As a rule, rock remarkably fresh and unaltered.

As a rule, most of these dykes are remarkably fresh and unaltered and all of those mapped as occurring in the vicinity of the Murray mine, are of this description. On the other hand, with the single exception of the large dyke which runs in a northwest direction near the Ontario Smelting Works, all of the others are much altered and decomposed, and thin sections prepared from these, cannot be distinguished from the finer grained and more basic, altered facies of the norite. The

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(1) Quart. Jour. Geol. Soc. Lon., February, 1897, p. 63.

Altered varieties of diabase at Copper Cliff.

boundaries between the bisilicates and plagioclase are not well defined, the latter containing scattered shreds and grains of hornblende and biotite. The plagioclase shows the same cloud-like arrangement of sub-microscopic inclusions, presumably of ilmenite. The hornblende is in small, strongly pleochroic individuals, and is very abundant. Biotite is also abundant, while the ilmenite is largely represented by sphene. The ophitic structure still remains, but is not so pronounced. Most of the plagioclase is quite fresh, but some of it is altered to a saussuritic aggregate. Quartz is fairly abundant, filling in small, irregular interspaces between the other constituents. Small grains of sulphide material are also disseminated through the rock. The occurrence of such a rock in dyke-like form, with the same mineralogical composition of the norite, indicates that these dykes at least, are later and differentiated portions of the norite, representing the dying efforts of the very pronounced and long continued vulcanism. The occasional presence of olivine in the norite of the Little Stobie mine, and the recognition of quartz in some of these later dykes, have supplied the links hitherto missing and necessary for a proper understanding of the relationship existing between these two rocks. As shown by Walker, in the analysis quoted of a fresh type, this olivine-diabase contains small quantities of copper, nickel, and cobalt, which the same author regards as original constituents of the olivine-diabase magma. The relations of these dykes to the various ore bodies through which they are intruded, show distinctly, that these latter had already attained their present dimensions, at some time previous to the intrusion of the dykes. For the most part, they have a fairly constant direction, but present frequent broad curves and occasional faults. Two of the largest dykes met with, vary in width from 150 to 200 feet, and were traced with practically unbroken continuity, from the northwest corner of McKim township, southeast to Ramsay lake. There is no local enrichment whatever of the ore bodies, in the vicinity of the dykes, as has frequently been surmised. The influence occasioned by their passage through these ore bodies is extremely local and very insignificant. In the vicinity of the Copper Cliff and Murray mines and the area intervening, many of these dykes have been encountered, and it has been found possible over this limited area, to accurately determine and map their dimensions and direction, and although the prevailing direction is perhaps northwest and southeast, many of them occupy fissures with courses very widely divergent.

Diabase at Copper Cliff resembles finer grained varieties of norite.

Significance of discovery of original quartz in diabase, and olivine in norite.

Diabase contains both nickel and copper.

Mode of occurrence of diabase dykes.

No local enrichment of ore bodies in vicinity of these dykes.

No constant direction.

MINERALS ASSOCIATED WITH THE NICKEL AND COPPER OF THE SUDBURY MINING REGION.

PYRRHOTITE AND CHALCOPYRITE.

The ore bodies, with which the nickel and copper are immediately associated, consist essentially of pyrrhotite ($Fe_8\ S_9$) which is by far the most predominant constituent, and chalcopyrite ($Cu\ Fe\ S_2$) usually in much smaller amount, and a varying proportion of gangue, consisting mainly of the associated eruptive or its constituent silicates. The nickel present in the ore bodies is not, as so many have supposed, an essential constituent of the pyrrhotite, isomorphously replacing an equivalent amount of iron, but is mainly present, at least, as a distinct and magnetically separable nickel-iron-sulphide known as pentlandite. This mineral is, as a rule, very intimately associated with the pyrrhotite, but occasional hand specimens from the lower levels of the old Copper Cliff mine, show a rather intimate association of nearly pure pentlandite and chalcopyrite. The pyrrhotite and chalcopyrite will be described more fully in that portion of the bulletin, dealing with the composition of the ore bodies.

Ore bodies manil composed of pyrrhotite and chalcopyrite.

Nickel always present as pentlandite.

PENTLANDITE.

This mineral is usually very intimately associated with the pyrrhotite, and is so finely disseminated through the mass of this mineral, that a separation can only be effected by very fine grinding. Though pentlandite itself is feebly magnetic, and in finely powdered form is attracted by an ordinary hand magnet, advantage is taken of the great difference in the magnetism of these two minerals, to effect their separation. It requires repeated trials to eleminate the last traces of the pyrrhotite, but this has been successfully done by Penfield, Browne and Dickson, and their analyses which are quoted give all necessary details of the chemical composition of this mineral, showing it to be very uniform over the whole district. It is essentially the same as the original pentlandite (eisennickelkies), analyzed by Scheerer, but contains more nickel, and less iron and sulphur. Sometimes as at the Worthington mine, it occ[illegible] in tolerably large pieces, which can be readily distinguished from [illegible] enclosing pyrrhotite, but even these contain a considerable amount of disseminated pyrrhotite, so that material thus secured, rarely assays over 30 per cent of nickel. The mineral is very abundant at the Creighton mine, and can be readily recognized on account of its perfectly developed, octahedral parting. It is somewhat paler in co-

Pentlandite usually very finely disseminated through pyrrhotite.

Successfully separated magnetically by Penfield Browne and Dickson.

Pentlandite in large and rather pure fragments at Worthington and Creighton mines.

Colour of pentlandite.

Physical characters of pentlandite.

lour than the pyrrhotite, varying from steel-gray to silver-white, and almost invariably breaks with flat surfaces, which are planes of parting, parallel to the octahedron. The mineral, however, in freshly broken material, cannot readily be distinguished from the equally fresh pyrrhotite, especially if the planes of parting are imperfectly developed. Exposure to the weather brings about a rapid change in colour to a peculiar pale bronze, yellow, which is very characteristic and quite distinct from the pyrrhotite.

Chemical analyses by Penfield, Dickson and Browne.

The material obtained by Penfield (1) was crushed and sifted to a grain of from 1-2 mm. in diameter, and the pyrrhotite was extracted by means of an ordinary magnet. The pentlandite, for analysis, was further carefully selected by hand-picking.

Similar, preliminary, careful preparation of material was used by Mr. C. W. Dickson (2). The following are the analyses :—No. 1 (Penfield); 2-4, (Dickson); 5-9, (Browne) (3). Analyses 5-7 inclusive, are stated to contain some pyrrhotite, as fine dust. Analyses 10 and 11, are by Scheerer (4) of the pentlandite from Lillehammer. Analysis No. 2, is from Creighton mine; No. 3, Worthington mine; No. 4, Frood mine; No. 5, Copper Cliff mine; No. 6, Stobie mine; No. 7, Evans mine; No. 8, Copper Cliff mine (hand-picked); No. 9, Evans mine (hand-picked).

	1	2	3	4	5	6	7	8	9	10	11
Ni	34·23	34·82	33·70	34·98	35·05	34·70	34·12	35·00	34·90	18·35	21·07
Co	0·85	0·84	0·78	0·85							
Fe	30·25	30·00	29·17	30·04	29·80	29·90	29·95	30·30	29·60	42·70	40·21
S	33·42	32·90	32·30	33·30	34·35	33·90	35·43	33·50	33·55	36·45	36·64
Cu										1·16	1·78
Gangue	0·67										
	99·42	98·56	95·95	99·17	99·20	98·50	99·50	98·80	98·05	98·66	99·70

Ratios of constituents of pentlandite.

The ratios in Prof. Penfield's analysis are S : (Fe + Ni) = 1·044 : 1·047, almost 1 : 1, or that of a normal sulphide (Ni + Fe) S. The ratio of the Fe : Ni is 1 : 1·32, while in that from Lillehammer, it is about 2 : 1. Dickson remarks that the ratio of the (Ni & Fe) : S varies from 10·91 : 10 to 11·07 : 10, and points out that this ratio 11 : 10 is not accidental, but constant for all analyses of pure material. He therefore suggests, that the formula for this mineral be written $(Fe + Ni)_{11} S_{10}$ which seems rather clumsy and an unnecessary refinement of expression of material, which, even when every precaution is taken, is

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(1) Amer. Jour. Sc. (3rd Series) Vol. XLV, 1893, pp. 493-494.

(2) Trans. Amer. Inst. Min. Eng., Albany Meeting, February, 1903.

(3) Eng. & Min. Jour., December, 2nd 1893, Vol. LVI, p. 566.

(4) Dana, System of Mineralogy, 6th Ed. 1892, p. 65.

still not absolutely pure. The formula of the Lillehammer pentlandite is given as $2\,FeS + NiS$. The ratio of nickel to cobalt in the Sudbury pentlandite varies, running from 40 to 42 : 1, is worthy of remark, as this proportion is almost identical with that found in the ore bodies.

Composition and magnetic separation of sulphides from Creighton mine.

A magnetic separation of the nearly pure sulphides, forming the ore from the Creighton mine, was made, by means of the Wetherill separator, the material thus used being crushed to different degrees of fineness, and graded by means of sieves. The original product showed an assay value of 1.20 per cent of copper, and 4.87 per cent of nickel, with 2.49 per cent of insoluble matter. The very fine material gave the cleanest separation, and some of that which passed through a 100 mesh sieve, was divided into three products which may be distinguished from one another as strongly magnetic, feebly magnetic and non-magnetic. The feebly magnetic product showed the presence of 30.41 per cent of nickel, and the non-magnetic 30.36 per cent of nickel. A complete analysis, and an adjustment of the various constituents, showed that the feebly magnetic portion consisted of chalcopyrite and pentlandite, in the proportion of 1 : 21, while the non-magnetic product showed these same minerals present, in the proportion of 1 : 7.

PYRITE.

Pyrite at Elsie mine.

Nickel bearing pyrite at Copper Cliff mine.

Nickel-bearing pyrite from Century Copper mine.

Chemical analysis of true nickeliferous pyrite from Murray mine by Dr. Walker.

A sulphide which presents all the ordinary physical characters of pyrite, such as hardness, specific gravity, colour, lustre, and magnetism, is by no means uncommon in most of these deposits, and can generally be found when a special search is made for this mineral. Large cubical crystals of pyrite, are mentioned by Dr. Coleman, (1) as occurring in fissures, with quartz and calcite, at the Elsie mine, but the assay of one of these showed no nickel. Dickson mentions the fact that a number of his samples from the Copper Cliff mine, were associated with secondary quartz, calcite and millerite. Pyrite was also noticed occurring with pyrrhotite, chalcopyrite and danaite, at the Century Copper mine on the north half of lot 4, con. IV., of the township of Graham. A determination by Mr. F. G. Wait of the Geological Survey, showed 0.49 per cent of nickel, with a trace of cobalt. Dr. Walker (2) found what he regards as a true nickeliferous variety at the Murray mine, and has published a full description and analysis of the specimen. The following is the analysis under I, and if the mineral be considered as pyrite, in which part of the iron is replaced isomorphously by nickel, the explanation is given under II and III.

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(1) Ann. Rep. Bur. of Mines, Ont. 1903 p. 281.

(2) Amer. Jour. Sc. Vol. XLVII, 3rd Series, April 1894, pp. 312-314.

I		II			III	
Nickel	4·34	Nickel		4·34	NiS_2	9·12
Iron	39·70	Sulphur	49·31	4·78		
				44·53	FeS_2	83·49
Sulphur	49·31	Iron	39·70	38·96		
				·74	Fe_3O_4	1·02
Moisture	·10	Oxygen (calculated).		·28		
Copper	traces	Water..				·10
Insoluble	5·76	Insoluble				5·76
Arsenic	none					
		Total				99·49

Nickel bearing pyrite from Gertrude mine.

A peculiar, grayish-green, bronze-coloured, non-magnetic mineral, was found by Mr. McVittie on the location where the Gertrude mine now is. The mineral occurred massive, with small crystals of magnetite, and specks of chalcopyrite disseminated through it ,in a streak about six inches wide, adjoining the granite. An analysis of the mineral, after removing the magnetite, gave Mr. Mickle (¹) the following results under I, while under II, is given the proportions, omitting the insoluble matter and recalculating to 100.

Chemical analysis of nickeliferous pyrite from Gertrude mine by Mickle.

	I	II
Iron	37·28	41·48
Sulphur	46·54	57·79
Nickel	5·95	6·62
Copper	0·10	0·11
Insol.	9·66	.....
Total....	99·53	100·00

Mr. Mickle regards this as an agregate made up of pyrite, millerite and chalcopyrite, the composition, as given above, practically agreeing with such a mixture. A very similar compound is found at the old Beatrice mine (Davis property), on lot 1, con, III., of the township of Blezard. After an analysis of this material, Dr. Emmens (²) decided, that the mineral was a new nickel-iron-sulphide, and proposed for it the name 'Whartonite'. The mineral is not homogeneous and is very evidently a mixture. It has a peculiar bronze-yellow colour, is cellular, the cavities being lined with minute cubical crystals, with an intermediate, finely, granular material. It was usually referred to by

nite mineral but a el bearing p ite.

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(1) Ann. Rep. Bur. of Mines, Ont., 1903, p. 282.

(2)Ann. Rep. Bur. of Mines, Ont., 1892, p. 170.

the miners as 'matte', on account of the resemblance to this artificial product. The chemical analysis by Emmens showed it to contain (1).

Nickel	5·40
Iron	42·90
Sulphur	45·00
Insoluble	4·80
Total	98·10

Marcasite.

Distinguishing characters of marcasite.

The mineral thus designated, is distinguished from pyrite, chiefly by its silver white colour, which even weathering only deepens slightly to a very pale, bronze-yellow. Samples of such material, submitted to Prof. Penfield, by Mr. C. W. Dickson, were considered by him as massive marcasite. The analyses conform to the formula, FeS_2 and show the presence of from 2 to 4 per cent of nickel, probably as pentlandite. Dr. Walker mentions the occurrence of marcasite, in the midst of the usual sulphides at the Murray mine, but assays of this material failed to show the presence of any nickel. Perhaps the most noted specimens which may be included under this name are those for which the name 'blueite' was proposed by Dr. S. H. Emmens (1). The mineral has a metallic, somewhat silky lustre, while the colour is pale olive-gray inclining to bronze. The type specimens came from the Gersdorffite mine (lot 12, con. III., Denison), which, at the time, was worked under option, by the Emmens Metal Company. The mineral also occurs on the lot to the south (lot 12, con. II.,) as, well as at the Totten mine (lot 1, con. II., Drury), and at the Worthington mine (lot 2, con II., Drury). Dr. Emmens' analysis showed the presence of 3·5 per cent of nickel with 38·8 per cent of iron, and 5·4 per cent of insoluble matter, but the su[illegible] per cent, calculated by difference, is evidently too high. At [illegible] ffite mine, the nickeliferous marcasite occurs in associatio[illegible] lite, gersdorffite, pyrrhotite and chalcopyrite, in a small qu[illegible] cutting a hornblende schist.

Marcasite without nickel at Murray mine.

Blueite of Emmens is nickeliferous marcasite.

Chemical composition of blueite.

At the Worthington and the Totten mines this very white nickel ore occurs in the form of circular or oval patches, which are very conspicuous, embedded in the pyrrhotite, chalcopyrite, and associated with rocky matter. An assay of a specimen from the Worthington mine, by T. L. Walker, showed the presence of 4·5 per cent of nickel. A specimen was also sent to Prof. F. W. Clarke, chief chemist of the

Chemical analysis of nickeliferous marcasite by Dr. Hillebrand

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(1) Ann. Rep. Bur. of Mines, Ont., 1892, p. 170; also Jour. Am. Chem. Soc. Vol. XIV. No. 7.

(1) Jour. Am. Chem. Soc., Vol. XIV., No. 7; also Ann. Rep. Bur. of Mines, Ont., 1892, p. 168

U.S., Geological Survey, and an analysis of this ore was made by Dr. W. F. Hillebrand, his results being reported as follows (1)

Iron	38·36
Nickel	4·57
Manganese	0·10
Sulphur	45·11
Sulphuric acid	0·95
Carbonic acid	1·49‡
Calcium oxide	1·91
Magnesia	0·41
Insoluble	4·80
Water at 100° C.	0.55
Water combined	?
Loss and oxygen	?
Total....	98.25

Probable mixture of marcasite and pentlandite.

A consideration of the above analysis, shows that it agrees very closely with the assumption that the nickel is present in the form of pentlandite, disseminated through the marcasite. Prof. Clarke, in his letter, states. 'It seems to me that the material is a mixture, not a definite species. Your Sudbury minerals deserve an exhausive study, and the work would be well repaid.'

MILLERITE.

Millerite probable source of some of the nickel.

The simple or normal sulphide of nickel is occasionally met with in some of the mines, and may be the source of some of the nickel of these deposits. Agreeably with its formula NiS, this mineral should contain, when pure, 35.3 per cent of sulphur and 64.7 per cent of nickel. Undoubted slender crystals of millerite were found at the Copper Cliff mine, in workings 150 feet below the surface. Another specimen containing this mineral, associated with pyrrhotite, was obtained at the Beatrice mine, on lot 1, con. III., of Blezard township. Dickson mentions having found 'small bunches of hair-like crystals of this mineral, in the cavities of some radiating pyrite, mixed with calcite'. He regards the millerite as undoubtedly secondary, and probably derived from preexisting pentlandite.

Millerite at Copper Cliff and Beatrice mines.

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(1) Ann. Rep. Geol. Surv. Can., Vol. V., 1890-91.. Part S.S., p. 116.

‡ Calulated on the supposition that all the calcium exists as carbonate.

POLYDYMITE.

Association of polydymite at Vermilion mine.

This mineral occurs in association with chalcopyrite, chalcocite, pyrrhotite and pyrite at the Vermilion mine, lots 5 and 6, con IV., of the township of Denison. It is steel-gray, massive, and exceedingly alterable in the air. It has a specific gravity of 4.5. An analysis of carefully selected material,gave Clarke and Catlett the results under I, (1) A good sample of the Vermilion ore, analyzed by Mr. Browne, after deducting 1.5 per cent of silica, gave the results under II, evidently impure polydymite. (2)

Chemical composition of polydymite.

	I	II
Nickel	41·96	36·85
Iron	15·57	18·70
Sulphur	40·80	38·43
Copper	0·62	4·47
Silica	1·02	
Totals.	99·97	98·45

Formula of polydymite.

These figures give approximately the formula Ni_3FeS_5. Neither cobalt nor arsenic could be detected. If we deduct silica, together with the copper reckoned as admixed chalcopyrite, and recalculate the remainder of the analysis under I, to 100, we get the following figures

Nickel	43·18
Iron	15·47
Sulphur	41·35
Total...	100·00

In short, the mineral has the composition of Ni_4S_5 with about one quarter of the nickel replaced by the iron, which agrees with Laspeyres polydymite, of which it is doubtless a ferriferous variety. The polydymite from which the above was selected, came from a mass in which an average of 35.39 per cent of nickel and 5.20 per cent of copper had previously been found.

Analysis of polydymite and associated minerals by Johnston.

A specimen of the so-called polydymite, was presented to the writer by Mr. F. L. Sperry, at one time chemist of the Canadian Copper Co. The mineral at the time was known to be impure, but was the best sample which could be secured for the museum. The material was mainly polydymite, in a gangue composed of diorite and small quantities of quartz. Carefully selected material—which however it was

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(1) Amer. Jour. Sc., Vol. XXXVII, 1889, p. 372-374.

(2) Eng. and Min. Jour., Dec. 2, 1893. Vol. LVI, 566,

found still contained a little intermixed gangue and chalcopyrite—was found, by Mr. R. A. A. Johnston to contain 40·80 per cent of nickel with no cobalt.

SPERRYLITE.

Discovery of sperrylite

Examination and description by Wells and Penfield.

Sperrylite was first found at the Vermilion mine in the gossan or loose material, and was named after Mr. Francis L. Sperrry of the C. C. Co. by Profs. Horace L. Wells and S. L. Penfield, of the Sheffield Scientific School, who examined and described this new species(1). The material as received, consisted of a heay, brilliant sand, composed largely of the sperrylite, but intermixed with this, a considerable number of fragments of chalcopyrite, pyrrhotite and some silicates could be seen. After the material was purified, it was found to contain some transparent grains which proved on examination, to be oxide of tin or cassiterite (SnO_2).

Physical characters of sperrylite.

Sperrylite is isometric, simple cubes are common, octahedrons are exceptional, while the majority of the crystals are combinations of the cube and octahedron. Hardness is between six and seven, as it scratches felspar, but not quartz. The specific gravity is 10,602. The crystals have no distinct cleavage, but are very brittle, and break with an irregular, probably conchoidal fracture. The chemical composition, according to the mean of two analyses, was as follows :—

Chemical composition.

Arsenic	40·98
Antimony	0·50
Platinum	52·57
Rhodium	0·72
Palladium	trace
Iron	0·07
Cassiterite or oxide of tin	4·62
Total......	99·46

Formula.

The composition is therefore represented by the formula $PtAs_2$, a small portion of the platinum and arsenic being replaced respectively by rhodium and antimony. The colour of the mineral was nearly tin-white, or about the same as metallic platinum. The fine powder is black. Nearly all the grains showed extremely brilliant, crystal faces, though most of the crystals were rudimentary in size, usually $\frac{1}{30}$ to $\frac{1}{500}$th of an inch in diameter.

Size of grains.

No iridium present.

The presence of an appreciable amount of iridium was expected by Professor Wells, but careful search failed to reveal even traces of this element

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(1) Amer. Jour. Sc. Vol. XXXVII, 18[illegible] pp. 67-63

Source of platinum in the matte.

Sperrylite is regarded as the source of the metals of the platinum group, which are invariably present in appreciable amounts in the bessemer matte, assays of the Copper Cliff and Victoria mines mattes showing from 0·4—0·5 oz. per ton. Wherever occurrences of this mineral have been examined, it is directly and intimately associated with the chalcopyrite, so that, mattes rich in copper, contain a large amount of platinum, while those containing very little copper, show a correspondingly small amount of platinum. In Dr. Walker's (1) analysis of the bessemer matte from the Murray mine, the presence of iridium and osmium is noted in almost equal amounts, but in Prof. Wells' analysis, as noted above, these metals were not detected. Baron von Foullon concludes from the absence of these elements, that there is another mineral present, which contains the iridium, but although this is possible, Dr. Walker considers that a more likely explanation is that, in some cases, part of the platinum in sperrylite, is replaced by the elements iridium and osmium.

Iridium and osmium sometimes replaces platinum.

NICCOLITE.

Geological associations of niccolite.

This mineral, in intimate association with gersdorffite and with variable quantities of intermixed pyrrhotite, chalcopyrite and pyrite, has been found in connection with the occurrence of two small 'stocks' or intrusions of quartz-mica-diorite (altered norite), in the township of Denison. This diorite forms two small hills, which rise above the surrounding country, which is underlaid by the slaty variety of the tuffs or greywackes, these rocks surrounding the diorite on all sides. One of these masses, known as the Macdonell or Gersdorffite mine is situated in the southeastern corner of lot 12, con. III., of Denison while the other, constituting what is known as the Hiram Robinson property, is on the northeastern corner of the west half of lot 12, con. II., of the same township. The country rock, in the immediate vicinity, is usually a more or less schistose diorite or hornblende schist, produced by the shearing of the more massive diorite, of which most of the hill is composed. The rock is made up, chiefly, of irregular crystals of hornblende, closely aggregated together, the few and small remaining interspaces being occupied by quartz and plagioclase. At the Gersdorffite mine, from which the first and finest specimens of this mineral, and the associated gersdorffite were obtained, they occur in a small vein, interfoliated with a chloritic actinolite schist, at the north side of the small area of diorite, shown on the map. The vein consists mainly of quartz, with a very small amount of felspar and calcite, with

Localities where found.

Mineral constituents of associated rocks.

Constituents of vein containing niccolite.

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(1). Amer. Jour. Sc., Vol. 1. 1896. p. 112.

Composition of niccolite.

Analysis of niccolite and gersdorffite by Mr. Walker.

grains and small disseminated masses of the sulphides already mentioned, the most abundant and conspicuous being the niccolite and especially the gersdorffite. No analysis of the niccolite was made. This, when pure, is represented by the formula $Ni\,As =$ arsenic 56·1, nickel 43·9 = 100·0. It usually contains a little iron and cobalt, also sulphur, while sometimes part of the arsenic is replaced by antimony. The mineral occurs massive, and the peculiar pale, copper red is quite distinctive. A sample containing niccolite and gersdorffite was submitted by the writer to Mr. T. L. Walker who found them too intimately associated to separate for analysis. He therefore made an analysis of the two minerals together, which resulted as follows : (¹)

Nickel	20·87
Cobalt	0·64
Copper	trace.
Iron	2·43
Sulphur	10·60
Arsenic	26·04
Silica	26·70
Alumina	5·43
Magnesia Lime Soda	7·29
Total....	100·00

GERSDORFFITE.

First recognition of gersdorffite.

This mineral was first recognized in a small sample brought to the Geological Museum, in 1891, by Mr. Eagleson, who had obtained the specimen from Mr. Dan. O'Connor, of Sudbury, the owner of the Gersdorffite mine, where it had been found. The particulars of the association of the mineral have already been described under niccolite. When pure, the mineral is essentially a sulph-arsenide of nickel, with the formula $NiAsS$ or NiS_2, $NiAs_2$ = sulphur 19·3, arsenic 45·3, nickel 35·4 = 100·0. Iron replaces the nickel, often to considerable amount, also sometimes cobalt. The following is the description of the specimen collected by the writer in 1891, prepared by Dr. Hoffmann and Mr. R. A. A. Johnston. (²)

Physical characters of gersdorffite.

Structure, for the most part lamellar, but occasionally granular, a few minute, fairly well developed crystals exhibiting the forms of the

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(1) Ann. Rep. Geol, Surv, of Can., Vol. V. 1890-91, Part SS. p. 118.

(2). Ann. Rep. Geol. Surv. Can., Vol. V, 1890-91, Part R, p. 22.

octahedron and cubo-octahedron, with the faces of the octahedron predominating, were also observed. Colour, steel-gray, here and there tarnished blackish. Specific gravity (after correction for a little included quartz) at 15·5°C., 6·231.

Chemical analysis of gersdorffite by Johnston.

The material upon which the analysis was conducted, although selected with all possible care, and, so far as could be seen, apparently pure, nevertheless contained, it was subsequently found, a very appreciable amount of quartz. Its analysis afforded Mr. R. A. A. Johnston the results given under I. Deducting the gangue (silica), and recalculating the remaining constituents to one hundred parts, we obtain the figures given under II.

	I	II
Arsenic	40·31	46·96
Sulphur	14·34	16·71
Nickel	22·50	26·32
Iron	6·78	7·90
Cobalt	1·73	2·01
Copper	0·09	0·10
Gangue (quartz)	13·55	.....
Total..........	99·39	100·00

This mineral had not previously been identified as occurring in Canada.

MORENOSITE.

Composition of morenosite.

Localities where morenosite is found.

This mineral, which is also known as "Nickel vitriol" is a hydrous, nickel sulphate $(Ni\ SO_4 + 7\ H_2O)$ = sulphur trioxide 28·5, nickel protoxide 26·6, water 44·9 = 100·0. 'It occurs as a greenish-white and pale apple green incrustation on associated gersdorffite, niccolite, chalcopyrite and pyrrhotite at the Macdonell or Gersdorffite mine (lot 12, con. III, of Denison); also but more sparsely as a greenish-white incrustation on some of the nickeliferous ore of the Worthington mine (Lot 2, con II., Drury)'. (1) It has also been noticed at the Wallace mine on Lake Huron.

ANNABERGITE.

Some specimens of gersdorffite, which had been in the drawers of a mineral cabinet for about a couple of years, were found to have undergone a partial decomposition, with the formation of hydrous nickel ar-

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(1) Ann. Rep. Geol. Sur. Can., Vol. VI, 1892-93, Part R, p. 27.

Composition and physical characters of hydrous nickel arsenate.

senate. The material which came from the Gersdorffite mine, (lot 12, con. III., Denison), consisted of gersdorffite, with a few scattered particles of chalcopyrite. The nickel arsenate, which occurred both lining and filling cavities in the gersdorffite was, in the former case, in the form of botryoidal, globular, or mammillary crusts of a greenish-yellow colour, pale grass-green, and honey-yellow to brownish colours, and exteriorly of a sub-vitreous to vitreous lustre, whilst that filling the cavities was compact and amorphous, texture colloid, of a greenish-yellow colour and waxy lustre, also occasionally, but more rarely, earthy, chalk-like and dull. (1)

DANAITE, (COBALTIFEROUS ARSENOPYRITE).

Theoretical composition of cobaltiferous arsenopyrite or danaite.

This mineral is a sulph-arsenide of iron ($Fe\,As\,S$), with part of the iron replaced by cobalt. Agreeable with the formula given above, it should contain, theoretically, arsenic 46·0, sulphur 19·7, iron 34·3 = 100·0. It is not abundant in the Sudbury district, and has only been recognized as occurring in two localities, and in both of these places it is found in association with the older diorites and hornblende schists. The first place in which it was found is on the north half of lot 6, con III., of the township of Graham, this lot forming a portion of what is known as the Russell location or property.

Associations of danaite.

Physical characters.

The mineral is massive, with a steel-gray colour. Intermixed with it, were small quantities of white, translucent quartz, some pyrrhotite, a little galena and a trifling amount of chalcopyrite. The specific gravity at 15·5° C. = 5·988.

Analysis of danaite by Johnston.

An analysis by R. A. A. Johnston (2), of carefully selected material, is given under I. Deducting the gangue or silica, and recalculating to 100 we obtain the results under II.

	I	II
Arsenic	40·16	42·22
Sulphur	17·92	18·84
Iron	31·69	33·32
Cobalt	3·89	4·09
Nickel	0·88	0·93
Antimony	0·57	0·60
Gold	trace.	trace.
Gangue (quartz)	4·77	
Totals.........	99·88	100·00

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(1) Ann. Rep. Geol. Sur. Can., Vol. VI, 1892-93, Part R, p. 27.

(2) Ann. Rep. Geol. Sur. Can., Vol. V, 1890-91, Part R, p. 19.

Danaite of Century Copper mine.

This mineral also occurs in considerable quantity on the N. ½ lot 4, con. IV., of the township of Graham, at a deposit which was being worked for copper, and known as the Century Copper mine. It is present in intimate association with pyrrhotite, chalcopyrite and pyrite, abundantly disseminated through a hornblende and biotite schist, and also through a pale grayish quartzite, which is embedded in the hornblende schist.

SMALTITE.

Recognition of smaltite from McKim by Kenrick.

This mineral so far as known, is rare in the Sudbury district, although it occurs in large masses in the Temagami region, to the northeast. It is a cobalt diarsenide, $CoAs_2$=arsenic 71·8, cobalt 28·2=100·0. This mineral was observed by Mr. E. B. Kenrick, of the Geological Survey of Canada, in the form of minute crystals, with well marked octahedral cleavage, in association with chalcopyrite, from the township of McKim. (¹)

GALENA.

Galena always present in association with Sudbury ore bodies.

This mineral has been found at all the mines, wherever search was made for it. It is the common sulphide of lead PbS=sulphur 13·4, lead 86·6,=100.0; usually contains a little silver. It generally occurs in thin seams penetrating the other sulphides. It may be the source of much of the silver found in all the mattes produced from the Sudbury ores. It shows the usually bright lead-gray colour, with distinct cubical cleavage. No analysis was made of this mineral in immediate association with the ore bodies.

CHALCOCITE.

Chalcocite in association with polydymite at Vermilion mine,

This mineral, also known as copper glance, has only been described as occurring at the Vermilion mine, in Denison township. Its occurrence at this place is noticed by Mr. Johnston, in a specimen which was given to the writer by Mr. F. L. Sperry. This specimen consisted of chalcocite and chalcopyrite, through which was disseminated some polydymite. Some of the fragments were coated with green carbonate of copper. Mr. Johnson found that the specimen contained 9·40 per cent of nickel with no cobalt. No chemical analysis of the chalcocite was made.

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(1) Ann. Rep. Geol. Sur. Can., 1886, Part I, p. 13.

BORNITE.

Bornite occasionally occurs according to Dickson.

This mineral is mentioned as occasionally seen by Mr. C. W. Dickson. Some of the chalcopyrite, obtained at the Vermilion mine, which was greatly weathered, has a general resemblance to this mineral. No undoubted bornite was, however, noticed by the writer.

MAGNETITE.

Titaniferous magnetite an invariable constituent of the norite.

Magnetite of Murray mine.

Mass of magnetite weighing 5 tons found at Clarabelle mine.

This mineral is an invariable constituent of the norite, and is always more or less titaniferous. It is generally disseminated in minute grains through the ore bodies, but, as a rule, in very subordinate amounts. Occasionally, small masses of titaniferous magnetite are associated with the pyrrhotite, and an analysis of such a mass, from the Murray mine, gave Dr. Walker, (1) 18·34 per cent of titanic acid. The largest mass yet noticed was recovered from the workings of the Clarabelle mine, where, according to Capt. McArthur, about five tons were found enclosed in the sulphides. This magnetite is readily attracted by the magnet, and contains grains of pyrrhotite and chalcopyrite, as well as small portions of a green silicate. (2)

CASSITERITE.

Cassiterite occurs associated with sperrylite.

The purified material from which the analysis of sperrylite was made by Professor Wells, of Yale University, contained as stated, 4.62 per cent of oxide of tin, in the form of minute transparent grains. These were carefully examined and pronounced to belong to the species cassiterite.

NATIVE COPPER.

Native copper found at Vermilion and Copper Cliff mines.

Dendritic or leaf-like forms, are occasionally met with, as at the Vermilion mine, where a few specimens of chloritic schist were obtained, showing native copper, developed along the planes of cleavage. L.P. Silver has a specimen of the diorite, obtained from the twelfth level of the Copper Cliff mine, showing a good deposit of leaf copper, which he considers must have been formed, by the reduction of the chalcopyrite, by reducing solutions leaching through the rock (3).

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(1) Quart. Jour. Geol. Soc. Lon., Vol. LIII, Feby., 1897, p. 52.

(2) Ann. Rep. Bur. of Mines, Ont., 1903, p. 281.

(3) Jour. Can. Min. Inst., Vol. V, 1902, p. 536.

NATIVE GOLD.

Samples of the ore obtained from the Vermilion mine contain appreciable quantities of native gold, and specimens may be obtained from this mine, showing abundantly disseminated grains and strings of gold, often of large size. All of the mattes produced from the Sudbury ores contain gold, the percentages of this metal, varying in the bessemer matte, from strong traces to 0.3 oz. per ton. The average amount would be about 0.15 oz. of gold per ton, although Silver (1) reports having found 0.75 oz. of gold, in a matte which contained 39.64 per cent of nickel and cobalt, and 42.75 per cent of copper.

Native gold at Vermilion mine.

All the mattes contain appreciable quantities of gold.

GRAPHITE.

Dr. Coleman (2) reports having found a few scales of graphite, in the country rock, occurring on the dump at the Lady Macdonald mine.

Graphite notice by Dr. Coleman.

CUBANITE.

David H. Browne (3) for some time chemist to the Canadian Copper Co., at Copper Cliff, found this mineral, which is represented by the formula $Cu\ Fe_2\ S_4 =$ sulphur 35.4, copper 23.3, iron $41.3 = 100.0$, in the roast heaps, being one of the products formed during the roasting.

Cubanite, one of the products of roasting noticed by Browne.

In addition to the above mineral varieties mention may be made of the fact that quartz, calcite, dolomite and ankerite are found in association with the massive sulphides, but these minerals are relatively very unimportant, and even at such deposits as the Victoria mines considerable quartz has to be added to the furnace charges on account of the basicity of the associated rocks. Nearly all of the gangue occurs as intermixed norite or diorite.

Composition of the ore-bodies.

The ore bodies, with which the nickel and copper are immediately associated, consist essentially of a mixture of sulphides, in which pyrrhotite (Fe_8S_9), is, by far, the predominant constituent; chalcopyrrite is almost invariably present, and usually in considerable amount, although proportionately much less than the pyrrhotite. It has been conclusively proved by means of the magnetic separations carried on by Browne,

Ore bodies made up principally of pyrrhotite and chalcopyrite.

Proved conclusively that the nickel occurs in the form of pentlandite.

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(1) Jour. Can. Min. Inst., Vol. V, 1902, p. 534.

(2) Ann. Rep. Bur. of Mines, Ont., 1903, p. 284.

(3) Ann. Rep. Bur. of Mines, Ont., 1903, p. 284.

Pentlandite usually very finely and evenly distributed.

Occasionally occurs in large spots and patches.

Nickel bearing pyrite.

Walker's belief that the nickel in pyrite isomorphously replaces iron.

Other sulphides occur but relatively unimportant.

Presence and abundance of rocky admixture or gangue.

Other impurities present in ore bodies.

Dickson and the writer, that the nickel present in these ores is all contained in the pentlandite, although the first mentioned authority is still inclined to the belief, that the small amount retained by the magnetic portion or pyrrhotite proper, occurs in part, at least, as an essential constituent of the pyrrhotite. This pentlandite is usually very finely and uniformly distributed throughout the whole mass, although in certain mines as the Creighton, Copper Cliff, Evans and very noticeably the Worthington mine, it occurs in spots and patches, often as much as half an inch to an inch, or even more, in diameter, of fairly pure material. The relative abundance of this nickel-iron-sulphide, determines the richness, or otherwise, of the containing deposit. Pyrite also contributes to the formation of these deposits, and much of it is nickeliferous. Present opinion varies somewhat in regard to the form in which the nickel is present in this compound, Dr. Walker's researches tending to prove, that this element replaces isomorphously an equivalent amount of iron in chemical combination, while others regard intermixed pentlandite as the source of the nickel. Certain other sulphides of nickel already mentioned and described, also contribute to the unusual richness of these deposits, but these are relatively much less important, and many of the occurrences, where such minerals are present, are, so far as known, of no commercial importance. A varying amount of gangue, usually of the associated eruptive, but occasionally also of the older green schists, greywackes and even quartzite, is always present. The percentage of such intermixed rocky matter is sometimes unusually large, as in certain portions of the Elsie and Murray mines, where material has been used in large amount, which consists of sulphides and rock in about equal proportion, while, in other instances, as at the Creighton and Victoria mines, the sulphides are so pure and massive that large quantities of associated norite have to be added to the furnace charge to act as a flux. Magnetite, and certain of the silicates, peculiar to the norite, usually more or less decomposed, such as hornblende, actinolite, serpentine or chlorite are almost always present. A comparatively small amount of quartz, calcite, dolomite and very occasionally crystals of tourmaline molybdenite and apatite are also found.

Relation of sulphides to one another.

Sorting by hand not practicable.

The pyrrhotite and chalcopyrite, are not, as a rule, so intimately commingled as to form a homogeneous mass, but each may be described as occurring in pockets, spots, bunches or threads, in the other. The chalcopyrite is not so closely intermixed with the pyrrhotite but tends to isolate itself rather in patches or spots, usually enclosing, but occasionally enclosed by the pyrrhotite. It is sometimes possible to separate considerable masses of chalcopyrite, assaying over 30 per cent of copper, or pyrrhotite, that will only show traces of that metal. In practice, however, careful examination and trial have proved that the two minerals are too intimately associated, to make sorting by hand, at all practicable. Although the chalcopyrite seldom occurs free from the pyrrhotite, large and massive deposits of the latter occur comparatively free from copper. The first ore shipped from the Gertrude mine, was so free from copper, that it was proposed to utilize it for the production of ferro-nickel, and this deposit was purchased by the Lake Superior Power Company, with this object in view. Analyses made of a large mass of the Creighton mine ore obtained near the surface, show the nickel to vary from 4.87 per cent to 5.31 per cent, with 0.72 per cent to 1.20of copper. The prevailing intimacy of association, however, of the pyrrhotite and chalcopyrite, will perhaps be better appreciated by mention of the fact that hand-picked specimens from the Evans, Stobie and Copper Cliff mines, collected and analyzed by Mr. Browne (¹), showed the presence of from 13.86 to 15.71 per cent of copper with a sufficient quantity of intermixed pyrrhotite and pentlandite in the same, to assay from 1.28 to 2.47 per cent of nickel. On the other hand, selected nickel ore from Copper Cliff mine, with 8.12 per cent of nickel, contained only 0.80 per cent of copper, while similarly picked ore from the Evans mine containing 5.36 per cent of nickel showed the presence of only 0.49 per cent of copper. In certain of the deposits, as for instance, at the main shaft of the Victoria mines, the nickel and copper are almost identical in quantity, assays of a large number of samples, neglecting the insoluble matter, showing the presence of 3.66 per cent of each metal. At the Dominion, Murray and Elsie mines, the nickel is usually nearly double that of the copper. Thus, Mr. George Attwood, M. E., (²), at one time manager of the Dominion Mineral Company, under date of March 18th, 1891, stated that the 'kies' or metallic portion of the Blezard mine, averaged 4 per cent of nickel and 2 per cent of copper this result being the average of a large number of assays, as also of the practical working of the mine. About the same date, Mr. F. R. W. Daw, then manager at the Murray mine, stated that an average of the ore smelted at this mine, contained 1.5 per cent of nickel and 0.75 per cent of copper. Other assays of an average sample of ore from this mine, show 0.9 per cent of copper, with 1.5 per cent of nickel and 46 per cent of insoluble, or the equivalent of 1.66 per cent of copper and 2.76 per cent of nickel, in the pure sulphide material.

Masses of pyrrhotite occur comparatively free from chalcopyrite.

Partial analyses of the ores from some of the principal mines.

Nickel and copper nearly equal in amount at Victoria mines.

Nickel nearly double the copper at Dominion, Elsie and Murray mines.

Assays of 'kies' of Dominion mine.

Assays of ore from Murray mine.

The Gertrude and the Creighton mines, and especially the latter are deposits in which the nickel is often present in the ore in the proportion of 3 or 4 to 1. In the first years of the development of the mines of the Canadian Copper Company, the copper was greatly in excess of the nickel, and assays of specimens of raw ore, taken without selection

Preponderance of nickel in Gertrude and Creighton mines.

Copper greatly in excess in first years of operation of Copper Cliff mine.

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(1). Eng. and Min. Jour. Dec. 2nd. 1893, Vol. LVI, p. 566.
(2). Ann. Rep. Geol. Surv. Can., Vol. V, 1890-91, Part F., p. 52.

Proportion of nickel and copper in mattes from Dominion mine.

Analyses of matte Can. Cop. Co.

Percentage of nickel in the ore.

from these mines, showed a range in copper from 4·03– 9·98 per cent, with an average of 6·44 per cent, while the nickel, in the same specimens, varied from 1·12 per cent to 4·21 per cent, with an average of 2·38 per cent. This preponderance of the copper was maintained for some time, for an average of two samples of the blast furnaco matte, taken 22nd February, 1889, and the 2nd March, of the same year, showed copper 26·91 per cent and nickel 14·14 per cent. About the same time, the Dominion Mineral Company produced mattes, containing from 18 to 20 per cent copper and 24 to 26 per cent nickel. At the present time, however, this condition of affairs is reversed, and two specimens of this matte, analyzed by Mr. Donald Locke, of this Department, showed 14·53 per cent and 14·69 per cent of copper with nickel 26·34 per cent and 28·17 per cent, respectively.

Amount of cobalt present.

Gold, silver and platinum are present in appreciable quantities.

Amount of gold present in mattes.

Amount of silver present in mattes.

The nickel present in the pyrrhotite of the Sudbury District, varies usually from 2·25 per cent to 5·50 per cent, the lower figure being characteristic of such deposits as the Stobie, Murray and Elsie mines, while the latter is approached, and at times, exceeded by the ore of the Creighton, Victoria, Blezard, Copper Cliff and Evans mines. Small specimens are occasionally met with which contain as high as 30 per cent of nickel, as at the Worthington mine, but such material is only obtainable by careful hand-picking, at either the Worthington or Creighton mines. These ores contain appreciable quantities of cobalt, gold, silver, and metals of the platinum group. Cobalt is almost invariably present, but in most of the assays of the ores, which have been made, it is included with the nickel. The cobalt is usually very uniform in amount, in the proportion of 1 to 40 or 50 of the nickel present. The amounts of the rarer elements such as gold, silver and platinum are, usually so small, that the proportions of these can be best determined by analyses of the bessemer or higher grade mattes. Analyses of this product, which are available, containing about 80 per cent of combined nickel and copper, contain from 0·10 to 0·20 oz. of gold with an average of probably about 0·15 oz. to the ton of 2,000 lbs., although L. P. Silver (1) obtained as high as 0·75 oz. of gold, in the high grade matte, of the Orford Copper Company, containing 39·64 per cent of nickel and cobalt and 42·75 per cent of copper. Locke, of the Geological Survey, shows that in this same matte, containing 40·37 per cent of nickel and 24·95 per cent of copper, only 0·10 oz. of gold per ton is present. In the matte produced by the Mond Nickel Company, containing 41·88 per cent of nickel and 37·37 per cent of copper, this same chemist found $\frac{1}{15}$ of an oz. of gold.

The silver in the ore is still more variable, as Locke found 2·5 oz. to the ton, in the Orford Copper Company's matte, and 4·87 oz. to the

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(1) Jour. Can. Min. Inst., Vol. V, 1902, p. 534.
(2) Ann. Rep. Bur. of Mines Ont., 1900, p. 218.

Percenaage of platinum in mattes.

ton, in the matte produced by the Mond Nickel Company. J. W. Bain's (2) analysis shows 5·1 oz. to be present in the Orford Copper Company's matte. L. P. Silver shows that 5·30 oz. are present in each ton, while Ulké states that 7 oz. of silver are present in this same matte. The platinum, as already mentioned, is directly associated with the chalcopyrite, and therefore, should be found in mattes which are relatively richer in copper. Locke found that the Orford matte contains, 0·44 oz. per ton of metals of the platinum group, while the Mond Nickel Company's matte, contains 0·4 oz. per ton of these same metals. Ulké mentions that the platinum and palladium, in about equal amounts, together made up about 0·50 oz. per ton, while L. P. Silver has secured the same result.

Nickel and copper in Sudbury ores.

Nickel and Copper in Sudbury Ores.

—	Nickel.	Copper.	Total Nickel & Copper.	Authority.
	%	%	%	
1 Copper Cliff, Evans & Stobie mines	2·38	6·44	8·82	Can. Copper Co.
1a Copper Cliff mine, average 1890	3·69	6·24	9·93	"
2 Copper Cliff mine (mixed ore)	4·75	5·69	10·44	"
3 " (picked nickel ore)	8·12	0·80	8·92	"
4 " "	9·25	0·51	9·76	"
5 " "	11·00	0·00	11·00	"
6 " (picked copper ore)	2·74	14·13	16·87	"
7 " "	1·25	23·78	25·03	"
8 Evans mine (mixed ore)	4·00	2·60	6·60	"
8a Evans mine, average 1890	3·62	2·84	6·46	"
9 Evans mine (picked nickel ore)	5·36	0·49	5·85	"
10 " "	9·02	0·00	9·02	"
11 " (picked copper ore)	1·34	13·86	15·20	"
12 Stobie mine (mixed ore)	2·28	2·21	4·49	"
12a Stobie mine, average 1890	2·00	1·99	3·99	"
13 Stobie mine (picked nickel ore)	2·75	0·00	2·75	"
14 " "	2·99	0·37	3·36	"
15 " (picked copper ore)	1·28	15·71	16·99	"
16 " "	0·64	24·23	24·87	"
17 No. 2 mine (picked nickel ore)	4·70	0·38	5·08	"
18 " (picked copper ore)	1·87	13·76	15·63	"
19 No. 2 Extension (picked ni. ore)	4·32	0·35	4·67	"
20 No. 3 mine (Frood mine) (picked nickel ore)	4·85	0·42	5·27	"
21 No. 4 mine	4·33	1·39	5·72	"
22 "	4·15	2·49	6·64	"
23 Creighton mine	7·03	1·81	8·84	"
24 "	4·87	1·20	6·07	Geol.Surv. Dept.
25 "	5·31	0·72	6·03	"
26 Victor mine	3·50	4·50	8·00	Mond Nickel Co.
27 "	3·05	3·05	6·25	"
28 "	2·67	2·81	5·48	"
29 "	3·21	2·41	5·62	"
30 Worthington mine	3·00	3·00	6·00	C.W. Dickson.
31 " (picked ni. ore)	17·48	0·00	17·48	T. L. Walker.
32 Blezard mine (metallic portion)	4·00	2·00	6·00	Dom. Min. Co.
33 Murray mine	1·50	0·75	2·25	H.H. Vivian&Co

EXPLANATIONS.

Analyses by
F. L. Sperry.

1. Average of nine analyses, made by F. L. Sperry, of raw ore taken without selection, from the Copper Cliff, Evans and Stobie mines, of the Canadian Copper Co., in November, 1888. 1*a*. Average of Copper Cliff mine ore, for year 1890. (Ann. Rep. Geol. Surv. Can. Vol. V, 1890-91, Part F, p. 51.)

Analyses by
D.H. Browne.

Analyses, 2, 3, 5, 6, 8, 9, 10, 11, 12, 13, 15, are by David H. Browne, chemist to the Canadian Copper Company. (Eng. and Min. Jour. Dec. 2[illegible] 1893, p. 566).

Analysis 8*a*. Average of Evans mine ore for the year 1890. (Ann. Rep. Geol. Surv. Can. Vol. V, 1890-91, Part F, p. 51.)

Analyses by
Canadian
Copper Co.

Analyses, 4, 7, 14, 16, 17, 18, 19, 20, 21, 22, 23, 26, are from the catalogue of the mineral exhibit of Ontario, at the Pan-American Exposition of 1901. pp. 33 and 35.

Analysis 12*a*. Average of Stobie mine, for the year 1890. (Ann. Rep. Geol. Surv. Can. Vol. V, 1890-91, Part F, p. 51.)

Analyses by
C. W. Dickson.

Analysis 30, is the result of a number of analyses of average samples, by Mr. C. W. Dickson, (Trans. Am. Inst. Min. Eng., Albany meeting, Feby., 1903).

Analyses by
DonaldLocke.

Analyses 24 and 25, are by Mr. Donald Locke, of the Geological Survey Department, Ottawa, of material obtained within a few feet of the surface.

Analysis 27, is the result of an average of a large number of assays of samples of [illegible]w ore, from the Victoria mines, as supplied to the smelter, by T. M. Paris, the chemist. The insoluble amounted to an average of 16·81 per cent.

Anal[illegible] by
T. M. [illegible]is.

Analysis 28, is the average of the raw ore, for July, 1902, by T. M. Paris, chemist to the Mond Nickel Company. Insoluble, 17·2 per cent.

Analysis 29, is the average of the raw ore for September 1902 by T. M. Paris, chemist to the Mond Nickel Company. Insoluble, 13·9 per cent.

Analysis by
T. L. Walker.

Analysis 30, is the result of an analysis of the pyrrhotite, from the Worthington mine, which contained a large amount of pentlandite, by T. L. Walker. (Ann. Rep. Geol. Surv. Can., Vol. V, 1890-91, Part SS, p. [illegible])

nalyses by
ominion
Mineral Co.

An[illegible] 32, according to Mr. George Attwood, manager for the Dominion Mineral Company, is the average of the results of many hundreds of assays of the "kies" or metallic portion of the ore of the

Blezard mine, also the practical working of the mine on a large scale. (Ann. Rep. Geol. Surv Can. Vol. V, 1890-91, Part F, p. 52.)

Analyses by H. H. Vivian & Co.

Analysis 33, is the average percentage of the ore smelted at the Murray mine, according to Mr. F. R. W. Daw, the manager for Messrs H. H. Vivian & Co. The "kies" or metallic portion of the Murray mine ore contains on an average of about 2·75 per cent of nickel and 1·65 per cent of copper.

Determinations for nickel and cobalt in Sudbury ores by Dr. G. C. Hoffmann and assistants.

NICKEL AND COBALT IN ORES FROM SUDBURY DISTRICT.

Locality.	Insol.	Cu.	Ni.	Co.	Ni. in Metallic portion.	Authority.
	%					
1.—Location W. 7, (W. side Lake Wanapitei).....	40	Small quantity	2·00	None	3·33	R. A. A. Johnston.
2.—Boucher's mine, N.E. side Lake Wanapitei	25	Present.	1·57	,,	2·09	,, ,,
3.—Neelon Township, Lot 12, Con. III....	....	Small quantity	3·10	Trace.	3·10	,,
4.—Boundary line bet. Districts of Algoma & Nipissing, 2 miles N. of Lumsden Tp.....	....	....	2·70	None	2·70	F. G. Wait.
5.—Lorne Township, Lot 11, Con V.....	Small proportion.	Trifling amount.	1·95	,,	....	R. A. A. Johnston.
6.—Lorne Township	33	Small amount.	1·57	,,	2·34	,, ,,
7.—Nairn Township Lots 1 & 2, Con. III.......	Small proportion.	None.	1·95	Trace.	..	,, ,,
8.—Drury Township, Lot 3, Con. III............	Trifling amount.	Little.	2·01	,,	...	,, ,,
9.—Denison Township, Lot 6, Con. II....	12·5	None.	1·55	None	1·77	,, ,,
10.—Levack Township, Lot 7, Con. II	22	,,	2·36	Trace.	3·02	,, ,,
11.—Levack Township, Lot 7, Con. II............	None.	,,	4·13	None.	4·13	,, ,,
12.—Levack Township, Lot 3, Con. IV...	18·5	Very small amount.	1·96	Trace.	2·40	,, ,,
13.—Ross mine, W. R., 5, North Nickel Range....	16·5	Small amount.	2·75	None.	3·29	,, ,,

Explanations.

Descriptions of specimens on which determinations were conducted.

1. Association of a somewhat coarse granular pyrrhotite, with a small quantity of chalcopyrite, in greenstone.

2. An intimate association of chalcopyrite and pyrrhotite, in a gangue of greenstone.

3. A somewhat coarse granular pyrrhotite, associated, with small quantities of chalcopyrite, from what was then known as the McCormick mine.

4. Pyrrhotite, in association with small quantities of dark-coloured greenstone.

5. Pyrrhotite, with a trifling amount of chalcopyrite, with greenstone.

6. Pyrrhotite, with a little chalcopyrite, with greenstone.

7. Pyrrhotite, with a small proportion of greenstone.

8. Pyrrhotite, with a little chalcopyrite, through which was disseminated a trifling amount of a quartzose gangue.

9. A somewhat coarse granular pyrrhotite, through which was disseminated a small amount of quartz.

10. A somewhat coarse granular pyrrhotite, through which was disseminated a quartzose gangue.

11. A very coarse granular pyrrhotite, free from gangue.

12. A somewhat coarse granular pyrrhotite, with a very small amount of chalcopyrite, in association with greenstone.

13. A coarse granular pyrrhotite, with a small amount of chalcopyrite. The gangue was readily discernible.

These analyses, 1 to 13, were done in the chemical laboratory of the Geological Survey Department, by Messrs R. A. A. Johnston and F. G. Wait, assistants to Dr. G. C. Hoffmann. (Ann. Rep. Geol. Surv. Can. Vol. V. 1890-91, Part R, pp. 41-44 (Nos 7 to 19).

THE SUDBURY PYRRHOTITE.

Composition of pyrrhotite not constant.

The composition of pyrrhotite, as shown by a large number of analyses, is not constant, and although repeated trials have been made by various chemists and mineralogists, to obtain a formula which would be satisfactory, and representative of this mineral, their attempts so far have been attended with only a fair amount of success.

Formula for pyrrhotite.

It has, therefore, been the custom to express the composition of pyrrhotite, by the formula $Fe_n S_{n+1}$ the available analyses, collected by Lindstrom in 1875, and by Habermehl in 1879, showing a variation of Fe : S = 1 : 1., 1902, corresponding to $Fe_5 S_6$, to 1 : 1.0610 which agrees with the formula $Fe_{16} S_{17}$. Habermehl, from a mean of 14 determinations, ten of which were essentially identical, showed that the Bodenmais pyrrhotite contains 60.57 per cent of iron, thus conforming closely to the formula $Fe_7 S_8$, the theoretical composition of which would require 60.40 per cent of iron. This material was obtained on portions separated successively from the fine powder, suspended in water by, a strong magnet. Doelter, by artifical means, produced a compound closely resembling, if not identical with the natural pyrrhotite, the analysis of which agreed with the formula $Fe_{11} S_{12}$.

Variation in composition of pyrrhotite suggests a possibly mixture.

This variation in composition has suggested the possibility, that pyrrhotite is not really a definite species, in a mineralogical sense but rather, a mixture in varying proportions, of perhaps several closely related compounds. Such a view was regarded as also supported by the wide range in the specific gravity of the mineral, (3.98 to 4.80) as well as, observed differences in the possession of certain physical properties, especially noticeable in regard to its magnetism Some specimens exhibit this property in such a feeble manner, that only the finer powder is attracted by the magnet, while others are so intensly magnetic, as even to exhibit the phenomenon of polarity

Discrepancies in results can be explained on other grounds.

Careful consideration of all the facts available, suggest, that much, at least, of the discrepancies in composition, can perhaps be better explained, on other grounds. Thus, although it is known that, a considerable number of these analyses, were conducted on material which had been selected with great care, and using every known precaution to ensure a pure and homogeneous product, by far the larger number of determinations were of impure, often intermixed material. Besides, the methods of analysis were not always above reproach, so that errors constantly occurred, not only in the determination of the sulphur, but also of the iron. In addition, even with the possession of the requisite knowledge of analytical methods, as well as skill in their manipulation it is usually extremely difficult, if not impossible, in all cases, to obtain sufficiently homogeneous material, on which to base a formula, which would be thoroughly reliable and representative. If we regard pyrrhotite as a sulphide, intermediate in chemical composition between the normal sulphide FeS and the disulphide FeS_2 it is possible to obtain every gradation of material showing a range in the iron content, from 63·61 per cent, to 46·60 per cent, while the sulphur to correspond,

Difficulty of obtaining homogeneous material.

Range in composition of sulphides.

would show a gradual increase from 36·39 per cent, to 53·40 per cent. There is, however, a wide gap between $Fe_7\ S_8$ with iron 60·40 per cent and sulphur 39·60 per cent, and $Fe\ S_2$ with iron 46·60 per cent and sulphur 53.40 per cent Those analyses, however, which have evidently been conducted with the greatest care, show a variation in formula from $Fe_{11}\ S_{12}$ with iron 61.60 per cent and sulphur 38.40 per cent, to $Fe_7\ S_8$ with iron 60.40 per cent and sulphur 39·60 per cent. These determinations are as uniform and accurate as could be expected, from material so manifestly impure as pyrrhotite.

Difficulties of obtaining a reliable analysis of Sudbury pyrrhotite.

A satisfactory and reliable analysis of Sudbury pyrrhotite is, perhaps more than usually difficult to obtain, owing to the very intimate association of various closely related sulphides. In the first place, it was the generally accepted view, that the nickel really replaced isomorphously, an equivalent amount of iron, and was thus an essential constituent of the pyrrhotite, whereas, it is now a well ascertained fact, that by far the greater proportion of the nickel, at least, occurs as a distinct and separable nickel-iron sulphide. Many, however, still cling to the belief, that a small portion of the nickel may exist in a state of chemical combination, but such persons can find little support for this view, in the fact, that, by repeated use of a magnetic separator and with material sufficently comminuted, it is possible to remove almost the last trace of nickel, from a compound, which originally contained from 2 to 5 per cent of this element, while the isolated nickel-iron sulphide or pentlandite, is usually pure enough for analytical purposes. The process is, however, tedious and repeated trials are necessary, before the pyrrhotite or pentlandite is obtained of the degree of purity desired.

Presence and means of separation of pentlandite

Presence of chalcopyrite.

In addition, other sulphides, mainly chalcopyrite, but sometimes also pyrite are present, the former almost invariably accompanying the pyrrhotite, and all of these are so intermixed with one another, that very fine grinding, and the assistance of magnetism is necessary, before a satisfactory and complete separation can be effected. Such a dissociation, however, may be conducted at the same time as the trials for the elimination of the pentlandite are proceeding, while this latter mineral, which is itself feebly magnetic, can, in turn, be separated from the copper and iron pyrites, which do not possess the property of magnetism, in any sensible degree. The chief difficulty, however, encountered in the purification of the pyrrhotite, arises from the fact that a small quantity of magnetite (Fe_3O_4), often amounting to not less than 1 per cent of the whole, is almost invariably present. C. W. Dickson, after a number of experiments, found, that by treating the sample with dilute (10 per cent) solution of nitric acid, the pyrrhotite

Magnetite which is always present the chief difficulty.

could be largely removed, while the magnetite was but little affected. The separated sulphur was removed by means of bromine and carbon-bisulphide; and after several treatments, the residue of magnetite was obtained pure, and the iron was estimated by titration, The nature of these operations, as he remarks, involves the possibility of some loss, especially as the amount of magnetite is comparatively small, but, on the whole, the method answered very well. The greater number of the analyses indicated that the pyrrhotite could be represented by the formula Fe_8S_9, while two or three others worked out to Fe_7S_8 and Fe_9S_{10}. The first mentioned formula may be regarded as the most probable for the pyrrhotite from the Sudbury District. He likewise mentions the interesting fact, that a trial of a specimen from Rossland, B.C., showed it to be represented by the same formula (Fe_8S_9).

Methods for removal of magnetite.

Formula for Sudbury pyrrhotite.

Formula for Rossland pyrrhotite.

The pyrrhotite is always massive and amorphous, showing all gradations of texture from very finely to very coarsely granular, the coarser varieties possessing well marked cleavages in two directions. As may be seen by a reference to the analyses, there is little or no foundation for the popular belief, that the coarsely crystalline varieties are relatively poorer in nickel, than those which are finer grained. Good crystals are extremely rare, and although occasional fragments are found which are apparently bounded by crystal faces, such planes are really the direct result of cleavage. Perhaps the only authenticated crystal of pyrrhotite, was obtained by Mr. G. R. Mickle, from a man working in the Worthington mine. Mr. Mickle thus describes it: 'The crystal is evidently a hexagonal prism showing strongly marked basal cleavage; two of the sides are intact and portions of two others remain. The dimensions are $1\frac{5}{16}$ inches, or 32mm., by $\frac{1}{2}$ inch, or 13mm.; the weight 27·4 grains: and an analysis of a very small fragment from the crystal gave 2·3 per cent of nickel.'

Physica properties of pyrrhotite.

Description of Mickle's crystal of pyrrhotite.

The colour of the pyrrhotite is a bright steel gray on fresh fracture, quickly weathering to a deep bronze-yellow, often, however, tarnished or iridescent.

Colour.

CHALCOPYRITE.

The copper contained in the ore is all obtained from chalcopyrite, the common sulphide of copper and iron, ($CuFeS_2$ sulphur 35·0 per cent, copper 34·5 per cent, iron 30·5 per cent=100·0). It is always massive, with the usual deep brass or yellow colour. As usual, this mineral is very subject to tarnish, and beautiful iridescent specimens can be obtained from the ore heaps, or scattered around the works. The composition of the ore varies greatly, as may be seen by a reference to the analyses, and according to the preponderance of either the pyrrhotite or chalcopyrite, the resulting furnace product or

Theoretical composition of chalcopyrite.

Colour.

Mines of Canadian Copper Co. first operated for copper.

matte is relatively richer or poorer in nickel or copper. The mines of the Canadian Copper Company, as the name implies, were first operated for their copper contents and it was not until considerable work had been done that nickel was discovered to be present in the ore. A large shipment of ore had been made to New York, and a chemist there who was making a volumetric determination of the copper contents, by the potassium cyanide process, was struck by the great variation in his results, which led him to make a more minute examination of the ore, when he found that nickel was present. The ore has now become of more value on account of its nickel, than its copper contents, and Dr. Peters himself, greatly doubted, if the mines would pay to work for copper alone.

Discovery of presence of nickel.

Dr. Peter's, doubted if Sudbury mines could be worked profitably for copper alone.

NICKEL AND COBALT IN SUDBURY PYRRHOTITES.

Determinations of nickel, copper, cobalt &c. in Sudbury pyrrhotites.

Locality.	Insol.	Cu.	Ni.	Co.	S.	Iron.	Ni in pure. Pyrrhotite.
	%	%	%	%	%	%	
1. Elsie mine (a)........	2·00	Trace.	2·40	0·06	....	.....	2·46
2. " " (b).......	3·45	"	2·35	0·05	.....	.....	2·44
3. Stobie mine (a)......	1·50	"	3·00	0·08	.....	.....	3·05
4. " " (b)......	4·00	"	2·05	0·05	.....	.	2·15
5. No. 3 mine (a)......	0·40	"	2·35	0·05	....	.....	2·40
6. " 3 " (b)......	5·00.	"	2·34	0·06	.....	...	2·48
7. Mount Nickel.........	2 20	"	3 00	0·07	.....	.....	3·06
8. Copper Cliff No. 4 mine (a)........	1·10	"	3·24	0·06	.....	....	3·30
9. Copper Cliff No. 2 mine (b)........	5·00	"	3·70	0·08	.....	.....	4·00
10. Copper Cliff No. 5 mine (c).........	0 [illegible]	"	3·47	0·08	.....	.....	3·50
11. Creighton mine (a)...	3·25	"	3·81	0·10	.....	.....	4·00
12. " " (b)...	0·50	"	2·26	0·06	.....	.....	2·32
13. Gertrude mine (a)....	5·00	"	3·83	0·11	.....	.....	4·05
14. " " (b)...	6 00	"	3·61	0·09	.....	.....	4·00
15. Victoria mine (a).....	0·50	"	3·36	0·07	.....	.....	3 40
16. " " (b)....	0·40	"	3·14	0·08	.....	.....	3·20
16*a*. " " (b)....	3·00	4·50	3·50	.....	32·00	55·00	....
17. Levack Township ..	3·20	Trace.	2·80	.....	.....	.....	2·88
18. Wisner " ...	4·10	"	2 22	.....	.....	.....	2·32
19. Creighton mine (a)...	2·28	0·72	5·31	.....	34·28	.....	....
20. " " (b)...	2·49	1·20	4·87	.....	34·62	.....	....
21. Copper Cliff (7th level) (a)..................	.....	0·00	11·00	.....	38·01	50·40	11·00
22. Copper Cliff (7th level) (b)..............	......	0·00	4·62	.....	38·58	55·70	4·62
23. Stobie mine (a). ..	......	0·00	2·75	.....	35·35	58·00	2·75
24. " " (b).......	......	0·00	2·15	.....	36·10	57·00	2·15
25. Evans mine (a). ...	.....	Trace.	9·02	.....	39·28	51·50	9·02
26. " " (b)...	.....	0·00	3·82	.....	40·18	56·00	3 82
27. Copper Cliff mine...	7·75	Trace.	3·40	0·175	.....	.....	Co=0·2, Ni 3·98
28. Crydermn mine.....	2·96.	"	4·46	0·174	.....	.....	Co=0·18, Ni 4·60
29. Cochrane mine. ..	11·10	0·10	3·52	0·146	.....	.....	Co=0·16, Ni 3·96
30. Little Stobie mine...	2·70	Trace.	4·06	0·165	.....	.....	Co=0·17, Ni 4·17

EXPLANATIONS.

Methods employed for obtaining samples.

Analyses 1-18 inclusive, with the exception of 16a., were made by Mr. C. W. Dickson, (Trans. Amer. Inst. Min., Eng., Albany meeting, Feb. 1903) in duplicate or triplicate, to insure the greatest possible accuracy. These were made to ascertain as accurately as possible, the average nickel and cobalt contents, of the general run of the pyrrhotite, from the whole region. The pyrrhotite was coarsely crushed, and the mineral picked out as pure as possible, under a lens, when necessary. From the massive varieties, good samples were easily obtained, but, in other cases, the pyrrhotite was so intimately mixed with chalcopyrite and rock, that it was very difficult to obtain satisfactory samples, some rock always adhering to the sulphide. The results obtained, show, that the percentage is fairly constant over a wide area. The pyrrhotite includes both fine and coarse-grained. In the case of the coarse grained varieties, where the nickel mineral pentlandite can often be recognized, this was carefully rejected, as far as possible. But the difficulty of separation accounts for the fact, that some of these varieties show less nickel than the finer grained ones, although the former are usually considerably richer. Had the coarse grained samples been treated in their original condition, the results would have been more uniform. These analyses, therefore, represent the nickel which is most intimately associated with the pyrrhotite, and does not appear as particles of pentlandite.

Explanation of variation in results.

Description of specimens analyzed.

1. Coarse pyrrhotite, with a small amount of chalcopyrite and rock; 2. Compact fine-grained pyrrhotite, with a small amount of rock; 3. Massive, fine-grained pyrrhotite; 4. Pyrrhotite and chalcopyrite, in diorite; 5. Pure, coarse pyrrhotite; 6. Fine-grained pyrrhotite; 7. Massive pyrrhotite; 8. Coarse pyrrhotite; 9. Massive, fine grained pyrrhotite; 10. Massive, fine-grained pyrrhotite; 11. Massive, fine-grained pyrrhotite; 12. Coarse pyrrhotite; 13. Massive pyrrhotite; 14. Massive pyrrhotite; 15. Massive, fine-grained pyrrhotite; 16. Coarser than No. 15, but with more chalcopyrite: 16a. Analysis of ore by Mond Nickel Company; 17. Massive pyrrhotite (Tough and Stobie's property); 18. Coarse, massive pyrrhotite, from the Northern Nickel Range; 19 and 20 are analyses by Mr. Donald Locke. Analyses 21 to 26 inclusive, are of ore selected for purposes of magnetic concentration, by Mr. David H. Browne. Analyses 27 to 30 inclusive are by Mr. M. F. Connor of this Department, and were of hand picked ore, as free as possible from chalcopyrite and gangue. All of the specimens were of pyrrhotite, of medium-grain, with the exception of that from the Little Stobie mine, which was a very coarse cleavable variety.

MODE OF OCCURRENCE OF THE SUDBURY NICKEL DEPOSITS.

Deposits are not veins.

Most geologists, at least, who have examined these deposits in detail, are agreed, that they are not true fissure veins, and although, at times certain sloping surfaces are obtained, which seem to have a uniform inclination and limit the distribution of ore in their direction, yet, it seems certain, that there are no regular walls, in the miner's sense of the term, and at both sides of the deposit, the enclosing rock is impregnated, more of less, with pyritous matter. Although mining is thus rendered somewhat difficult and uncertain, on account of the absence of the walls, and irregularity in the distribution of the ore, so that there is very little means of knowing in what direction to drive the levels, this uncertainty is usually more than compensated by the extent and massiveness of the deposits, when found.

No regular walls.

Irregularity of distribution of ore.

Shape of ore bodies.

The ore bodies are of irregular, oval or pod-shaped outline, and all agree in having their longer axes to correspond very closely with the direction of the foliation of the enclosing rocks. The shapes and dimensions of the ore bodies of the International Nickel Company's mines at Copper Cliff, are accurately shown on the accompanying large scale maps. There are three main types of these ore deposits in the Sudbury Mining District.

Three main types of occurrence.

Marginal deposits.

1. Those which occur at the southern border of the immense body of hypersthene-gabbro, or norite, which reaches without interruption, from Drury to Garson townships. Under this division, are included the Gertrude, Creighton, North Star, Tam O'Shanter, Lady Violet, Elsie, Murray, Cameron, Little Stobie, Mount Nickel, Blezard, Beatrice, Kirk. wood and Cryderman mines.

Offset deposits.

2. Those which are developed in connection with offsets or dyke-like forms of the norite, extending southward from the main mass, and which are intruded into the older rocks, almost at right angles to the planes of foliation and bedding. This would embrace such mines as the Victoria, Clarabelle (No. 6), No. 4, Lady Macdonald (No. 5) and No. 2, and the extensions of No. 2 mine.

Deposit occurring with small isolated masses of norite.

3. Those which are associated with smaller, and at present, completely isolated bodies of norite. These separate masses of the nickel bearing eruptive, are so closely identical, in mineralogical composition, structure and behaviour to the parent eruptive, that they are probably connected with it, in some way, at a distance below the surface.

The original Copper Cliff, No. 1 and its extensions, Evans, Frood (No. 3) and Stobie mines are all examples of this last mentioned class.

The first mentioned division of deposits, are all situated at the immediate contact between this huge mass and the older rocks, into which

Description of marginal type of deposit.

Differentiation of norite into micropegmatite.

it is intruded. The intrusive nature of this contact is well shown, the impregnation of the older green schists consisting, for the most part, of small, dyke-like forms, or veins of sulphide material, injected along the planes of schistosity, while, on the other side, the line of separation between the ore-body and the norite is even more uncertain, the sulphide material gradually fading out, until it is only represented by occasional disseminations. To the northwest, this basic rock shows a gradual differentiation or passage into the peculiar and characteristic type of gneissic granite, usually referred to as 'micropegmatite'. On the Levack or Middle Range (Windy lake eruptive), this condition of affairs, is reversed, and we find the deposits at the northwestern margin of the norite, while its differentiate, the micropegmatite lies to the southeast. This same condition of affairs obtains on the Northern Nickel Range where the norite comes in contact with the older granites and green schists on the north side, while the micropegmatite underlies the area to the south.

Worthington and Vermilion mines not connected with main body of norite.

The Worthington and the Vermilion mines are the only deposits which have been developed, having no visible connection with the main mass of norite already noticed. As has been shown on a previous page, the Worthington mine occurs on a narrow neck of actinolite diorite, which is, without doubt, the altered representative of the older norite. To the southwest and east, this norite is directly connected with a much larger mass of basic eruptive material. As far as can be learned, no large deposit of ore was encountered at the Vermilion mine, and the small amount of norite found, resembles very closely, the decomposed variety of the older type of this rock.

Significance of occurrence of gossan.

Explanation of formation of gossan.

Depth of gossan.

Rounded hills of gossan, indicating the presence of the more or less pure and unaltered ore beneath, extend with almost unbroken continuity, for miles along the line of junction, while by far the larger portions of the offsets and isolated masses, with which the ore-bodies are associated, are also of a prevailing brownish colour, from the decomposition of the abundantly disseminated sulphides. This gossan has resulted, as usual, from the alteration of the pyrrhotite and chalcopyrite, and the formation of hydrous oxide of iron, which gives a prevailing brownish colour to the upper portions of the deposits. This covering of iron oxide is sometimes as much as six feet in depth, although usually it is only two or three feet, gradually merging into the unaltered ore beneath. The depth to which this gossan extends depends largely, of course, on the length of time the deposits have been uncovered, and thus exposed to processes of weathering. Some, from which the green forest and overlying soil have but lately been removed, Gossan from Elsie mine northeast.

Gossan at Copper Cliff and Creighton mines.

show little or no iron oxide, while others like the Murray mine which have been exposed to the action of the weather for years, exhibit an extensive covering of this characteristic decomposition product. From the Elsie mine, in a northeasterly direction, past the Murray mine as far as the boundary between McKim and Blezard townships, a considerable belt of rock occurs at the immediate margin of the norite, so heavily charged with sulphides, that its weathered outcrop at the surface is covered with this gossan. At the old Copper Cliff mine, as well as at the Creighton mine, this overlying gossan is very wide spread and deeply impressive.

Brecciation of ore body.

Explanation of brecciated structure.

In most cases, these ore-bodies show a brecciated character, large angular or partially rounded blocks, of almost barren rock being mingled with the ore. Some of these horses, as they have been called, are made up of the material derived from the wall rock, against which the pyritous matter cooled. Their presence, in this connection, is no doubt due to the shattering of the invaded formation, at their contact with the plutonic magma. In fact, they form an illustration, on a small scale, of the phenomenon of 'overhead stoping', so fully described and explained by Dr. R. A. Daly.(1) In other instances, however, this comparatively barren material is of norite but such inclusions are seldom sharply defined from the sulphide, exposures showing a gradual transition from one to the other, while the blocks themselves are generally more or less plentifully impregnated with the prevailing sulphide.

No great depth reached by marginal deposit workings.

Open pit at Creighton mine.

No great depth has yet been reached by the workings of any of the mines of the marginal type of deposits. The deepest of the shafts is at the Blezard mine, which has only been sunk a distance of 172 feet while those of the Murray and Gertrude are 160 and 120 feet deep respectively. On the other hand, the diamond drilling undertaken at the Creighton, is stated to have proved the existence of this phenomenally large body of nickel ore, to a depth of at least 400 feet. This wonderful deposit of pyrrhotite has been worked, mainly, as a large open pit, measuring 150 by 200 feet, and extending to a depth of 62 feet. All of these deposits dip to the north and northwest at an angle varying from 30° to 70°.

Depth of offset deposits.

Of the mines belonging to the second group of those developed along the offsets, the two most important are the Victoria mine and the No. 2 mine, of the International Nickel Co., at Copper Cliff. The Victoria mine, of the Mond Nickel Company, with seven levels and extensive slopes, has reached a depth of 557 feet. The No. 2 mine has

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(1) Amer. Jour. Sc. Vol. XVI., 1903. p. 108.

afforded a large amount of ore, being worked, for the most part as a large open pit, measuring about 250 feet in length, by 100 to 150 feet in width, and with a depth of 217 feet.

Description of Copper Cliff ore body.

The original and famous Copper Cliff mine has often been, referred to as a chimney of ore, averaging in width from 50 to 100 feet in the cross section, through the shaft, while at right angles to this direction, it varies from 30 to 210 feet. The first or old shaft, now in large part abandoned, except for pumping purposes was sunk to a depth of over 500 feet, on an incline of 40°, while shaft No. 2, or the new shaft to take its place, starts from the third level, at a distance of 150 feet from the surface, and continues at an angle of 77° 30′, or approximately parallel to the ore body, to the 14th level (depth 1,058 feet.)

Depth reached at Copper Cliff mine.

Depth of Stobie mine.

The ore body of the Stobie mine, developed in connection with a small isolated mass of norite, has an inclination of 65°, and, although, the workings have only reached a vertical depth of 250 feet, it has yielded a larger amount of ore than any other mine in the district (415,000 tons).

ORIGIN OF THE ORE DEPOSITS.

Origin a matter of much speculation and discussion.

Two principal theories.

The question, as to how these abnormally large masses of sulphide material, acquired their present position and dimensions, has furnished a fruitful topic for speculation and discussion, ever since their first discovery. Fortunately, however, only two theories, with some minor modifications. have been advanced, in explanation of the manner of their formation, and which may be summarized as follows :—

Igneous origin.

1. That the sulphides are directly of igneous origin, the products of the differentiation of a gabbro or norite magma, being segregated along its margin in obedience to Soret's principle, the order of formation of the minerals being in accordance with Fournet's series.

Secondary or aqueous origin.

2. That these ore bodies are altogether of secondary and aqueous origin, occurring as replacements along crushed and faulted zones.

Extreme advocates of both theories ignore certain evidence.

The extreme advocates of either theory, seek to ignore the share of the other in forming these deposits, as they exist at present. Thus, those who originally held that these ores were the immediate product of magmatic segregation, failed to mention, or at least emphasize the possibility, that those deposits, were, in any way, influenced by the presence of these heated solutions, which to a certain extent accompany, and in all cases immediately follow all plutonic action. On the other hand, those, who consider these deposits as of secondary origin, in seeking to explain the source of the metals, although they acknowledge as a fact, 'that the universal association of these ores with essentially similar rocks is also striking' and again 'that the norite, (or gabbro) has an intimate connection with the development of the ores cannot be doubted, but in just what way they are related is not clear', still at the same time, they nullify any effect which might be produced by such information. by a statement, to the effect, that 'an appeal must be made to a more distant source of the metals, probably minutely disseminated in the rocks through which the depositing solution passed.' (¹)

First statement in regard to origin of these sulphide deposits.

The writer, who was one of the first to affirm a direct igneous origin for these Sudbury ores, giving independent expression to precisely similar views, which about the same time were stated, in much more detail, by Professor J. H. L. Vogt, of Christiania, Norway, realizes the fact that, in the first endeavour to fix definitely, the responsibility for these unusual occurrences, too much emphasis was perhaps given to the idea of magmatic differentiation, as in itself, giving an adequate explanation of all the phenomena witnessed. This can only be excused on the ground that, this doctrine as applied to ore deposits, was an entire innovation, and its strongest affirmation, was at first, very necessary in order to effect its recognition as a previously ignored, though important factor, in the development of ore deposits. More recent and detailed examination of the various ore bodies, has shown that while the first hypothesis of a segregation of these sulphides, directly from the magma, is in the main, the true explanation of their present position, other agencies, which are usually grouped together under the name of secondary action, have contributed rather largely, to bring about their unusual dimensions.

Magmatic differentiation although in the main the true explanation is not the only contributing cause to the formation of these ore deposits.

Prof. Kemp regards igneous rocks as original source of ore.

As Professor Kemp remarks, (²) 'increasing experience leads us to look with especial favour on the igneous rocks as the original source of the ore, whose widely disseminated, although, when considered in comparison with their mass, whose small percentages of all the metals, except the invariably abundant iron, suggest to us original stores for leaching. We are also attracted to them, as a source, because without doubt, all other rocks must be ascribed to them in the last analysis: because they are so often in close association with ores as mined, and because, above all, they are the natural stimulators of those heated solutions, to which we can, with most reason, attribute the results.'

Present opinion in regard to fused magmas.

At the present day, fused magmas are regarded as more or less complex solutions, which, by reason of their high temperatures, obey the same laws in the order and method of their solidification, as those which govern the crystallization from ordinary solutions, of a simi-

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(1) Trans. Amer. Inst. Min. Eng., Albany Meeting, Feb., 1903.
(2) Min. Industry, Vol. IV, 1895, pp. 756-757.

larly heterogeneous composition. A study of thin sections of igneous rocks, under the microscope, reveals the fact, that a certain definite order in the generation of the component minerals is always observed, which is closely followed, in the cooling of any body of magma. Thus, in a gabbro or norite magma, the oxides of iron and titanium, the sulphides of iron, nickel and copper, zircon and apatite are the first to crystallize. These are followed by the ferromagnesian silicates, olivine, hypersthene, biotite and diallage. The plagioclase may antedate, accompany or immediately follow the crystallization of one, or more of the coloured constituents, depending on its basicity, while quartz is invariably the last to form, filling up all the irregular inter-spaces remaining. One of the main laws, governing the crystallization from a solution, or an igneous magma, is known as Soret's principle, according to which, the dissolved matter is concentrated in the coolest part of the solution. Gravity, temperature and pressure are also important factors, but these have not yet been deeply investigated.

Order of generation of component minerals as determined by microscope.

Laws governing crystallization of magmas.

Perhaps one of the most significant developments of modern petrographic geology, has been the recognition of the fact, that an originally homogeneous molten mass, tends to so separate or split itself, upon cooling, as to ultimately produce rocks of varying composition. This fact, bearing so intimately on the genesis of igneous rocks, has caused the formulation of the hypothesis known as magmatic differentiation. The hypothesis may be briefly described as the division or differentiation of a more or less viscous magma, or fused mass of rock, into chemically and mineralogically diverse parts, which on cooling, yield correspondingly different types of rocks. It would be manifestly unwise in this connection, to enter into any detailed explanation of this very generally accepted hypothesis, as the conditions attending the consolidation of a large body of magma, are now believed to be much more complex than at first supposed. Moreover, our knowledge regarding these conditions, and the several processes which are no doubt involved, is so vague and incomplete, that no full or satisfactory explanation can yet be offered of this phenomenon. All geologists of repute are, however, agreed on the main fact, that magmatic differentiation furnishes the only reasonable explanation of most of the observations made in connection with any extended exposure of igneous rocks.

Definition of magmatic differentiation.

Unnecessary to discuss hypothesis at length.

Our knowledge still incomplete.

All geologists agreed on general hypothesis.

Applying these principles to the geological relations of the Sudbury gabbro or norite, and the associated sulphide deposits, the subjoined facts seem to furnish unanswerable proof that the hypothesis of a segregation of these ore bodies, directly from the magma, is, in the main, the true explanation of their position.

Sudbury ore bodies mainly segregations from magma.

Deposits all occur at the margin of the norite.

1. The deposits, without exception, all occur at the margin of the gabbro or norite, the rock itself in immediate association with the ore being finer in texture and relatively much more basic in composition, than portions further removed from the contact. There is a very gradual increase in the basicity of the gabbro, outward from the micropegmatite, although a rather abrupt transition takes place in the immediate neighborhood of the contact. The sulphides are also finer grained near the contact, while further away, they become coarser grained. (1)

Sulphides more sharply defined against the walls of the intrusion.

2. The sulphides are always much more sharply defined against the walls of the intrusion, than on the inner side towards the main mass of the gabbro, the transition in this direction showing a more gradual decrease in the amount of ore in the rock, as the contacts are left This phenomenon, as has been mentioned, is explained by the fact, that the sulphides in obedience to Soret's principle, become concentrated towards the cooling surface of the mass.

Deposits always found in intimate connection with norite.

3. These deposits are always found in such intimate association with the norite or hypersthene-gabbro, that we are forced to the conclusion, that the ore bodies stand in some genetic relation to this plutonic igneous rock. This is not only true in regard to the Sudbury District, but is also the invariable association of precisely similar deposits, found in Norway, Sweden, Lombardy and Pennsylvania. The importance of geological studies, in connection with ore deposits, is emphasized by the fact, mentioned by Adams, (2) that although, in these several widely separated countries, the pyrrhotite deposits, associated in the manner described, with the gabbros, are so rich in nickel, the celebrated Fahlbands of Norway, which are bedded or apparently bedded deposits, consisting of heavy impregnations of pyrrhotite, pyrite, chalcopyrite, etc., but occurring in gneisses and schists of various kinds, contain hardly any nickel, hundreds of analyses showing the nickel and cobalt contents, to range from 0·1 to 0·5 per cent, and what is still more remarkable, the same is true of the similar Fahlbands, associated with our Laurentian in Canada, so far as these have been examined. In these, the pyrrhotite and pyrite is present in large amount, and is often associated with copper pyrites, but only a very small quantity of nickel and cobalt, ranging from faint traces to 0·16 per cent, occurs in the pure sulphide material. In addition, pyrrhotite, chalcopyrite and pyrite occur sometimes, in promising quantities, in the older green schists and tuffs of the Sudbury District, but even the richest of these deposits, were shown by analyses, to contain a much smaller amount of nickel, ranging from 0·15 to 0·96 per cent, in the pure pyrrhotite.

Fahlbands quite distinct in origin and nickel contents.

Sulphides in older green schists and tuffs contain much smaller amounts of nickel.

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(1) Quart. Jour. Geol. Soc. Lon., Vol. LIII, 1897, p. 52.

(2) 'On the Igneous Origin of Certain Ore Deposits,' Montreal, 1894, p. 17; also, Ann. Rep. Geol. Surv. Can., Vol. VI, 1892-93, part J.

Sulphides are ordinary primary constituents of norite.

Occurrence of 'pyrrhotite-norite.'

4. Pyrrhotite, chalcopyrite and pyrites are all ordinary constituent minerals of the normal norite, and are, at times, comparatively abundant even in exposures situated some distance from the contact. We may readily obtain, at any of the mines, specimens which exhibit every gradation in the amount of these sulphides present in the rock, from the ordinary type of norite, with occasional disseminated grains of the pyritous matter, to what has been referred to by Vogt, as 'pyrrhotite-gabbro or norite' with from 5 per cent to 50 per cent, or even 80 per cent of pyrrhotite, while portions of some of the deposits, are made of practically pure pyrrhotite and chalcopyrite, with little or no gangue matter.

Sulphides undoubtedly of primary origin.

Similarity of mode of occurrence of sulphides and iron ore.

Occurrence of large masses of magnetite.

Resemblance to iron ore deposits of central Ontario.

5. The sulphides are, undoubtedly, of primary origin, and are among the earliest of the minerals to crystallize out from the original magma, sometimes even antedating the iron ore, in which they are occasionally completely enclosed. They occur in very much the same way as the iron ore, embedded in, or in the immediate vicinity of the various coloured constituents. In fact, individual grains can only be distinguished from one another by their colour in reflected light. This intimate association between the iron ore, not only occurs in the normal norite, but even the ore bodies themselves, especially those of the North Range, which almost invariably contain titaniferous magnetite often in appreciable quantities. Occasionally, considerable masses of magnetite, sometimes several tons in weight, are encountered in the working of the mines, which are completely enclosed in the sulphide material, while this iron ore itself contains disseminated grains of the pyrites, in addition to certain decomposed silicates belonging to the norite. The relations which obtain between the sulphides and the norite, are closely analogous to deposits of magnetite, occurring in connection with certain basic igneous rocks in central Ontario. In these deposits, the magnetite is the abundant ore, while the sulphides are usually present in subordinate amount. The enclosing rock, usually shows much more alteration, than in the case of the norite associated with the Sudbury sulphide deposits.

Evidence that sulphides were formed during cooling of norite magma.

6. The transitional type between the normal norite and the richer forms of the pyrrhotite-norite, furnishes unmistakeable evidence, that in these cases, at least, the sulphides were formed during the cooling and crystallization of the norite magma, and that they were very little affected by any secondary action. The only effects of pneumatolytic or vein action noticed, consisted in the more or less complete alteration of the pyroxene minerals, while much of the plagioclase is surprisingly fresh and glassy. Although, most of the rock matter associated with the ore bodies is more or less decomposed, the alteration is not of the

Alteration not of extreme type.

extreme type, which [illegible] be expected if the whole of the deposits resulted from secondary action. The writer's collection of rocks contains specimens of the pyrrhotite-norite, sometimes containing as high as 10 per cent of the sulphides, from most of the principal mines, which are so free from alteration, as to permit of the precise identification of both the orthorhombic and monoclinic pyroxenes. The rocks in the immediate vicinity of the ore bodies are not, therefore, as generally described, so made up of secondary minerals, as to thoroughly obscure their original composition and structure, but, on the contrary, the least altered representatives of the norite, may readily be obtained at, or in the immediate vicinity of any of the mines.

Occurrence of fresh representatives with high content of sulphides.

Least altered varieties often found in vicinity of mines.

Fournet's series.

7. Fournet has shown, that sulphur, when dissolved in a molten magma of silicates, shows affinity for the metals in the following order: copper, nickel, cobalt, iron, tin, zinc, lead, silver, antimony and arsenic. The small percentages of copper, nickel and cobalt, present in the original magma, unite with the sulphur, and thus become concentrated in any sulphide of iron which separates, while any tin, zinc, lead, silver, antimony or arsenic, present in the magma, is not so concentrated.

Explanation of order of formation of sulphides.

Percentages of nickel, cobalt and copper in nickeliferous rocks of Norway.

8. Vogt (¹) mentions, that if we were to distribute the whole metallic contents of the ore deposits, through their respective mother rocks, in Norway, these would have the following percentages: nickel, 0·03 per cent to 0·12 per cent; cobalt 0·005 per cent to 0·017 per cent; and copper 0·015 per cent to 0·05 per cent. No attempt has been made to calculate these percentages, with regard to the Sudbury District, but the above results are just about what would be expected from our knowledge of the nickel contents, generally, in the basic silicates of rocks.

9. One difficulty which has often been urged against the direct development of these deposits from a state of igneous fusion is, that it would be impossible to obtain such large and comparatively pure concentrations of the sulphides. Mr. David Browne (²) has shown by numerous analyses and diagrams, that in a pot of matte the nickel tends to concentrate towards the centre, while the copper is much richer at the outer margins. This is exactly the experience in mining. 'These observations', Prof. Kemp remarks, 'are extremely important, showing as they do the migration of metallic matter even in so viscous and quickly chilling a mass as a pot of matte.'

Browne has shown that differentiation Takes place in pot of matte.

Proofs of solution of sulphides in eruptive magmas.

10. Vogt believes that eruptive magmas may keep dissolved even very considerable quantities of sulphides, supporting his belief by the

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(1) Min. Industry, Vol. IV, 1895, p. 748.

(2) School of Mines Quarterly, Columbia College, July 1895, p. 297; also Min. Industry Vol. IV., 1895, p. 762.

fact, that basic blast furnace slags usually hold from 3 to 5 per cent of sulphides, especially CaS and MnS; likewise, the basic ferriferous slags from copper, nickel and lead smelting may contain from 4 to 6 per cent FeS and the basic zinc slags even 6 to 8 per cent ZnS. Sandberger separated the dark silicates of many rocks and proved them to contain copper, nickel, cobalt, lead, tin, antimony, arsenic, bismuth and silver.

11. Galena, zinc blende, and compounds of arsenic and bismuth are either completely wanting or present in very insignificant amount.

Compounds of lead arsenic and bismuth rare.

12. The remarkable scarcity of boracic and fluoric minerals and other secondary products which usually attend any pronounced or long continued vein action.

Secondary minerals scarce.

13. Secondary quartz, calcite and dolomite are occasionally present, in appreciable amounts, but the prevailing scarcity of these minerals, at most of the deposits, has always been a subject of remark, and the first mentioned mineral has often been brought from considerable distances, not only to line the converters, but also to add to the furnace charges, even at such mines as the Victoria, where secondary quartz is relatively perhaps more abundant than at any other deposit in the district.

Quartz, calcite and dolomite by no means abundant.

14. Platinum, usually, at least, in the form of sperrylite, is found in small quantities, at all of the deposits. Such an occurrence seems to be closely related to the native platinum and osmiridium metals, in the altered basic olivine rocks of the Urals and elsewhere.

Occurrence of platinum also points to igneous origin.

15. The deposits are singularly uniform in chemical and mineralogical composition, and their monotonous character, in this respect, has been frequently commented upon. A careful study of the analyses will serve to further emphasize this fact. This peculiarity holds good, not only with regard to the Sudbury deposits, but applies with equal force to those of Norway and elsewhere, wherever full details of composition are available. The characteristic minerals of this 'world group,' as it has been called, is everywhere the same. Pyrrhotite, with generally from 2 to 4 per cent of nickel and cobalt, although occasionally reaching as high as 10 to 11 per cent of nickel, pyrite (in Norway relatively rich in cobalt), pentlandite, together with some chalcopyrite, and some of titaniferous magnetite are always present in the norite or gabbro. The nickel minerals polydymite, millerite, etc., are also often present, but only in very subordinate amounts.

Uniformity in composition of deposits.

Occurrence of 'world group' of sulphide minerals.

16. Brecciation, which is so frequently characteristic of these deposits, is an almost constant feature of eruptive contacts, resulting from the detaching of material from the containing walls. The frequent angular

Brecciation, characteristic feature of eruptive contacts.

character of these blocks is due to their imperfect assimilation by the fused basic magma, in which they have been floated off.

Many of these views previously stated.

These are some of the main points, which may be urged in support of the hypothesis of magmatic differentiation, as explanatory of the origin of these Sudbury ore deposits. Many of them are not new, and have been stated in more detail by Vogt, Adams, Kemp and others. They are introduced, in the present instance, as the trend of some of the more recent examinations seeks to ignore the full significance of the intimate genetic relationship which exists between the norite and the ore bodies, affirming that secondary causes or replacement are alone and directly responsible for the present position and dimensions of these deposits.

Trend of some modern work seeks to ignore full significance of association.

Classification of eruptive ore deposits by Vogt.

Vogt, (1) in his classification of eruptive ore deposits, divides them into two chief groups. 1. Deposits formed by 'magmatic differentiation'; that is by the concentration of some metallic parts within the still fluid eruptive magma. 2. Deposits formed by processes subsequent to the eruption or 'after actions' as they have been sometimes called ;—that is by pneumatolysis, fumarole action, hydrothermal agents and the like, directly consequent on the eruption.

Transition between Vogt's subdivisions.

The trend of modern geological investigation, seems to emphasize, more and more, the fact that no really sharp division exists, as indicated by Vogt's subdivisions but that processes, which at the two extremes are manifestly very widely divergent in their effects, are so intimately associated, in time and manner of operation in nature, that the resultant product cannot, with any degree of propriety, be attributed wholly to either group of processes.

Researches of Fouqué and Michel-Lévy.

Thus, although the researches of M. Fouqué and Michel-Lèvy, have clearly shown that diabase and kindred basic eruptive rocks may be artificially reproduced from a simple state of dry fusion, it is equally certain, that no extended intrusive process, produced by natural causes, is ever unaccompanied by a greater or less abundance of superheated waters and vapours, as an integral portion of the fused mass. As a general rule, these heated solutions are relatively much more abundant in the case of the acidic magmas than those of more basic composition. It is thus obvious, that all igneous action is both accompanied and, in a more extended manner, immediately followed by more or less pronounced vein or pneumatolytic action (secondary causes), and certain rocks and mineral occurrences may be representative of the various

Fused magmas always accompanied and immediately followed by superheated waters and vapours.

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(1) Zeit für Prak. Geol., 1893, pp. 4-11 ; 125-143 ; 257-284 ; also 1895, pp. 145-156 ; 367-370 ; 444-459 ; 465-484.

transitions between what has been termed aqueo igneous fusion and igneo-aqueous solution. The abnormally large amount of original or primary quartz, so uniformly distributed throughout the Sudbury norite or gabbro, has been repeatedly mentioned and commented upon by the various geologists, who have examined these rocks in detail under the microscope. It thus naturally follows, that the agencies grouped together under the name of secondary action, would be much more actively effective in connection with the ore bodies and other segregations resulting from the eruption of such a rock, than with the ordinarily less quartzose or basic varieties of such rocks. The manner of formation of these ore bodies, as thus indicated, is much more complex than was at first supposed. There can be no doubt, however, that much of the sulphide material was introduced simultaneously, as an integral portion of the same magma, along with the other minerals of which the norite or hypersthene-gabbro is composed. There can, moreover, be little doubt of the abundant presence of heated solutions and vapours, which were capable of dissolving out, and under certain conditions, of redepositing these sulphides. Such agencies certainly began their work before the whole magma had cooled, bearing their heavy burdens of sulphide material, most of which was obtained from the magma in the immediate vicinity, to occupy the various cavities and fissures as fast as these were formed. The whole of this action was practically completed before the intrusion of the later dykes of the olivine-diabase which are now regarded by the writer, as the end product of the vulcanism to which the norite masses owe their intrusion. In certain of the deposits, the various hydrochemical agencies accompanying dynamic action have been more active than in others, as at the Victoria mine, and some of the Copper Cliff mines, but in others, as for instance, the Creighton mine, magmatic differentiation has been the main and almost sole principle, determining and favouring the development of this the largest and richest sulphide nickel mine in the world. The enunciation, in the first place, of the simple doctrine of the direct igneous origin of these ore bodies and their intimate relationship in this respect, to certain bands of norite or diorite, served an excellent practical purpose, in directing and controlling all the earlier prospecting work.

Significance of occurrence of abundant primary quartz.

Manner of formation of ore bodies much more complex than at first supposed.

Concentration of ore completed before intrusion of diabase dykes.

Magmatic differentiation at Creighton mine.

After all, however, the origin of these ore deposits is largely a matter of theory and opinion, and strong arguments may be adduced in support either of the view, that they are the direct result of magmatic segregation, or that the sulphides were brought up in a state of solution from considerable depths, to replace certain portions of the rock, or to fill up spaces caused by structural weakness. The real practical side

Origin of ore bodies a matter of theory and opinion.

Outlining of norite of great practical importance.

of the geological investigation, consisted in the outlining of the immense masses of intrusive norite or gabbro, with which the nickel and copper deposits of the region are alone associated.

MAGNETIC SEPARATION OF NICKELIFEROUS PYRRHOTITE.

Early separation of pyrrhotite by magnetism.

The application of magnetism, either to free the pyrrhotite from impurities, with which it is so frequently intermixed, in order to obtain a homogeneous and pure product, for analytical purposes, as well as to effect a separation of the nickel present in the pyrrhotite ores, is by no means a novel idea, and many experiments have already been undertaken with this end in view. In 1879, Habermehl succeeded in dividing the Bodenmais pyrrhotite, into magnetic and non-magnetic portions respectively, using fine powder, suspended in water, by a strong magnet. The magnetic portion thus separated, by successive trials, furnished a product which was so homogeneous and uniform, that ten out of fourteen of the determinations for iron content were essentially identical.

Magnetic trials by McTighe.

In 1890, T. J. McTighe (1) applied magnetic separation in the treatment of the nickeliferous pyrrhotite of Canada.

Edison's description of constitution of pyrrhotite.

In July, 1892, Mr. Thomas A. Edison, in applying for a United States patent, embodying the same principle, gave the following explanation in support of his claim. 'I have discovered that when magnetic pyrites, called "pyrrhotite," is nickeliferous, as it usually is, to a more or less extent, the nickel is distributed generally throughout the whole body of the pyrrhotite, but certain crystals are pure pyrrhotite or magnetic pyrites, while other crystals have some of the iron replaced by nickel and sometimes by cobalt, and that the crystals, containing the nickel or cobalt, are considerably less magnetic than the pure pyrrhotite.'

Magnetic experiments by Dr. Emmens.

In the same year, (1892), Dr. S. H. Emmens (2) carried on certain magnetic experiments on material obtained from the Gap mine, Penna, and Sudbury, Ont. These were undertaken, not only for the purpose of testing the accuracy, or otherwise, of the theory of the replacement of a portion of the iron by nickel in pyrrhotite, but also to arrive at a more accurate expression of the composition of pyrrhotite, by means of a formula. The practical side of the question was not ignored, and a

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(1) Ann. Rep. Bur. of Mines, Ont., 1892, p. 164; also Jour. Am. Chem. Soc., Vol. XIV, No. 10.

(2) Ann. Rep. Bur. of Mines, Ont., 1892, pp. 163-166; also Jour. Am. Chem. Soc., Vol. XIV, No. 10.

statement of the relative abundance of the separated portions is given, with their respective contents of nickel.

Methods of separation employed by Dr. Emmens.

Dr. Emmens mentions that he obtained his material from a mine near Sudbury, but does not specify the precise locality. He also neglects to give necessary details of the composition of the ore selected, except that the gangue formed 10·7 per cent of the whole. In regard to the preparation of the material for purposes of separation, he states that the sample was very finely powdered, and carefully separated by means of a magnet into three grades, namely, 'magnetic', 'feebly magnetic' and 'non-magnetic'. The magnetic and non-magnetic grades were then submitted to analysis, resulting as follows, after deduction of gangue.

Composition of separated products.

Magnetic.	Analysis.	Feebly Magnetic.	Non-Magnetic.	Analysis.	Division of total nickel contents.		
					Magnetic portion.	Feebly magnetic.	Non-magnetic.
92·95%	Ni 1·30 Fe 58 27 S 40·43	2·09	4·96%	23·16 33·92 42·92	58 01	7 60	34·39

Magnetic experiments by D. H. Browne.

A short time after (1893), David H. Browne (1) contributed the most valuable article on the question of the magnetic separation of these ores which had yet appeared, showing the existence of a rich nickel-iron-sulphide, almost identic [illegible] hemical composition with pentlandite, which formed the non-[illegible] portion of the separation. In the same article, Mr. Browne quest [illegible] ot only the validity of Dr. Emmens conclusions, as 'hasty generalizations from insufficient premises', but points out, that 'he has never yet found the non-magnetic residue of the analysis given by Dr. Emmens.'

Browne's criticism of Dr. Emmens' results.

Source of material separated by Browne.

The material selected for experimental purposes by Mr. Browne, consisted of carefully hand-picked nickeliferous pyrrhotitite, from the Copper Cliff, Stobie and Evans mines, altogether free from gangue, and with no copper, or at the most [illegible]ly traces of this metal. He mentions that the samples were crushed to pass a 60-mesh sieve, experiment having shown that a very fine powder did not yield such perfect separations. The following tables show, in brief form, the results obtained :—

Preparation of material to be separated.

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(1) "Engineering and Mining Journal", Dec. 2, 1893. page 566.

COPPER CLIFF MINE, (SEVENTH LEVEL.) PICKED NICKEL ORE.

Percentages and composition of separated products.

Analysis of total ore.	Magnetic.	Analysis.	Non-magnetic.	Analysis.	Nickel in magnetic pyrrhotite.	Nickel in non-magnetic pentlandite.
Cu .... 0·00	78·6 %	0·00	21·4 %	0·00	34·00	66·00
Ni.......... 11·00		4·62		35·05		
Fe.......... 50·40		55·70		29·80		
S............ 38·01		38·58		34·35		

STOBIE MINE, PICKED NICKEL ORE.

Cu .... 0·00	97·175 %	0·00	2·825 %	0·00	72·00	28·00%
Ni.......... 2·75		2·15		34·70		
Fe.......... 58·00		57·00		29·90		
S............ 35·35		36·10		33·90		

EVANS MINE, PICKED NICKEL ORE.

Cu.......... trace	84·04	0·00	15·96	0	35·47 %	64·53 %
Ni.......... 9·02		3·82		34·12		
Fe.......... 51·50		56·00		29·95		
S............ 39·2[illegible]		40·18		35·43		

Magnetic work by J. N. Judson.

Samples obtained from Copper Cliff.

Percentages and composition of the separated portions.

In 1900, Mr. J. N. Judson, of the Wetherill Separating Company, carried on an extensive series of experiments, an abstract of the results, accompanying Mr. C. W. Dickson's paper, on 'The Ore Deposits of Sudbury, Ontario'. (1) The material experimented with, consisted of nearly pure pyrrhotite from Copper Cliff, containing by analysis, nickel 3·14, copper 0·42, iron 49·78 per cent. The results showed, that with a current strength of one ampère, on material crushed to 30-mesh, 90·11 per cent of the total sample was magnetic, and this contained 2·46 per cent of nickel or the equivalent of 70·58 per cent of the total nickel in the original pyrrhotite, and 0·22 per cent copper, or the equivalent of 47·48 per cent of the total amount of this metal in the original sample. The remaining, non-magnetic portion, forming 9·89 per cent of the total sample, contained 9·33 per cent nickel and 2·21 per cent copper or 29·42 per cent and 52·52 per cent of the total of these metals, respectively, in the original sample. The other trials, with

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(1) Trans. Amer. Inst. Min. Eng. (Albany Meeting), 1903.

samples of the same material, crushed to pass a 60-mesh, at $\frac{1}{4}$ ampère, showed 86·22 per cent was magnetic and contained 1·92 per cent of nickel. The remaining 3·78 per cent or non-magnetic portion was a comparatively rich nickel ore, but the losses in the magnetic portion were so great, that he concluded that a commercial separation, by means of magnetism, was out of the question.

Magnetic separations by C. W. Dickson.

During the winter sessions of 1901-1902, and 1902-1903, Mr. C. W. Dickson, a post-graduate student at Columbia University, carried on a series of experiments, by means of magnetism, in order to determine, as near as possible, how much of the nickel occurs as a separate mineral, and how much, if any, replaces iron, and also to ascertain the composition of the nickel mineral.

Preparation of material.

A number of representative samples of pyrrhotite were ground to pass through 100 mesh, and the non-magnetic portion was removed, as completely as possible, by repeated treatments with a small horseshoe magnet. The nickel present in the original samples, is given under I, and that, of the magnetic concentrates, under II.

Exhaustive trials to eliminate last traces of nickel from pyrrhotite.

In the second experiment, the original samples were coarsely crushed, and the magnetic portion was sized between 40 and 60-mesh, then freed, as well as possible, from non-magnetic material, crushed between 60 and 80 mesh, and again concentrated By successive treatments, the mineral was finally reduced to fine powder. The ultimate product was then assayed for nickel, and as shown under III, the nickel was much reduced in quantity, but not entirely eliminated.

In the third experiment, to see if it was possible to still further reduce the nickel contents, a number of samples were very carefully prepared. They were coarsely crushed, and the purest mineral selected.

This was crushed to pass through 10 on 20-mesh, and the finest material rejected. All the non-magnetic portion was eliminated, and the concentrate was then crushed to 20 on 40-mesh, the finer part being again rejected. The operations were repeated until the ore was finally ground in an agate mortar, the non-magnetic part being very carefully removed each time. The nickel in the final concentrate is given under IV.

Composition of original sample and separated portions.

Location.	I. Ni & Co	II. Ni.	III. Ni.	IV. Ni.	Description of sample.
1. Elsie mine	2.44	2·22	0 98	....	Fine-grained pyrrhotite.
2. Stobie mine	3.05	2 14	0.68	....	" " "
3. Frood mine	2.40	2 07	1·05	0 65	Coarse " "
4. Mount Nickel mine.	3·06	2·14	0·75	0·70	Medium " "
5. Copper Cliff No. 2 mine...	4·00	2·00	0 70	....	Coarse " "
6. Copper Cliff No. 4 mine...	3 30	2·32	0·83	....	" " "
7 (a.) Creightonmine.........	2·32	2·25	1 20	0 70	" " "
7 (b.) Creighton mine........	4·15	...	....	0 45	Fine " "
8. Gertrude mine..	4·00	2 30	1 10	..	Massive pyrrhotite.
9. Victoria mine....	3·40	2·46	0 80	....	Fine-grained pyrrhotite.

Nickel does not replace iron in pyrrhotite.

Explanation of presence of nickel in magnetic portion.

As stated by Mr. Dickson, the results show in the most conclusive manner, that even in the lower grades of pyrrhotite, the nickel is not present, as replacing part of the iron in the pyrrhotite, but exists as a separate mineral. The fact, that all the nickel could not be eliminated by the methods used, does not indicate, that even the small amount that remained was an essential part of the pyrrhotite, as several factors enter which render its complete removal practically impossible. In the first place, the nickel mineral is very intimately associated with the magnetic pyrrhotite and even a minute adhering fragment of the latter, will cause it to be carried over with the magnetic portion. It must also be noted, that the nickel mineral itself is slightly magnetic and in the form of a fine powder, is attracted by even a small magnet.

Magnetic work by W. M. Ogilvie for Geological Survey Dept.

Selection and location of samples.

Strength of magnetic current.

Creighton mine ore least magnetic.

The magnetic experiments, in connection with the present work, were carried on by Mr. W. M Ogilvie, B. A. Sc., by means of a Wetherill magnetic separator of the ordinary type, in the mining laboratories of McGill University, the authorities, with the recommendation and approval of Dr. J. B. Porter, having kindly placed the machine at the disposal of the writer, for a considerable period, during the winter of 1901-1902. The samples selected, consisted of the richer grades of ore in use at the different mines. Such samples were obtained from the Creighton, Victoria, Cryderman and Mount Nickel mines, the Tough and Stobie property, in Levack township, and the Cochrane property, near Blue lake, on the Northern Nickel Range. It is to be regretted, that the chemical analyses could not be undertaken while the experiments were in progress, as otherwise much more important results could have been obtained. The voltage of the current employed was 110 and the strength of the current was varied according to the magnetic permeability of the different samples. The least magnetic of the material, was that obtained from the Creighton mine, and with such material, a current as high as 15 ampères was employed, while the pyrrhotite from the Cochrane property, on the Northern Nickel Range, was so strongly magnetic, that much weaker currents had to be used, the greatest reaching a strength of only 1.5 ampères.

Preparation of material for separation

In the case of the Creighton mine, the original sample weighing 36 pounds, was divided into two products, according to the size of grain obtained by crushing. The first product was obtained by passing the powdered mineral through a 40-mesh sieve, and catching it on a 100-mesh sieve, this part weighing 21 pounds. The second product, 15 pounds, was made up of the finer material which passed through the

Composition of original samples of Creighton mine ore.

Percentage of separated products.

Assays by Mr. Donald Locke.

Loss in magnetic portion too serious to be neglected.

Division of copper contents.

Separation of gangue.

100-mesh sieve. The coarser phase of the original sample gave the following analysis, insoluble 2.28, copper 0·72, nickel 5·31 and sulphur 34.28 per cent. The composition of the finer material was, insoluble 2·49, copper 1·20, nickel 4·87 and sulphur 34·67. Each of these two original samples, was divided into three equal portions, and subjected to magnetic currents of 1·5, 3·8 and 15 amperes respectively. By means of the magnetic current, each of these three portions was again subdivided into three grades, which may be designated as 'magnetic'; 'feebly magnetic' and 'non-magnetic'. The coarser material showed that the magnetic portion varied from 86·3 to 90·2 per cent of the whole sample, with a loss of 2·4 to 9·7 per cent in handling, which loss, however, could be over come, while the feebly magnetic portion contained from 4·2 to 8·6 per cent, and the non-magnetic from 1·3 to 2·7 per cent. In the finer material, the magnetic portions varied from 74·6 to 78·3 per cent, the feebly magnetic from 2·3 to 10·9 per cent, while the non-magnetic varied from 4.1 to 8 per cent. The loss, in the case of the fines was very great, owing to the dust adhering to the belts, the percentages of such loss varying from 9·2 to 11·4 per cent. Assays of all the separate products from the Creighton mine were made by Mr. Donald Locke, who for a short time was attached to this Department as assayer and metallurgist, but certain unexplained discrepancies in the results, will prevent, at present, the publication of all the details of the chemical investigation. In this connection, however, it may be sufficient to state that a very rich nickel ore was always obtained, the greater part of which was contained in the feebly magnetic portion, although a small proportion was carried over into the tailings or non-magnetic portion. The loss, however, in the magnetic portion, amounting to from 40 to over 50 per cent of the total nickel present in the original ore, was too serious to be disregarded. In addition to the nickel present, the magnetic part also contained from 28 to 48 per cent of the total amount of copper present in the original ore, while from 16 to 18 per cent is contained in the feebly magnetic part, and the remainder is carried over with a large proportion of the gangue into the non-magnetic residue, which is really a very rich copper concentrate, some of the assays showing as high as 28·38 per cent of this metal. The proportion of gangue present in the non-magnetic residue, generally amounts to about one-third of the total product.

Fine material free from dust gives best separation.

The best separation is effected on the fine material, although the presence of dust must be avoided, as this clings to and fouls the belts. The stronger the current, the greater the proportion of nickel remaining in the magnetic portion, while, at the same time, although the total amount of nickel present in the feebly and non-magnetic portions is less, the assay value of such products is much higher, and some of these, which were examined in detail, consisted almost wholly of pentlandite, with intermixed chalcopyrite. Thus, the feebly magnetic product of the fine material, obtained by using a current of 3·9 ampères with only one trial, showed, on analysis, the following composition, insoluble 5·81, copper 1.52, iron 30·41, nickel 30·01, sulphur 33·56 per cent. Knowing the composition of the pentlandite and chalcopyrite, and distributing the above constituents in their proper proportions in these minerals, we find that this product consists of chalcopyrite and pentlandite in the ratio of 1 : 21. In the same way the non-magnetic product obtained by using a current of 1·5 ampères on this fine material and from which most of the gangue had been removed by means of hydraulic separation, showed, by analysis, the following composition, insoluble 2.66, copper 3·58, iron 30·01, nickel 30·36 and sulphur 33·77 per cent. This product is made up of chalcopyrite and pentlandite in the proportion of 1 : 7.

Composition of feebly magnetic portions.

Proportions of pentlandite and chalcopyrite.

Composition of non-magnetic portion.

Percentages of separated products in Victoria mine ore.

In the Victoria mine's separation, the ore was much more strongly magnetic, and the currents employed were only 0·2 and 1.5 ampères. The magnetic portion varied from 86·4 to 90.6 per cent on the coarser material, while with the fine material, using a current of 0·2 and 1·2 ampères, the magnetic part varied from 71·4 to 86·7 per cent. The feebly magnetic part never exceeded 2·1 per cent and in one case was as low as 0·5 per cent. No assays of these products, however, have been made, as the results obtained in the case of the Creighton mine, although of great scientific and practical interest, demonstrated rather clearly that under present conditions, an economic and commercial separation of these ores is out of the question.

Cryderman mine ore more magnetic than that from Creighton.

Preparation of material and methods of separation.

Percentages of separated products.

The Cryderman mine ore is also more magnetic than the Creighton mine, although less so than the Victoria. The original sample, on which the experiment was conducted weighed 30 pounds. This was divided into two portions, according to size, one portion consisting of crushed ore which passed through a 40-mesh and was caught on a 100-mesh sieve and finer material consisting of ore which passed through the 100-mesh sieve. The current used had a strength of 0·2, 1·5 and 4 ampères respectively. The magnetic portion of the coarser product varied from 75 to 85·6 per cent, the feeble magnetic from 2 to 7·7 per cent and the non-magnetic from 1·9 to 2·3 per cent. There was no loss using the 0·2 and 1·5 ampères current but with the 4 ampères current the loss was 4·8 per cent. With the finer material the magnetic part varied from 65·6 to 71·8 per cent, although the loss of 10·9 per cent belongs very largely to the first mentioned amount. The feebly magnetic part varied from 1·6 per cent to 17·2 per cent, the latter amount being obtained with the 4 ampères current, while the non-magnetic varied from 6·3 to 28·1 per cent.

The magnetic separation of the ore from the Nickel Mountain mine was effected by using currents having a strength of 1·5, 3·8 and 13·5 ampères respectively. The original simple weighed 63 pounds. The magnetic part of the coarser product (through 40-mesh on 100-mesh), varied from 91·2 to 92·5 per cent with losses of 0·9 and 2·5 per cent respectively, the feebly magnetic from 4 1 to 4·4 per cent, and the non-magnetic from 1·2 to 3 8 per cent. The losses varied from 4 to 5·7 per cent and are accounted for by the fact that the fine material has a great tendency to stick to the belts. Also the cross belts were given their maximum velocity to effect the best separation.

Magnetic separation of Nickel Mountain mine ore.

Percentages of separated portions.

The original sample from the Levack property (Tough and Stobie's), weighing [illegible] pounds was crushed in the same way as the above, and the magnetic currents used had a strength respectively of 0·2, 1·5 and 3·8 amperes. The magnetic portion varied from 92·5 to 96.3 per cent, with losses belonging chiefly to this part of 1·9 to 2·5 per cent, the feebly magnetic from 1.3 to 3·8 per cent and the non-magnetic from 1·3 to 2·5 per cent. With the fine product, the magnetic portion varied from 91·6 to 93·8, with a loss in one instance of 1·9 per cent, the feebly magnetic from 1·1 to 2·1 per cent, and the non-magnetic from 5·2 to 6·3 per cent.

Magnetic separation of Levack ore.

Percentages of separated products.

The pyrrhotite from the Cochrane property on the Northern Nickel Range is very strongly magnetic and the current used had a strength of 0·2 and 1·5 ampères. The magnetic portion of the coarser product varied from 85·3 to 89 per cent, with a loss of 1·4 to 2·8 per cent, the feebly magnetic 1 to 4·8 per cent and the non-magnetic from 4·8 to 10.9 per cent. With the finer material, the magnetic portion varied from 77.7 to 83 per cent, the feebly magnetic from 0·8 to 4·1 per cent and the non-magnetic from 15·2 to 18·2 per cent.

Magnetic separation of pyrrhotite from North Nickel Range.

The various factors which enter into the construction of the Wetherill magnetic separator suggested, at the the outset, that by its employment, it might be possible to accomplish a separation on a commercial basis, which, at the same time, would be much more thorough and complete, than any previously recorded attempts, making use of different types of hand magnets Thus, it was possible on this machine, not only to vary at will the strength of the magnetic current, to be used, but also to make any required adjustment in the distance between the two magnets, while, at the same time, the speed of the

Wetherill separator very efficient.

Various adjustments available.

Expectations from separation work.

belts was under complete control. With these refinements or aids to efficient separation, it was hoped to make such a thorough division of the products, that the nickel present in the magnetic portion would constitute such a small proportion of the whole, as to render this product of no commercial value, and thus, at one simple operation, get rid of about 80 per cent of practically barren ore. At the same time, it was believed that the feebly and non-magnetic portions would contain by far the larger proportion of both the nickel and copper.

Trials disappointing and so far of no great practical importance.

The preliminary trials of the Creighton mine ore, and assays of the separated products were disappointing, as they showed most conclusively that an efficient and economical separation by this method was impossible. It was, therefore, considered unwise to analyze the products from the other mines, although the main facts in connection with these separations have been mentioned.

Dickson and Judson both conclude that magnetic separation is a commercial impossibility.

About the same time, Mr. C. W. Dickson published the results of his magnetic experiments, which gave further emphasis to this conclusion. Mr. Dicksen's final utterance on this subject, published in 1903, also contained a summary of Mr. J. N. Jadson's results, to which reference has already been made, all tending to show that the removal on a commercial scale of the nickel from the pyrrhotite, by magnetic methods, is, in the light of our present experience, an impossibility. On the other hand, the fact that all of the nickel cannot be eliminated from the pyrrhotite, does not prove that even the portion remaining, occurs as a replacement of an equal amount of iron, in chemical combination. Examination under the microscope, reveals the fact that even the smallest grains of sulphide material, are often made up of intricate intergrowths of chalcopyrite and pyrrhotite, which minerals, moreover, can be distinguished from one another by the use of reflected light. Such an intimate relationship, doubtless, obtains in the case of the pyrrhotite and pentlandite, although this could not be proved, as these minerals cannot be separately recognized under the microscope. In addition, a large proportion, at least, of the pentlandite, is itself feebly magnetic, and this is apt to remain with the pyrrhotite.

Sulphides intricately intergrown with one another as shown by microscope.

Difficulties of obtaining pure product by magnetic methods.

The difficulty of obtaining an absolutely pure product, even of minerals of widely different magnetic permeability, is well known to all who have carried on experiments in magnetic separation, so that it is not surprising, that the magnetic portion of the separated sulphide, always contains an appreciable amount of nickel. In the light of our present experience, it is safe to say that the nickel is doubtless present as very minute grains of pentlandite embedded in or adhering to the grains of pyrrhotite. The fact that material originally containing 5·31 per cent of nickel, with the application of a current of 1.5 amperes on material crushed, to only pass through a 40-mesh sieve can, at one operation, be separated into a magnetic product containing only 1·48 per cent of nickel, while this, in turn, by successive grinding and magnetic treatment, can be ultimately forced to give a product which contains less than 0·50 per cent of nickel, is in itself sufficient proof, for regarding all the nickel in these Sudbury ores as occurring in the form of a distinct sulphide, chiefly pentlandite. With all of the foregoing results we may well pause and repeat with Dickson the question, 'Is there such a thing as a true nickeliferous pyrrhotite?' and we might even extend it and ask, is there such a thing as a true nickeliferous pyrite? The matter is still open for further investigation, although at the present stage, the 'onus probandi' rests with those chemists and mineralogists, who are still wedded to the old idea. A most convincing proof might be possible, by repeated magnetic treatment of some of the masses of pyrrhotite occuring in central Ontario, which are known to contain from 0·05 to 0·23 per cent of nickel. Any enrichment of the feebly magnetic or non magnetic product obtained from the separation of such material, would no doubt furnish the most ample proof, which even the most skeptical would be forced to accept.

Proof that all of the nickel is present as pentlandite.

Is there a true nickeliferous pyrrhotite or pyrite?

More experiments needed and suggestions for their undertaking.

LOCATION OF PYRRHOTITE DEPOSITS BY MAGNETOMETRIC MEASUREMENTS.

The magnetic permeability of pyrrhotite early suggested the employment of magnetic instruments, to determine the location of valuable deposits of this nickel bearing sulphide in the Sudbury District. All the earlier measurements, however, were made by means of the ordinary dip-needle and the observers were content to obtain such data as would enable them to form a rough judgment of the approximate area underlaid by rocks containing more or less of the magnetic pyrrhotite, although this mineral might be so sparsely disseminated as to be of no economic importance.

Early employment of dip needle to locate pyrrhotite deposits in Sudbury District.

In 1901, however, it was decided by the Mond Nickel Company, to inaugurate a more extensive and elaborate system of magnetic surveying, not only in examining the properties they had already purchased, but also in determining the probable value of other nickel properties which were known to be in the market. It was realized that such delicate instruments as the Thalen-Tiberg magnetometer, in the hands of experts who had been trained in the Swedish methods, would yield data in regard to the location and extent of workable deposits of pyrrhotite,

Extensive magnetic surveying by Mond Nickel Company.

Employment of Swedish instruments and experts.

Magnetic work by Kojer and Nystrom.

Deposits magnetically surveyed.

which would enable a very close estimate to be formed of their commercial value. Early in the spring of 1901, Messrs. Karl Kojer and Erik Nyström, mining engineers of Stockholm, Sweden, and pupils of the well known Professor Nordenstrom were engaged. Mr. Kojer only stayed about a month, but Mr. Nystrom was employed for the greater portions of the two seasons of 1901 and 1902, in making detailed magnetic surveys of various mining locations and mines in this district. Most of the lots in the vicinity of the main shaft of the Victoria mines were thus minutely examined, and later, other properties such as the Murray, Lady Violet, Mount Nickel, Beatrice and Cryderman mines were also similarly treated. A magnetic survey was also made of the Cochrane property on the Northern Nickel Range. It is impossible to get the details of the results of this work, as the maps which were prepared with great care, are the property of the Mond Nickel Company, the information being regarded as of a confidential nature.

Relative magnetic permeability of pyrrhotite.

Methods employed in magnetic surveying.

Work by Thomas A. Edison and assistants.

Magnetic surveys made by Robert and Kay for Lake Superior Power Co.

Report by Dr. Haanel.

The value of such work, however, when properly undertaken, is beyond all doubt, although, considerably more care and expense is necessary, than is the case with magnetite. Speaking roughly the magnetic permeability of magnetite is about five times as great as pyrrhotite although this latter mineral varies very greatly in this respect. It is, therefore, imperative, that the lines along which the magnetic observations are made, should be correspondingly closer together. In most of the detailed work undertaken by the Mond Nickel Company these lines were only separated by intervals of 20 feet, while, in some special cases, where fuller information was desired or necessary, a distance of only 10 feet intervened between the various observation stations. For some time, commencing in 1902, Mr. Thomas A. Edison carried on rather extensive magnetic surveying in the area between Sudbury and Wanapitei lake, with a view of discovering new deposits of nickel ore. The efforts of the several parties engaged in this work, are stated to have met with a considerable degree of success, as on the strength of the information obtained, various mining locations were applied for. Messrs. J. A. Robert and G. F. Kay, have also conducted magnetic surveys under the auspices of the Lake Superior Power Company. The publication of Dr. Haanel's report (1) 'On the Location and Examination of Magnetic Ore Deposits by Magnetometric Measurements' should stimulate this method of inquiry, not only in connection with these pyrrhotite deposits, but also as regards our magnetic iron deposits. It is the only detailed account of the Swedish

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(1) Published by the Department of Interior, Ottawa, Canada.

method which has yet appeared in the English language. With the exception of magnetic observations to assist in the geological mapping, chiefly, of the iron formations and associated rocks of the Lake Superior district, details of which are furnished by Prof. H. L. Smyth (²), no very extensive use of magnetic instruments has been made in any other country outside of Sweden. The Swedish instruments may be obtained from J. Fr. Berg, instrument maker, Stockholm, and are the most perfect and suitable for the work, which have yet been manufactured. All necessary descriptions and information in regard to their operation may be obtained by consulting Dr. Haanel's work which he hopes may be of service to the mining profession.

Use of magnetic surveying by Prof. H. L. Smyth.

Where Swedish instruments may be purchased.

CLASSIFICATION AND GENESIS OF NICKEL ORES.

Mineralogically, the ores of nickel may be divided into eight classes, as follows: 1. Sulphides; 2. Arsenides and sulph-arsenides; 3. sulph-antimonides; 4. Sulpho-bismuthides; 5. Tellurides. 6. Silicates: 7. Oxides and Salts; 8. Carbonates.

Mineralogical classification of nickel ores.

Many of the nickel minerals, included under these divisions, are unimportant in an economic sense, and Vogt (¹) has shown that all of those which are commercially valuable, fall naturally into three main groups.

Vogt's classification of nickel ores into three groups.

1. Ores containing arsenic and antimony, with or without bismuth, such as niccolite, gersdorffite, chloanthite, &c.

Ores containing arsenic and antimony.

2. Sulphide ores (without arsenic), as for example, nickeliferous pyrrhotite and pyrite, pentlandite, polydymite, millerite, &c.

Sulphide ores

3. Silicated nickel ores, such as genthite, garnierite, &c.

Silicates of nickel.

The arsenides and sulph-arsenides, belonging to the first group, occur principally in veins, as for instance, the old and well known metalliferous lodes of Saxon and Hungary: Mine la Motte and Bonne Terre, in Missouri; the Gem mine in Fremont county, Colorado; the Macdonell or Gersdorffite mine, in the Sudbury District, Ont.; and the recently discovered deposits near Haileybury on the west side of Lake Timiskaming, Ontario.

Principal localities where arsenide ores are found.

By far the largest deposits, belonging to the second group, are the nickel-copper sulphide ores, of the Sudbury District, in Canada, which are the subject of the present bulletin, but Norway has, for many years, operated, on a large scale, precisely similar concentrations. Other

Chief localities where sulphide ores are found.

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(2) Trans. Amer. Inst. Min. Eng. Vol. XXVI. pp. 640-709.

(1) Zeit fur Prak. Geol., 1893.

Where nickel silicates occur.

closely related ore bodies have also been worked as mines, as at Varallo, in Piedmont, Italy and at Lancaster Gap in Pennsylvania. The deposits which have been partially developed and worked, near St. Stephen, in the Province of New Brunswick, Canada, are also apparently of the same nature. The most celebrated and extensive of the deposits, representative of the third group, are those of New Caledonia. Important bodies, however, of similar silicates, are known to occur, and have been developed, to some extent, near Riddle's, in Douglas county, Oregon, and near Webster, the capital of Jackson county, in western North Carolina.

Geological associations and origin of arsenides and sulph-arsenides of nickel.

The veins of the first group occur, either, penetrating, or in intimate connection with eruptive rocks of the peridotite or gabbro type, and are generally found in the more decomposed or altered portions. These basic igneous rocks, as is well known, contain appreciable quantities of nickel, as a normal constituent. The extremely rich nickel ore, contained in these veins, has therefore, evidently been derived from the leaching out of the nickel from the neighboring rock, during certain processes of alteration, to which it has been subjected.

Sulphides, direct result of magmatic differentation, modified by some secondary action.

The method of formation of the sulphide deposits of the second group, typified by the Sudbury deposits, has already been discussed at length, and the conclusion reached, that they are the direct product of the differentiation of a basic igneous magma, modified, to some extent, by processes, which are usually grouped together under the designation of secondary action.

Geological associations of silicates of nickel.

The silicates of nickel are always confined to areas underlaid by intrusive masses of non-felspathic basic magnesian rocks, of the peridotite family, the several varietal forms of which are distinguished from one another by the names of dunite, saxonite, websterite and lherzolite These rocks are always more or less decomposed to a serpentinous material, so that the type of rock with which these deposits occur, is usually described as serpentine.

Mode of occurrence of silicates of nickel.

The ore rarely crops out at the surface, but is covered with a thick mantle of decomposed material, from which most, if not all, of the nickel has been leached, to be concentrated in places a few feet lower down. This covering or soil is very highly ferruginous, with occasional large 'chert' fragments lying about. These pseudo-boulders of so-called chert, are considered a favourable sign, in prospecting for the ore bodies, for they invariably indicate the presence of the peridotite beneath.

Explanation of occurrence of 'chert' fragments.

They really represent residual portions of the peridotite, which escaped the wholesale decomposition, on account of their being held together by an intricate series of quartz veinlets, the interstices of which are

Nickel bearing gossan.

occupied by only partially decomposed peridotite. The surface mantle or soil usually varies from nothing, up to a few feet, when it gives place, gradually, to a loose, brownish material, representing the decomposition of the peridotite 'in situ.' This usually shows abundant, but small and intricate veins and veinlets of the greenish silicate of nickel and magnesium, often with abundant scales of chrome mica. In places, irregular fissures and cavities, often of considerable size, are occupied by rather pure silicate material. This brownish, loose material gives place, in turn, to a brownish, soft, friable rock, filled with smaller but harder and rich veinlets of the nickel silicate, while this, again, is replaced further down, by the unaltered peridotite, which, it is believed, will contain little or none of the silicate concentrations.

Determinations for nickel in peridotite rocks associated with silicated ores.

Origin of silicated ores of nickel.

Comparatively shallow deposits.

Attractive deposits.

Analyses of the associated dunite or websterite, from the North Carolina occurrences, show the undecomposed rock to contain, from 0·15 to 0·35 per cent of nickel oxide, while the saxonite, in which the Oregon occurrences are developed, contains, according to Diller, 0·10 per cent of nickel oxide, while the olivine itself, of which the rock is mainly composed, contains 0·26 per cent of nickel oxide. This is a very usual occurrence, and the undecomposed peridotite of New Caledonia often contains as high as 1 per cent of nickel oxide. Similar rocks, from the Eastern Townships of Canada, show the presence of 0·15 to 0·26 per cent of oxide of nickel, without cobalt while the associated chromic iron ore also contains 0·22 per cent of oxide of nickel, with distinct traces of cobalt. It is almost impossible to collect any of the brownish material, resulting from the decomposition of these peridotites, without finding an appreciable amount of nickel present. It appears certain, therefore, that the nickel has been leached out of the surrounding rock, and redeposited along with silica and magnesia in all available cracks and interspaces. The peridotite is always readily decomposed under ordinary conditions of atmospheric decay, the magnesia being the first ingredient to be carried away in the form of a carbonate. This is followed by the silica and nickel, which is redeposited at lower levels and in suitable places. The result of such an origin, will be the occurrence, at these several localities mentioned, of comparatively shallow deposits, their downward extension, depending almost entirely on the depth to which decomposition has proceeded. On the other hand, the ease with which many of these deposits may be mined, and the large amount of comparatively rich and desirable nickel ore, which may be thus secured, make them particularly attractive.

DISTRIBUTION OF NICKEL ORES.

Ores of nickel of world wide distribution but rarely of economic importance.

Ores of nickel are much more evenly and abundantly distributed over the whole world than is generally supposed, but in only a few countries are the deposits of such dimensions, as to warrant their development as working mines, and, at the present day, the mines of New Caledonia, and those of Sudbury produce almost the whole of the world's supply of nickel.

Vein deposits of Saxony and Hungary.

Small quantities of the arsenides and sulph-arsenides of nickel are found in association with ores of silver, lead, bismuth and cobalt, in the well known veins of Saxony and Hungary. As a rule, however, this nickel may be regarded as a by-product obtained in the refining of these ores, and although valuable, it forms a comparatively small proportion in comparison with the other metals present.

Nickel ores in Sweden, Finland and especially Norway.

Nickel in Scotland, Ireland and Wales.

Nickel also occurs in Sweden and Finland, and the famous deposits of Norway, for many years produced a comparatively large proportion of the nickel of the world. Nickel is also known to occur in Scotland while the serpentines of the west of Ireland, and those of Cornwall, a contain a little nickel associated with them.

Nickel in Russia.

Nickel in U.S.A.

Nickel at Mine la Motte.

Nickel in Colorado.

Nickel in California.

Nickel in Connecticut.

In Russia, nickel has been reported from Rewdinsk and Zangi [illegible] The most celebrated deposit of nickel in the United States is a Gap mine, in Lancaster Co., Pennsylvania, but this mine suspended operations in 1891. The domestic production of nickel in the United States is, at present, all derived as a by-product, from the treatment of the lead ores, which are found in the mineralized portion of the sedimentary limestones at Mine la Motte, Missouri. Very rich nickel ore has been found in the 'Gem mine' in Fremont Co., Colorado. Nickel minerals are also known to occur at other localities in this state, as for example, in the hornblendic rock near Salida, associated with copper, and also in small quantities, in some of the ores from the Leadville region. The occurrence of nickel has also been reported from several places in California. At the Kelsey mine, in Los Angeles county, nickel and cobalt are found in the form of arsenates, together with silver-glance and native silver, in a fissure vein, in close relation with a dyke rock, probably diorite. The associated ores contain 7 to 15 per cent cobalt, and 2 to 3 per cent nickel, and 1,000 to 1,400 ounces of silver per ton. (1) Nickel also occurs at the cobalt mines near Chatham, Connecticut. Some important bodies are known to exist in Nevada but these have not been extensively developed. Nickel ores are also

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(1) Proc. Col. Sci. Soc. [illegible] l. IV, 1891-93, pp. 419-20.

reported from Idaho, Arizona and New Mexico. Rich ores of nickel also occur in the copper district south of Lake Superior. The most important deposits of nickel ore at present known to exist in the United States, are the silicates of North Carolina and Oregon, to which more detailed references will be made.

Nickel in Idaho, Arizona, New Mexico.

In Canada, the distribution of the nickel deposits occurring at Sudbury, have already been described, but important bodies of similar sulphide material are also known to occur, and have undergone preliminary development at St. Stephen, New Brunswick. Other occurrences are reported from British Columbia, and the Province of Quebec, but these are at present of no economic importance. In Newfoundland, rich nickel ore has been found in considerable quantities at the Union mine, at Tilt cove, in Notre Dame bay. Australia, New Zealand, South Africa and Chili, all contain deposits of nickel ore, but New Caledonia is the only formidable rival with which Sudbury has at present to deal.

Nickel ore near St. Stephen, N.B.

New Caledonia only possible rival of Sudbury.

NICKEL IN CANADA.

The Wallace mine, about a mile west of the mouth of the Whitefish river, on the north shore of Lake Huron, is of historic interest, as being the first place in which the presence of nickel was recognized in Canada. It was first opened as a copper mine, in 1847. During the season of 1848, this location was visited by Mr. Alex. Murray, Assistant Provincial Geologist, who reported on the geological associations and probable extent of the deposit. (1) This occurrence has also been described by Mr. C. W. Dickson (2), as consisting of pyrrhotite, pyrite and chalcopyrite, occurring at the junction of two small dykes of mica-diorite, which are intruded into the surrounding quartzites. The mining development work undertaken did not reveal any large body of ore, and although a considerable amount of copper ore was encountered, in assotion with a rich arsenical ore of nickel, the occurrence of the latter in very small veins, adjacent to the southern wall of the mine, did not encourage extensive mining operations, and the mine was accordingly soon abandoned. The material, obtained by Murray, in 1848, was handed to Dr. Hunt for analysis. This specimen, weighing forty-five ounces, is described by Dr. Hunt, as 'a steel grey arseniuret, the species of which I have not yet determined, with iron pyrites and pro-

Nickel first noticed in Canada at Wallace mine.

Description of Wallace mine deposit by C. W. Dickson.

No large body of ore.

Mine abandoned.

Description by Hunt of specimens collected by Murray in 1848.

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(1) Rep. of Progress, Geol. Surv. Can., 1848-49, pp. 42-45; also pp. 61-64; also Geol. of Canada, 1863, pp. 59-60, 506, 695, 737; also Min. Res. Ont., 1890, pp. 24, 67, 91 and 97.

(2) Trans. Amer. Inst. Min. Eng. 1903.

Character and chemical composition of ore of Wallace mine.

bably some arsenical sulphuret of iron.' The analysis of the whole mass, when powdered, gave the results under I. The first five substances making 59·30 per cent of the ore, are separated, as corresponding to the metallic portion of the mass, although, it is probable, that a portion of the iron is derived from the gangue. The cobalt equals about three parts in a thousand of the weight of the nickel. Removing the gangue, and re-calculating the remainder to 100, we get the results under II.

	I		II
Iron	24·78		41·79
Nickel (with a trace of cobalt)	8·26		13·93
Arsenic (mean of two determinations)	3·57		6·02
Sulphur	22·63		38·16
Copper	0·06		0·10
		59·30	100·00
Silica	28·40		
Carbonate of lime	4·00		
Magnesia	4·40		
Alumina	3·21		
		40·01	
		99·31	

Description and chemical composition of niccolite and domeykite of Michipicoten island.

Two ores of nickel are described by Dr. Hunt, (1) as occurring 'in a vein, cutting a bed of amygdaloid, on Michipicoten island, in Lake Superior. The first of these is a brittle, massive ore, associated with quartz and having a brilliant metallic lustre and a colour varying from tin-white to bronze-yellow. Its hardness is 5 and its specific gravity varies from 7·35 to 7·40. The mineral is variable in composition. The results of four analyses were as follows :·

	I	II	III	IV
Arsenic	37·36	44·67	.....	.....
Copper	44·70	30·81	27·60	10·28
Nickel	17.03	24·55	27·29	36·39
Silver	.....	0·25	0·21	.....
Total	99·09	100·28		

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(1) Geol. of Can., 1863, pp. 506 and 737.

The above variable results are due to the material analyzed, consisting of a mixture, in different proportions, of niccolite (nickel 44·1 per cent and arsenic 55·9 per cent) and domeykite (copper 71·7 per cent and arsenic 28·3 per cent).

Description of occurrence and chemical composition of silicate of nickel of Michipicoten island.

The second ore, said to be from the same mine as the preceding, occurs as the gangue of native copper and native silver, which are scattered through it in grains. The material is amorphous, greenish-yellow or apple-green in colour, with a waxy lustre and a conchoidal fracture. It is very soft, polishing under the nail, and falling to pieces when immersed in water. It is decomposed by acids, and is found to be essentially a hydrated silicate of nickel. Under I, is an analysis of one specimen dried at 212° F. Under II, is an analysis of another specimen dried at a higher temperature. It contains, besides, traces of cobalt and copper, and appears to be identical with nickel-gymnite or genthite. Under III, is a partial analysis of a specimen, which contained small disseminated grains of the native metals.

	I	II	III
Silica	33·60	35·80	....
Oxide of nickel	30·40	32·20	20·85
Protoxide of iron	2·25	.....	.....
Lime	4·09	.....	.....
Magnesia	3·55	.....	.....
Alumina	8·40	.....	....
Water	17·10	12·20	.....
Cobalt	.....	traces	.....
Silver	....	.....	2·55
Copper	.....	traces	18·51
	99·39		

Niccolite in Thunder Bay District, Ont.

The arsenide of nickel (niccolite), has also been found at the 3 A mine, on lot 3 A, of the township of McGregor, in the District of Thunder Bay, Ont., where it occurs in somewhat large, nodular grains and bunches, together with native silver, of a similar form, freely disseminated through a gangue of calc-spar, with some quartz. (¹)

Nickel in basic magnesian rocks of Province of Quebec.

Nickel is seldom or never absent from the magnesian rocks of the Eastern Townships, in the Province of Quebec, and the various serpentines, steatites, diallages, actinolites, etc., always contain small quantities of this metal, rarely, however, more than two or three thousandths. It has never yet been found in any considerable quantities, although

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(1) Ann. Rep. Geol. Surv. Can. Vol. V, 1890-91, Part R, p. 47.

Nickel from Montreal river.

the chromic iron ore from Ham, gave, on analysis, 0·22 per cent of oxide of nickel. (1). Dr. Harrington also found a small amount of nickel, in the serpentine, brought by Dr. Bell, from Pigeon lake, on the Montreal river, Ontario. (2)

Orford Nickel mine.

Mining for nickel was, at one time, carried on at lot 6, con. XII., of the township of Orford, in the Province of Quebec, but operations had evidently been suspended for a considerable time, before the year 1883, when Mr. Willimott visited the locality. (3) The presence of nickel at this locality, had been known for a long time (4) but the deposit had not been opened up as a mine, until long after its discovery. The location, known as the Orford Nickel mine, was developed by means of two small shafts, sunk on what appears to be a large calcite vein, enclosing small transparent green crystals of chrome garnet, and often penetrated by long filaments of pyroxene, of a greenish or yellowish colour. The chrome garnet also forms large granular masses, holding sparingly disseminated, small, brass-like grains and crystals of millerite. The largest crystals, however, are generally found penetrating a beautiful cleavable variety of calcite, and often exceed three inches in length. The houses, mining buildings and smelting furnaces were abandoned in 1883, with the exception of one house, which was occupied by a caretaker.

Description of deposit.

Occurrence of millerite.

Mine abandoned before 1883.

Nickel from Joliette Co., Que.

A sample of iron pyrites, from the eleventh concession of the Seigniory of Daillebout, Joliette Co., in the Province of Quebec, yielded Dr. Hunt, 0·55 per cent of oxide of nickel (= 0·43 per cent of nickel) mixed with cobalt. (5)

Nickel bearing pyrite at St. Jerome.

A carefully picked sample of iron pyrites, occuring on lot 163 of the cadastral plan of St. Jerome, P.Q., was analyzed by Dr. Harrington and found to contain copper 0.05 per cent, cobalt 0.22 per cent and nickel 0.10 per cent. (6)

Pyrite with nickel aad cobalt at N. Burgess, Ont.

Dr. Hunt mentions that a bronze-coloured, impalpable variety of iron pyrites, in irregular, reniform or globular masses, which occurs with copper pyrites, in the township of North Burgess, Ont., gave him on analysis, 3.47 per cent of cobalt and 2.21 per cent of nickel. (7)

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(1) Rep. of Progress, Geol. Surv. Can. 1853-56, pp. 435-474; also Geol. of Can. 1863, pp. 507 and 614.

(2) Ann. Rep. Geol. Surv. Can., 1876-77, p. 483.

(3) Rep. of Progress Geol. Surv. Can. 1880-82, Part G.G. p. 5.

(4) Geol. of Can., 1863, p. 738.

(5) Geol. of Can., 1863, p. 506.

(6) Rep. of Progress Geol. Surv. Can. 1876-77, p. 482.

(7) Rep. of Progress, Geol. Sur. Can. 1863-66, p. 217.

Dr. Adams analyzed a specimen of pyrrhotite, associated with a little chalcopyrite and sphalerite, with a small amount of intermingled chlorite, from Pic island, Lake Superior, and found it to contain 0.562 per cent of nickel and 0.138 per cent of cobalt. (1)

Pyrrhotite with nickel at Pic island, Lake Superior.

Dr. Hoffmann analyzed a specimen of iron pyrites, from Londonderry, N.S., which he found to contain 0.144 per cent of nickel and 0.813 per cent of cobalt. (2)

Pyrite with nickel at Londonderry, N.S.

Nickel has also been met with in British Columbia, at various localities, associated with pyrrhotite and other sulphides. Gersdorffite has been observed, in the form of small octahedral crystals, distributed through specimens which show an intimate association of massive pyrrhotite and chalcopyrite, from the Columbia-Kootanie property, one mile and a quarter northeast of the town of Rossland. The whole sample which weighed 6 lbs. 10 ozs. was analyzed by Mr. F. G. Wait (3) who found it to contain 0.65 per cent nickel, with traces of cobalt

Occurrence of gersdorffite near Rossland, B.C.

Determinations for nickel.

Considerable interest has been manifested in the deposits nickeliferous pyrrhotite occurring near St. Stephen, N.B. These deposit were first visited and described by H. P. H. Brumell. (4) Dr. R. W Ells, who visited the localities, where these ore bodies occur during the summer of 1903, has furnished the following description. (5)

St. Stephen deposits first described by Brumell.

The nickel bearing rocks of St. Stephen were specially examined, and found to consist of newer intrusives, instead of the Laurentian granites, as at one time supposed. The rocks are chiefly of the gabbro type, which have penetrated and altered a series of black and gray slates, the age of which has also been a matter of much doubt. They were, at one time, supposed to be of Silurian age, but from the absence of fossils, this point has never been fully determined. As developed about the head of Oak bay, it was supposed, that here, they might be the equivalents of some portion of the primordial of the St. John area, but this point also has never been determined by finding fossils. On the geological map of the district, they are provisionally coloured Cambro-Silurian. They apparently underlie, conformably, the sandy

Description of nickel bearing rocks of St. Stephen, N.B., by Dr. Ells.

Age of nickel bearing rocks of St. Stephen.

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(1) Ann. Rep. Geol. Surv. Can., 1880-82, Part H., p. 15.

(2) Ann. Rep. Geol. Surv. Can., 1874-75, p. 14 and Vol. V, 1890-91, Part R. p. 48.

(3) Ann. Rep. Geol. Surv. Can., Vol. IX, 1896, Part R. p. 15, 16 and 38.

(4) Ann. Rep. Geol. Surv. Can., Vol. IV, 1890-91, Part SS. pp. 112-114; also Vol. X, 1897 Part M. pp. 27-30.

(5) Summ. Rep. Geol. Surv. Can., 1903, pp. 156-159.

slates, which are regarded as Devonian and which occupy the northwest portion of the county, and on this basis, their age might be Upper Silurian.

Alteration of associated rocks.

They are extensively altered in many places, changing into mica and chiastolite schists, but these alterations are purely local, and caused by intrusions of the gabbro masses. They resemble, in certain points, pre-Cambrian schists, but not as a series. Further detailed examinations for fossils, will be required, to finally settle the question of their true horizon.

Nickel occurs in pyrrhotite at St. Stephen, N.B.

The nickel near St. Stephen, occurs in pyrrhotite, as at Sudbury, but the associated rocks are of a very different geological horizon from those of the latter district. The pyrrhotite is found in gabbro masses, which cut a series of slates, and have altered these extensively along the contacts. The mineral occurs, apparently, in pockety masses, which are probably quite local in character. The ore is found at a number of points, but attempts at mining for nickel have been made chiefly at two places, on what are known as the Rogers and Hall farms. The former is usually styled the Todd mine, the latter the Carroll mine.

Todd and Carroll mines.

Mining development work at Todd mine.

On the Rogers farm, considerable work, mostly of an exploratory nature, has been done. A shaft, 12 x 12, has been sunk for 24 feet, and three trenches have been cut, with depths ranging from three to eight feet, the principal one being rather more than two chains in length, on a course of S. 54° W., magnetic. In this trench, the ore is exposed for a little more than 30 feet along the line of excavation, the rest of the cut showing partly mixed ore and partly rock. The width of the ore body was not ascertained, as sufficient development work has not been done to decide this point.

Mining work undertaken at Carroll mine.

On Hall's lot, (Carroll mine), several shafts have been sunk, one of 77 feet, one of 14 feet and one of 12 feet. In addition, a bore-hole with a diamond drill, was carried down from the bottom of the deepest shaft, to a further depth of 163 feet. From information obtained from Mr. J Carroll, the first 40 feet of the main shaft was in ore, but from that point, to the bottom, the ore was mixed with rock.

Openings near edge of gabbro mass.

The formations at this place are practically the same as on the Todd area. The openings are apparently near the eastern edge of the gabbro mass, since altered slates are seen in close proximity.

An examination of the specimens collected from one of these deposits, about three miles north of St. Stephen, was conducted by Mr. R. A. A. Johnston, (1) who gives the following description.

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(1) Ann. Rep. Geol. Surv. Can., Vol. V., 1890-91, Part R, p. 39.

Description and partial analysis of ore from St. Stephen.

'The material consisted of pyrrhotite, through which was disseminated a little copper pyrites, and a very small amount of quartzose gangue.' A partial analysis gives the results under I, or calculated on the material free from all gangue, under II.

	I	II
Nickel	1·72	1.82
Cobalt	0·16	0.17
Copper	0·31	0·33

Association of pyrrhotite and partial analysis from Thompson's farm.

Pyrrhotite, in association with chalcopyrite, and a little magnetite, in a gangue of greenish-gray serpentine, obtained from Thompson's farm, St. Stephen, was partially analyzed by Dr. F. D. Adams. (1) The pyrrhotite constituted approximately, about one fourth, by weight, of the whole. The pyrrhotite, carefully freed from the associated minerals, was found to contain, nickel 0·923 per cent, and cobalt 0·394 per cent.

Analyses of ore from Todd and Carroll mines.

Partial analyses, by Mr. M. F. Connor, of this Department, were made of specimens, selected by Mr. R. A. A. Johnston, from both the Todd and the Carroll properties. The specimen from the Todd mine, consisting of nearly pure pyrrhotite, with a small proportion of intermixed chalcopyrite, and with about 10 per cent of gangue, gave nickel 1·38 per cent, and cobalt 0·21 per cent. The specimen from the Carroll mine, which was almost pure pyrrhotite, with very little chalcopyrite, and less than 5 per cent of gangue, gave nickel 1·35 per cent and cobalt 0·21 per cent.

St. Stephen ore of lower grade than that of Sudbury.

It will thus be seen, that the ore is of lower grade than that generally met with and mined at Sudbury, so that, for the present, at any rate, unless large bodies are encountered, these deposits will not be able to compete with the much larger and richer deposits of Sudbury.

Geological association of pyrrhotite.

No well defined contact or vein structure.

Occurrence of gossan.

The rocks, at all these places appear, to be very similar in character' and consist, for the most part, of a gabbro, varying from fine to somewhat coarse-grained. The presence of the pyrrhotite, is indicated by masses of gossan at the surface, and in places, the ore is largely mixed with rock. There does not appear to be any well defined contact of the ore body with the adjacent rock, and but little indication of a vein structure is visible. Outside of the ground covered by the trenches and pits, the surface shows the gossan cap at a number of points, with a thickness ranging from a few inches to several feet. From the fact that this capping shows at several places, east of the main trench, on the Rogers farm, it is probable, that masses of pyrrhotite will be found over a considerable area, but probably, in many, cases, so mixed

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(1) Ann. Rep. Geol. Surv. Can. 1880-82. Part II. p. 16.

Diamond drill operations recommended.

No very definite information yet available.

with rock, that careful separation would be necessary after mining. The existence of these ore-bodies could be best proved by judicious boring with a diamond drill. The areas of gabbro are limited, and appear to rise, in dome-shaped masses, through the slate formation, at a number of places. In the present state of development of the district, but little information of a definite nature can be given as to future values.

Pyrrhotite at Moore's mill.

At the location near Moore's mill, while the gabbro is seen at different points, the pyrrhotite appears to be disseminated in a mass of altered schistose slates. The ore here is, apparently, also of a low grade, and the extent of the deposit not large.

Nickel at Calumet island, Pontiac Co. Que.

Another locality, where mining for nickel has been undertaken, is on lots 11 and 12, range IX., of the township of Calumet (Calumet island), Pontiac county, in the Province of Quebec. (1) The ore is mostly a pyrrhotite, containing both nickel and cobalt. The associated rocks are diorites, that cut a series of grey and rusty gneisses and crystalline limestones. A large knoll of the diorite, rises to the south of the ore bed, which has a thickness of about twelve feet, and between it, and the diorite mass, is a band of crystalline limestone. The ore itself is associated with another band of diorite, that apparently traverses grey gneiss, the latter being seen beneath, or to the north of the ore deposit. On the river, a short distance to the south of this mine, the formation is mostly a crystalline limestone, and the intrusions of diorite and granite, in this rock, can be readily seen. The band of pyrrhotite at the Cowen mine, dips to the south, at an angle of about 50°. A shaft has been sunk to a depth of about forty feet, and cross-cuts have been made, to test the width of the deposit.

Mode of occurrence and geological associations.

Cowen mine deposit.

Partial analysis of ore obtained from E. P. Cowen.

A compact massive pyrrhotite, through which was disseminated small quantities of quartzose gangue, handed to Dr. G. C. Hoffmann by Mr. E. P. Cowen, was partially analyzed by Mr. F. G. Wait, giving the results under I. The gangue constituted 4·30 per cent, by weight, of the whole ; so that, neglecting this, the pure sulphide would give the results under II.

	I	II
Nickel	3·88%	4·06%
Cobalt	0·32%	0·33%

Other nickel bearing sulphides at Calumet Island.

A quartz-amphibolite, carrying a somewhat large quantity of pyrrhotite, some pyrite, a small quantity of chalcopyrite, and a very little zinc blende, was obtained from the southeast half of lot 6, range II, of

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(1) Ann. Rep. Geol. Surv. Can., Vol. XI., 1898, Part A p. 119.

the township of Calumet. The pyrrhotite, freed from all gangue and associated minerals, was found, by Mr. F. G. Wait, to contain nickel 1·48 per cent, with no cobalt. (¹).

Cobaltiferous löllingite in Galway, Ont.

Cobaltiferous löllingite (diarsenide of iron), occurs on lot 16, concession XIV, of the township of Galway. The specimen was received by Dr. Hoffmann, from the late Mr. J. B. Campbell, on July 21, 1888. (²).

Association and physical character of löllingite.

The mineral, which was associated with a small quantity of pyrrhotite, and a little white translucent quartz, was massive and exhibited only in parts, and that but very indistinctly, any approach to crystalline structure. Colour, steel-grey; lustre, metallic; brittle; fracture uneven; streak, greyish black; specific gravity, after correction for a little included quartz at 15·5° C., 7·028.

Chemical analyses of löllingite by Johnston.

An analysis by Mr. R. A. A. Johnston, of carefully selected material, afforded the results under I. Deducting the gangue (silica), and re-calculating the remaining constituents to 100, we obtain the results under II.

	I	II
Arsenic	70·11	70·85
Sulphur	0·80	0·81
Iron	24·41	24·67
Cobalt	2·85	2·85
Nickel	0·78	0·79
Gangue (quartz)	1·69	.....
Totals	100·64	100·00

This mineral had not previously been identified in Canada, and, if found in quantity, would be of economic importance.

Cobalt, nickel, arsenic and silver ores appear.

The discovery of cobalt, nickel, arsenic and silver ores, on the west side of Lake Timiskaming, Ontario, was made public in November, 1903. The deposits were discovered during the building of the Timiskaming and Northern Ontario Ry., the road bed of this new government railway running almost over the top of the first of the deposits discovered. The deposits lie five miles south of the village of Haileybury, which is 106 miles north of North Bay, and 333 miles north of Toronto. At the time of Prof. Miller's (³) visit, from whose description the present information is obtained, four veins or deposits had been located, in the vicinity of a small body of water, known as

Lake Temiscaming discovery of deposits.

Examination of deposits by Prof W. G. Miller.

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(1) Ann. Rep. Geol. Surv. Can., Vol. XI, 1898, Part R p. 39.

(2) Ann. Rep. Geol. Surv. Can. Vol. VI, 1892-93, Part R p. 19 and 43.

(3) Eng. and Min. Jour., Vol. LXXVI, Dec 10. 1903, pp. 888-889; also Canadian Mining Review, Dec. 31st, 1903.

Location of deposits. Veins cut Upper Huronian rocks.

Presence of basic eruptives suspected but not recognized. Strike of veins.

Long lake, lying about half a mile south of the southern boundary of lots 8 and 9, con. I of the township of Bucke. All of the veins cut through the slate and slate conglomerate, of the Upper Huronian. The presence of dykes or sheets of the darker coloured eruptives was suspected, but they were not definitely recognized. The slate and slate conglomerate have a slight dip, and the veins referred to, cut them [illegible] vertically. The strike of the veins Nos. 1 and 3, is approximately northeast and southwest, that of 4, is east and west, that of 2 [illegible] and southeast.

Location and association of vein No. 1.

Ores consist principally of niccolite and smaltite with much native silver.

Presence of annabergite and genthite. Mode of occurrence of native silver.

Order of generation of component minerals.

Vein No. 1 lies east of the railway track, at the edge of a swamp, about a quarter of a mile [illegible] of the end of Long lake. It has been uncovered at three points [illegible] few yards of one another. Medium-grained, dark [illegible] is found on one wall. At the widest opening, the [illegible] width of over 6 feet, but the vein matter is more or less mixed with rock. The ore consists of niccolite or the arsenide of nickel, and smaltite, the diarsenide of cobalt, together with much native silver. On weathered surfaces, the vein matter is coated with the beautiful decomposition product, erythrite (cobalt bloom). The green nickel stain (annabergite ?) is also seen on some surfaces, but is usually masked by that of the cobalt. Nickel silicate (genthite) may also be present. The secondary mineral arsenolite (As_2O_3) also occurs. Native silver, in leaves, films and fine threads, and moss-like forms, is intimately associated with the nickel and cobalt minerals especially with the niccolite, as well as in cracks in the rock and in the calcite veinstone. In weathered portions of the ores, the silver shows distinctly. One sheet, composed chiefly of silver, had a thickness of nearly 0.375 of an in. and a diameter of about one foot. The silver appears to have crystallized earlier than the niccolite, which has been deposited around it. The smaltite has formed still later than the niccolite.

Vein No. 1 made up of smaltite and niccolite.

On location No. 2, which lies about half a mile southwest of No 1, the ore body is distinctly vein-like in form. The ore is a mixture of smaltite, and probably some closely related arsenide, such as safflorite ($CoAs_2$), and niccolite. It was found to have the following composition :

Composition of ore.

	I.	II.	III.	IV.
Cobalt	16·8	16·76	19·80	21·70
Nickel	7·0	6·24	4·56	
Iron	6·3	...	6·20	8·89
Arsenic	69·0	66·60	60·30	63·55
Sulphur		3·57	4·09	5·38
Insoluble	0·9	.....	2·40	0·60
Water	....	....	2·00	.. ..

Analysis I. was made by O. S. James; II. and III. are of average samples collected by W. G. Miller, the former from the uppermost opening, the latter from the middle or main opening the analyst being A. G. Burrows. It was evident that III. was somewhat weathered, as it showed considerable cobalt bloom. Analysis IV. is by Dr. J. Waddell. It represents a specimen collected by Prof. Nicol. This specimen was not taken like II. and III., with the object of determining the average composition of the vein. Prof Nicol states that a qualitative analysis showed the presence of small amounts of copper and lead, and the absence of antimony, bismuth and zinc.

Mode of occurrence of Vein No. 2.

This ore body, unlike the others examined, carries no silver, in the parts so far discovered. Three openings have been made on the vein, over a length of 300 feet. The massive ore has a width of 4 inches, but vugs in the wall rock, 2 feet or more from the vein, are filled with cobalt bloom. The walls, which are well defined, are of slate, and the vein is almost perpendicular, lying on the hillside about 70 feet above the level of Long lake, and a few hundred yards east.

Character of No. 3 vein.

Ore body No. 3, lies at the southern edge of Long lake, about half a mile southwest of No 2. It is very similar to No. 1, consisting of native silver, smaltite, erythrite, and, in all probability, niccolite.

Mode of occurrence and character of vein No. 4.

Vein No. 4, is about half a mile southeast of No. 3. The vein, averaging not more than 8 inches, cuts a perpendicular bare cliff, facing the west, nearly 70 feet high. The vein is weathered away, leaving a crack in the face of the cliff, in some places, 4 or 5 feet in depth. Thin leaves of silver, up to 2 inches in diameter, were lying on the ledges, and the decomposed matter was cemented together by the metal. It was found impossible to get a fresh sample of the ore, with the hammer, the vein being so much decomposed. The weathered specimens, however, in addition to the native silver, contained erythrite, and the unaltered ore will be found in all probability to consist of smaltite and niccolite, in addition to the silver. Across a distance of 8 inches, a distinct banded structure was noticed, and there were 12 or 14 layers of ore lying parallel to the walls. A sample of the much weathered ore from vein No. 4, which appeared to contain less silver than most of the samples collected, was found by Mr. A. G. Burrows to have the following percentage composition: Silver 16·60, cobalt 3·91, nickel 1·42, arsenic 16·79, gold none. This ore is brownish to yellowish in colour, and has an earthy appearance. Its colour is due to the presence of several decomposition products, the oxides of iron, cobalt and nickel. A small amount of cobalt bloom is present. At the bottom of the cliff, the vein cuts thin banded, dark grey or greenish, at times, almost

Ore body made up of smaltite, niccolite and native silver.

Composition of ore body.

black slate, which has a slight dip. The slate passes gradually, as far as could be discovered, from the steep character of the cliff, into a coarse breccia-conglomerate, in the upper part. The fragments in the conglomerate, consist of quartz, slate, granite and other rocks.

Occurrence of heterogenite and asbolite.

On some of the native silver specimens, there are small, black, speroidal masses, with little lustre. These appear to be the hydrated oxide of cobalt (heterogenite). Some of the deposits, on the silver, resemble asbolite. The carbonates of cobalt and nickel are also probably present.

Recognition of dyscrasite and chloanthite by Prof. Nicol.

Prof Nicol, of the Kingston School of Mines, who afterwards examined the material collected, recognized the silver antimonide, dyscrasite, in association with the native silver of No. 1. He has also definitely determined the presence of chloanthite, (arsenide of nickel). It is associated with the niccolite, and also occurs rather free from cobalt, in some of the nodular masses.

Occurrence of smaltite and erythrite west of Rabbit lake.

Smaltite and erythrite, have also been met with in small quantities, associated with the basic igneous rocks, to the west of Rabbit lake, so that the whole area, where such rocks occur in the Timiskaming and Temagami districts, should be carefully prospected. Although the width and extent of these veins, may not be very great, the character of the ore is such as to make them a distant economic possibility, at the present ruling prices of the metals contained in them.

OTHER ASSAYS FOR NICKEL OF THE SULPHIDE ORES IN CANADA.

Active prospecting for nickel after discovery of Sudbury deposits.

Numerous assays made by Geological Survey Dept.

Since the discoveries of the highly nickeliferous pyrrhotite of the Sudbury Mining District, there has been very active prospecting for similar sulphide material. Numerous specimens, from all parts of the Dominion, have come to the laboratory of the Geological Survey Department, for assay. The material, thus submitted, has been examined, and partial analyses have appeared, from time to time, in the reports of the Section of Chemistry and Mineralogy, which, besides, appearing as separates, are included in the various annual volumes. It has been thought advisable to tabulate these results, arranging them according to provinces. All of the analyses have been conducted by Messrs. R. A. A. Johnston and F. G. Wait, assistants to Dr. G. C. Hoffmann, the chemist and mineralogist to the Geological Survey. These analyses are in addition to those which have been already quoted, on previous pages of this bulletin.

Analyses performed by Messrs R. A. A. Johnston and F. G. Wait.

PARTIAL ANALYSES OF NICKEL ORES IN CANADA.

Partial analyses of nickel ores from Ontario.

ONTARIO.

No.	Locality.	Gangue.	Cu.	Ni.	Co.	Ni. in metallic portion.	Analyst.
1	Clarendon, Frontenac Co.	60·00	.....	Trace.	0·20	...	R. A. A. Johnston.
2	Lot 10, con. IV., Creighton, Algoma	16·00	....	None.	None.	......	R. A. A. Johnston.
3	Schreiber, (2 miles west of) Thunder Bay Dist.	None.	....	0·03	Trace.	...	R. A. A. Johnston.
4	Same locality.	10·00	....	Trace.	Trace.	.	R. A. A. Johnston
5	Darlington Bay, L. of the Woods.. ...	20·00	....	„	„	.....	R. A. A. Johnston.
6	E. ½ lot 18, con. III., Dalhousie, Lanark Co...	20·50	....	0·09	„	0·11	F. G. Wait.
7	Lot 15, con. A. Anglesea. Addington Co.	37·89	Present.	0·10	„	0·16	F. G. Wait.
8	Lot 12, con. III., Galway, Peterborough Co....	.....	... ...	0·16	„	.....	F. G. Wait.
9	Lot 18, con. IV., Galway, Peterborough Co......	17·25	....	0·10	„	0·12	R. A. A. Johnston.
10	Lot 16, con. XIV., Galway, Peterborough Co...... ..	......	Present.	0·10	„	.....	F. G. Wait.
11	S. end lot 16, con. XIV., Galway, Peterborough Co ..	....	„	0·05	„	.	R. A. A. Johnston.
12	Lot 16, con. XV., Galway, Peterborough Co....	38·46	.. ...	faint traces			R. A. A. Johnston.
13	Galway, Peterborough Co...... .	....	....	0·04	Trace.		F. G. Wait.
14	Lot 1, con. XI, Somerville, Victoria Co	62·26	.. ...	fai. tr.	.		R. A. A. Johnston.
15	Somerville, Victoria Co	18·97	.....	0·06	Trace.	0·12	F. G. Wait.
16	N. part of Victoria Co.........	...	....	0·15	„	..	F. G. Wait.
17	S. E. shore Vermilion lake, Nipissing Dist.... .	....	.....	0·05	Pres't.	.	F. G. Wait.
18	Lot 6, con. I., Hyman, Algoma Dist......	....	....	...	None.	1·55	R. A. A. Johnston.
19	English River, 9 miles N. of C. P. Ry., District of Rainy River............	10·50	....	0·12	None.	0·13	F. G. Wait.
20	Near Jackfish station, C. P. Ry., Thunder Bay Dist.	... .	......	Trace.	...	..	F. G. Wait.
21	Twelve Mile lake, Minden, Haliburton Co.	6·92	....	0·13	Trace.	0·11	F. G. Wait.

No.	Locality.	Gangue.	Cu.	Ni.	Co.	Ni. in metallic portion.	Analyst.
22	Lots 32 and 33, con. XI., Sebastopol, Renfrew Co......	......	Present.	......	None.	0·10	F. G. Wait.
23	E. ½ lot 18, con. III., Dalhousie, Lanark Co..............	29·35	... .	0·165	Trace.	0·23	F. G. Wait.
24	Matawatchan, Renfrew Co....	... .	....	......	"	0·29	F. G. Wait.
25	Cutting on Whitney and Opeongo Ry., 7¾ miles from junction with C. A. Ry., Sproule, Nipissing District..........	....	Present.	0·19	"	......	F. G. Wait.
26	Lot 17, con. II, Westmeath, Renfrew Co	....	"	fai. tr.	None.	...	R. A. A. Johnston.
27	N. ½ lot 4, con. IV., Graham, Algoma District	1·04	....	0·49	Trace.	0·49	F. G. Wait.
28	S. ½ lot 8, con. IV., Dowling, Algoma District...........	....	Present.	...	"	0·26	F. G. Wait.
29	W. ½ lot 10, con. IV., Olden, Frontenac Co....	3·32	"	0·98	"	1·02	F. G. Wait.

EXPLANATIONS.

Explanation and description of specimens analyzed from the Province of Ontario.

1. A grayish-white, gneissoid rock, through which was disseminated a somewhat large amount of pyrrhotite. The metallic portion of the ore contained, 0·5% of cobalt. 2. Coarse, granular pyrrhotite, in association with zinc blende, through which was disseminated a somewhat small amount of a dark gray, schistose rock and white quartz. 3. Pyrrhotite, from an extensive deposit. Examined for Mr. Thomas Marks. 4. A fair sample of the pyrrhotite, from the same locality. Collected by Dr. Selwyn. A fine, granular, massive pyrrhotite, through which was disseminated a little quartzose gangue. 5. Pyrrhotite, with a dark gray gneissoid rock. Examined for Mr. Mather. 6. Pyrrhotite, with a little pyrite, in quartz mica diorite. Examined for Mr. W. C. Caldwell. 7. A dark gray gneissoid rock, through which was disseminated a fairly large amount of pyrrhotite, and a trifling quantity of chalcopyrite, 8. A compact, massive pyrrhotite. Examined for Mr. E. D. Orde. 9. A massive pyrrhotite, in association with very small quantities of pyrite in quartz. Collected by Dr. F. D. Adams. 10. A compact, massive pyrrhotite, with a little pyrite, and trifling amounts of chalcopyrite and quartz. Examined for Mr. R. H. G. Chapman. 11. Massive pyrrhotite, with very small quantities of chalcopyrite, quartz and felspar. Collected by Dr. F. D. Adams. 12. Quartz, carrying some pyrrhotite, and a small quantity of pyrite. 13. Lot and concession not

communicated. Massive pyrrhotite, with a very trifling amount of calcite. 14. Quartz, a little felspar, and a very little garnet, carrying a small quantity of pyrite and pyrrhotite. Collected by Dr. F. D. Adams. 15. Pyrrhotite, with quartz, and a little garnet. Number of lot and concession not communicated. 16. A compact, massive pyrrhotite. 17. From E. V. Wright's claim, north of Northeast Arm of Lake Temagami. A very fine, crystalline, massive pyrite, in a gangue of quartz-diorite. Collected by Mr. A. E. Barlow. 18. Pyrrhotite, with mica and but little visible quartz. Collected by Mr. W. McInnes. 20. A very fine, granular pyrite with small quantities of pyrrhotite. 21. Compact massive pyrrhotite, with a little pyrite, and a small quantity of quartz. 22. Compact, massive pyrrhotite, with small quantities of chalcopyrite and pyrite, in a gangue of calcite, pyroxene, some hornblende, felspar and a little garnet. Examined for Mr. L. Meany. 23. Quartz, with a little hornblende, carrying large quantities of pyrite and pyrrhotite. Examined for Mr. T. B. Caldwell. 24. Compact, massive pyrrhotite, with a small quantity of quartz and hornblende-gneiss. 25. Compact, massive pyrrhotite, with a few particles of chalcopyrite, and a small quantity of gangue, mainly quartz and felspar, with a very little garnet. Examined for Mr. A. H. N. Bruce. 26. Pyrrhotite, with a little chalcopyrite, apatite and hornblende. 27. Massive pyrite, associated with pyrrhotite, chalcopyrite and danaite, (cobaltiferous arsenopyrite). 28. A massive pyrrhotite, with which was associated a little chalcopyrite and a somewhat large proportion of gangue (vitrophyre-tuff). 29. Granular, massive pyrrhotite, with a very little chalcopyrite, with a little gangue of felspar, quartz and hornblende. Examined for Mr. J. Bawden.

Brief descriptions of specimens examined from Province of Ontario.

QUEBEC.

Results of partial analyses of sulphides from the Province of Quebec.

No.	Locality.	Gangue	Cu.	Ni.	Co.	Ni. in metallic portion.	Analyst.
30	Lake Mistassini.....	27·00	....	Dist. traces	Dist. traces	......	R. A. A. Johnston.
31	Lot 24, R. 18, Potton, Brome Co...... ..	Small amount	....	Small amt.	... ..	.....	R. A. A. Johnston.
32	Lot 24, R. 7, Clarendon, Pontiac Co...	None	....	1·50	Trace.	1·50	R. A. A. Johnston.
33	Lot 2, R. 8, Eardley, Ottawa Co........	....	....	0·13	None.	....	R. A. A. Johnston.
34	Lot 14, R. 6, Aylwin, Ottawa Co.........	....	....	....	"	1·68	F. G. Wait.
35	Lot 14, R. 5, Masham, Ottawa Co...	....	Present.	A litt.	.....	Co. Ni 0·28	F. G. Wait.
36	Lot 14, R. 5, Masham, Ottawa Co....	....	......	0·11	None.	....	F. G. Wait.
37	Same locality.	....	....	0·10	"	....	F. G. Wait.

Description of geological association of specimens selected for analysis from Province of Quebec.

EXPLANATIONS.

30. Pyrrhotite, in gangue of hornblende schist. Collected by Mr. Walter McOuat (Survey) in 1872. 31. Pyrrhotite, chalcopyrite and pyrite, with small amount of gangue. One specimen contained a very small amount, and the other, a trace of nickel. 32. Pyrrhotite, but the material does not, so far as is known, occur in quantity. 33. A massive pyrrhotite. Examined for Mr. W. A. Allan. 34. Pyrrhotite, almost pure, or with quartz, felspar, mica, hornblende and calcite. 35. Massive pyrite, with a few particles of chalcopyrite, and a somewhat larger proportion of granite. 36. Massive pyrrhotite, with a very little quartz. 37. Taken from a different part of the deposit. Pyrrhotite, a little pyrite and a very small amount of gangue of black garnet and pyroxene, and a very little quartz. Nos. 36 and 37, were examined for Mr. W. L. Marler.

BRITISH COLUMBIA.

No.	Locality.	Gangue.	Cu.	Ni.	Co.	Ni. in metallic portion.	Analyst.
38	Near head of Barclay sound, Vancouver I	......	....	Trace.	Trace.	......	R. A. A. Johnston.
39.	Monashee mine, near head of Cherry creek..	....	Present.	None.	Trifl'g Am't.	.....	R. A. A. Johnston.
40	Illecillewaet dist....	16·75	Present.	0·12	Trace.	0·14	F. G. Wait.
41	Creek flowing into Downie creek, 20 miles above fork with Columbia R., West Kootenay district..........	....	....	Faint traces	... .	.....	R. A. A. Johnston.
42	Crawford bay, Kootenay lake.	....	Present.	Trace.	.....	.....	F. G. Wait.
43	Same locality......	10·70	Present.	0·048	None.	0·053	F. G. Wait.
44	A few miles N. of Savona station, C. P. R., Yale dist...	10·17	Present.	0·031	....	0·034	F. G. Wait.
45	Between N. Thompson and Clearwater rivers.	....	Present.	Trace.	......	.....	F. G. Wait.
46	Mission City claims, townships 17 and 18, Westminster dist.	36·50	Present.	0·055	Trace.	0·09	F. G. Wait.
47	Jarvis inlet........	14·80	Present.	0·24	Trace.	0·28	F. G. Wait.
48	King Solomon mine, Kaslo-Slocan mining camp, West Kootenay dist.....	0·36	.. ..	0·15	Trace.	. . ..	F. G. Wait.
49	E. side, Upper Arrow lake, about 12 miles from its head, W. Kootenay dist....	....	Present.	......	None.	0·12	F. G. Wait.

BRITISH COLUMBIA.—*Cont.*

Results of assays for nickel and cobalt of sulphides from the Province of British Columbia.

No.	Locality.	Gangue.	Cu.	Ni.	Co.	Ni. in metallic portion.	Analyst.
50	Monte Cristo claim, Trail creek, Columbia river.........	....	Present.	......	Strong trace.	0·13	F. G. Wait.
51	Iron Colt claim, Trail Creek, Columbia river	14·50	Present.	0·20	Strong trace.	0·234	F. G. Wait.
52	Bunbury claim, near Lac le Bois, Interior Plateau Region	17·83	....	0·065	Trace.	0·08	F. G. Wait.
53	Humphrey claim, Lac le Bois. Interior Plateau Region.............	59·20	....	0·04	Trace.	0·10	F. G. Wait.
54	Quartz creek (Salmon R.), 20 miles south of Nelson...	....	....	.....	......	Trace.	F. G. Wait.
55	Kootenay-Columbia property, 1¼ miles N.E. of Rossland.	29·03	Present.	0·65	Trace.	0·92	F. G. Wait.
56	Queen Victoria claim, 8 miles W. of Nelson	37·15	Present.	0·43	Trace.	0·68	F. G. Wait.
57	Evening Star mine, E. slope Mt. Monte Cristo, 1 mile N. of Rossland.	62·73	Present.	0·25	0·59	Ni.0·67 Co.1·58	F. G. Wait.
58	Leviathan Group of claims, Campbell creek, E. side of Kootenay lake....	61·84	Present.	0·06	None.	0·16	F. G. Wait.
59	R. & K. claim, 1 mile N. of Argenta, W. Kootenay dist.....	....	Present.	0·05	"	....	F. G. Wait.
60	Kennedy lake, W. coast, Vancouver island	7·50	"	0·15	Trace.	0·16	F. G. Wait.
61	Two Sisters and Crow Claim, Deer creek, Clayoquot, Vancouver island.. ...	41·00	Present.	0·69	Trace.	1·70	F. G. Wait.
62	N.E. ¼ Section, Block I., W. side of Texada island..	....	....	Faint trace.	....	.....	R. A. A. Johnston.
63	Near Kruquot, W. coast Vancouver island.....	....	Present.	Trace.	...	. . .	F. G. Wait.
64	Mt, W. of Ice river, 6 miles from forks with Beaverfoot R., East Kootenay district...........	0·20	....	0·12	None.	0·12	F. G. Wait.
65	N. bank of the Thompson, about 5 miles above Lytton, Yale district.	17·72	Present.	0·08	Trace.	0·097	F. G. Wait.
66	Shuswap lake.......	15·75	Present.	Trace.	None.	....	F. G. Wait.

EXPLANATIONS.

Explanation and description of sulphides assayed for nickel and cobalt from the Province of British Columbia.

38. A massive pyrrhotite. Examined for Capt. J. Jaques. 39. An association of white translucent quartz and dark green diorite, carrying large quantities of pyrrhotite, and a little chalcopyrite. 40. Pyrrhotite, with a little chalcopyrite, and a small quantity of a dark green rock. 41. Quartzo-felspathic rock, with a large amount of pyrrhotite. Examined for Mr. J. D. Boyd. 42. Pyrrhotite, with a very small amount of chalcopyrite, in quartz. 43. Pyrrhotite, with small quantities of chalcopyrite and graphite, quartz, felspar and mica. These two last were examined for Cockle Bros. 44. Massive pyrrhotite, with a few specks of chalcopyrite, and a small quantity of quartz. Examined for Mr. J. Dickenson. 45. Pyrrhotite, with small quantities of chalcopyrite. 46. Fine, granular pyrrhotite, with small quantities of pyrite and chalcopyrite, and a somewhat large proportion of gangue. Examined for Mr. D. Elliott. 47. Pyrrhotite, with some chalcopyrite, and a little galena, with a small proportion of gangue, composed of quartz and fine-grained diorite. 48. Compact, massive pyrrhotite, through which was disseminated very small quantities of quartz. Examined for Mr. H. E. Porter. 49. Quartz, with a little chlorite and mica, carrying small quantities of a compact massive pyrrhotite, a little pyrite and a few specks of chalcopyrite. Examined for Mr. R. Sanderson. 50. Pyrrhotite, with a little chalcopyrite, and small quantities of a quartzose gangue. 51. Exceedingly fine-grained pyrrhotite, with a little chalcopyrite, and small quantities of a quartzose gangue. 52. A felspathic rock, carrying small quantities of pyrrhotite. 53. Quartzo-felspathic rock, carrying small quantities of pyrrhotite. 54. Pyrrhotite and pyrite, with small quantities of calcite and felspar. 55. Pyrrhotite and chalcopyrite, with a little gersdorffite, in a somewhat calcareous gangue. 56. Pyrite and chalcopyrite, with some pyrrhotite, in a gangue of andradite, quartz, and a few scales of mica. 57. Arsenopyrite and chalcopyrite, in a gangue of hornblende and calcite. Danaite or cobaltiferous arsenopyrite, carrying 3.05 per cent cobalt, also occurs at this mine (Ann. Rep. Geol. Surv. Can., Vol. VIII, 1895, Part R p. 13). 58. Quartz, with a little felspar, hornblende and graphite, with a small quantity of pyrrhotite, and a very little chalcopyrite. Examined for Mr. F. W. Pettit. 59. Massive pyrrhotite, with a very little chalcopyrite, and a trifling amount of quartz and felspar. Examined for Mr. J. Turner. 60. Massive pyrrhotite, with a few particles of chalcopyrite, and a small quantity of gangue, made up mainly of garnet and calcite, with a little quartz and hornblende. 61. Chalcopyrite, with some pyrrhotite, and a small quantity of quartz.

Examined for Mr. F. Jacobsen. 62. Very fine, granular, massive pyrrhotite. Examined for Mr. Alfred Raper. 63. Granular, massive pyrrhotite, with a very little chalcopyrite. Examined for Mr. G. H. Franklin. 64. Compact, massive pyrrhotite, with a little quartz. Examined for Mr. James Walker. 65. Fine, granular, massive pyrrhotite, with some pyrite, and very little chalcopyrite, with a gangue mainly of hornblende and quartz. Examined for Mr. Geo. de Wolf. 66. Compact, massive pyrrhotite, with a little chalcopyrite, and a somewhat large quantity of quartz. Examined for Mr. J. T. Edwards.

NEW BRUNSWICK.

Assay, for nickel and cobalt, of pyrrhotite from New Brunswick.

No.	Locality.	Gangue.	Cu.	Ni.	Co.	Ni. in metallic portion.	Analyst.
67.	L'Etete, Charlotte Co	....	present	present.		......	R. A. A. Johnston.

EXPLANATION.

Description of association.

67. Pyrrhotite, like that from St. Stephen, with a little chalcopyrite in a gangue of diorite.

NOVA SCOTIA.

Determinations of nickel and copper, of sulphides from Nova Scotia.

No.	Locality.	Gangue.	Cu.	Ni.	Co.	Ni. in metallic portion.	Analyst.
68.	Barrachois harbour, Cape Breton Co...	....	....	trace..	none .	trace..	R. A. A. Johnston.
69.	Lutche creek, Cape Breton Co...	25·40	....	0·75	trace..	1·00	F. G. Wait.
70.	Boularderie Centre, Victoria Co......	12·41	present.	0·07	trace..	0·08	F. G. Wait.

EXPLANATIONS.

Description of geological association.

68 Pyrrhotite. Examined for Mr. Alex. McLeod. 69. Pyrrhotite, with a somewhat large amount of silicious gangue, from the land of Mrs. O'Hanley, on the rear of George river. Examined for Mr. Alex. McLeod. 70. Massive pyrrhotite, with a few particles of chalcopyrite, and a little hornblende and quartz. Examined for Mr. William Haggerty.

MISCELLANEOUS.

Assays, for nickel and cobalt, of pyrrhotite from North-west Territories and Ungava District.

No.	Locality.	Gangue.	Cu.	Ni.	Co.	Ni. in metallic portion.	Analyst.
71	Deer river, (tributary of Churchill R., N. W.T)...............	42·20	....	0·06	Trace.	0·10	F. G. Wait.
72	Island, off W. point of Kogaluk R., East coast, Hudson bay, Ungava district..	48·00	....	0·08	Present.	0·15	R. A. A. Johnston.

EXPLANATIONS.

Description of geological association.

71. Pyrrhotite in a gangue of quartz, felspar, and a little mica and graphite. Collected by Mr. D. B. Dowling. 72. Massive pyrrhotite, with a large amount of quartz.

THE NICKEL DEPOSITS OF SCANDINAVIA.

Nickel deposits of Norway very closely analogous to those of Sudbury.

The nickel deposits of Norway and Sweden are of especial interest to us, since they resemble, in all essential particulars, the larger and richer deposits of the Sudbury District. It would be impossible, within the scope of the present bulletin, to give a full, or even satisfactory account of these occurrences, and the various phenomena attendant on their geological associations, and the reader is referred for such details, to the elaborate and epoch-making work of Prof. J. H. L. Vogt, of Christiania, Norway. (1)

Work by Prof. J. H. L. Vogt.

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(1) Vogt, J. H. L., 'Nikkel forekomster og Nikkelproduktion.' Geol. Soc. Norway, Christiania. 1892. 'Sulphidische Ausscheidungen von Nickelsulphiderzen.' Zeit. für. Prak. Geol., 1893, also 1894, 1895, 1900 and 1901. 'Ueber die Bildung von E lagerstätten durch Differentiationprocesse in Eruptivmagmaten.' Internatio Geol. Congress, Zurich, 1894. 'The Formation of Eruptive Ore Deposits.' M Ind. Vol. IV, 1895. 'Problems in the Geology of Ore Deposits.' Trans. Am. Inst. Min Eng. Richmond, 1901. 'Platingehalt in norwegischen Nickelerz.' Zeit. für Prak. Geol., Aug. 1902.

All of the Scandinavian nickel deposits are intimately related to masses of gabbro or norite. In Norway, there are about 40 of these masses, with which deposits of nickeliferous pyrrhotite are associated, these being the largest nickel deposits in Europe.

All Scandinavian deposits associated with gabbro or norite.

These masses, which are undoubtedly of igneous origin, are either composed of gabbro, which is essentially an admixture of plagioclase felspar and augite, or of norite, a closely related rock, made up principally of plagioclase felspar and hypersthene (rhombic pyroxene). These masses of gabbroic material, occur in the Archaean hornblende schists and gneisses, generally intruded parallel to their foliation or lamination but often cutting across them. The norite of all these masses, shows a remarkable tendency to differentiation, so that the same mass, in different parts of its extent, will vary greatly in the relative proportions of the constituent minerals. The principal types of such differentiates, are often distinguished as gabbro, olivine gabbro, and pyrrhotite gabbro and norite, olivine norite and pyrrhotite norite, while the decomposed representative is distinguished as uralite-gabbro.

Mineralogical composition of norite.

Norite intrusive in Archaean schists and gneisses.

Differentiation of norite.

The ore is chiefly pyrrhotite, containing, when pure, from 2·5 to 5 per cent of nickel and cobalt, but as much as 7 per cent is sometimes found. These metals are usually present in the proportion of one part of cobalt, to from seven to twelve parts of nickel. Associated with the pyrrhotite (Fe_8S_9) are pyrite (FeS_2), chalcopyrite ($CuFeS_2$), and, in some places, ilmenite or titaniferous magnetite. Chalcopyrite is never present in large amount. The pyrite usually contains more cobalt than nickel. In the nickel ore, in a few places, the mineral pentlandite (eisennickelkies), is distinctly discernible, and, in a single case, the mineral cobaltite.

Average percentage of nickel and cobalt in Scandinavian pyrrhotite.

General character of ore.

Occurrence of pentlandite.

The pyrrhotite, chalcopyrite and pyrite, are regular constituents of the gabbro or norite, occurring in small quantities, all through the various masses, but, like the other constituents of the rock, are found more abundantly in certain places, and a gradual transitition can often be observed, from the normal gabbro to pyrrhotite-gabbro, and to masses of pure pyrrhotite, with little or no rocky or silicate admixture. Occasionally, the ore occurs in masses, sharply separated from the norite, as at the Ertelien mine. These segregations of ore, are, in the great majority of cases, situated either directly at, or near the edge of the igneous masses, and Vogt regards these concentrations as distinctly comparable to the basic borders or edges, so often observed, about granites and other igneous rocks, in which the basic borders are sometimes marked by similar gradual passages, and, in some cases, by rather abrupt transitions.

Sulphides are regular constituents of norite.

Ore bodies situated near edge of norite mass.

Ore bodies regarded by Vogt as analogous to ordinary basic edges of igneous masses.

Ratio of copper and nickel in Scandinavian, Italian and Canadian occurrences.

Prof. Vogt draws attention to the fact, that the average proportion of nickel to copper in the Norwegian ores is about 100 to 40 or 50 and that in the Varallo (Piedmont, Italy) occurrence about the same proportion holds good, while in Canada, where the associated igneous rocks are more acid in composition, there is sometimes relatively more copper, 100 parts nickel to 100 or 150 parts of copper being found in some of the deposits.

Ratio of Nickel to Copper in some of the most important of the Scandinavian mines.

Name of Mine.	Content of Copper corresponding to 100 parts of nickel.	Percentages of nickel and cobalt in the pure pyrrhotite.
Grägalten mine......	75-80	about 2·50
Klefva mine..........	55	about 2·75-3·00
Ertelien mine	45-50	about 3·00
Bamle district. . .	35-40	about 3·50-4·00
Flaad mine.....	37	about 4·50
Senjen mine.........	35-40 (about)	about 3·50-4·00
Dyrhaug mine.......	30-35	about 3·80-4·20
Beiern mine...	20-25 (about)	about 7·00

Amount of gold, silver, platinum, iridium and osmium in Scandinavian mattes.

The Scandinavian ores also contain small quantities of silver, gold, and metals of the platinum group, including platinum, iridium and osmium. The amount of these metals is shown by the following analyses of the matte, from the Ringerike and Evje nickel smelters. (1)

Analyses of mattes from Ringerike and Evje nickel smelters.

—.	Ringerike %	Evje %
Nickel.........	51·16	41·50
Cobalt.........	1·98	0·97
Copper.	16·41	23·60
Iron.........	10·87	(13)
Sulphur.......	19·58	(20)
	g. per t.	g. per t.
Silver.........	85	140
Gold....	0·5	1 (about)
Platinum......	2·6	3 (about)
Iridium.. ...	0·1 (about)	....
Osmium.		....

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(1) Zeit. fur Prak. Geol., Aug., 1902, p. 259.

The mineral associations of the precious metals, is shown by the following table (¹) of analyses of the ore from the Flaad mine at Evje.

—	Ni & Co.	Cu.	Insoluble.	Ag.	Au.	Pt.
Pyrrhotite (mainly)	4·37	0·35	9·02	4	Trace	...
	·50	0·50	16·00	Trace.	0	...
	2·90	0·21	20·63	6	...	...
	3·31	0·67	17·46	Trace.	6	...
Chalcopyrite and pyrrhotite..	2·60	8·00	18·96	11	Trace.	
	1·70	13·33	14·10	18	"	Trace.
Chalcopyrite.........	....	.....	.....	37		
				80	..	Trace.

Analyses of Norwegian ore showing mineralogical associations of the precious metals.

Mining for nickel began in Sweden between 1838 and 1840, at Klefva (Smaland), and in Norway, between 1847·50 at Espedal and Ringerike. In 1838, Berzelius showed that the pyrrhotite from the Klefva mine, in Smaland, in southern Sweden, contained nickel. Before that time, this mine had been worked for copper. When the fact was announced that the ore contained about 3 per cent nickel, it was decided to erect a smelting plant for nickel, this being the oldest nickel smelting plant in Scandinavia. In the beginning of 1840, Th. Scheerer, the professor of metallurgy in the University of Christiania (who had been born in Saxony, and was manager of the Modums works), described the new mineral eisennickelkies (with 22 per cent of nickel), from Espedalen (Gausdal). Scheerer also announced that nearly all the Norwegian pyrrhotite and pyrite contained nickel and cobalt. The publication of these results, was really the cause of the erection of the nickel plant at Espedalen, which was in operation, on a large scale, between 1840 and 1850, with a staff of 200 men. This smelter, however, was closed down about 1855. In 1837, Scheerer analyzed the pyrrhotite from Modums, and found it to contain 2·80 per cent of nickel. This pyrrhotite had been obtained from the Ertelien mine, which, later on, proved to be the chief mine supplying the Ringerike nickel smelter. About 1700, these works had been used for copper, and had, in the first half of the last century, a small plant for the production of vitriol and red paint. Scheerer supplied information to his friend, A. Roscher, (who is described as being descended from a mining engineer), as to where

History of nickel mining in Sweden and Norway.

Discovery of nickel in Scandinavian ores.

Erection of nickel smelters.

Reasons for establishment of Scandinavian nickel industry.

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(1) Zeit. für Prak. Geol., Aug., 1902, p. 258

he had found the pyrrhotite. This man had also been working in connection with the paint plant at Modums and Snarums. All of these facts combined, helped to bring about the establishment of the nickel industry in Scandinavia.

Kragero nickel smelter.

Many refineries erected in 1870.

Curtailment of operations owing to abundance of New Caledonia ores.

Supremacy of Canadian ores.

Between 1850 and 1860, and towards the latter end of this decade, the nickel mines in connection with the Kragero nickel smelter, were started by D. Forbes and the two brothers J. and T. Dahll. During the nickel boom about 1870, there were several nickel refineries located in Norway, while, at the same time, the plants of Sweden, Austria Hungary, and Italy, supplied a large quantity of nickel, but Norway, during this period, was the largest producer of nickel in the world. After the discovery of the nickel in New Caledonia, and its advent on the market, between 1876 and 1878, the price of nickel fell to such a degree, that most of the European nickel smelters closed down, or decreased their production, and from 1877-80, up to 1888-89, New Caledonia produced from two thirds to three fourths of all the nickel in the market. Quite recently, the production of nickel from New Caledonia, has, in turn, been exceeded by that of Canada.

Production of metallic nickel in Norway.

From 1848 to 1892, about 330,000 metric tons of nickel ore were mined in Norway. The maximum yearly output was in 1876, when 42,500 tons were mined. From that time, till 1892, from 5,000 to 7,000 tons per annum, were produced. The average nickel contents of the ore per annum have been as follows; 1851-1860, 20 tons; 1861-1872, 45 tons; 1873-1876, 245 tons; 1876, 360 tons; 1877-1880, 100 tons; 1881-1885, 125 tons; 1886-1892, 105 tons.

Since 1892, the production of Norwegian nickel ore and nickel, have been as follows.

Table of production of ore and nickel in Norway from 1893 to 1900.

	Nickel Ore metric tons.	Value. $	Metallic Nickel. metric tons.	Value. $
1893	2397	6,480	113	70,605
1894	2355	5,400	103	63,450
1895	494	1,080	17	10,530
1896	315	.....	16	8,100
1897	nil	.....	nil	.....
1898	nil	.....	nil	.....
1899	220	810	5	2,700
1900	1888	12,690	13	9,720

Production of nickel from Norwegian ores in 1901.

In 1901, the *Mineral Industry* states that 27 tons of nickel were produced from Norwegian ores, but this is included in the United States production from imported ores.

Rich nickel ore at Beiern.

Average percentage of nickel in Norwegian ores.

Cost of mining.

In some of the mines, small bodies of rich ore have been found, as for example, at Beiern, where ore was encountered with an average of 7 per cent nickel (nickel-bearing pyrite and pyrrhotite); and, in other places with an average of about 5·5 per cent. In the better mines, first class smelting ore can often be sorted out, but the grade of the bulk of the ore is much lower. In 1870, miners were satisfied with a yield of 0·8 to 1·3 per cent of nickel from the smelting ore, the actual assays of which were from 0·9 to 1·5 per cent In later years, when only the richer mines have been operated, and hand sorting has been practiced, with more care, the yield has increased from 1·1 to 1·5 per cent, almost to 2·5 per cent, with an average of 2 per cent. In the mines, the cost of producing one ton of ore, assaying about 2 per cent nickel, varies from $1.67 to $3.09, averaging $2.38. (1)

Production of nickel ore and metallic nickel in Sweden.

No Norwegian mines at present working owing to abundance of material from Canada and New Caledonia.

From 1861 to 1891, Sweden produced nearly 80,000 tons of ore. From 1866 to 1875 the nickel contained in the Swedish ores averaged from 65 to 70 tons per annum; 1876-80, 50 tons, 1881-85, 30-40 tons Since 1886, however, the nickel contained in these ores, has only averaged from 10 to 15 tons per annum. The last year in which there was any production of Swedish nickel ore was in 1891, when 183 tons were mined. None of the Norwegian mines are at present in operation. although attempts are being made to revive the nickel industry in that country. The keen rivalry of Canada and New Caledonia will, however, prevent any extensive operations, at least, for many years to come.

NICKEL IN EUROPE.

Nickel first produced at Schneeburg.

Discovery of deposits in Germany and Austria-Hungary.

Nickel was first produced at Schneeburg, on the suggestion of Dr. Geitner, who erected a plant for the manufacture of the alloy known as 'new silver'. They used, as their raw material, the dumps from the cobalt works. These dumps were soon exhausted, and it became necessary to prospect for nickel ore. Early in the last century, several small nickel deposits were discovered. in Germany and Austria-Hungary, as for instance, at Dillenburg, in Nassau, which was provided with a smelting plant in 1843, Dobschau, in Hungary, etc.

Deposit of nickel at Varallo, Italy.

Production of nickel from Italian ores.

The nickel deposits of Varallo, in Piedmont, Italy, are very closely analogous to the Norwegian occurrences, but the ore bodies are much smaller in size. The mines, which are at Cevia and Sella Bassa, were worked and the ore smelted between the years 1860 and 1870, the smelter being operated by the same company as the Schneeburg works,

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(1) Zeit. für. Prak. Geol., 1893, p. 143.

in Saxony. Badoureau gives the production as about 54 tons of metallic nickel a year.(¹)

Occurrence of nickel in Spain.

In Spain, in 1875, they mined 440 tons of ore, but the ore bodies were not operated after 1877 or 1878. The mines which were situated in the province of Malaga, were on small deposits of nickel silicate (pimelite) with 3·96 per cent of nickel.

Deposits of nickel in Russia.

Production of nickel from Russian ores.

At Rewdinsk, in Russia, attempts have been made several times, to mine the deposits of the nickel-magnesia-silicates (rewdinskite) with 4·8 to 19·2 per cent of nickel oxide, but the deposit is small. In 1873, 47·4 tons of ore were mined, and in 1887, 4·9 tons of metallic nickel were produced in the first three months, from which they calculated the yearly production at 40·9 tons of nickel.

Nickel in Wales.

In Wales, in 1882, 38 tons and in 1883, 49 tons of ore were, mined containing 1·4 per cent of cobalt and 0·7 per cent of nickel.

Nickel refining in Great Britain.

Nickel refining is quite an important industry in Great Britain, where a large amount of foreign nickel ore is refined at the various works. The most important of these nickel refineries are at Kirkintilloch (near Glasgow), in Scotland, and at Erdington (near Birmingham) in England. Both of these belong to 'Le Nickel,' of New Caledonia, and are principally using garnierite as ore. Vivian and Sons' old and well known copper and nickel refinery at Swansea, Wales, the Mond Nickel Co's. refineries at Clydach (near Swansea) and Smethwick (near Birmingham), as well as the Wiggin's refinery in Birmingham, are, for the most part, working with foreign nickel sulphide material.

Nickel refining in France.

Nickel at Paris Exhibition.

In France, no nickel ore has been mined, but, after the discovery of the New Caledonia ore, several refineries were erected, the first one being at Septèmes, near Marseilles, where, from 1876 to 1882, experiments were conducted on a large scale, for producing ferro nickel. Christofle's well known works at St. Denis, near Paris, between 1870 and 1880 produced about 120 tons of metallic nickel yearly. Later on the 'Le Nickel' plant at Havre was erected. The copper plant at Eguilles (Vancluse, near Lyons) has several times conducted experiments in the refining of nickel, and at the Paris exhibition of 1889, several samples were shown produced by bessemerizing according to the Manhés process, which contained from 91 to 95 per cent of pure nickel. (²)

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(1) Annales des Mines, 1877.

(2) J. H. L. Vogt., 'Nikkelforekomster og Nikkelproduktion' Nor. Geol. Soc., Christiana, 1892, pp, 38-40.

Martha and Benno mines in Austria.

Location of mines.

Character of ore.

Composition of ore.

Smelting of Austrian ores

Composition of matte.

Production of metallic nickel.

Lately, however, the Martha and Benno mines in Silesia, Austria, have produced ore. In 1899, according to the Mineral Industry, only 80 tons of nickel ore were mined, but this rose to 3,896 tons in 1900, and during the half year ending June 30th, 1902, when there were 1,036 laborers employed at the mines and works, the quantity of ore treated was 5,689 tons, which yielded 108 tons of nickel. The mines are situated at Kosemitz, Zusendorf and Glasendorf, a short distance north of Frankenstein. They are described by Illner. (1) The ore, which contains from 0·5 to 3 per cent of nickel, fills fissures in serpentine. Occasionally, these veins carry from 4 to 18 per cent of nickel. Only the two mines, already mentioned are operated, the Martha having two shaft furnaces, capable of treating 50 tons of ore daily. The composition of the ore ranges as follows: SiO_2 60 65·4 per cent; MgO 8·5–12 per cent; Fe_2O_3 and Al_2O_3 6–8 per cent; Ni 2·3–3·5 per cent, and loss on ignition 8 15 per cent. Before smelting, the ore is first mixed with gypsum or with calcium sulphite and limestone, crushed to 12mm. size and pressed into bricks. The shaft furnace is 5m. high, and is charged with the bricks and coke in the proportion of 180 kg. of the former, to 50 kg. of the latter. A very fluid slag is produced, containing 0·3 per cent of nickel, which is used in making slag bricks. The matte composed of about 31·4 per cent of nickel, 49·7 per cent of iron and 14·5 per cent of sulphur, is crushed and subjected to an oxidizing roast, in a two stage reverberatory furnace, which is 6·13m wide, and has a capacity of 300 kg. in eight hours. There are four furnaces of this type, at the works. The roasted matte, containing approximately 65 per cent of nickel 15 per cent of iron and 20 per cent of sulphur is run into a bessemer converter with sufficient sand to slag the iron oxide and is blown for 45 minutes, thus rasing the tenor in nickel to 77·8 per cent. This fine matte is pulverized and treated to a dead roast in the reveberatory, which converts it into a greyish green nickel oxide, containing 77·6 per cent of nickel. This oxide is pulverized, moistened, cut into small cubes, dried and charged with charcoal into fire brick mufles, that are heated in a regenerative gas furnace. After three hours treatment in this furnace, the metal contains 99 per cent of nickel, and 0·3 per cent of iron. The sulphur dioxide, from the roasting, is caught in water and the solution neutralized with lime, the resulting calcium sulphide being used as a flux in the shaft furnace.

Nickel occurs in Greece, Switzerland and Sardinia.

Nickel ore is known to occur in Greece, Switzerland and Sardinia, but in none of these countries, are the deposits large enough to permit of them being mined at a profit.

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(1) Zeit fur das Berg-Hutten-und Salinenwesen, No. IV., 1902 p. 816; also Mineral Industry, Vol. X 1901, pp. 485-486, and Vol. XI, 1902, p. 486

NICKEL IN THE UNITED STATES.

Discovery of nickel in United States

The existence of nickel in the United States was probably first made known in 1818, when Seth Hunt opened up the cobalt deposit, near Chatham, Conn. This important announcement was made as the result of an analysis of a trial shipment of this ore to England. (1)

Various attempts to open up mines near Chatham, Conn.

These mines were at first opened for their supposed silver contents as far back as 1661. They were not, however, very remunerative to their successive owners, who in turn tried to operate them. In 1762, they were again tried, and in 1770, several parties associated themselves together for the purpose of operating them for their cobalt contents. In 1787, a quantity of the cobalt was shipped to China. In 1853, a creditable exhibit was made by the Chatham Cobalt Mining Co. of the ore from their mines and its products.

Location of Gap mine.

Perhaps the best known nickel deposit in the United States, is that situated at Lancaster Gap, in Pennsylvania, about three miles south of the main line of the Pennsylvania railroad, and a little over 50 miles west of Philadelphia.

Discovery of Gap mine.

Formation of Gap Mining Co.

Millerite and pyrrhotite regarded as of no value.

Discovery of nickel by Dr. Genth.

According to authentic history, the Gap mines had been worked for their copper prior to the year 1744, and tradition, in the neighborhood, states that they were discovered about the year 1718. For eighty or ninety years, they proved unremunerative to the four or five different companies who tried to operate them, but in 1849, after they had been lying idle for 30 or 40 years, the Gap Mining Company was formed, to again open them up for copper. This company obtained considerable supplies of copper, about enough to pay for running expenses, selling their product to copper smelters in Boston and Baltimore. In all of these earlier operations, the millerite and pyrrhotite were cast aside as useless, being regarded by the miners as ordinary 'mundic' or pyrite. In the beginning of 1852, however, Capt. Dobie, who had come to the work, first as a miner, but who, subsequently, became superintendent, was convinced that the material on the dump was not ordinary sulphide of iron, but some other mineral. Analyses of specimens, sent to so-called experts in Boston and Baltimore, were unsatisfactory, so that, in the latter part of 1852, or the beginning of 1853, a sample was sent to Prof. F. A. Genth, who, after analysis, pronounced it to be a nickel ore, at the same time giving the percentage of pure nickel present. The mines, which had hitherto been known as the Gap Copper mines, changed to the 'Gap Nickel mines',

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(1) Whitney. 'The Metallic Wealth of the United States', 1854, p. 497; also Proc. Col. Sc. Soc., Vol. IV., 1891-93, p. 381.

but the expenses of mining the ore, and especially the difficulties of the smelting operations, rendered the enterprise too costly, so that the whole of the works were closed down in 1860. (¹)

Purchase of Gap mine by Joseph Wharton.

Closing down of Gap mine.

In November 1862, Joseph Wharton acquired possession of the 'Gap mine,' and the deposit became a nickel producer in May. 1863, the ore obtained being treated at the refinery, built by Wharton, at Camden, opposite Philadelphia. The development of the new Caledonia mines had, in 1882, reached such a stage, that the world's consumption of metallic nickel, which had heretofore been about 800 tons per annum, was exceeded by several hundred tons. On account of this over production, prices immediately fell in the forced sales, and Wharton's Camden refinery was obliged to close down about the end of this year. The advent, in large quantities, into the market, of the Sudbury nickel, proved a further disturbing feature, resulting in the final closing of the 'Gap mine' in 1891.

Character and mineralogical composition of rock associated with nickel deposit at Gap mine.

Occurrence of millerite.

Situation of ore body.

Extent of mining.

Composition of ore.

The dark, basic rock, with which the ore body at the Gap mine is associated forms a lenticular mass or stock, extending about 1,500 feet east and west and 500 feet north and south, and lying in the midst of mica schists, of the Georgetown series, of Frazer. The rock consists mostly of green secondary hornblende, and although the change is very thorough, recognizable remains of orthorhombic pyroxene and of olivine were revealed, after careful search through a number of microscopic slides. Reddish-brown biotite is present, and, in some instances considerable plagioclase appears, with occasional accessory titanite. The ore consists of pyrrhotite and chalcopyrite in largest amount, but pyrite is not lacking. Crusts of secondary millerite are also encountered, and often this mineral furnished a not unimportant portion of the nickel contents. Although some ore has been found in bunches within the lens-shaped mass of rock, the productive ground lies near the walls. The ore body is nearly, if not quite vertical, and the depth reached by mining was 250 feet, while, at times, the workings were as much as 30 feet wide. As mined, the ore contains from 1·3 per cent of nickel, 0·25-0·75 per cent of copper, and 0·05 to 0·15 per cent of cobalt. The ore is believed by Prof. Kemp, (from whose description the foregoing information has been obtained) to be the direct result of igneous action, the ore bodies being concentrated, as such, by reason of magmatic differentiation, (²) in this respect resembling the Canadian, Norwegian and Italian occurrences.

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(1) 2nd Geol. Surv. Penn., 'The Geology of Lancaster Co.' CCC., 1880, pp. 163-176.

(2) Trans. Am. Inst. Min. Eng., Vol. XXIV., 1894, pp. 622-631.

Production of nickel from Gap mine.

The 'Gap mine' at one time produced one sixth of the world's supply of nickel, although its total production is only given as 2,000 tons.

Nickel deposits near Webster, North Carolina.

Means of access to Webster occurrences.

Character of Webster ore.

Physical characters of Webster ore.

The nickel deposits, associated with the peridotites of the south-eastern Appalachians, have, from time to time, claimed public attention and several attempts have been made, not only to ascertain their true economic value and extent, but also to develop them to the stage of producing mines. Probably the largest and best known of these occurrences is situated in the vicinity of the town of Webster, the capital of Jackson county, in western North Carolina. The deposits in question, underlie a strip of land, running approximately north and south a distance of about 7,000 feet, and east and west nearly 1,500 feet. The north end of the deposit immediately adjoins, to the east, the town of Webster. The nearest railway station is Dillsboro, on the Murphy branch or division of the Southern Railway, this station being 48·9 miles southwest of Asheville. A wagon road connects Dillsboro and Webster, the distance being about 3·5 miles. The ore is very closely allied to the celebrated garnierite or noumeaite from New Caledonia. It is a hydrous silicate of magnesium and nickel, but very variable in composition, particularly as regards the mutual replacement of nickel and magnesium. It is, therefore, not a homogeneous compound. It is amorphous, filling certain cracks with encrusting, delicate, hemispherical, or stalactitic forms, usually soft and friable, falling to pieces in water, unctuous to the touch, and adhering slightly to the tongue. It varies, in colour, from pale yellowish-green to rather deep apple-green, and depth of colour usually accompanies an increase in the nickel contents.

Analyses of ore from Webster, N.C.

Analyses of Genthite (nickel-gymnite), from Webster, N.C.

	I.	II
	%	%
Silica	49·89	55·38
Nickel oxide	16·60	17·84
Magnesia	22·35	15·62
Water	12·36	10·77
Alumina	.....	....
Fe_2O_3 } Iron	.....	0·56
FeO } Oxide	0·06	....
Cobalt oxide	.....	.....
Total	101·26	100·17

Explanation.—I. Analysis of genthite, from Webster, N.C., by Dunnington (Ch. News, 25,270, 1872, and Dana, System of Mineralogy, 6th Ed., 1892, p. 676). II. Analysis by P. H. Walker, (Am. Chem. Jour., 10, 44, 1888, also Dana System of Mineralogy, 6th Ed., 1892, p. 681).

Authorities for analyses.

Although, as shown, some of the ore contains from 16 to 18 per cent of nickel oxide, no very large amount of similarly rich material could be secured in mining, and most of the rich nickel seams are occupied by greenish nickel silicate, which will assay from 5 to 7 per cent of nickel oxide. Much of this secondary vein matter is mixed with comparatively barren, partially decomposed peridotite, so that it would be impossible to effect a separation, on an economic basis, and the bulk of the material, which could be secured as ore, would assay from 1·50 per cent to 3 per cent of nickel oxide. The ore assaying from 2 to 8 per cent of nickel, contains, in addition, 0·02-0·10 per cent cobalt oxide. These nickel deposits are found in intimate association with a mass of peridotite, made up principally of two varieties, which are, doubtless, differentiates of the same magma, viz.: dunite, made up almost entirely of olivine and chromite, and websterite, composed essentially of bright green diopside, and pale brown bronzite. The mode of occurrence and origin of these deposits, are precisely analogous to those occurring in New Caledonia, Oregon and elsewhere. The development work undertaken, consists of a series of parallel trenches or ditches, which are excavated, in some cases, simply to the solid rock beneath, and, in others, to a uniform depth, in no case exceeding 30 feet. These trenches are designed to give an idea of the relative abundance and disposition of the veins of silicate material. A shaft was sunk, but to what depth has not been learned, while considerable prospecting by diamond drill has also been undertaken.

No large amount of very rich ore.

Nickel and cobalt contents of ore.

Geological associations of Webster deposits.

Deposits similar to those of New Caledonia, &c.

Extent of mining development.

Nickel has, for many years, been known to exist in considerable quantities in southern Oregon, and some of the deposits are regarded as of commercial importance. The mineral josephinite, a nickel iron compound (Ni. 60·45; Fe. 23·22), has been described by W. H. Melville as occurring in the form of pebbles and smooth boulders, in the placer gravels of a stream in Josephine county, Oregon, which are supposed to have been derived from some dyke of ultra-basic rock, whose location has not yet been discovered.(¹)

Nickel in Oregon.

Occurrence of josephinite.

Nickeliferous pyrrhotite has also been noticed in both Jackson and Douglas counties, but the nickel silicates of Douglas county are the only ores which appear to be worthy of other than a passing notice.

Nickeliferous pyrrhotite in Jackson and Douglas counties.

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(1) Amer. Jour. Sc. Vol. XLIII. 1892, pp. 509-515.

Location of Oregon deposits.

Altitude of Piney mountain.

Mineralogical composition of peridotite associated with the deposits.

The deposits occur near the small village of Riddles, in the southern part of Douglas county, a station on the Oregon and California railway, 226 miles from Portland, and 547 miles from San Francisco. The nickel mines are situated on Piney mountain, about 3 miles west of Riddles, and are connected with this village by an excellent wagon road of easy grades. This mountain, as its name implies, is thickly covered by forest, rising to a height of about 3,400 feet above sea level, occurring as an isolated ridge in a sea of other mountains. It is, approximately, 2½ miles long by 1 mile wide, thus embracing an area of 1½ square miles, in which nickel deposits might be expected to occur. The rocks, underlying this area, is a peridotite or 'saxonite', composed essentially of olivine and enstatite, with a small quantity of accessory chromite and magnetite. The olivine predominates, forming more than two-thirds of the mass of the rock. The ore is a silicate of nickel and magnesium, and, as usual, very variable in composition. The mode of occurrence and origin of ores of this class, have already been discussed in detail, and the Oregon occurrence presents no unusual features which are worthy of special or extended reference. The following analyses, of carefully selected material, well illustrate the chemical composition of the pure nickel mineral, but the bulk of the ore which could be economically secured and utilized, would, of course, be much lower in nickel contents.

Analyses of nickel silicates from Oregon.

	I	II.	III
Loss at 110° C.	8·87	6.63	7·00
Loss on ignition	6·99	....	...
Al_2O_3 & Fe_2O_3	1·18	1·38	1·33
SiO_2	44·73	48·21	40·55
MgO	10·56	19·90	21·70
NiO	27·57	23·88	29·66
Total	99·90	100·00	100·24

Explanation.—Analysis I, is by F. W. Clarke, (Am. Jour. Sc., Vol. XXXV, pp. 468-487; Nos. II and III are by Dr. Hood, (Min. Res. U. S., 1883, p. 404.)

Discovery of Oregon deposits.

The first discovery of these deposits was in 1864, and, in the fall of 1881, Mr. W. Q. Brown secured control of what appeared to be the most valuable portion, transferring his interest to an incorporated company, known as the 'Oregon Nickel Mines'. It is stated that about $30,000 was expended in development work. In 1891, some of the nickel bearing area was secured by a Chicago corporation, called the 'International Nickel Mining Co,' which is said to have expended about $60,000 on development work. Extensive preparations were made to mine and smelt this ore, but much of the smelting and other machinery purchased, was never even set in position. The Anglo-American Nickel Co., incorporated in 1893, and the Oregon Nickel Mining Co., also own property in this neighbourhood. The amount of development work done, in connection with these deposits, is hardly sufficient to test their commercial capabilities. Numerous open cuts, short tunnels and shallow shafts from 20-40 feet deep, have been made, but nowhere has a vertical depth of over 50 feet been reached. (1)

Mining development work.

Extent of mining development work.

The Gem mine, in Fremont county, Colorado, may be mentioned at some length, in this connection, as it is very similar, in mineralogical composition, to the Haileybury occurrences discovered last autumn in Northern Ontario. The vein at the Gem mine is in hornblende schist, and the ores were principally copper, but nickel soon made its appearance, and at a depth of 15-20 feet became quite prominent. From the surface, down to a depth of 75 feet, the vein has an average width of 3·5-4 feet. At this point, it pinched out, and, with the exception of a narrow streak of ore, which may be its continuation, and which contained the same cobalt and nickel minerals, no further ore was encountered lower down. The nickel-cobalt minerals of this mine are accompanied by native silver, some of the mineral specimens being occasionally so permeated by fine wire silver as to be broken with difficulty. In 1882, 12 tons of ore, containing 12 per cent of nickel, and 2·2·5 per cent of cobalt, with considerable chalcocite, were shipped. Later, about half a ton of selected ore, containing 31 per cent of nickel and 3·4 per cent of cobalt, were sent to Swansea, England. The mine, however, was involved in litigation, and the ore body was seemingly too small for any extended mining operations. (2)

Nickel in Colorado.

Similarity to Haileybury occurrences.

Depth of deposit.

Character of ore.

Production of ore from Gem mine.

Reasons for closing down.

Since the closing down of the Lancaster Gap mine the entire United States production of nickel, from domestic ores, has been derived from Mine la Motte, Mo., the metal being secured as a by-product in the treatment of lead ores. In 1899, this production amounted to 22,500 lbs., but in 1901, it had decreased to 6,700 lbs., while in 1902, the 20 tons of matte, containing nickel and cobalt, which were refined at the works of the Mine la Motte Lead and Smelting Co., yielded 5,748 pounds of metallic nickel. (3)

Nickel now produced in U.S. all from ores of Mine la Motte.

Production of nickel from Mine la Motte.

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(1) Dr. W. L. Austin. "The Nickel Deposits near Riddles, Oregon." Proc. Col. Sc. Soc., Vol. V., 1894-96, pp. 173-196.

(2) Thomas Charlton, Proc. Col. Sc. Soc., Vol. IV., 1891-93, pp. 420-421.

(3) Min. Res. U.S., 1902, pp. 265,266.

NICKEL IN NEW CALEDONIA.

Reasons for celebrity of New Caledonia deposits.

Production of Canada exceeds that of New Caledonia.

The nickel deposits of New Caledonia have, for many years, enjoyed an enviable reputation, not only for the large and continuous supply of ore they have produced, but also for the high grade they have been able to furnish for purposes of export. From about the year 1880, to 1888, these mines produced from two-thirds to three-fourths of all the nickel in the market. From the latter year, however, the mines of Canada have been gradually increasing their output, and, in spite of many adverse circumstances, it is believed that, at the present time, the amount of nickel secured from Canadian sulphide ore, is considerably in excess of that produced from the New Caledonia silicates.

General character and mineralogical associations of New Caledonia silicates.

Early misconceptions.

The only nickel ore that occurs in New Caledonia is a hydrated silicate of nickel, in which more or less of the nickel oxide is replaced by magnesia, ferric oxide and alumina. The ore is associated with chalcedony, a magnesian silicate resembling meerschaum or sepiolite, limonite or bog iron ore and serpentine. In addition to these, there are usually small quantities of chromite and asbolite. The mineral is entirely free from sulphur, arsenic or copper, and, although, in the first instance the deposits were regarded as the gossan like material produced by the sub-aerial decay of nickeliferous sulphides, the extensive workings already undertaken have failed to reveal any traces of such material even in the deepest workings.

Discovery of garnierite in 1865.

The mineral garnierite or noumeaite, characteristic of these deposits, was discovered by M. Jules Garnier, in 1865, and was noticed by him in 1867, (1) and was described by Liversidge in 1874 (2). The mineral is closely related to the nickel-gymnite, described by Genth, in 1851, and for which the name genthite was proposed by Dana, in 1867

Chemical analyses of garnierite and related silicates.

As the following analyses will show, it is very variable in chemical composition. The material analyzed was selected with great care, and will give a good idea of the composition of the purest varieties of garnierite as well as its intimate connection with sepiolite, or silicate of magnesia, with which it is associated, and into which it passes by insensible gradations.

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(1) Bull. Soc. Geol. de France, Vol. XXIV, p. 438, Paris, 1867.

(2) Jour. Chem. Soc., Vol. XII, p. 613, July, 1874.

ANALYSES OF GARNIERITE FROM NEW CALEDONIA.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Silica	35·45	44·40	37·78	38·35	47·24	50·00	48·00	50·15	51·91	53·80	41·80
Nickel oxide	45·15	38·61	33·91	32·52	24·01	18·50	15·39	10·20	2·32	0·24	....
Magnesia	2·47	3·45	10·66	10·61	21·66	15·80	16·92	17·13	21·35	24·82	37·38
Water	15·55	10·34	15·83	17·97	5·27	10·00	20·75	21·65	23·17	21·47	20·39
Alumina		...		0·40	1·67	...			1·36	..	.....
	0·50	1·68	1·57					0·57			1·26
Iron Oxide Fe_2O_3	...	...	.....	1·15		3·50					
Iron Oxide FeO	...	0·43	...								
CaO		1·07	......	....	Traces	2·70					
	99·12	99·98	99·75	100·00	99·85	100·50	101·06	100·00	100·14	100·33	100·83

Authorities for chemical analyses.

Explanation. I. Analysis by Dana (Ber. Nied. Ges., Jan. 7, 1878). II. Analysis by Garnier (Comptes Rendus, 86,684, 1878). III. Analysis by Kiepenheuer (Ber. Nied. Gest., July, 11, 1879). IV. Analysis of dark green garnierite, from Nakety, by Liversidge (Minerals of New South Wales). V. and VI. Analyses by Garnier (Soc. des Ingrs. Civils, 1887). VII Analysis of a translucent, pale green variety, from Ouaillou, by Liversidge. VIII. Analysis of similar mineral from same locality, by Liversidge. IX. A very pale-green variety from Bel Air mine, Kanala, by Liversidge X. Another similar specimen from same locality. XI. Analysis by Garnier of white veins, in the green mineral (garnierite), resembling sepiolite.

Ore at first to contain from 12 to 15% of nickel.

Average composition of New Caledonia ores from shipments.

Ore at first thrown away is now being used.

At first, when mining operations were started was stipulated that the ore should contain from 12 to 15 per cent nickel, but now, the minimum has been reduced to 7 per cent and it is stated to be difficult to secure more than 60,000 to 70,000 tons per annum of such a grade of ore, although, if the European smelters would lower their limit to 5·5 per cent, the production could be more than doubled. From 1875 to 1884, R. Flechner has calculated that 8·3 per cent of nickel was the average contained in the ore, while Du Peloux states that in 1884, 850 tons of metal were produced, from 12,000 tons of ore. thus giving an average of 7·1 per cent. Croissille states that between 1880-85, 28,933 tons of ore were produced with an average of 10·5 per cent nickel. In the first years, a large amount of ore, containing from 3 to 11 per cent nickel, was discarded as valueless for purposes of export but lately, these dumps have been overhauled and some of the material shipped. The largest New Caledonia company 'Le Nickel' in its catalogue, issued at Paris, in 1889, stated that the various grades of their ore contained 8, 10 and 12 per cent of nickel. From 1876 to the present time, the ore has varied in composition, as shown under I; under II, is given the composition of the ore, which was being shipped to Europe in 1876; under III, the average composition of New Caledonia smelting ore, (according to Levat); under IV, is given the average composition of the nickel ore, as it was shipped in 1899, according to E. A. Wineberg (Min. Industry, Vol. VIII, 1900, p. 435.

Variation in composition of the ore.

Average composition of New Caledonia ores.

	I.	II.	III.	IV.
Nickel oxide	9 to 17	18·00	7 to 8	10·00
Silica	41 to 46	38·00	45 to 50	42·00
Iron oxide	5 to 14	7·00	14 to 16	10·50
Alumina	1 to 7	....	3 to 5	2·50
Magnesia	6 to 9	15·00	10 to 12	22·00
Water	8 to 16	22·00	14·00	12·00
Lime	....	.....	......	1·00

The nickel contents of the New Caledonia garnierite, lately smelted, has averaged about 7 per cent of nickel, but each succeeding year sees a poorer product handled and shipped.

Average nickel contents of New Caledonia ore at present shipped.

The ore is intimately associated with a peridotite, and its various decomposition products, grouped together under the name of serpentine. Fresh, undecomposed pieces of this rock, made up chiefly of olivine, are said to contain as high as 1 per cent of nickel. These serpentines, which cover the larger portion of the area of the island, rise into a series of hills, which are from 400 to 4,000 feet above the sea, the general elevation being about 2,000 feet The deposits generally occur on the tops of these mountains, so that transportation of the ore, mining materials and supplies is very tedious and difficult, and in many cases, expensive roads and aerial rope ways have been constructed to deposits which, in some cases, came far from realizing expectations as to extent and richness. The ore bodies occur as veritable 'stockworks', cutting the decomposed peridotite in all directions. Invariably, where the nickel occurs, the surface is covered with a highly ferruginous soil, in which pisolitic iron ore is very abundant. Although this decomposed remnant of the peridotite contains a little nickel, most of the nickel has been leached out, to be deposited in secondary veins of nickel silicate, in locations at various depths below, favourable places for such concentrations being in the vicinity of faulting and jointing planes The veins vary in size, from a few inches to as much as thirty feet, but they are exceedingly irregular in this respect, at one time becoming gradually narrow, while, in other cases, large deposits end abruptly against barren rock. These veins or deposits are comparatively shallow. It is true, that one fissure was followed down about 600 feet in depth, but generally the veins give out from 75 to 100 feet below the surface. Without reference to the surface mantle or covering, from which most if not all of the nickel has been removed by leaching, the richest deposits are those nearest the surface, while the higher parts of any deposit are richer than those lower down. The comparative shallowness of the deposits is, however, compensated by the large areas they cover, and some of the mines have yielded from 30,000 to 100,000 tons of ore, and are still in operation. The mining is carried on by means of open cut work, the ore being secured by means of a series of benches. The pick and shovel are usually sufficient to loosen and remove the ore, but occasional blasting is sometimes necessary. The ore, when properly mixed, is carried, by means of aerial rope-ways to ground tramlines, from which it is transported by lighters to the ships.

Mode of occurrence of New Caledonia deposits.

Altitude of hills on which deposits occur.

Transportation difficult.

Character of ore bodies.

Secondary origin of nickel silicates.

Irregularity of deposits.

Deposits are comparatively shallow.

Deposits cover a large area.

Methods of mining.

Transportation.

Various methods, for the extraction of nickel from these ores have been attempted. Garnier, whose name has been associated with these

Various methods of extracting nickel.

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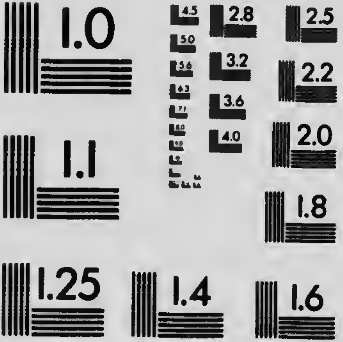

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deposits from the date of their discovery, tried to smelt the ore directly to a nickeliferous pig iron, which was afterwards to be refined in a reverberatory furnace to ferro-nickel. The first part of the process proved satisfactory, and the nickel-iron pig, obtained from the richer lumps contained from 65-68 per cent of nickel, 23-29·5 per cent of iron, 1·5-2·5 per cent of sulphur, 3·5-5·5 per cent of silica and carbon occurring as graphite and from 1·5 to 2·5 per cent of other impurities, and amongst them, phosphorus. It was found impossible to economically handle or to refine this product owing to the presence of sulphur, which has a strong affinity for nickel. Various wet methods were then employed, which followed, on a large scale, the different operations used in making chemical analyses. The ore was first dissolved in acid and the metals removed by the use of lime or bleaching powder, and finally a solution, containing nickel alone, was obtained. From such a condition it is easy to produce the nickel, by fusing with charcoal the dried nickel salt.

Nickeliferous pig iron.

Composition of nickel-iron pig.

Difficulty of refining product.

Method of obtaining metallic nickel.

Later methods for refining nickel ores.

Later on, however, they adopted a dry method, in the preliminary stages. In the first years, they smelted it with the addition of a special Norwegian pyrrhotite, containing nickel and copper. In order to remove the excess of iron and copper, they now smelt the ore in low water-jacketed blast furnaces, with materials containing sulphur (calcium sulphide obtained in the manufacture of soda by the Le Blanc process), or with gypsum. The gypsum, which is made up of both lime and sulphur, is reduced, the sulphur uniting with the nickel by reason of its greater affinity for this metal, while a portion of it is taken up by part of the iron, the rest of it combining with the silica, magnesia and lime, and the rest of the iron to form a slag. This slag contains about 48 per cent of silica, 12-13 per cent of iron and not more than 0·40 to 0·45 per cent of nickel. The nickel-iron matte contains about 50-55 per cent of nickel, 25-30 per cent of iron and 16-18 per cent of sulphur. This matte, by reason of its greater specific gravity sinks to the bottom, permitting the lighter slag to be drawn off. This matte is, in turn, roasted and a portion of the sulphur thus removed. It is re-smelted with sand, and the nickel will again combine with by far the larger share [illegible] the sulphur, leaving a comparatively small proportion for the iron, [illegible] the remainder of the iron combines with the silica or sand to form a slag. By a repetition of these, or similar methods, the iron is finally removed, leaving a compound made up essentially of nickel and sulphur, which is roasted with nitrate of soda to produce nickel oxide. This is then mixed with charcoal, and reduced, by the application of intense heat, to metallic nickel.

Explanation of reactions.

Composition of slag and nickel-iron matte.

Methods of producing nickel oxide and metallic nickel.

Refineries first erected in New Caledonia.

Attempts have been made, from time to time, to partially refine these ores in New Caledonia, and blast furnaces were erected and in operation, both at Noumea and Thio, as well as at Newcastle, in New South Wales, but the difficulties of procuring coke, suitable flux and labour have hindered their progress and most of the ore at least is now exported for smelting and refining purposes. Most of this ore is refined in France, where 'Le Nickel' company have extensive refineries at Havre, but a large proportion is also refined at Kirkintilloch (near Glasgow), in Scotland, Erdington (near Birmingham), in England and at Iserlohn (Westphalia), in Prussia. The Engineering and Mining Journal of May 20, 1899, notes that a cargo of 3,000 tons of New Caledonia ore, is being sampled for the Orford Copper Co., the ore averaging 7 per cent nickel. The merging of the Nickel Corporation, Limited, and the Société Minière Caledonienne, of New Caledonia, as part of the International Nickel Co., will result in the smelting, by this company, of a considerable amount of New Caledonia ore, at their refinery at Constable Hook, N.J.

Ore now refined in Europe.

Some New Caledonia ore refined in United States

First active mining operations.

Although these deposits were discovered in 1865, it was not until 1873 that active mining operations were undertaken. In 1880, the Société le Nickel acquired the celebrated mines at Thio, but did not commence mining until 1887.

The following figures represent the production of ore and nickel from the New Caledonia mines.

Production of ore and nickel from New Caledonia mines

PRODUCTION OF ORE AND NICKEL FROM NEW CALEDONIA.

Year.	Ore mined.	Ore exported.	Nickel contents.	Nickel contents.
	Tons.	Tons.	Tons.	Tons.
1875	327	....	......	
1876	3,406	....	......	
1877	4,377	....	....	
1878	155	....	.....	
1879		....	....	
1880	2,528	....	210	
1881	4,070	......	388	
1882	9,025	.....	749	
1883	6,881	....	561	
1884	10,838	.....	904	
1885	5,228	....	850	
1886	920	....	150 ?	
1887	8,602	....	1,350 ?	

PRODUCTION OF ORE AND NICKEL FROM NEW CALEDONIA.—*Con.*

Year	Ore mined.	Ore exported.	Nickel contents.	Nickel contents.
	Tons.	Tons.	Tons.	Tons.
1888	6,616	....	900 ?	
1889	19,741	.....	1,381	
1890	22,690	.. ...	1,633	
1891	35,000	......	2,449	
1892	....	. . . . .	1,244	
1893	69,614	45,614	2,493	
1894	61,243	40,089	2,422	
1895	29,623	38,976	2,548*	(2,548)
1896	6,417	37,467	2,972*	(2,707)
1897	26,464	57,439	2,858*	(2,858)
1898	53,200	74,614	3,608*	(4,205)
1899	103,908	103,908	3,845*	(4,205)
1900	....	100,319	4,676*	(4,526)
1901	.....	132,814	6,202*	(5,210)
1902	....	.. ....	....	(3,620)

* Nickel contents of ore refined in Europe, according to Mineral Industry. The figures in brackets, are production of nickel from New Caledonia ores, in France, Germany and England (according to Metallgesellschaft and Metallurgische Gesellschaft, August 1903, p. 23.)

METHODS OF MINING AT SUDBURY.

Methods of mining in Sudbury District.

Occasional accidents owing to imperfect timbering.

Every reasonable precaution now being taken to ensure safety to miners.

The methods usually employed throughout the Sudbury District for obtaining the requisite supply of ore, consist, partly, in the sinking of shafts and the opening up of the ore body, by means of underground levels, drifts and stopes, the whole of such mining operations being carried on under a solid roof. For this work, very little timbering is required, although, in some cases, serious accidents, involving the loss of one or more human lives, have resulted from neglecting to provide even the small amount of timbering necessary, where occasional slips, faults or slickensides occur. As a rule, however, the walls and roof are very solid, and, at the present time, every reasonable precaution is taken to guard against such accidents, by frequent, careful and systematic scaling, removing all loose or menacing portions of rock or ore. The larger part of the ore, however, is secured by a combination of this method and a system of open cast work. This, which, in reality, is a species of deep quarrying, is a very cheap and effective method of

Mining chiefly done by open-cast work or deep quarrying.

Drawbacks to use of open pits.

Lately more usual mining methods adopted.

obtaining large supplies of ore, and these considerations, no doubt, contributed to its adoption in the first place. On the other hand, these open pits being exposed to the weather, work is, at times, carried on only with extreme discomfort to the men, or is even seriously interrupted during periods of extreme cold or otherwise inclement weather. At the same time, it is open to the serious objection, that it is much more dangerous to the men, and, in spite of the most careful inspection and frequent scaling, large bodies of rock and ore are liable to be detached by the action of frost, gravity or other agencies. Lately, a disposition has gradually developed, to abandon in large measure, much of the open mining, and to remove the ore by means of levels and stopes at regular intervals, beneath these pit floors, cross-cutting the ore body frequently by a series of drifts. Finally, after breaking away overhead, and providing an arched roof, the whole is stoped away to the level below, and the ore hoisted from thence by means of shafts. Only such pillars and supports, as are necessary will remain standing, and the intervening spaces will be filled by rock and ore too lean to be utilized, the whole being supplemented, when necessary, by material from the dumps.

Explanation of open pit mining methods.

The system of open cast work, which has hitherto found most favour in the district, consists, first, in the sinking of a shaft of the required dimensions, at varying angles, this inclination being governed, mainly, by the general dip and direction of the ore body. This shaft secures the necessary accommodation for the skipway for hoisting the ore, while, at the same time, it provides a manway for ingress to or egress from the underground workings, by means of ladders, with landings at frequent intervals.

Creighton mine is the largest open pit in district.

Dimensions of pit at No 2 mine.

Size of pits at Victoria mine.

The largest pit in the district is at the Creighton mine, where on the first of June last (1904), ore was being hoisted from an open cut or quarry, measuring about 350 feet long, by 275 feet wide and 62 feet deep. The pit, known as No. 2 mine, of the Canadian Copper Company, at the end of January, 1903, was opened up on a chimney of ore, which, below the 200-foot level is growing larger. At the bottom of the open pit, which has reached the third level, at 217 feet below the surface, the average diameter is 120 feet. The new vertical shaft had, at the same time, reached a depth of 390 feet, the fifth level being at 374 feet. At the Victoria mine, the main shaft has been sunk to a depth of 557 feet, with various levels, drifts and stopes. The west open pit at this mine measures 70 by 125 feet at the surface, gradually tapering to 50 by 100 feet at the first level.

Each mine is provided with a rock house, as soon as its permanency is established, and a double skiproad leading to it from the mine. The steel skips having a capacity of 1½ tons each, are hoisted to the top of the rockhouse, dumping automatically, on a large inclined 'grizzly' sizing-screen, which separates the fine from the coarse ore. Most of the ore is sledged to a proper size for the crusher in the mine, although, sometimes, this operation takes place on the floor of the rock house The coarse ore falls near the mouth of the 15 x 9 Blake crusher, set to about 1¾ inches, which has a capacity of about 20 tons per hour, (or 400 tons for the usual two shifts, of 10 hours each). Occasionally, as at the Creighton mine, there are two of these Blake crushers, but usually one is considered sufficient. The ore is then passed into the upper end of a slightly inclined revolving trommel screen, where it is sized into three classes, for the succeeding operation of roasting. The fines pass through ¾ inch mesh holes in the trommel screen, the medium or ragging, through 1¾ inch holes, while the coarse is discharged at the lower end of the screen and is caught on an oscillating sorting table, also slightly inclined lengthwise. The jerking motion of this table provides such a rate of travel of the pieces of ore, as enables a certain number of boys, stationed along the side, to pick out, and cast aside, a considerable proportion of barren rock or very lean ore, at the same time permitting the purer and higher grades to continue their journey to the ore bins. Each of these sizes falls into a separate series of bins, from which ore of the required class is automatically loaded, by means of inclined steel chutes, into standard gauge cars, and hauled by locomotives to the roasting yards. At the time the surveys for the Copper Cliff mines area were being carried on, there were three roasting yards. The old one, which was graded by Dr. E. D. Peters, is situated immediately west of the old or East Smelter, and measures roughly 2000 feet long and 125 feet wide. This still remains in use, and by the removal of the East Smelter buildings, which is about accomplished, this will be increased to 3000 feet. For some years, a small roast yard, was utilized about midway between the original Copper Cliff mine and the Ontario Smelting Works. The site of this, which measured about 1000 feet by 125 feet, is shown on the large scale maps, but it has now been abandoned, as its situation so close to the works and residences, at times occasioned great discomfort to the workmen and inhabitants. The main roast yard which is in use at present, and which is capable of much greater expansion, is located to the northeast of the West Smelter towards the Manitoulin and North Shore railway. At the time the surveys were made, it was about 2700 feet, long by 150 feet wide, and it could be very readily extended to measure 4000 feet. It will thus be seen, that without any great effort, roasting ground, with a capacity of from 250,000 to 300,000 tons, is already available. Many of the mines situated at Copper

Equipment of rock houses.

Ore sledged to proper size for crusher.

Use and capacity of Blake crusher.

Use of trommel screen and oscillating tables in sizing ore.

Different sizes fall into separate bins.

Number and extent of Copper Cliff roast yards.

Main roast yard near Clarabelle junction.

Size and capacity of main roast yard.

Cliff, are, of course, handy to the roast yards, but most of the ore at present being utilized by the Canadian Copper Company, is brought from the Creighton mine, coming over the Manitoulin and North Shore railway, a distance of about 7½ miles to Clarabelle Junction, about a mile northeast of the main roast yard. The ore from the Stobie mine has to be brought by a branch railway to Sudbury, a distance of about 3½ miles and then down the 'Sault' branch of the Canadian Pacific railway to the southern roast yard at Copper Cliff, a further distance of about 4 miles. The ore from the Frood, or No. 3 mine, has to be hauled first to the Stobie mine, by a spur about 1·25 miles long, and thence, by the same route from the Stobie mine to Copper Cliff. Neither of these mines are, however, in operation, as an abundant supply of very high grade ore, is more easily procurable at the Creighton mine. At the Victoria mines, of the Mond Nickel Company, an aerial tramway carries the ore from the mine to the roast yard, and thence to the smelter.

Creighton mine ore has to be hauled about 8½ miles.

Ore from the Stobie and Frood mines is hauled considerable distances.

METALLURGY.

In the production of nickel and copper from a sulphide ore, the following operations have to be considered.

Operations necessary for the production of nickel oxide and nickel.

1. Treatment of the ores, for low grade copper-nickel matte.

2. Treatment of the copper-nickel matte, for concentrated copper-nickel matte.

3. Treatment of this matte, for copper-nickel alloys.

4. Treatment of the concentrated copper-nickel matte, for nickel matte.

5. Treatment of the nickel matte, for nickel oxide and metallic nickel.

The first two of these operations are carried out at the smelting works in the Sudbury District.

ROASTING.

The metallurgical treatment of this ore commences at the roast yard, whither it is conveyed from the mines, and being piled in convenient heaps, on previously laid cordwood, is exposed at high temperatures, without fusion, or at most, incipient fusion, to the action of currents of air. The object of this roasting, is to bring about the oxidation of the iron, and incidentally of the sulphur, as complete as is possible without involving an undue loss of metal, in the slags of the following smelting, and second, the expulsion of arsenic, if any should happen to

Roasting first step in metallurgical treatment.

Objects of the roasting.

With rare exceptions no arsenic in Sudbury ores.

Care has to be exercised in oxidizing the ore and in building roast yards.

Levelling and draining of surface.

Precautions taken to prevent loss of nickel and copper.

Proportion of loss of metals not known.

Analyses of copper-nickel stalactites.

Water of marshes contains copper.

be present. With the possible exception of the Worthington mine, and some other deposits in that vicinity, none of the ore of the Sudbury District contains any appreciable amount of arsenic or antimony. If the oxidation be very imperfect, the resulting matte will contain so much iron, that its bringing forward will be unduly costly, while if the oxidation be too thorough, an undue loss will occur on smelting the roasted ore. At Copper Cliff and at Victoria mines, the Canadian Copper Company and Mond Nickel Company, have spared neither trouble nor expense in the construction and equipment of their roast yards. The sites selected, consisted of flats or swamps, which have been further graded or filled up, any natural roughness or unevenness being cleared away and levelled, and the whole being given a gentle slope, with carefully made drains, serves to remove, at once, any rain or surface water. These precautions have to be taken, to prevent loss of metal as soluble sulphates. It has been frequently stated, that any great loss is thus fully guarded against, but, so far as known, no deliberate attempts have been made to determine what amount is thus actually carried off by rain and melting snow. After the heap has been fired, a crust rapidly forms, which is believed to give further assistance against loss, but during heavy or long continued wet and stormy weather, it is believed an appreciable amount is thus removed. Whether the saving of this is a commercial possibility, is well within the range of experiment. Hollows in the burnt out heaps are filled with stalactites, an analysis of one of which gave Mr. Donald Locke, the following composition Cu O, 8·42 per cent ; Ni O, 10·21 per cent ; Fe O, 7·18 per cent and S O_3 27·53 per cent. The water too, of the marsh adjoining, has a decided bluish tinge, and an iron object immersed in it, is immediately covered with [illegible] coating of copper.

Open air heap roasting cheap and effective.

Sulphur cannot be economically saved.

Open air heap roasting, as practised at Sud[illegible]h favourable weather conditions, an old, simple, cheap an[illegible]tive method of treatment, for the elimination of the undesire[illegible] sulphur, from low grad sulphide ores. Experiments and tr[illegible]ve been made, to profitably save this sulphur, by present methods, but the sulphur contents, averaging from 16 to 30 per cent, and, for the most part, approaching, in this respect, the first mentioned figure, with iron from 33 to a little over 50 per cent, is, apparently, too low to permit of its economic winning.

Experiments to make use of pyrrhotite for the production of sulphurous

Titus Ulké (1) states that, 'during 1902, was demonstrated the commercial impracticability of cheaply roasting Sudbury pyrrhotite nickel ores, which do not average over 25 per cent of sulphur, in Herreshoff furnaces, in order to utilize the sulphurous acid gas thus obtained, to

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(1) Min. Industry, Vol. XI, 1903, p. 490.

make sulphite pulp or liquid acid. The use of the dead roasted residue, in the making of ferro-nickel, was also found to be commercially unsuccessful. It is recognized that, unless this roasting in the Herreshoff furnace can be done mainly without the aid of extraneous heat, the cost, compared with heap roasting, is prohibitive, and that, in any case, the average percentage of sulphurous acid in the gas produced, is too low to be economical for use in the manufacture of calcium bisulphite for making sulphite pulp.' On the other hand, Mr. E. A. Sjostedt (2) metallurgist to the Lake Superior Power Company, who initiated and carried on these trials, states that the process has been worked out in a satisfactory manner, the pyrrhotite being roasted without extraneous heat, and yielding sulphurous acid in quantities that more than repay the cost of converting the raw ore into briquettes.

acid and ferro-nickel not commercially successful according to Ulke.

Sjostedt holds the reverse opinion based on practical experience.

The results of operations for two weeks in 1903, showed an average recovery of 86·4 per cent of sulphur, and a total working cost of $1.86 per ton of ore. Such are the conflicting statements of experts, who have been concerned in the practical working out of the process, but the popular opinion seems general, that failure has followed these elaborate trials, which had the advantage of being conducted on a commercial basis, by skilled men, with every modern appliance to ensure success. The fact that the Lake Superior Power Company, during their later operations in the Sudbury District, had practically adopted the general system of heap roasting and smelting, seems to lend support to the view expressed by Mr. Ulké.

Adoption of ordinary smelting methods argues the lack of success in experiments.

The sulphurous fumes from the roast heaps, have destroyed most of the vegetation, from within an area of between one and two miles of Copper Cliff, and have a very injurious effect on vegetation, and especially young and tender trees and plants, as far as the town of Sudbury. In the immediate vicinity of Copper Cliff, the destruction wrought to all growing plants and trees is very complete, and a more desolate scene can hardly be imagined, than the fine white clay or silt of the flats, through which protrude, at intervals, rough rocky hills, with no trees, or even a blade of grass, to break the monotony. Of late years, vegetation has, so to speak, become accustomed to the sulphur, and gradually, and as a result, the area affected by the fumes is becoming more circumscribed. The maple seems to withstand the sulphur the best, and trees of this species may be found fairly green in the immediate proximity of the roast yards. To add to this scene of desolation, the houses are of wood, rarely painted, while most of the area is covered with half-decayed logs, stumps and upturned roots, all of which have a peculiar brownish tinge, the result of the sulphur, which acts as an

Destruction of vegetation by sulphur fumes.

Injury done at Copper Cliff.

Vegetation becomes accustomed to sulphur.

Maple withstands the fumes the best.

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(2) Eng. & Min. Jour., April, 25th, 1903.

Iron objects rapidly eaten away.

Removal of one of the roast yards.

Improvements at Copper Cliff.

Sulphur fumes have no injurious effects on man or beast

Sensations produced by sulphur fumes.

excellent preservative. On the other hand, all the barbed-wire fences, telegraph lines and other iron objects are rusted, and rapidly eaten away, requiring to be frequently replaced. The removal of one of the roast yards, has had a most marked effect and the beneficial results which were sure to follow, are even now beginning to be apparent, for the two remaining are situated to the east and northeast of the town and thus the prevailing winds, which are from the southwest, will tend to carry the fumes away. With the persistent influence and guidance of the president and general manager, Mr. A P. Turner, trees are being planted, certain areas graded and made into lawns, roads opened up and culverts and bridges fixed, while the tortuous course of a small stream, running through the town, has been straightened and deepened. It is hoped that these efforts at beautifying the place, will meet with the success they deserve, and already the town has taken on a new appearance, due to these improvements. The fumes, which are free from arsenic, seem to have no injurious effect on man or beast, except on occasions, when particularly dense and accompanied by fog, when they produce a peculiar strangling or choking sensation, accompanied, on rare occasions, by bleeding at the nose. The residents are all seemingly healthy, and suffer from no unusual complaints, while some even assert that the sulphur is a positive cure for catarrh, consumption, and kindred diseases. People, moreover, at first, complain of a strangling sensation, but this gradually disappears, and those, who have resided there for a time, miss the sulphur when removed to another place, and have even an ill-defined though rarely expressed longing for this seemingly heavy and satisfying atmosphere.

Erection of roasting shed.

Carelessness at first in location and construction of roast yards.

Dry pine main fuel used in roasting.

Large consumption of fuel.

At the Murray mine, a huge shed, with numerous large chimneys, was erected, for the purpose of roasting the ore during the winter, but it was not a success in any respect. No great thought or care, has in the past, marked the efforts of some of the companies, in the selection of a site for the roast yard, and the ore has been placed in heaps where the natural surface of the ground permitted, with scarcely any previous preparation, such as grading and draining. The mechanical loss, alone, from such carelessness, must have been far from negligible. The main supply of fuel that can be secured and is used for the heap roasting, is dead or dry pine, often still standing as tall bare rampikes, the remains of extensive fires which swept over the area about thirty-five years ago. This during the first years of the operations, could be secured very readily and cheaply, but the extensive and continuous roasting has used up all available sources of supply close at hand, and this wood has now to to be brought considerable distances by rail, and is now often mixed with ordinary cordwood. At the Victoria mines, however, there is an abundant supply of this dry pine for years to come, and it is brought in by teams and sleighs during the winter, from the area immediately adjoining. This dry pine is very efficient for this purpose, as it is readily kindled, and produces almost immediately a short though fierce heat, which serves to ignite the pile thoroughly, and this, once started, continues burning, on account of its sulphur contents.

Dry pine plentiful at Victoria mine.

Suitability of dry pine for roasting.

Construction and size of roast heaps.

Amount of ore in roast heaps.

Duration of roasting.

Amount of fuel used.

Reduction in amount of sulphur.

Analyses of roasted ore.

The roast heaps are rectangular in shape, varying in size from 40 by 60 feet, and 7 feet high, to 60 by 120 feet and 18 feet high, and containing, in general, from 200 to over 3,000 tons of ore. The small heaps of 200 tons are of 'spilt matte,' of which mention will again be made. Ore heaps are not less than about 600 tons. Heaps of from 800 to 1,000 tons should burn out in from 40 to 50 days, the larger heap taking, in general, from 3 to 4 months, while occasional heaps containing 4,000 tons, which are the largest yet attempted, and which were by no means a brilliant success, have been known to burn from 6 to 7 months. The ore is piled on a bed of split wood, about one cord being used to twenty tons of ore. This wood serves to start the oxidation of the sulphur, iron, nickel and copper, the sulphur to sulphurous acid, the iron to iron oxide, the nickel and copper chiefly to sulphates. The sulphur, which, in general, averages about 25 per cent, is reduced to about 6 or 8 per cent, while the iron is, in large part, oxidized to ferrous oxide, and the associated norite or gangue is rendered more or less porous or disintegrated by the swelling and oxidation of the ore. An analysis of roasted ore, in December, 1888, gave F. L. Sperry 5·40 per cent of copper, 2·43 per cent of nickel 7·92 per cent of sulphur and 25 per cent of iron and the rest gangue, chiefly norite or diorite. L. P. Silver (¹) states that an average sample of the roasted ore gave 3·25 per cent of copper, 2·16 per cent of nickel, 8·32 per cent of sulphur, 25·61 per cent of iron and the rest gangue.

Average of Copper Cl roasted ore in 1902.

No assays made of Victoria mine roasted ore

Donald Locke says, that the roasted ore, in 1902, being used by the Canadian Copper Company, assayed about 1.5 per cent of copper, 2.5 per cent of nickel, 6 per cent of sulphur and 26 per cent of iron. At the Mond Nickel Company, no assays of the roasted ore are made, as it is so variable in composition and difficult to obtain representative material, and one tenth is added to the assays of the raw ore, to enable the furnace manager to make up a charge for smelting.

Ore fines used to make bed for roast heaps.

When an abundance of ore fines is in stock, over and above the usual requirements for covering and finishing the heaps, the excess is

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1. Jour. Can. Min. Inst. Vol. V., 1902, p. 544.

Method of building roast heaps.

Disposition of fuel.

Chimneys at first used to help kindle the pile.

Number and method of building chimneys.

Canals are sufficient for draught purposes.

Incipient fusion to be guarded against.

Use of temporary trestles in building heaps.

Disposition of coarse, medium and fine ore.

generally used to cover the ground on which the roast heap is to be built, to a depth of about six inches. The material is thus 'caked' together, in the roasting, and after having served for several roastings, is broken up and used as coarse ore, as it has only enjoyed an incipient oxidation. These roast piles are built up as follows: the place selected, may or may not be covered with the 'fines', as already mentioned, as occasion demands. Sticks of cordwood, of nearly uniform size, should be placed side by side, across both sides and ends of the rectangular area. The whole interior of this may be filled in with old stumps, roots, ties or cordwood, as material comes to hand, but, in such a way, as to form a level and solid bed, on which the ore is to rest. Over this, is placed small wood and chips, to fill up all the larger interstices, care being taken to provide small canals, filled with kindlings, at intervals of 8 to 10 feet, leading from the outer air to the center of the heap. As first practised, these canals connected with 'chimneys', along the centre which were specially designed to rapidly and certainly kindle the whole heap. These chimneys were usually built of four sticks or old boards, so fixed together as to leave an opening, communicating below with the draught passages. Five or six such chimneys sufficed for each pile, and they were made to project two feet above the upper surface of the heap, so that no pieces of ore could fall into the flue opening. Such precautions, to insure certain kindling, are, however, not needed, and the canals are amply sufficient for this purpose; besides, it was found that they induced undue local heating in their immediate vicinity, thus tending to incipient fusing or matting of the ore, which is to be specially guarded against. The bed of cordwood varies from 9 to 18 inches in depth, according to the size of the pile. This bed of fuel being completed, the coarse ore to the extent of about 65 per cent of the whole heap, is transferred by wheel barrows, from the cars, over a narrow and roughly constructed trestle platform, running the whole length of the heap. This plan is sometimes adopted by the Mond Nickel Company, at the Victoria mines, although, in some instances, the tram cars are deflected, by means of a spur or branch line, from the aerial tramway, running over the roast beds. The car is then lowered, and the ore dumped directly at any place desired. The medium sized ore or 'ragging', about the size of nut coal, is then carefully spread over the coarse ore, and lastly, the whole heap is covered up with fines, till a height of from 6 to 18 feet is reached, according to the size of the pile. The whole structure should then form a shapely rectangular pile, with sharp corners, and as steeply sloping sides as the ore will naturally lie on without rolling (about 45°).

The heap is now finished, and only those openings, connecting with the canals around the base of the pile are left exposed. Kindlings or cotton waste, saturated with oil, are applied to these openings, and these are simultaneously ignited. These openings are themselves covered with 'fines', as soon as the cordwood is burning freely. In spite of this ample covering, the whole of this fuel, as stated by Mr. James McArthur, (1) is burned out in about 60 hours after lighting up. 'A complete oxidizing roasting process then begins, and continues until the end, namely, until the sulphur contents are so far reduced and burned off, that there is not sufficient left to promote further combustion. The remaining portion of the sulphur (6 to 8 per cent) is enclosed and sealed up in non-porous portions of ore or matte, the semi-fused covering of which would require to be re-broken, in order to expose fresh faces under heat and thus liberate the remaining sulphur. This could only be done by turning over and re-roasting the ore, after the first roast was finished, but it is not at all necessary, as the remaining sulphur is essential in the smelting of the ore, in order to produce a clean slag'. About twelve hours after firing, the whole heap should be pouring forth dense pale yellow fumes of sulphurous acid. Great attention is paid to the pile for the first few days, to prevent excessive local heating, which frequently causes partial fusion of the ore, this tending to prevent successful roasting. The heap is carefully and systematically watched day and night, and all holes or fissures, caused chiefly by settlement due to the burning out of the fuel, are at once covered with 'fines' of raw ore. After the first few days are over, the pile may be left to itself, until cold enough to remove to the storage bins or furnace. After the period of roasting is over, and the pile is cold enough to be handled, the outer covering of partially roasted ore is first removed. This is more abundant along the sides and base, and the precaution is sometimes taken to cover up these portions of the pile, with old iron sheeting, which materially assists in preserving the heat, thus aiding the roasting. The longer the period of roasting, the less the matting, and of course the larger the heap, the smaller quantity of the outside covering or margin is left only partially roasted. When this outer covering is removed to be re-roasted, the remainder af the heap is conveyed in wheel-barrows a few yards, in one case, to a sunken railroad, which runs alongside of the roast yards. At the Mond Nickel Company, it is loaded into cars, which are hauled up an inclined tramway, to an elevated series of storage bins at the roast yard, from whence it is loaded, as required, into the aerial tramcars, and thus conveyed to the smelter.

Igniting of roast heap.

Roasting is an oxidizing process.

Only from 6 to 8 % of sulphur remains.

Remaining sulphur essential to produce a clean slag.

Great attention given to roast heaps, after firing, for first few days.

Outer covering first removed.

Different methods of handling roasted ore.

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1. Ann. Report, Bur. of Mines, Ont., 1903, p. 300.

Appearance of roasted ore.

Removal of ore to stock bins.

The ore, when roasted, is aggregated together, in large clinker-like masses. These are loosened, and broken up into suitable pieces for smelting, usually by pick and shovel, but often the assistance of explosives are needed to help in the removal. This roasted ore is loaded on large side-dumping cars, and hauled by locomotives to the stock bins at the furnaces. An experienced workman, knows the difference in the quality of roasted ores at sight, and is able to mix them roughly, as they are loaded into the cars at the heaps, to be taken to the smelter and dumped into separate bins. Here it is sampled, and again mixed by the furnace men, and made into smelting charges and fed into the furnaces.

SMELTING.

Smelting in Sudbury district.

Production of matte by Lake Superior Power Co.

Ore selected for manufacture of ferro-nickel.

The copper nickel ores of the Sudbury District are, at present, (June, 1904,) being treated by only one corporation, the Canadian Copper Company, but during the progress of our work in 1901 and 1902, both the Mond Nickel Company and the Lake Superior Power Company were also conducting smelting operations. The Mond Company produced both the blast furnace or standard matte, and the bessemer or converter matte, while the last mentioned corporation restricted their refining process to obtaining the lower grade or blast furnace matte. The smelter of the Lake Superior Power Company, situated at the Gertrude mines, was completed early in June, 1902, and for some time was treating from 100 to 160 tons of ore daily. The matte, resulting from these operations, steadily accumulated at the works, until the suspension of all operations of this concern in 1903, and, during this period about 2,000 tons of the standard matte were produced. This matte is stated to have contained 29 per cent of nickel and copper combined, the proportion of the nickel to the copper being as 2 to 1. It was proposed to further refine this product at a converter plant, being erected at Sault Ste. Marie, or to ship it elsewhere to be refined. In addition, about 20 tons of ore, daily, out of a total production of 200 tons, were picked out as free as possible from chalcopyrite, which quantity was laid aside, to be shipped to Sault Ste. Marie, for the manufacture of ferro-nickel.

Smelting at Murray mine.

Smelting at Blezard mine.

From 1889 to 1893, the Murray mine conducted rather extensive smelting operations, making both standard and bessemer matte. The average of the lower grade product was 8·5 per cent of nickel and 4 per cent of copper, while Walker's analysis of the latter, showed it to contain 48·82 per cent of nickel and cobalt and 25·92 per cent of copper. The Dominion Mineral Company, during the same period, produced only standard or blast furnace matte, containing from 18 to 20 per cent of

Drury Nickel Co.

Bessemer matte produced by Canadian Copper Co.

Erection of Ontario Smelting Works.

copper and 24 to 26 per cent of nickel. About 1893, and later in 1896 and 1898, the Drury Nickel Company and the same corporation reorganized under the name of the Trill Mining Company, smelted and sold about 420 tons of blast furnace matte. During the early '90's, the Canadian Copper Company produced a considerable amount of high grade matte by the bessemer process, but the refiners seeming to prefer the standard or blast furnace matte, the manufacture of this product was abandoned, and the bessemer plant, consisting of a cupola, and 3 converters, located at the East Smelter, has been left idle for the greater part of the time since. In the fall of 1900, the plant of the Ontario Smelting Works was installed by the Orford Copper Company, an organization closely related to the Canadian Copper Company, both of which, in April, 1902, were included in the amalgamation of these and kindred corporations, under the name of the International Nickel Company. These works were designed to further refine the low grade or blast furnace matte of the Canadian Copper Company.

Equipment at the East and West smelters at Copper Cliff.

Canadian Copper Co's. lease of Victoria Mines Smelter.

Before the erection of the new smelter, which will be described and figured later, the Canadian Copper Company had smelting plants installed in two separate buildings, known respectively as the East and West Smelters. The processes at the two smelters were alike, and they differed only in the number of their blast furnaces. At the West Smelter there were eight, and at the East Smelter five blast fuanaces, in addition to the bessemer plant. Lately, the East Smelter has been dismantled, and in a short time it is stated to be the intention of the Company to pull down the West Smelter also, and concentrate all refining operations under one roof. At the time of writing, no smelting is carried on at Copper Cliff, but the Company have leased the Mond Smelter at Victoria Mines, for a period of six months, this lease expiring about the 1st of August next, and all refining operations going on at present are carried on at this place.

Description of blast furnace.

The smelting or blast furnaces have the form of a flattened ellipse, are 9 feet in height to the charging door, and measure 9 feet by 5 feet at the top, and 8 feet 5 inches by 4 feet 4 inches at the tuyeres, of which there are 25 (2 inch), arranged in two rows. They are made of rolled steel, with a water space of two inches, between the outer and inner plates, and have for a bottom a cast iron plate, 1¾ inches thick, protected by fire-brick, the whole supported by four strong cast iron legs. A light dome of plate steel, brick-lined at the top and sides, covers the furnace, and in one side of this dome, on a level with the ore bins, is the feed door. The furnace gases pass to the stacks, (one to each pair of furnaces), through brick chambers, with trough-shaped sheet

Location of blast furnaces.

Description of forehearth.

Matte or metallic portion sinks to the bottom.

Use of McArthur granulating trough.

Disposition of granulated slag.

Use of granulated slag for ballast and roads.

iron bottoms. Here the flue dust, having an opportunity to be precipitated, is taken periodically from these chambers and added to the blast furnace charges. The smelters are situated at or near the ground level, and ore, coke and flux are brought into the building on an elevated track, and dumped into the bins on the feed floor level. The well, forehearth or settling pot, is built of cast iron water-jackets in four sections, with a water space of six inches, and rests upon four wheels, for convenience of moving it whenever repairs are necessary, a second well standing ready to be put in its place. When the forehearth is in position, a square opening on one side, is fitted by fire-clay, to a corresponding opening in the furnace, and the molten slag and matte flow into the forehearth, when the furnace is in blast. The feeding of the furnace is continued, at frequent and stated intervals, and as the molten mass gathers at the base of the furnace, it flows through the discharge hole, into the forehearth, where the heavier or metallic portion (matte), sinks to the bottom, while the lighter slag rises to the surface, to flow out in a continuous stream from a water cooled, phosphor-bronze slag spout, to a McArthur granulating trough, where it comes in quiet contact with a stream of water, that has already done duty in the water-jackets of the furnace, and flowing in the same direction as the stream of molten slag. This granulated slag is carried by the water, which gradually filters away into the dump or into the slag wells, out of which the slag is elevated, by means of a bucket elevator, into high waste heaps. From these immense dumps, road makers, and especially the Canadian Pacific and Manitoulin and North Shore railways, help themselves, loading this slag on cars, by means of steam shovels, for use as ballast, for which it is excellently adapted. It is much heavier than ordinary ballast, and does not retain water, and, therefore, is not so liable to wash-outs, or to freeze in winter and heave up the tracks, as does the ordinary sandy or silt ballast often used in the district.

Tapping of matte.

Matte is allowed to settle in pots.

The matte is drawn off periodically, the tap-hole for this purpose being situated at a lower level, which is opened with a pointed iron rod, and afterwards closed with a plug of fire-clay. This process is usually attended with a display of fireworks, but, as the men engaged at it become very expert, the stream of liquid matte is very quickly and effectively stopped. The matte is then allowed to remain in the cast iron pots or moulds, into which it has been tapped, until cool, when it is dumped out, broken by means of sledge-hammers, weighed, loaded on cars, and shipped to the Ontario Smelting Works for further treatment.

Use and strength of blast.

The blast is furnished by No. 7 Connersville blowers, discharging 67 cubic feet of air blast per revolution, and making from 90 to 130 revolutions per minute, each blower being driven by an engine of 50 H. P. The blast is delivered at the tuyeres at a pressure of about fourteen to sixteen ounces per square inch.

Description of roasted ore.

Proportion of coke used.

The roasted ore, with which the furnace is principally charged, is a mixture of oxides, sulphates and sulphides of nickel, copper and iron, together with a certain amount of the basic silicate of the gangue. The process of smelting is very economical, the ore furnishing in itself the exact ingredients for fluxing. By the smelting of the ore, with a small quantity of quartz, in the blast furnace, using from 15 to 17 per cent of Connellsville coke, the iron is chiefly reduced to ferrous oxide and forms a slag with the gangue and quartz.

Analyses of blast furnace slag.

Under I and II, are analyses of this slag by Mr. Donald Locke, late assayer of this Department. Under III, is an average analysis, published by M. John Herdt, (1) while under IV, is an analysis by Mr. J. W. Bain. (2).

	I	II	III	IV
Silica	34·16	32·58	38·00	26·67
Ferrous oxide	41·24	44·37	43·00	50·82
Ferrous sulphide		.....	.....	3·52
Lime	8·23	6·62	4·50	3·38
Magnesia	3·44	2·77	2·00	2·95
Copper	0·25	0·13	0·40	0·20
Nickel	0·23	0·23	0·45	0·10
Alumina	9·03	10·41	10·00	12·88
Sulphur	0·91	.....	.....	.....
Totals	97·49	97·11	100·85	100·52

Authorities for analyses.

Analyses of blast furnace matte.

The nickel and copper, and some of the iron, unite with the sulphur to form a matte. Under I and II, are analyses of this blast furnace or standard matte, the results obtained by Mr. Donald Locke, in November, 1902; under III, is an analysis, by Mr. J. W Bain, (1900); under IV, is the mean of two analyses of matte, which were made by Mr. F. L. Sperry, on the 22nd February, and the 2nd of March, 1889. Under V, is the copper and nickel determination for this matte, in February, 1891, while under VI, are determinations for these same metals, by Mr. L. P. Silver (1902).

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(1) "Les Mines de Nickel du District de Sudbury (Ontario)." Rep. Cham. de Commerce, Montreal, 1892, p. 39.

(2) Ann. Rep. Bur. of Mines, Ont., 1900, p. 217.

	I	II	III	IV	V	VI
Copper	14·69	14·53	19·87	26·910	17.24	20.35
Nickel	28·17	26·34	16·75	14·140	21·44	16·48
Iron	31·89	34·15	43·90	31·235		
Sulphur	24·96	24.93	18·72	26·950		
Cobalt	.....	.....	0·63	0·235		
Slag	.....	.....	0·05	0·935		
Totals	99·71	99·85	99·92	100·405		

Average daily charge and production of blast furnace.

Each furnace, of which there were 13 installed, puts through about 130 tons every 24 hours, the total capacity being about 1800 tons per day.

Mr. Donald Locke gives the following average for a day's work of a furnace. In a day of 23 hours, using 12 oz. blast pressure, there were smelted 264,000 lbs. of roasted ore, assaying :—

Copper	1·43	per cent.
Nickel	2 56	"
Silica	26·00	"
Sulphur	5 57	"

Nickel and copper contents of matte produced.

To this was added 3,600 lbs. of quartz, with 98 per cent of silica, using 45,300 lbs. coke (17 per cent). There were produced 26,318 lbs. of matte, containing :—

Copper	11·90	per cent.
Nickel	22·10	"

Composition of slag.

and 207,425 lbs. of slag, containing :—

Copper	0·27	per cent.
Nickel	0·40	"
Silica	32·00	"
Iron	40·00	"

Description of extraordinary run.

An extraordinarily good run was as follows :—With a 16 oz. blast, there were smelted in 24 hours :—

Ore	510,000	lbs.
Quartz	2,250	"
Using coke	87,200	"

There were produced :—

Matte	44,231	lbs.
Slag	439,233	"

Formation of flue dust.

The furnace gases pass to the stacks (one to each pair of furnaces), through brick chambers, with trough-shaped sheet iron bottoms. Here the flue dust, having an opportunity to be precipitated, is taken periodically from these chambers, and added to the blast furnace charges. Four samples, assayed by Mr. Locke, in 1902, resulted as follows :—

Nickel and copper contents of flue dust.

	I.	II.	III.	IV.
Copper.........	1·45	1·49	1·55	1·39
Nickel..	3·28	3·84	3·79	3·62

An assay of a typical sample, by Mr. L. P. Silver, (1) gave copper 4.25 per cent and nickel 3·37 per cent.

Production of 'spilt' matte.

In the roasting of the ore, a large proportion is badly roasted, or, owing to the heat in the pile being too intense, the ore melts to matte, and is not roasted at all. This should be re-roasted, and is so, to a certain extent, but when large orders are on hand, this unroasted and partly roasted ore, is smelted in the blast furnace, and the resulting low grade matte is 'split,' that is, poured out on the ground in layers of about half an inch in thickness, and broken up. Two assays of this 'spilt' matte, collected in November, 1902, gave Mr. Locke the following results :—

Composition of 'spilt' matte in Nov. 1902.

Nickel	2·30 per cent.	3·43 per cent.
Copper......	3·26 "	3·56 "
Iron.	63·08 "	61·18 "

Other assays of 'spilt' matte.

This matte usually contains from 7 to 15 per cent of the metals and a typical sample, analyzed by Mr. L. P. Silver, (op. cit.), contained, nickel 6·01 per cent and copper 7·45 per cent.

Roasting of 'spilt' matte.

This 'spilt matte' is broken up and taken to the roast-yard, where it is roasted in small heaps (about 200 tons). After the necessary oxidation, the roasting usually lasting about 30 days, it is re-smelted being added to the blast furnace charge, in place of some of the ore, the matte thus produced heing thereby much richer in metallic contents.

Bessemerizing by Canadian Copper Co.

Previous to the installation of the plant at the Ontario Smelting Works, the Canadian Copper Company still further refined their own blast furnace or standard matte, by the 'Bessemer Process.' In these earlier years, about 1893, this was done on [illegible] an extensive scale, but during the later '90's, there was no very constant or large demand for this higher grade of matte, and this method of concentration was only practised as occasion demanded. The converter used was of the Manhés type, with a capacity of one and a half tons, with a new lining, and three tons with an old lining.

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(1) Jour. Can. Min. Inst., Vol. V, 1902, p. 546.

Dimensions of converters.

The process is very similar to that followed in bessemerizing iron. The Manhès converters are cylindrical shaped vessels, with convex ends measuring usually about eight feet in length, with a diameter of about four feet. They are made of boiler plate, and lined with a thick layer of clay mixed with quartz.

Employment of quartz from Bruce Mines.

Silica used now comes from near Kelley lake.

In the first years, much of the quartz used, and especially at the Murray mine was obtained from the Bruce Mines, where great quantities of 'skimpings' exist, resulting from the jigging of the ore from that mine during its operation in past years. This material consists of the crushed quartzose gangue, cleaned of all but a small proportion of the sulphides of copper, constituting the ore. It carries but a small proportion of felspar. The silica, now to be used, is obtained from a large vein of massive quartz, situated on the high range of norite hills near the shores of Kelley lake, a little over a mile south of the large new smelter.

Description of converter.

The converter rests, with its axis horizontal, on a carriage running on a track. It is provided, on its upper side, with a mouth or throat through which it can be charged. The dimensions are: length 7 feet, 3 inches; diameter 5 feet, 8 inches. The blast is driven through the charge from two parallel series of small tuyere holes, piercing the lining, along either side, below and along the length of the vessel. Opposite each of these tuyere holes, corresponding holes are pierced through the tubes, which run along the outside of the converter, to supply them with blast. These holes are closed with wooden plugs, removable to admit an iron bar, which, being poked through them successively during the process of blowing, keeps the tuyeres clear and the charge stirred.

Motions of converter.

A gearing enables the converter to be rotated on the car about its horizontal axis, and the throat having been thus lowered, a charge of low grade matte, from the well or forehearth of the cupola, is run into it by means of a trough. It is then rotated back, till the mouth is again vertical, and run around underneath a large hood, connected with a stack, in another part of the smelter house where it is connected with the blower.

Gradual application of pressure.

At first, a pressure, starting at 5 lbs. of an air blast, is blown through the mass of metal, when a violent agitation takes place, and on raising the pressure to 7 lbs., white fumes appear. As there are none of the usual flame reactions, the point at which to stop the blast, after the iron has been removed, and before the nickel has also begun to slag, in undue amount, requires special experience and judgment. The end of the operation is determined mainly, by a perceptible decrease in the temperature of the mass, as shown by the flame, but also of the fragments splashed or blown out of the converter, as well as by the size and appearance of the particles, which gradually become larger and more frothy, at the last issuing in pieces about the size of a man's hand. The duration of the blowing operation depends on the size of the charge, and the displacement of the converter spaces for the silicious lining is gradually appropriated by the iron in the charge. Each charge is, therefore, greater than the preceding one, until the sixth or seventh charge is blown, when the converter is laid to one side for relining. As a result of this, the continuance of the blast generally varies from 20 to 80 minutes, averaging about 50 minutes.

Criteria for judging when end of process is reached.

Charge of converter dependent on use.

During this bessemerizing process, the iron is almost entirely removed, the sulphur lowered to from 10 to 15 per cent, and the copper and nickel combined to from 80 to 85 per cent. The iron unites with the silicious lining, to form a very fluid slag which is spilled off the top. The amount of nickel, lost by oxidation, is very trifling, cobalt is perfectly scorified, zinc, arsenic and antimony are completely driven off, while bismuth, silver, gold and platinum are entirely concentrated in this matte.

Objects of bessemerizing.

The following are analyses of this bessemer matte :—

Analyses of bessemer matte.

	I.	II.	III.	IV.	V.	VI.
Nickel... Cobalt...	39·96	40·93	31·35	41·18	39·64	48·82
Copper....	43·36	45·71	48·86	44·87	42·75	25·92
Iron......	0·30	0·40	0 81	0·94	1·03	2·94
Sulphur....	13·76	.....	.....	11·62	14·05	22·50
Gold....	0·1 to 0·2 oz.	....	.....	0·3 oz.	0·75 oz.	·000075
Silver......	7 oz.	....	.....	5·1 oz.	5·30 oz.	·001775
Platinum .	0·25 oz.	.....	.....	....	0·50	·000430
Iridium....	....	.....	....	....	....	·000056
Osmium....	....	.....	....	..	...	·000057
Rhodium ..	....	....	..	....	....	Trace.
Palladium .	0·25 oz.	.....	..	...	...	Trace.

Explanations.—Analysis I, is by Titus Ulké and is styled 'a fair average analysis of the Canadian Copper Company's bessemer matte.' (Min. Industry, Vol. III., 1890, p 460); II. and III., are by Roberts-Austen, (Min. Proc. Inst. Civ. Eng., Vol. CXXXV, p. 30); IV., is an analysis, by J. W. Bain, (Ann. Rep. Bur. of Mines, Ont., 1900, p. 218); V., is an analysis by L. P. Silver, (Jour. Can. Min. Inst., Vol. V, 1902, p. 534); VI., an analysis by Dr. T. L. Walker, of the besse-

Authorities for analyses.

Comparison of Norway and Sudbury mattes in regard to precious metals.

mer matte, from the Murray mine, (Amer. Jour. Sc., Vol. I., 4th Series, 1896, p. 112 ; also Ann. Rep. Bur. of Mines, Ont., 1903, pp. 283-284).

Under Norway, on a preceding page, analyses of similar concentrated matte, obtained from the Norwegian pyrrhotite, are also quoted. These show the presence also of gold, silver and platinum in appreciable quantities. Speaking roughly, the silver is only from ½ to ⅔ of that present in the Sudbury matte, the gold about the same as that in the Murray mine matte, which is only about ¼ of that present in the mattes from the Copper Cliff and Victoria mines, while the metals of the platinum group occur in about half the amount of that present in the Murray mine, this matte itself only containing less than half that usually present in the mattes produced from the Copper Cliff and Victoria mines.

Relative proportions of precious metals in Norwegian mattes.

Prof. Vogt, also gives the interesting information, that the proportion of these metals present in the Norwegian ores and mattes, is one part of gold to 20 of silver, one of platinum to 30 of silver, one of silver to 5,000 of nickel and one of platinum to 150,000 of nickel.

Analyses of bessemer slags.

The following are analyses of the converter or bessemer slag. All converter slags are returned to the furnaces for re-smelting, as they are so high in nickel.

	I.	II.	III.
Ferrous Iron	66·6	67·1	67·6
Silica	28·5	27·9	27·5
Nickel	1·9	1·6	1·4
Copper	1·1	0·8	1·2
Sulphur	0·5	0·4	0·5

Authorities for analyses.

I and II., are analyses by Edwards, (Eng. & Min. Jour., May 2nd, 1896) ; III., is an analysis by L. P. Silver, (Jour. Can. Min. Inst., Vol. V., 1902, p. 549).

Canadian Copper Co's mattes refined at Ontario Smelting Works from 1900.

From about the beginning of November, 1900, until the destruction of the plant early in the spring of 1904, the blast furnace matte produced by the Canadian Copper Company, was further refined at the Ontario Smelting Works, built and operated by the Orford Copper Company, at Copper Cliff. This company was a closely allied corporation, and both were consolidated in 1902, under the management of the Canadian Copper Company, itself a subsidiary organization of the International Nickel Company.

Preparation of matte at Ontario Smelting Works.

The standard matte is brought from the Canadian Copper Company's works on cars, and put through a Blake crusher. It passes from that directly into a Krupp ball mill, where it is reduced to a fine powder. From the ball mill, it runs on a belt conveyer, which raises it to a storage bin, and from this storage bin, it is conveyed still further, as required, on belt conveyers, to the feed hoppers of the roasting furnace.

Description of equipment at Ontario Smelting Works.

The matte is roasted in two Brown, straight-line, automatic reverberatory calciners, each with a hearth area of 140 feet by 10 feet. Later, these furnaces were enlarged to 200 feet, and a third one of similar dimensions was also built. One furnace has six sets of ploughs, and the other seven. The ploughs make one complete trip in 6½ minutes. The plough carriage, on passing the automatic feeder, causes a certain amount of the powdered matte to fall into the furnace. Each furnace puts through 45 tons of matte in 24 hours, and reduces the sulphur from 25 to 30 per cent down to 5 to 8 per cent, using 4½ cords of wood per furnace per day.

Capacity of reverberatory calciners.

The roasted matte is discharged from the furnaces, into the trough of a screw conveyer, which takes it to the feeding floor of the blast furnace.

Dimensions of 'Orford' furnace.

The furnaces are of brick usually known as the 'Orford' furnace, cooled in the region of the tuyeres, by water circulating in pipes, embedded in the brickwork. The furnace measures 50 inches by 128 inches at the tuyeres, of which there are seven.

Blast.

The blast is furnished by two No. 9 Sturtevant, centrifugal blowers. The furnaces are fed by hand, the charge consisting of roasted matte, fed in powder form, with quartz tailings and some roasted ore.

Formation of large amount of flue dust.

Owing to the large amount of fines in the charge, great quantities of flue dust are formed—40 tons a week being a usual figure, and often as high as 80 tons a week being produced. This flue dust, assaying about 11 per cent of copper, and 18 per cent of nickel, is put through the furnace again.

Description of 'Orford' forehearth.

The matte and slag flow from the furnace continuously, into an Orford siphon-tap forehearth. This consists of a rectangular box about 4 feet long, 2 feet 6 inches wide and 18 inches high, formed of cast iron plates strongly bolted together at the corners and lined with a 6-inch brick wall. It is divided into two parts, in the ratio of about 2 to 3, by a 9-inch division wall, with a slot on the level of the floor of the forehearth, through which the matte can flow from the larger to the smaller compartment. The whole forehearth is supported on wheels. The matte and slag flow from the furnace into the larger com-

Settlement of matte.

partment, the forehearth fills, the slag, being lighter, floats, and only the matte is able to find its way to the smaller compartment, through the slot at the bottom of the division wall.

Discharge of matte and slag.

When the forehearth is full, matte and slag are discharged in separate and continuous streams, the former being received in cast iron pots. This refined product is shipped to the Orford Copper Company, New York, for the separation of copper and nickel. Two samples of this high grade matte, assayed by Mr. Donald Locke, contained as follows :—

Analyses of Ontario Smelting Works matte.

Nickel	41·58	40·37
Cobalt	0·71	0·78
Copper	24·99	24·95
Iron	9·62	9·64
Silver		2·50 oz. per ton.
Gold	0·15 oz. per ton.	0·10 oz. per ton.
Platinum	0·50 " "	0·44 " "

Analyses of Ontario Smelting Works slag.

Two samples of the slag collected at the same time, analyzed by Mr. Donald Locke, gave the following results :—

Silica	31·03	26·62
Ferrous oxide	64·31	66·72
Lime	0·22	0·24
Magnesia	0·08	0·09
Nickel	2·57	2·68
Copper	0·56	0·77
Alumina	0·54	0·54
Sulphur	0·49	0·30
Totals	99·80	97·96

Slag is re-smelted.

This slag is taken to the Canadian Copper Company's works, and put through the blast furnace, to recover the metal contents, which are too high to be neglected.

PYRITIC SMELTING.

Pyritic smelting in Canada.

Mr. James McArthur is authority for the following statement : (1) 'Cold blast pyritic smelting of sulphide ores has been carried on in Canada, off and on, and for long periods at a time, since 1879 ; not as

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(1) Ann. Rep. Bur. of Mines Ont., 1903, pp. 302 & 303.

an experiment but as a process. Thousands of tons of copper sulphide fines have been smelted with cold blast, and later on in recent years at Copper Cliff with cold and also with very moderately hot blast (the latter about 400°F.), making in these recent operations some 18,000 to 20,000 tons of matte product. The coke consumption was about 5 per cent for both temperatures of the blast, the grade of matte product being almost identical. With a blast temperature sufficiently high,—not less than 1200° F.—to counteract gumming at tuyeres, the sulphur contents of the ore, which should be the only fuel used apart from a small percentage of the iron, can be kept in ignition, and with a higher pressure of the blast we should get sufficiently rapid oxidation action, even in a large and fast smelting furnace, to produce a direct 30 per-cent matte, or over seven into one, from a raw 4 per cent ore as it comes from the mines, because if we can dispense with all carbonaceous fuel in first smelting and can use the sulphur contents of charge in its stead, we stop all reducing action, and in lieu thereof introduce a complete oxidizing action, oxidizing the iron and consuming the sulphur in the operation.'

Description of process.

Average metallic contents of matte.

Just to what extent green ore will be employed, in place of roasted ore, under the new conditions which will obtain at the new smelter, which is about to be described, and where the pressure will be 40 ozs. instead of 14 ozs., cannot be foretold, but it is expected that a very large amount of raw ore will be added to the furnace charge.

Extent of pyritic smelting to be employed, uncertain.

Preparation of plans for smelter for Canadian Copper Co.

The drawings, accompanying this bulletin, are plan and sectional elevations of a 1000-ton smelter designed by the Engineering Company of New York. (1) These were submitted to the Canadian Copper Company, who, after their approval and adoption, proceeded to instal this new smelting and power plant, in which are assembled the latest and best improvements and conveniences for every part of the work. It is confidently expected that this smelter will be in operation early in July (1904). (2)

Objects to be attained in building new smelter.

Disposition of slag.

In the erection of this smelter, there were several objects that had to be borne in mind, among them the cheap handling of a large tonnage of ore, the storage during the winter months of materials, such as coke and coal, which can be received by boat during summer; the elimination of all needless manual labor, and the thorough efficiency of the power department. The plant was designed to be erected on two levels; the large amount of slag produced had to be taken into consideration and the disposition of this slag was an important factor

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(1) The blocks for the drawings reproduced in this report were kindly loaned by the *Engineering and Mining Journal* of New York.

(2) Eng. Min. Jour. Vol. LXXVI. Dec. 31st, pp. 1003 1009.

in determining the site. The plant, as it now stands, was built along the face of a cliff, on the northern side of the flat, on which the town of Copper Cliff stands.

Description and location of storage bins.

On the upper edge of the cliff, a system of bins has been constructed for storage purposes. The smelter building proper, is situated parallel to these bins, with the power-house at the northeastern end. A trestle was built on the grade level of the bottom of the bins, which is also the grade level of the charging floor connecting the charging flooor with the bins and also with the power-house, making a circular track. running on both sides of the furnaces, and passing the coal chute in front of the power-house. · After roasting, the ore is loaded into 50-ton hopper-bottom cars, and drawn up to the top of the bins by 70-ton locomotives. The track leading to the trestle is on an easy grade all the way, and is also connected with the main line, leading to the Canadian Pacific railway.

Removal of roasted ore.

Disposition of various products.

All ore, flux, coke, coal, etc., is handled on these tracks, and dumped directly into the bins. Running on the circular track underneath the bins, and into the smelter building, and past the power-house, is an electric railroad, with side dumping cars drawn by electric locomotives. The ore, coke, etc. is loaded into these cars, and weighed on the end of the trestle. The furnace charge is dumped direct into the furnaces, and the coal into the pockets next the power-house.

Description of sectional elevations. Dimension of buildings.

As shown by the sectional elevations, the site consists of two levels, with a difference of 35 feet in elevation. The upper level is the same elevation as the feed-floor, and is occupied by a double-track pocket trestle, 35 x 35 x 600 feet.

On the lower level, are located the power-house, 156 by 102 feet; the blast furnace building, 84 by 283 feet; the foundation for the trestle carrying the electric tramway, connecting the storage pockets with the feed floor; the coal-bins of the boiler room; the dust-chamber, 16 feet wide, 18 feet high and 444 feet long; the stack, 15 feet inside diameter, 210 feet high; together with the necessary slag tracks, sunken tracks for loading metal for shipment, tracks to store house, etc.

Details of equipment of power-house.

The power-house is equipped with two Nordberg Manufacturing Company's horizontal, cross-compound, condensing, blowing engines, with steam cylinders, 13 inches and 24 inches by 42 inches and air cylinders 57 inches and 57 inches by 42 inches. When operating under usual working conditions, these engines will deliver 20,000 cu. ft. of free air per minute, against a pressure of 40 ozs., for use in the blast furnaces. One Nordberg Manufacturing Company's horizontal cross-compound, condensing, blowing engine, with steam cylinders 15 inches and 30 inches by 42 inches and air cylinders 40 inches and 40 inches by 42 inches, will deliver 10,000 cubic feet of free air per minute, against a pressure of 15 lbs., for use in the converters. Two 13 in. and 26 in. by 20 in. horizontal, compound, condensing engines, built by the Robb Engineering Company, to each of which is directly connected one 200 kw. 600-volt, 3-phase alternating current generator, built by the Canadian General Electric Company, each generator having its own exciter of 11 kw. capacity, belt driven from generator shaft. The electrical energy thus generated, is used for hoisting in and pumping at the mines, operating the electric tramway for charging cars, turning the converters, and operating the travelling crane in the furnace building. The station is also equipped with one 25 kw. motor driven generator set, for furnishing direct current to the electric locomotives. A travelling crane of ample capacity is installed in the engine-room for handling all this apparatus. A gravity oiling and oil filtration system is installed on all engines.

Electrical equipment.

Description of plant in boiler house.

In the boiler room, the present installation of boilers consists of four 400-H. P., 150-lb. pressure, horizontal water-tube boilers, built by the Aultman & Taylor Machinery Company, of Mansfield, Ohio, and space is provided for two more boilers of the same size. The boilers are equipped with Potter Super-heaters and Tread-Kill shaking grates. The ashes are removed from the boiler ash-pit by opening a grate in the bottom, which permits them to fall into a bucket resting on a small flat car, which runs on a track in the ash-tunnel under the boilers. The car is then run outside of the building and a hoist lifts the bucket and dumps the ashes into an ash-bin, from which it runs into cinder cars.

Movement of coal.

Coal is brought to the power plant by the electric locomotive train, above referred to, and dumped into bins built in the trestle along the west side of the building. Then it runs through coal chutes to one-half ton coal cars in the boiler room, from which cars it is shovelled into boiler furnaces.

Treatment of water before use in boilers.

The only available water for boiler use, contains considerable sulphuric acid and scale-forming elements, and, to eliminate these, the water is subjected to a chemical treatment and precipitation, in a water purifying system, built by the Industrial Water Company, of New York. In this way, the acid is neutralized, and the scale-forming material is removed, before the water enters the boilers. The condenser is of the elevated barometric shape, built by the Alberger Condenser Company, of New York.

Style of blast furnace used.

The blast furnace building contains two sectional, rectangular, water jacketted, Holthoff, copper blast furnaces, three stands for Holthoff converters; one 40-ton electric crane; the necessary matte-settlers, clay mills, silica and clay storage bins, etc. Room is provided for expansion.

Methods employed in movement of products.

In operation, the ore, coke and flux for the blast furnaces, silica and clay for lining the converters, and coal for the boilers, are delivered into the top of the trestle pockets, by standard-gauge cars—Ingoldsby drop-bottom in the case of the ore, and drawn from the bottom of the pockets into trains of six 2-ton, 36-in. gauge, side-dump, Koppel cars, which are hauled to the blast furnace, silica and clay storage bins, or coal bins, by 25 H. P. Canadian General Electric Company electric locomotives.

Disposition of slag and matte.

The slag and matte run from the blast furnace into 16-in. settlers, the slag overflowing into 30-ton Pollock cinder cars, which are hauled to the dump by standard gauge locomotives. The matte is tapped into 10-ton cast-steel ladles and taken to the converter by a 40-ton Case Manufacturing Company's electric crane. The same crane removes the converter shells for re-lining, and takes care of the converter slag and white metal, pouring them into moulds for return into the pocket trestle, or for shipment to the refinery. The coal bins at the boilers, and the silica and clay bins at the clay mills, are kept full by six-car train-loads of material.

Removal of flue dust.

The flue dust is drawn from the dust chamber into a standard gauge bottom-dump gondola, especially fitted for the service, and this car is hauled to the top of the pocket trestle on the upper level, and the dust drawn into a pocket fitted for the purpose, whence it is drawn to a briquetting machine, pressed into briquettes and added to the charge.

Operation of electric tramways.

The electric tramway consists of two parallel 36-in. gauge tracks, running under two lines of grates under the pocket trestle, then over suspension scales to opposite sides of the furnaces on the feed-floor level, passing over the top of the boiler room, coal bins and converter lining house, silica and clay bins. The two tracks have cross-over connections, but, under normal working conditions, each track carries a train entirely independent of the other.

Dimensions of blast furnaces.

The blast furnaces are 50 in. by 204 in. at the tuyeres; 14 feet 9 inches from centre of tuyeres to the feed-floor, and have, on each side, four lower jackets, each 51 in. wide and 8 feet 6 inches high, and two upper jackets, 8 feet 6 inches wide and 6 feet high. Each lower side-jacket carries four 6 in. tuyeres. Both ends of the furnace are made alike, so that either end can be used for removing matte and slag.

Size of converters.

There is no brick work under the deck beams. The converters are 84 in. by 126 in., and are tilted by a train of gears and a worm, driven by the electric motor.

Water supply.

The water for the plant is supplied by a 16-in. pipe, running from a dam, situated about 5,000 feet from the plant itself. The water is run by gravity into the jackets and when drawn out, is pumped into a tank above the smelting plant, for fire purposes, or into the reservoir, which is near the foot of the plant, and the hot water is also used in the boilers in order to economize at that point.

Location of Mond Nickel Co's smelter.

Modern equipment.

Average composition of bessemer matte.

Matte shipped to Wales for refining.

Lease of Mond Co's. smelter to Canadian Copper Co.

Expectation that Mond Co. will resume operations.

Mining at North Star mine.

The Mond Nickel Company refine the ore from their own deposits at Victoria Mines, a station on the 'Sault branch' of the Canadian Pacific railway, 22 miles west of Sudbury. Their smelter, before the erection of the new one, now about completed, at Copper Cliff, was the most modern and best equipped in the district. It not only produces standard or blast furnace matte, but further bessemerizes this into a concentrated matte, containing about 80 per cent of nickel and copper, these two metals being present in about equal amounts, 18 per cent of sulphur, about 0·75 per cent of iron, and 0·25 per cent of silica. This is sent to England, to be treated there, by the Mond process, for copper and nickel. Difficulties, in connection with the operation of their refining at Clydach, Wales, have, for the time being, caused a suspension in their mining and metallurgical operations in the Sudbury District, while their smelter has been operated by the Canadian Copper Company under a six month's lease, which expires about August 1st next (1904). It is authoratively stated, however, that these difficulties have now been successfully overcome, and that their refinery, greatly enlarged and with all the necessary changes, is ready to go to work. It is confidently expected that immediately on the expiry of the Canadian Copper Company's lease, the smelter will again resume operations, under the former management, on even a larger scale than before. The North Star mine, on the Manitoulin and North Shore railway, is, at present, being developed under option by this company, under the direction of Mr. C. V. Corless, and the ore secured is shipped to Victoria Mines for treatment.

Roasted ore carried by aerial tramway.

The roasting of the ore is carried on as at the Canadian Copper Company's works, The roasted ore is brought to the smelter, by means of an aerial teamway, from the roast yards, which are about one mile distant.

Location and general description of smelter.

The smelter is erected on a sloping hillside, and has three levels, those of the feed floor, the furnace floor and the converter floor. The roasted ore is brought into the smelter to a platform, above the third level, where the tubs are received by a boy, after having been automatically unhitched from the haulage rope. The boy runs the tubs to the bins, tips them and hitches them, again empty, to the outgoing rope. The ore bins are situated above and behind the feed floors, so that the roasted ore can easily be discharged, through chutes, into the dump cars on the feed floor.

No assays of roasted ore made.

Assays of the roasted ore are not made, owing to the difficulty of selecting samples, and without careful sampling widely different results are sure to be obtained. For the purpose of deciding the proper proportions of ore, to be included in the furnace charges, one-tenth is added to the assays of the raw ore. The averages of the daily assays of raw ore for July and September, 1902, made by Mr. T. M. Paris, chemist to the Mond Nickel Company, are given under I and II respectively, while, under III, is given an average of several months assays.

Average nickel and copper contents of ore from Victoria mine.

	I.	II.	III.
Nickel.........	2.[illegible]	3.21	3.05
Copper.........	2.01	2.41	3.05
Insoluble.	17.20	13.90	17.01

Description and dimensions of blast furnace.

The ore is smelted in rectangular, steel, water-jacketed furnaces, 12 ft. high, 42 in. by 120 in. at the tuyeres, and increasing slightly towards the top. The two furnaces (only one runs at a time) have each 16 tuyeres, 8 on each side, a cast iron water-cooled tap jacket and Hixon slag spout. This consists of a coil of 1 in. piping, cast around with cast iron so as to form a channel some four feet long, through which the matte and slag flow continuously into the forehearth. The spout is fully described in Hixon's 'Lead and Copper Smelting,' pp. 28-30. One furnace puts through about 170 tons a day, made up (for example) as follows :—120 charges each containing :—

Character of average furnace charge.

	A.	B.
Flue dust.............	200 lbs.	
Tailings...............	200 "	250 lbs.
Converter slag..........	500 "	500 "
North Star ore..........	300 "	250 "
Roasted ore.............	1,600 "	1,800 "
Coke.................	300 "	300 "

Tailings from Bruce Mines.

The tailings are practically pure quartz, with a small percentage of copper, from the Bruce Mines.

Use of North Star ore.

The North Star ore (obtained from the North Star mine) is not roasted, and the quantity used is varied according to the amount of

Simple device for charging furnace.

Use of blast.

Description and size of forehearth.

Formation and disposition of slag and matte.

sulphur in the roasted ore. The charges are dumped directly from the dump-cars into the furnace, through the open top, alternate charges being fed to the sides, by means of a simple device, consisting of a wrought iron pipe, about 8 in. in diameter, through the length of the furnace opening, and let down about three feet into the furnace. On this the charge falls and is deflected towards the sides. The blast for each furnace is furnished by a No. 6 Green blower. The forehearth is of boiler iron, 10 feet in diameter, with 6 in. lining of fire clay and quartz. In this, the matte and the slag have every opportunity for a complete separation, and, owing to its large size, the converter foreman can always be assured of having sufficient matte ready for him, when he requires it. When the hearth fills, the slag spout is at first kept stopped up, so that the bath rises right to the top of the hearth, and a stiff slag crust forms, which is covered with a layer of non-conducting coke. This forms the hearth cover. After the formation of the cover, the slag spout is opened and the slag overflows, and is granulated by falling into a powerful stream of water, and is carried to the slag dump by means of a large cast iron pipe.

Average metallic contents of blast urnace slag.

Under I, is given the average of the blast furnace slag assays for September, 1902; II, is the average for several months in the same year, by Mr. T. M. Paris, of the Mond Nickel Company, while, under III, IV and V, are similar assays, by Mr. Donald Locke of this Department.

	I.	II.	III.	IV.	V.
Nickel...........	0·30	0·34	0·31	0·25	0·28
Copper...........	0·36	0·35	0·33	0·28	0·29
Silica............	31·20	31·31	30·50	32·00	30·70

Removal and average production of matte.

The matte is tapped, periodically through the water-cooled tap-hole, flowing through cast iron channels, lined with clay, into the converters, which are situated on the lowest level of the smelter. About 20 to 25 tons of matte are produced per day, by one furnace.

Average nickel and copper contents of blast furnace matte.

Under I, is given the average of the metal contents of this blast furnace or standard matte for September, 1902. Under II, the average for several months, in the same year, by Mr. T. M. Paris, while III, IV and V, are assays, by Mr. Donald Locke, of this Department.

	I.	II.	III.	IV.	V.
Nickel......	15·20	16·53	13·80	15·00	15·50
Copper......	13·14	16·22	12·10	11·80	12·00

In the converter department, are 6 Leghorn converters, only one of which is in use at a time, the others being repaired, lined or dried.

Equipment of converter department.

The lining consists of a mixture of quartz and clay, the quartz being crushed and then ground in a Chilian mill, where it is also mixed with the clay and moistened.

Method of lining converters.

Preparing a converter for work.

In lining a converter, the bottom is first put in and tamped firm; a tapering iron tub is then placed in the converter, and round this the lining is firmly tamped. When the lining is completed to the top of the tub, the tuyere holes are punched, the tub lifted out, and the top of the converter put on. This is then lined, and the converter moved to where a blast pipe can be connected. A wood fire is lighted and the blast turned on. The fire is kept up until the converter is wanted. The converters are moved, from place to place, by means of a travelling electric crane, commanding the whole floor of the converter department.

Average converter charge.

Use and strength of blast.

The first charge of a newly lined converter is only about 1 ton, but as the lining is eaten away, the size of the charge increases, the average charge being about 2 tons. A lining lasts from 11 to 12 hours, about 6 charges being blown in this time. A blast of 10 lbs. pressure is employed.

Disposition of slag and matte.

During the blowing of a charge, the slag is twice poured off into slag pots, by tipping the converter, the blast being turned off during the pouring. The finished matte is poured into a clay-lined bucket, which is carried by the electric crane, and the matte tapped from it into flat, cast iron moulds.

Analysis of bessemer slag.

The following is an analysis of a clean converter slag, by Mr. Donald Locke, of this Department.

Silica	33·40
Ferrous oxide	46·50
Lime	0·93
Magnesia	0·08
Nickel	0·55
Copper	0·45
Alumina	4·60
Sulphur	1·17

Average metallic contents of bessemer slag.

The total amount of copper and nickel skimmed off, or poured from the matte during the converting, is, of course, much larger than this, as the last skimming contains much pasty, half fused substance, containing matte, and being higher in nickel than the clean slag. The average, therefore, of the converter slag would be considerably higher in nickel, averaging about 1·5 per cent of copper and from 1·5 to 2 per cent of nickel.

Analyses of bessemer matte.

The bessemer or converter matte contains as follows, according to two analyses, by Mr. Donald Locke, of this Department:

Nickel........	41·88	41·23
Cobalt	0·33	0·52
Copper........	37·37	37·83
Iron	1·07	0·77
Gold....	$\frac{1}{15}$ of an oz. to a	ton of 2,000 lbs.
Silver..........	4·87 oz. “	“
Platinum	0·40 oz. “	“

Slag returned to blast furnace.

The slag is broken as soon as it sets, loaded into small cars, and raised to the feed floor, to be put through the blast furnace on an inclined elevator, on the west side of the smelter.

Removal and shipment of matte.

The matte, when cold, is crushed in a Blake crusher, and packed in barrels, to be sent to England, for further treatment.

Location of railways.

A railway track passes the lowest level of the smelter, to take away finished products, etc., and a track enters the upper level, to bring coke, raw ore, quartz, etc.

Equipment of engine house.

The engine house, situated to the west of the smelter, contains the Riedler blowing engine for the converter, the blowers for the blast furnaces, a pump to furnish the hydraulic power for the converters, two dynamos—one working by day and one by night—which supply light and power for the crane, for the two crushers—one for matte, the other for the quartz for the converters—for the Chilian mill, and for the aerial tramway. Power is furnished by 5 horizontal tubular boilers.

REFINING OF NICKEL.

Neglect of nickel by scientific men.

The subject of nickel has not, until quite recently, received from truly scientific men, that proper share of attention and inquiry which the known, desirable, physical properties of the metal demanded, these giving ample promise of its possible, wide, industrial application. Several reasons might be assigned, for this apparently unwarranted apathy in regard to such a hopeful field of inquiry, but, doubtless, the most important influence, related directly to the apparently limited distribution and supply of ores containing this metal, and the great, and for a long time, insuperable difficulties, encountered in all attempts at refining the ores, so as to obtain an absolutely pure and uniform product. From 1840 to 1860, the production of nickel was less than 200 tons annually, derived principally from the mines of Saxony and Hungary, with much smaller quantities from Sweden and Norway.

Early production of nickel.

Supply of ore thought to be limited.

Entry on the market of New Caledonia ores.

Discovery of Sudbury deposits stimulated scientific enquiry.

Great purity of commercial nickel.

Between the latter date, and the year 1876, the greatest proportion of the world's supply of nickel was obtained from the mines of Norway and Sweden, with much smaller quantities fron Saxony, Hungary and the United States. Careful examination of the occurrences of these nickel deposits, in the countries mentioned, indicated their probable exhaustion at no distant date, especially, if called upon to maintain a large and steady output. The prospecting undertaken, resulted in no new discoveries of a startling nature, and everything pointed to a comparatively limited supply and demand. This state of affairs continued until about the year 1882, when the ores from the New Caledonia mines began to flood the market. A period of over production followed, with its accompanying losses and uncertainties. The discovery of the Sudbury ores, in 1883, proved a still further disturbing feature, although, at the same time, it prompted and stimulated that scientific inquiry, which had been so long delayed, resulting in the discovery of several processes, some of which, although far from realizing expectations in regard to simplicity, economy and ease of manipulation, have produced metallic nickel, on a commercial basis, which contains as high as 99·70 to 99·82 per cent of fine nickel, the impurities being chiefly very small quantities of carbon, iron and sulphur.

Unwillingness to give information on the part of nickel miners and smelters.

Lately all reasonable information cheerfully given by Sudbury companies.

Another influence, which has contributed, in no small measure, to retard the progress of nickel metallurgy, and, no doubt, prevented the wide industrial employment of nickel, is the secrecy which has always been maintained by most companies, who have been or are engaged in the mining and smelting of nickel. This indifference, and, at times, positive unwillingness, to impart information, which would be of value or profit to the general public, has probably received no greater emphasis than in the case of nickel. Various excuses, more or less urgent or reasonable, are furnished by those in control, to account for their action in this respect, but gradually, this barrier of silence is being withdrawn, and, in the case of the Sudbury District, the managers of the two principal companies, have lately shown a commendable desire, to give all reasonable details in regard to the mining and smelting operations carrried on in Canada.

Secrecy was formerly maintained in every department of the industry.

This universal secrecy has, in the past, not only been maintained with regard to the exact location, extent and production of the individual mines themselves, but was especially extended to embrace the metallurgical treatment of the ores, even in the preliminary stages of roasting, matting and bessemerizing, while many of the small details, on which most of the success of the later refining methods depend, are still jealously repressed, or made known in such vague terms as to be

Text books also fail to give adequate information.

Possible objects of secrecy.

practically valueless. All of our text books seem in sympathy with this lack of desire to impart information, and, in most of these, reference to the subject of nickel, or accurate and detailed knowledge in regard to this metal, is conspicuous by its absence. This secrecy was, no doubt, in the first place, prompted by the desire of deterring others from engaging either in the mining or refining of nickel, and if so, it has utterly failed in its purpose. It has permitted, and even greatly favored the spreading of the wildest and most exaggerated statements in regard to the enormous profits accruing to all engaged in this business.

Secrecy favours frauds on the public.

Prevent success of legitimate mining enterprises.

Exchange of opinion and experience of the widest benefit to all.

The public, and especially those who are interested in mining, are being constantly apprised of the location of nickel deposits, which not only surpass all others in point of magnitude, but also in their peculiar adaptability for refining purposes. Further investigation, by competent individuals, (when such are available, or happily chosen), usually discloses some well known prospect or abandoned mine. On the other hand, men who are possessed of ample means, and are willing to devote a considerable portion to the promotion of some legitimate mining or smelting proposition, are often approached by so-called experts, with a supposed new and secret process, but which is already well known to a certain few, favoured individuals, who have already expended large sums, only to find that it is not a commercial possibility. Very few people have the necessary knowledge, or any means of verifying or refuting the statements of these interested individuals, and are thus often prompted to unusual and unwise expenditures, while, on the other hand, their ill success in these particulars prevents them from investing in some good, wholesome mining and metallurgical enterprise, when occasion offers, which, if full details were available and offered, would not be the case. Fling wide the gates of knowledge ; break down the barriers of silence : and it is confidently predicted that the resulting free and wide exchange of opinions and experience, will be of incalculable, benefit not only to the smelters and refiners, who are engaged in the nickel industry, but will prompt, encourage and direct the inquiring students and investigators of nickel, with profit to the whole of mankind.

Numerous processes for refining nickel.

Scope of present report too limited for discussion.

Numerous processes, for the refining of nickel, have been suggested and published, and, in many cases, elaborate experiments have been conducted, with varying degrees of success, to determine definitely their economic practicability. These could not be adequately or even satisfactorily discussed or explained, within the scope of the present report, even if all the necessary details were available for publication, but it may be well to refer, in general terms, to a few of those, which are either, at present, producing nickel on a commercial basis, or seem to give promise of doing so in the near future.

'Wet' and 'dry' processes embrace governing principles of all methods.

All of these methods are based on certain well known and long established principles, which have, in some instances, been worked out in more or less detail, and which are embraced under the general description of the so called 'wet' and 'dry' processes. Certain minor changes and additions, chiefly in details, have made the latest refining of nickel much more readily and economically possible. Even with the present improvements, both are open to very serious and grave objections, as their adoption, in the first place, necessitates a very large and expensive plant, which is liable to frequent renewal and change, while the many complicated operations, which are still far from being fully understood, and the reactions appreciated, must entail a loss which is far from negligible. At the same time, however, the final product has, of late years, been all that could be desired from a commercial point of view. The 'wet' process, especially, which imitates, although on a large scale, the operations carried on in the chemical laboratory for the analysis of nickel, needs a very large and expensive plant, if any extensive output is contemplated. This must occupy a considerable area of ground, while a very long time must necessarily elapse, before the ore is sufficiently refined, to permit of its being placed upon the market. In the case of the Gap mine, it has been stated that a year sometimes passed from the time the ore was taken from the mine, before the product was in marketable shape.

Reaction not fully appreciated.

Wet process requires a large area for plant.

Combination of 'wet' and 'dry' processes in use at present.

The present methods of treatment make use of some of the more valuable features of both the 'wet' and the 'dry' processes, calling in the assistance of electrolysis in the final stages, and thus obtaining the metal in very pure form. In the treatment of the concentrated nickel-copper matte for the nickel-copper alloys, usually referred to under the general name of German silver, this bessemerized matte is first crushed to powder and roasted in a reverberatory furnace to remove all the sulphur, and the oxides are reduced directly to the alloy, either by smelting with charcoal or by reducing gases.

Manufacture of german silver.

Enumeration of principal processes.

In the treatment of the concentrated nickel-copper matte for nickel matte, nickel oxide and metallic nickel, the most important methods, for the separation of the nickel and copper, are the Orford or American process, the Mond process and some electrolytic processes.

Location of Orford Copper Co's refinery.

Nearly the whole of the matte, produced by the Canadian Copper Co., is refined by the Orford Copper Co., at their works, at Constable Hook, N. J., opposite Brighton, Staten Island, by what is known as the alkaline sulphide process. There is considerable dispute as to the origin of this process, some holding the discovery to be of recent date, while others contend that the principle, upon which it is based, has not only long been known, but has been in successful operation for many years. Mr. Robert M. Thompson, in an account of the discovery of this process, as far as the Orford Copper Co. is concerned, says that it was the result of an accident, following a long series of unsatisfactory experiments, to discover some process, which would successfully and economically treat certain mattes, which had been sold to the United States Government, by the Canadian Copper Co. In visiting the works one day, he noticed some pots of matte, which were cooling in front of the furnace, and which presented a somewhat unusual appearance. On calling attention to this fact, and failing to get satisfactory explanations from either the superintendent or foreman, he proceeded to investigate, the result being the discovery of the governing principle which effected the separation, and caused the yellow 'bottoms' and black 'tops.' After a long series of experiments, on a large scale, the process at present in operation, was gradually worked out. Mr. J. W. Bain, (1) in his 'Sketch of the Nickel Industry,' draws attention to the fact, that in certain descriptions accompanying applications for English patents, dating as far back as September 5th, 1839, undoubted reference is made to this principle. Moreover in a letter published in the Engineering and Mining Journal, in August, 1893, an ex-employee of the Vivian Company, at Swansea, states that the method had been employed for a number of years at that company's works. At any rate, the application of the alkaline sulphide process, as a definite scheme, for the separation of nickel and copper, was in a fair way of being lost to metallurgy, or, at least, to be employed in a very restricted manner, if the Orford people had not, so to speak, re-discovered the principle upon which it is based. Great credit is also due to this company, for the thorough manner in which they have worked out the details, and made it a distinct economic success.

Discovery of alkaline sulphide process by Thompson.

Reported previous use of alkaline-sulphide process.

Process would likely have been lost if not taken up by Orford Co.

In the Orford nickel process, the concentrated or bessemer matte is smelted in a small blast furnace, with salt cake or crude sodium sulphate, a chemical which can be obtained readily and cheaply. The sodium sulphate is reduced to sulphide, which forms, with the copper and iron sulphides, a very fluid matte, of lower specific gravity than the nickel sulphide. On cooling, 'tops' and 'bottoms' are easily separated; in the 'tops' being the bulk of the iron and copper as sulphides, together with sodium sulphide; while the 'bottoms' contain most of the nickel, with small quantities of iron and copper. On exposure to

Description of Orford or American process.

Formation and character of 'tops' and 'bottoms.'

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(1) Ann. Rep. Bur. of Mines, Ont., 1900, p. 220.

the weather, the soda in the tops is gradually converted into the caustic condition. These tops are now mixed with fresh matte and re-smelted, whereby the caustic soda is converted into sulphide of soda at the expense of the nickel in the bottom, producing again a fluid mixture of iron, copper and sodium sulphides while the nickel, in a semi-metallic state, sinks to the botton once more. By properly balancing these operations, a pure sulphide of nickel is at last obtained, which is simply calcined, with a little sodium nitrate to the nickel oxide of commerce. The oxide is either mixed with flour, molasses, etc., and pressed into cubes, or with charcoal, and reduced to metallic nickel in cube or powdered form. This product is not strictly a homogenous metal, but a loose sponge of metallic particles, which retain all the impurities contained in the oxide, with the addition of from 0.5 to 2 per cent of carbon. To produce the solid metal, the oxide is melted direct with charcoal and a small quantity of flux, and cast into ingots.

Production of nickel oxide and metallic nickel.

Ulke's diagram of American or Orford process.

On the following page a diagramatic scheme, that accompanied a paper by Titus Ulké (¹), is reproduced, which illustrates fully and briefly the various operations necessary in the Orford process:

Discovery and development of Mond process.

The Mond or carbon-monoxide process (²), is based on the fact, that if finely divided nickel, is exposed to a current of carbonic oxide, at a temperature below 150° C., a nickel carbonyl is formed, with the formula $Ni (Co)_4$, which is volatile at a temperature above 43°C, and which is decomposed at a temperature of 180° C, into metallic nickel and carbonic oxide. Iron forms a similar carbonyl, but no other metal has been found to do so. In the process, there were many technical difficulties to overcome, and it was not until 1898, that it was brought to that stage of development, that demonstrated its practical importance.

Description of Mond process.

Formation of sulphate of copper.

Use of towers.

The bessemerized Victoria Mines matte is first dead roasted, and for this purpose, any suitable furnace may be employed. After roasting, the matte averages about 35 per cent of nickel, 43 per cent of copper and about 2 per cent of iron. It is than treated with dilute sulphuric acid, for the extraction of part of the copper, (about 66 per cent) and not above 2 per cent of the nickel. This copper is sold as crystallized sulphate of copper. The residue, after drying, from this operation, assays from 45 to 60 per cent of nickel, (averaging about 51 per cent) and 21 per cent of copper. The third operation, has for its object, the reduction of the nickel and, incidentally, the remaining copper, to the metallic state, without including the iron. For this

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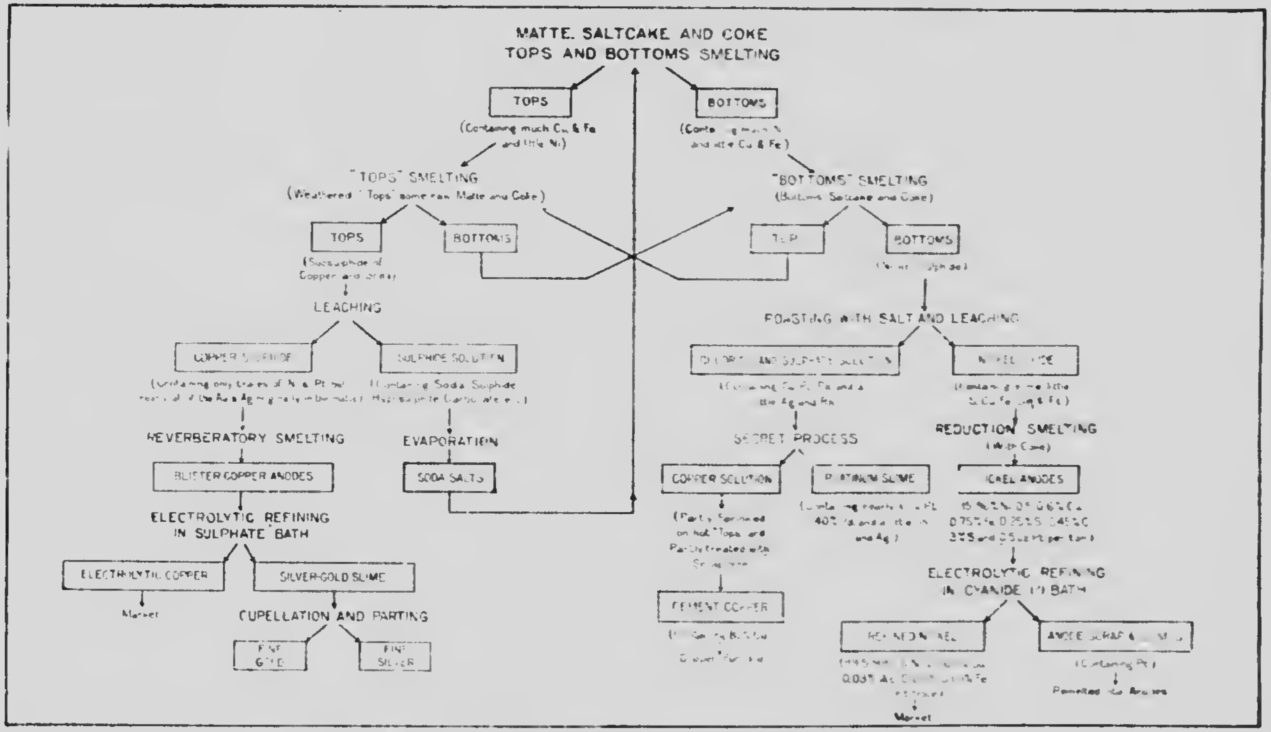
(1) Eng. and Min. Jour., Vol. LXIV., (July 3), 1897, pp. 8 9.

(2) Roberts-Austen 'Nickel Extraction by the Mond Process.' A paper read before the Institution of Civil Engineers, London, Eng., on the 8th November, 1898. Also Ann. Rep. Bur. of Mines, Ont., Vol. VIII., 1899, pp. 106-120.



Diagrammatic Scheme of the Orford Method of Treating Nickel-Copper Matte purpose, it is treated in a tower 7.5m. high, and containing 14 hollow shelves, which are heated with water gas, to not more than 300°C, and preferably 250°, when much iron is present. The ore is moved, from shelf to shelf, by means of rakes, operated by a vertical axle. The lowest shelves are cooled. The reduced charge is transferred to another similar tower, where voltatilization takes place, in which part of the nickel is taken away by carbon monoxide, and forms the compound nickel carbonyl, but the temperature must not exceed 100°C. The remainder, from this volatilizer, is returned to the reducing tower, and the charge continues to circulate, between the two towers, for a period of between 7 and 15 days, until about 60 per cent of the nickel has been removed as nickel carbonyl. The nickel carbonyl passes to the decomposer, either a tower or a horizontal retort, which is heated to a temperature of 180°C, so as to decompose this compound, and release the nickel in a metallic state, preferably on granules of ordinary commercial metal. The carbon monoxide is also released, and is returned to the volatilizing tower, to obtain a fresh charge of nickel. The commercial product contains between 99.4 and 99.8 per cent of nickel. It has been stated, that Dr. Mond's process, although ingeniously and thoroughly worked out, has developed certain weaknesses, such as imperfect extraction of nickel, and the necessity of repeating certain of the operations several times before satisfactory results are achieved, and the larger proportion of the nickel obtained. The danger of explosion and poison, from the carbon monoxide gas, have all, seemingly, combined to delay the successful operation of this process, on a large scale for any protracted period.

Duration of operations.

Some objections urged to Mond's process.

THE HOEPFNER ELECTROLYTIC PROCESS.

Hoepfner electrolytic process.

In this process, a chloride solution is obtained, which has been freed from other metals, either chemically or electrolytically. The solution is neutralized, and then accidulated with some weak oxygen acid, such as citric or phosphoric acid, and the electrolysis effected with insoluble anodes. The anodes are immersed in a chloride solution of some more electro-positive metal than nickel. The cathodes are rotating or vibrating metal plates. The chlorine evolved is collected.

THE FRASCH ELECTROLYTIC PROCESS.

Short description of governing principles of Frasch process.

This process depends on the reaction in the electrolytic decomposition of common salt. At the anode, chlorine is evolved, at the cathode, sodium hydrate is formed by a secondary reaction. When applied to copper nickel matte, the anode consists of a layer of carbonaceous material. This is covered with a layer of matte, and the matte with a layer of sand, which serves as a diaphragm, between the anode and cathode sections. The chlorine evolved, dissolves the metals of the matte, forming chlorides. The solution is treated for the contained metals by electrolysis or chemically. From the solution of sodium hydrate at the cathode, caustic soda is obtained.

BROWNE'S ELECTROLYTIC PROCESS.

Main facts in regard to Browne's Process.

In this process (1), the copper is first deposited from a solution of the mixed chlorides, using cathodes of pure copper and soluble anodes of copper nickel alloy. The original percentage of metal chloride in the electrolyte, is maintained, partly, by the solution of the anode and partly, by passing the electrolyte through a tower filled with bessemer matte or alloy to be treated, in contact with the chlorine gas evolved at the anode by the nickel precipitation.

When the electrolyte is rich in nickel, and nearly all the copper is deposited, the remaining copper is precipitated with hydrogen sulphide or a similar reagent, and the iron with ammonia. The nickel chloride solution is then electrolyzed, using cathodes of pure nickel and anodes of carbon, in water-sealed compartments, from which the chlorine is conducted to the regenerating tower.

ULKÉ'S ELECROLYTIC PROCESS.

Use of sulphate solution.

In this process, (2) a sulphate solution of the metals is used, instead of a chloride solution, as in the three processes described above.

General description of Ulke's continuous process for separating nickel and copper.

'With the Ulké process, it is most advantageous to use a material consisting of not over 20 per cent of nickel, and not less than 80 per cent of copper, which is cast into anode plates. The electrolyte consists of a solution of copper and nickel sulphate, and contains an excess of free sulphuric acid, and the cathodes are of pure sheet copper. The electrolyte is heated and kept in circulation and from time to time portions of it are withdrawn from the electrolytic vats to be re-standardized The electrolyte withdrawn is replaced with an equal volume of copper sulphate solution, containing an excess of free acid to re-standardize the electrolyte. A portion of this copper sulphate is obtained as a by-product in the extraction of the nickel, as is outlined later in the description. The copper is precipitated (from withdrawn electrolyte) with hydrogen sulphide, and after filtering, the copper sulphide precipitate is treated with sulphuric acid and heat to recover the hydrogen sulphide and make the by-product copper sulphate. The nickel sulphate is made ammoniacal, and used hot as an electrolyte for

Production of copper sulphate.

(1.) Min. Industry, Vol. X, 1901, p. 497.

(2.) Min. Industry Vol. X., 1901, pp. 497-498.

Process economical and high grade of nickel produced.

the precipitation of nickel using anodes of lead and cathodes of sheet nickel. To avoid impoverishment of this electrolyte, portions of it are periodically withdrawn, the ammonia recovered for re-use and the nickel sulphate added to the electrolyte as needed to preserve the proper strength. The process is economical and produces nickel of high quality continuously and cheaply.'

Another process for the electrolytic winning of nickel, which is in successful operation, is the Balbach process, as carried on at the Balbach works, N. J. This process, however, is kept strictly secret.

NICKEL.

Discovery of nickel by Cronstedt.

Analysis of China silver by Engstrom.

Nickel coins used 235 B.C.

Ancient coins made of same alloy at present used.

Nickel is a comparatively new metal, as far as our western civilization is concerned, for it was discovered in 1751, by the Swedish metallurgist Cronstedt. It was, however, not until 1754, that Cronstedt definitely determined that it was a new element. Its name was given on account of its being a constituent of niccolite or 'kupfer-nickel' as it was then called. Cronstedt's discovery was made in examining the ore, obtained from the mines of Helsingland. In 1776, Engstrom analyzed the material which had found its way to Europe, from China, under the name of 'Pachfong', finding it an alloy made up of variable quantities of copper, nickel and zinc, but usually present in the proportion of 40 per cent of copper, 15 per cent of nickel and 45 per cent of zinc. This alloy had been in use in China for thousands of years. Previous to this again, as noticed by Dr. Austen in his 'Historical Sketch of Nickel' the Bactrian King Euthydemos who reigned about 235 B.C., employed an alloy of nickel for coinage purposes, containing 77·58 per cent of copper, 20·04 per cent of nickel and 1·72 per cent of other impurities, such as iron, cobalt, tin, silver and sulphur. It is worthy of remark, that so long after this, the alloy at present in use for the manufacture of coins, is very similar in composition, containing about 75 per cent of copper and 25 per cent of nickel, which experience has taught us is the best proportion for such a purpose.

Physical properties of nickel.

Nickel, in its pure state, is silver-white in colour, hard, tough, fusible with difficulty, and is susceptible to magnetism, although not to the same extent as iron. It has the peculiar property of losing this magnetism when heated, and regaining it when cooled, this peculiarity being taken advantage of, in the manufacture of certain alloys for electrical purposes. Nickel has a specific gravity of 8·5 to 8·9.

Purity of nickel has steadily in-

The purity of the nickel, which has been on the market, has steadily increased since its first manufacture. This will be evident from the subjoined table of analyses of the commercial product. The three first analyses are quoted from the Mineral Industry, and were made in 1891. All the others were made in 1898 and 1899.

Authorities and references for analyses quoted.

Analyses of the nickel of commerce.

Table of Analyses of the Nickel of Commerce.

	I	II	III	IV	V	VI	VII	VIII	IX	X
Nickel	97.63	97.44	97.38	98.89	98.80	98.80	99.80	99.82	99.43	98.76
Cobalt	1.19	trace	1.70	0.14			none			
Iron	0.75	0.301	0.06	0.43	0.60	0.60	0.13	0.10	0.13	0.91
Copper	0.15		0.68	0.10	0.11		none			0·10
Sulphur	0.04	0.104	0.013		0·016	0.016	0.006	0.0068	0.0099	trace
Carbon				0.40	0.16	0.16	0.05	0.07	0.087	
Silicon				0.02	0.09	0.09	none			0.26
Manganese				0.02						
Tin					0.11					
Arsenic					0.11	0.11				none
Insoluble									0.026	
Carbon, Silicon, &c.	0.24	0.2155	0.167							

Analysis I. Rolled nickel anode (German): F. P. Dewey, analyst, 1891.
" II. Cast nickel, Gard, analyst 1891.
" III. Disk nickel: F. P. Dewey, analyst, 1891.
" IV. American nickel; by Forester, quoted by Ulke, Min. Ind. Vol VI, p. 595.
" V. Cubes; Ferro-nickel Co. Inst. Civil Eng., London, Eng., March 28, 1899.
" VI. Thompson nickel; Inst. Civ. Eng. London, Eng., Mar. 28, 1899.
" VII. Mond nickel; Inst. Civ. Eng. London, Eng., Mar. 28, 1899.
" VIII-IX. Mond nickel; Inst. Civ. Eng. London, Eng. Nov. 8, 1898.
" X. Wharton nickel; by J. W. Bain. Ann. Rep. Bur. of Mines, Ont. 1900, p. 223.

USES.

Nickel first used as German silver

The first and chief demand for this metal, was for making nickel or German silver, as a substitute for the more precious metal, in the manufacture of spoons, forks and other ware in general, for which silver had been previously used Its whiteness, and the facility with which it received and held the silver, after the process of electro-plating was introduced, has caused it to be still more widely used. This use, however, has been replaced, in a large degree, by plating iron with nickel, which gives a very similar effect to German silver.

Nickel in electro-plating.
Nickel-plated iron.

Use of nickel for coins.

Nickel is also used very extensively for coinage purposes, both in Europe and America, these coins generally consisting of an alloy of from 75 to 88 per cent of copper, and 12 to 25 per cent of nickel. Recently, both Austria and Switzerland have authorized the use of pure nickel in coins.

Pure nickel now used in place of alloys.

Pure nickel is now used in making small articles, which formerly were only electroplated with nickel. An alloy, with 20 per cent of nickel and 80 per cent of copper, is used for casing bullets. This alloy has a higher degree of tenacity than the best brass, and a high co-efficient of elongation.

Intense colouring properties of nickel.

Owing to the intense colouring properties of nickel, (it is greater than that of any other metal except tin), these alloys have almost the same colour as the pure nickel.

Importation into Europe of Packfong or China silver.

In far more general use are the nickel-copper-zinc alloys. These were first introduced into Europe from China, in the eighteenth century under the name of Packfong or China silver, and it was only later, that it was discovered that they consisted of nickel, copper and zinc. As European firms began to use these alloys, for manufacturing purposes, they gave them various names, such as german silver, argentan, etc.

Analyses of different varieties of 'New Silver.'

The following are analyses, from Ledebur's 'Technologie,' of some of these alloys :

	Copper.	Zinc.	Nickel.	Iron.
English new silver	63.34	17.01	19.13	0.52
Vienna " "	55.60	22.20	22.20	....
French " "	50.00	31.25	18.75	....
" " "	59.10	30.20	9.70	1.00
" " "	69.90	5.60	19.80	4.70

'New Silver' used for various purposes.

The chief uses of these alloys are for forks, spoons, etc., and various household goods to be silver-plated, and for many scientific instruments, where brass was formerly used.

A little magnesium, added to nickel when in a molten state increases its malleability, and this property has been utilized in the manufacture of nickel into sheets, and also in making sheets composed of an iron plate, with a nickel plate welded upon each side of the iron; the mass then becoming capable of being rolled to any desired thickness. This rolled nickel plate is an advance over ordinary tin plate, for culinary and other utensils.

Addition of magnesium to nickel increases malleability.

Rolled nickel plate.

Nickel-plated zinc or 'nickeloid,' as it is called, is being used to a considerable extent in the manufacture of reflectors, refrigerator linings, baths, etc.

Nickeloid.

The most important and extended use of nickel, however, is in the manufacture of nickel steel, and, at present, we must look to its more general employment in this direction, as replacing carbon and manganese steel, for the development of the nickel industry. The peculiar and desirable behaviour of nickel, in alloy with other metals, and especially with iron and steel, has often been remarked, the material partaking more of a chemical combination than an ordinarily intimate mixture. All these alloys are remarkably homogeneous, and susceptible of a high polish, though rather difficult of manipulation. In obtaining a correct idea of the usefulness or value of alloys of nickel with iron and steel, it should be borne in mind that these mixtures contain manganese, carbon, silicon, sulphur and phosphorus, whose influence must be carefully watched, requiring a long series of experiments. A comparison of steel alloyed with 4.7 per cent of nickel, raised the elastic limit from 16 up to 28 tons, and the breaking strain from 30 up to 40 tons, without impairing the elongation or contraction of area to any appreciable extent. A further gradual increase of hardness was noticed until 20 per cent is reached, when a change takes place, and successive additions of nickel tend to make the steel softer, and more ductile. The alloys polish well, and the colour of the steel is lightened, as the proportion of nickel is increased. They do not corrode as readily as other steel. The one per cent nickel steel welds fairly well, but this property lessens with each addition of nickel. It may, therefore, be said that considerable advantage can be expected from these alloys, especially where the amount of nickel present is less than 5 per cent. Nickel steel is now being used for a variety of purposes, among which may be mentioned rails for railways. These have been tried for a number of years, at Cumberland Gap, in the United States, and have given very great satisfaction. The first cost is considerably higher, but they can be made much lighter, and will outlast three ordinary steel rails. Its most important use, however, is for armour plates and

Use of nickel in alloy with steel.

Peculiar nature of alloys.

Good qualities of alloys.

Impurities in nickel steel.

Strength of nickel steel.

Physical characters of nickel steel alloys.

Uses of nickel steel.

Nickel steel rails.

Use of nickel steel in machine parts

Use in propeller shafts, rock drills, &c.

Nickel steel wire rope.

heavy ordnance. For machine parts, subjected to alternate stress and shock, and where increase of strength and decrease of weight are desired, it is unrivalled. On account of this marked quality, it has been used for engine and propeller shafts, and has proved so much superior to all other steels for this purpose, that it has no rival of importance. Owing to its resistance to 'fatigue' from persistent vibration and concussion, it is particularly valuable for steam hammer piston rods, rock drill piston rods, railway axles, or tank pins; also for light forged engine frames, bolts for extreme hydraulic pressure, bicycles, etc. It has also been recommended for the manufacture of dies and shoes in stamp mills, and of wire rope. Nickel steel wire rope would be less corrosive, and have more tensile strength, than the ordinary steel wire ropes, in use at present.

Co-efficient of expansion of nickel steel.

The co-efficient of expansion of nickel steel with 36 per cent of nickel, is only 0.00000087, that of ordinary materials varying from 10 to 20 times this figure. This low co-efficient of expansion will likely be of great value for many purposes. Alloys with 42 to 46 per cent of nickel, have the same co-efficients of expansion as various sorts of glass, which will make them valuable in replacing the more expensive platinum, in cases where metal and glass have to be welded together.

Other alloys of nickel are mentioned in "The Mineral Industry" Vol. X. They are nickel-aluminium, with a tensile strength of 40,000 lbs. per sq. in. and an elastic limit of 35,000 lbs. per sq. in.

Composition of chrome-nickel.

Tungsten-nickel.

Chrome nickel, containing usually 73 per cent of chromium, 23 per cent of nickel, 2.5 per cent of iron, 1 per cent of carbon and 0.5 per cent of silicon, is used in making steel for projectiles and armour plates, which is said to be better than Harveyized steel armour plates. Tungsten-nickel has a composition similar to chrome-nickel, tungsten taking the place of chrome.

Composition of molybdenum-nickel.

Molybdenum-nickel with 45 to 75 per cent of molybdenum, 20 to 50 per cent of nickel, 2 to 2.5 per cent of iron, 1 to 1.5 per cent of carbon and 0.25 to 0.50 per cent of sulphur is largely used in the manufacture of forgings, guns, wire, boiler-plate and shells.

The era of nickel steel has just been entered upon.

The era of nickel steel has only been entered upon, for it was not until 1888, that this desirable alloy was made, on any scale of commercial importance. Canada has the largest supply of the most desirable nickel ores in the world, and the quality of the metallic nickel, as shown by the analyses quoted, is of a very high degree of purity. It is beyond the scope of the present report, to enter upon a discussion of the manifold merits of nickel steel, and the numerous benefits to be derived from its use. In 1899, Messrs. R. A. Hadfield (1) and David H. Browne (2), published two very complete contributions on this subject, and the reader may have reference to these for more detailed information. Lately, Dr. Waddell has been employed, under the auspices of the International Nickel Company, in making an elaborate series of tests and experiments, with nickel steel, with special reference to its more extended use in bridge building. The general public, and more particularly, that numerous section of it in Canada, who are interested in the extension of the nickel industry, will look forward with pleasure to the appearance of Dr. Waddell's conclusions, which, it is hoped, will not be witheld, on the plea that the information is of a confidential nature.

Papers on nickel steel by Hadfield and Browne.

Experiments for International Nickel Company by Dr. Waddell.

PRODUCTION OF NICKEL AND COPPER FROM THE SUDBURY DISTRICT.

It is difficult to obtain the exact production of the nickel and copper ores of the Sudbury District, during the first three years of mining, from 1886 to 1888, inclusive. Thus, R. R. Maffett, Superintendent of the Orford Copper company, at New Brighton, L. I., N. Y., under date of April 18, 1904, answering an inquiry addressed to President A. P. Turner, of the Canadian Copper Company, at Copper Cliff, Ont., states, that during 1886, 1,040 tons of ore, carrying 7.2 per cent of copper and 3 per cent of nickel, were mined at Copper Cliff, and during 1887, 8,864 tons carrying 8.56 per cent of copper and 3.31 per cent of nickel, were also raised from the the same mine. According to details, furnished the Geological Survey Department, by the Customs Department, 3,307 tons of copper ore were shipped from Sudbury, in 1886, with a declared customs value of $16,404, and in 1887, 567 tons of similar ore were also shipped, with a declared customs value of $3,416. A careful and conservative estimate, to arrive at the total production, would place the amount mined during these three years at 30,000 tons, averaging about 5 per cent of copper and 3 per cent of nickel, this ore thus containing, approximately, 900 tons of nickel, and 1,500 tons of copper. Valuing the nickel, at the average price for the three years, at 62.12 cents per lb., the total ultimate value of the nickel in the ore, would amount to $1,118,160, while the copper, at the average price of 12 cents per pound, would amount to $360,000. According to the yearly returns, furnished the Geological Survey Department and the Ontario Bureau of Mines, the total ore mined in the district, including the estimate as above given for the first three years, has amounted to 2,093,427 tons. The total amout of nickel in matte, sold from 1889 to 1903, both years inclusive, amounted to 39,827 tons, with a final value in New

Figures of early production of nickel in Sudbury District difficult to obtain.

Returns for 1886-87 by Canadian Copper Company.

Shipments of of ore according to Customs Department.

Estimate of production in three first years.

Value of metals produced during first three years.

Matte sold from 1889-1903 inclusive.

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(1) Proc. Inst. Civil Eng., London, Vol. CXXX., pp. 1-167.

(2) Trans. Am. Inst. Min. Eng., Vol. XXIX., (Sept.), 1899, pp. 569-648.

Total amount and value of nickel and copper produced.

York, at the lowest average prevailing price in the year in which it was placed upon the market, amounted to $35,603,272, while the copper present in the matte, in the same period, amounting to 37,429, tons valued at the average price of copper in the year sold, realized $9,799,730. If we include the three first years, at the figures already given, we obtain a total amount of nickel sold of 40,727 tons, with a value of $36, 721, 432 ; while the copper amounted to 38,929 tons, with a value of $10,159,739.

Estimate of cobalt contents of matte.

Average contents of precious metals per ton of pure nickel.

Values of precious metals.

This nickel and copper ore also contains cobalt, and an average of a large number of assays, would indicate that the proportion of nickel to cobalt as 50 to 1, is a conservative estimate. If all of this could have been saved, 815 tons of cobalt would have been thus produced, and this, at a price of $3.00 per lb., would have amounted to $4,890,000. In addition, these ores contain appreciable quantities of the precious metals, gold, silver and metals of the platinum group. The platinum metals average about 1.25 oz., the gold 0.375 of an ounce, while the silver has been calculated on the assumption that 7.5 oz. are present to the ton of nickel, which is certainly below the average. On this assumption, the value of the precious metals, at the average of the ruling New York price in the years produced, would be as follows : Gold $305,460 ; Silver, $195,286 ; Platinum, $805,429 ; Total, $1,306.175. The total ultimate value in New York, of the various metals contained in these ores, would, therefore, be as follows :

Values of total production.

Nickel	$36,721.432
Cobalt	4,890.000
Copper	9,799.739
Gold	305.460
Silver	195.286
Platinum	805,429
Total	$52,717.346

Total production of ore from Canadian Copper Co's mines.

Of the total production of ore, about four-fifths must be credited to the Canadian Copper Company. This company does not wish, at present, to give the production of each individual mine, but through the courtesy of President A. P. Turner of the Canadian Copper Company, I am authorized to state that the three largest of their mines, have produced the following amounts of ore, up to the first of June, 1904.

Stobie Mine	419,000 tons
Copper Cliff Mine	366,000 "
Creighton Mine	310,000 "

Some of the other mines have also produced large quantities of ore, as the Evans mine, No. 2 and No. 3 (Frood mine) mines all three of which have produced between 100,000 and 200,000 tons of ore. The Creighton mine is, without doubt, the largest mine in the district, and is regarded as capable of producing many millions of tons of high grade ore. The ore at present being mined averages about 5 per cent of nickel and 2 per cent of copper. During the month of May last (1904) 19,000 tons of ore were mined, and, in June, it was expected that 22,000 tons would be secured. It is proposed, in the near future to erect another rock house, further west, on this same deposit, when the output will be nearly doubled. The old Blezard mine, belonging to the Dominion Mineral Company, probably produced about 100,000 tons of ore, while 25,000 tons seems a reasonable estimate for that produced by the Worthington mine. The Victoria mine, belonging to the Mond Nickel Company, has produced about 80,000 tons of ore, while the same company, up to the 1st of June, 1904, had obtained about 13,000 tons from the North Star mine. At the Murray mine 62,193 tons were produced, while the Lake Superior Power Company obtained 33,835 tons from the Elsie Mine, and 18,000 tons from the Gertrude mine, up to the end of 1903.

Creighton mine reserves of ore.

Large production of high grade ore from Creighton mine.

Production from Dominion Mineral Co's mines.

Production of ore from Victoria mine.

North Star mine.

Murray, Gertrude and Elsie mines.

The following tables are reproduced from the annual reports of the Division of Mineral Statistics and Mines, of the Geological Survey Department, and of the Bureau of Mines, of Ontario. Both have been prepared by Mr. J. McLeish, who has charge, under Mr. E. D. Ingall, of this branch of the work. They will show, in a diagrammatic manner, the details of the mining operations, carried on in the district from 1889 to 1903, both years inclusive.

Tables of production prepared by Mr. J. McLeish.

Production of Nickel and Copper, Sudbury District, Ontario, according to the Mines Section, Geological Survey.

Calendar Year.	Ore mined.	Ore treated.	Ordinary matte sold and shipped.	High grade matte sold and shipped.	Spot value of matte.	Nickel contents of matte sold.	Final value of nickel.	Copper contents of matte sold.	Final value of copper.
	Tons.	Tons.	Tons.	Tons.	$	Tons.	$	Tons.	
1886	3,307								
1887	567	30,000?	....	....		900?	1,118,160?	1,500?	300,000?
1888	....								
1889	44,990	40,146	3,274	....	....	432	518,602	[illegible]	201,678
1890	....	....	....	....	....	718	933,232	651	205,233
1891	83,300	72,558	10,336	....	....	2,018	2,421,208	2,064	531,234
1892	74,381	57,022	....	....	....	1,207	1,399,956	1,102	254,538
1893	....	....	9,425	....	....	1,991	2,071,151	1,821	391,461
1894	103,223	96,038	11,681	....	766,422	2,454	1,870,958	2,601	497,854
1895	74,135	68,618	10,188	....	[illegible]	1,944	1,360,984	2,288	492,414
1896	94,966	71,027	10,759	....	[illegible]	1,699	1,188,990	1,584	344,598
1897	93,154	96,370	13,968	....	....	1,999	1,399,176	2,750	621,023
1898	123,820	121,924	....	....	....	2,759	1,820,838	4,187	1,007,539
1899	159,957	172,761	....	....	702,341	2,872	2,067,840	2,834	998,135
1900	196,420	....	23,336	....	1,076,306	3,540	3,327,707	3,364	1,089,383
1901	315,692	255,958	....	....	1,661,839	4,594	4,594,523	4,318	1,392,018
1902	269,538	211,847	23,211	2,100	1,327,448	5,347	5,025,903	3,553	826,175
1903	136,033	207,030	....	13,832	2,686,469	6,253	5,002,204	3,576	946,456

Production of Nickel and Copper, Sudbury District, Ontario. Compiled from the Annual Reports of the Ontario Bureau of Mines.

Year.	Ore raised.	Ore smelted.	Ordinary matte produced.	High grade matte produced.	Spot value of matte.	Per cent of Ni and Cu contents in ore smelted.		Ni contents of matte.	Cu contents of matte.	Cobalt.	Spot value of nickel in matte.	Spot value of copper in matte.	Spot value of cobalt in matte.	Wages paid	Men employed.
	Tons.	Tons.	Tons.	Tons.	$	Ni.	Cu.	Tons.	Tons.	To's	$	$	$	$	
*1890	130,278	59,329													
*1891	85,790	71,480	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
*1892	72,349	61,924	6,278	1,880	826,750	3.362	3.126	2,080	1,936	8½	590,902	232,135	3,713	330,821	690
*1893	64,043	63,944	7,176	452	539,302	2.585	2.237	1,653	1,431	19	445,702	115,200	9,400	252,516	495
*1894	112,037	87,916	10,410	1,470	809,974	2.924	3.125	2,570½	2,748	3¼	612,724	195,750	1,500	311,719	655
*1895	75,439	86,546	12,525	103	565,774	2.675	2.733	2,315¾	2,365¼	.....	404,861	160,913	.....	299,960	441
1896	109,097	73,505	9,733	.....	487,660	2.651	2.534	1,948½	1,868	.....	357,000	130,660	.....	247,151	485
†1897	93,155	96,094	13,706	328	559,718	2.080	2.861	1,999	2,750	.....	359,651	200,067	.....	253,226	535
†1898	123,920	121,924	21,101	.....	782,300	2.283	3.433	2,783¾	4,186¼	.....	514,220	268,080	.....	315,501	637
†1899	203,118	171,230	19,109	106	702,340	1.677	1.655	2,872	2,834	.....	526,104	176,236	.....	443,879	839
†1900	216,695	211,960	23,336	112	1,076,307	1.670	1.587	3,540	3,364	.....	756,626	319,681	.....	728,946	1,444
†1901	326,945	270,380	29,588	15,546	2,449,050	1.642	1.552	4,441	4,197	.....	1,859,970	589,080	.....	1,045,889	2,284
1902	269,538	233,388	24,691	13,332	2,827,724	2.547	1.742	5,945	4,066	.....	2,210,961	616,763	.....	835,050	1,445
†1903	152,940	220,937	30,416	14,419	3,082,714	3·167	1,812	6,998	4,005	.....	2,499,068	583,646	.....	746,147	1,277
†															

* Year ending 31st October.
† Year ending 31st December.

THE WORLD'S PRODUCTION OF NICKEL.

Early production of nickel.

From 1840 to 1860, the annual production of nickel scarcely averaged 100 metric tons per annum, and in no single year was a production of 200 metric tons exceeded. From 1860 to 1880, a very gradual, though distinct, increase was noticeable, up to 600 metric tons, although, about the year 1874, a little over 700 metric tons were produced. In 1880, the product of the New Caladonia mines became a distinct factor on the market, at first with a production of about 200 metric tons per annum, but gradually increasing until the year 1884, when the production was about 1,000 tons. In the year 1889, the product of the Sudbury mines was placed upon the market, but only 432 tons were sold. In the year 1891, however, 2,018 tons (1,830 metric tons) of nickel were sold which had been produced from the Sudbury ores, while, at the same time, the product of the New Caledonia mines, which had reached the figure of 2,494 metric tons, dropped to 1,696 metric tons in 1892 In 1893, the world's total production of nickel amounted to 4,412 metric tons, the amount of the Canadian product placed on the market, aggregating 1,807 metric tons: while Norway, in the same year, produced about 90 metric tons, and the United States 22·4 metric tons.

Early production of nickel from New Caledonia mines.

Large increase in production of nickel.

These figures showed a still further and rather rapid increase up to the year 1901, when a total of 9,381 metric tons were produced, the Canadian nickel amounting to 4,168 metric tons, and the New Caledonia to 5,210 metric tons, while the United States produced only 3 tons of nickel from domestic ores.

Canada leads in production of nickel.

In 1902, the total of the world's production, amounted to 8,473 metric tons, but of this Canada's share was 4,850 tons, while the New Caledonia output showed a decrease to 3,620 tons.

In 1903, the amount of Canadian nickel produced amounted to 6,348 metric tons, while New Caledonia produced only 4,750 metric tons.

Future of Canadian nickel.

The world's total production of nickel for 1903 as stated by the Metallgesellschaft amounted to 9,850 metric tons. It is evident, however, that this is understated and that the actual production is considerably in excess of this amount, for the official returns for Canada and the United States, as reported to the Geological Survey and the Bureau of Mines of Ontario, give the production as 6,400 metric tons instead of 5,100 metric tons, as stated by this authority. Assuming the official figures as more nearly accurate and adding the production from New Caledonia as quoted by the Metallgesellschaft (4,750 metric tons), a grand total of 11,150 metric tons is obtained, as the aggregate of the world's production for 1903.

World's production of nickel.

These figures are full of hope for Canada, and with the gradually increasing knowledge of the true value and uses of nickel, by reason of its many desirable physical qualities, which is gradually becoming more general, the production of nickel should be doubled in the next five years. It is hoped and confidently expected, that Canada's share in this large output, will be fully three-fourths of the whole.

The following table will show, at a glance, and in much greater detail, the world's annual production of nickel, from 1889 to 1902. The figures for the foreign production for 1903 are not yet available.

These statistics are obtained mainly from the Metallgesellschaft and Metallurgische Gesellschaft (Frankfort on-the-Main), Aug., 1903, p. 23.

The production of nickel from domestic ores in the United States is quoted from Mineral Resources of the United States while that of Canada is from the Division of Mineral Statistics and Mines, Geological Survey of Canada, with the exception of 1903, which is from the Bureau of Mines. The figures of Canadian production, include nickel actually, sold while those of the Bureau of Mines, which are stated in a separate table, are of nickel produced, part of which remained in stock.

Authorities and references for table of world's production of nickel.

The figures for Germany, represent the production of Prussia. Saxony also produces nickel, but accurate details are not readily available.

Details of nickel production from Saxony not available.

THE PRICE OF NICKEL.

In 1876, the price of nickel per lb., amounted to $2.60. In 1877 it dropped to $1.60 per lb., and in 1878, it showed a still further decline to $1.10 per lb. In 1879, it recovered slightly to $1.12 per lb. but in 1880 it again decreased to $1.10, which latter figure was maintained until 1883, when the price steadily declined to about 60 cents. At present, the price quoted by leading producers, varies from 40 to 47 cents per lb., for large quantities down to ton lots, according to size and terms of order. The price for smaller lots, according to quantity, runs as high as 60 cents per lb., in New York.

Large prices prevailing at first.

Gradual decrease in price.

Present price of nickel.

World's Production of Nickel (in metric tons).

Year.	Sweden and Norway.	Nickel contents of ores exported from New Caledonia.			Total. (New Caledonia.)	Canada.	United States.	Grand total.	Average price per lb. in New York.
		Germany.	France,	Great Britain.					
1889	80	282	1,050		1,332	377	114·606	1,904	60 c.
1890	100	434	1,200		1,634	651	101·372	2,485	65 c.
1891	125	594	1,900		2,494	1,830	53·750	4,503	60 c.
1892	97	746	950		1,696	1,095	41·845	2,930	58 c.
1893	90	893	1,600		2,493	1,807	22·407	4,412	52 c.
1894	90	522	1,900		2,422	2,226	4·362	4,742	33½ c.
1895	40	698	1,850		2,548	1,764	4·673	4,357	35 c.
1896	20	822	1,545	340	2,707	1,541	7·788	4,276	35 c.
1897	....	898	1,245	715	2,858	1,813	10·753	4,682	35 c.
1898	....	1,108	1,540	1,000	3,648	2,503	5·055	6,156	33 c.
1899	....	1,115	1,740	1,350	4,205	2,605	10·224	6,820	36 c.
1900	....	1,376	1,700	1,450	4,526	3,211	4·407	7,741	47 c.
1901	....	1,660	1,800	1,750	5,210	4,168	3·030	9,381	50 c.
1902	....	1,604	1,110	1,310	4,024	4,850	2·007	8,877	47 c.
1903	....	1,600	1,500	1,650	4,750	6,348	51·801	11,150	40 c.

Evans mine, Canadian Copper Co., Copper Cliff, Ont.

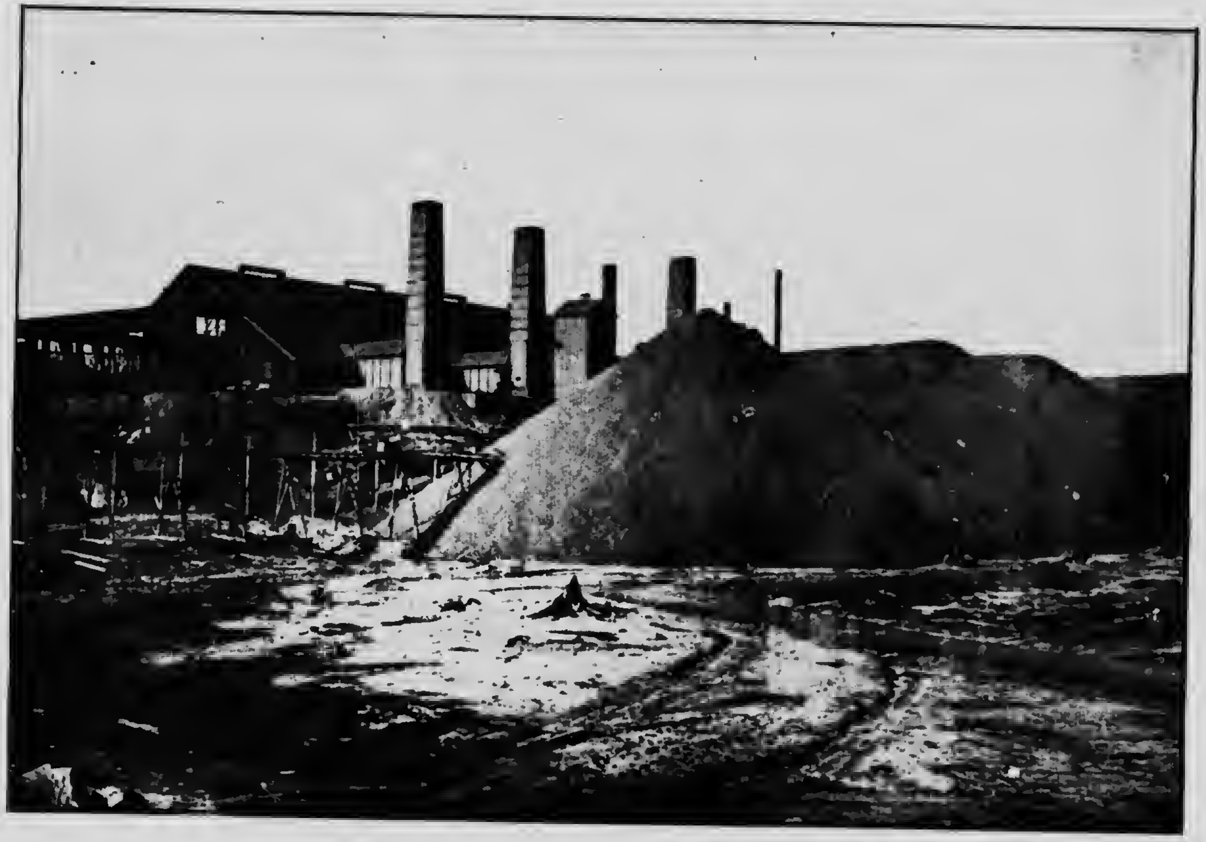
The Town of Copper Cliff, Ont.

West Smelter of Canadian Copper Co., at Copper Cliff, Ont.

THE ONTARIO SMELTING WORKS, ORFORD COPPER CO., AT COPPER CLIFF, ONT.

These buildings were destroyed by fire in the spring of 1904.

NO. 2 MINE, WEST SMELTER AND MATTE SHIPPING YARD, CANADIAN COPPER CO, COPPER CLIFF, ONT.

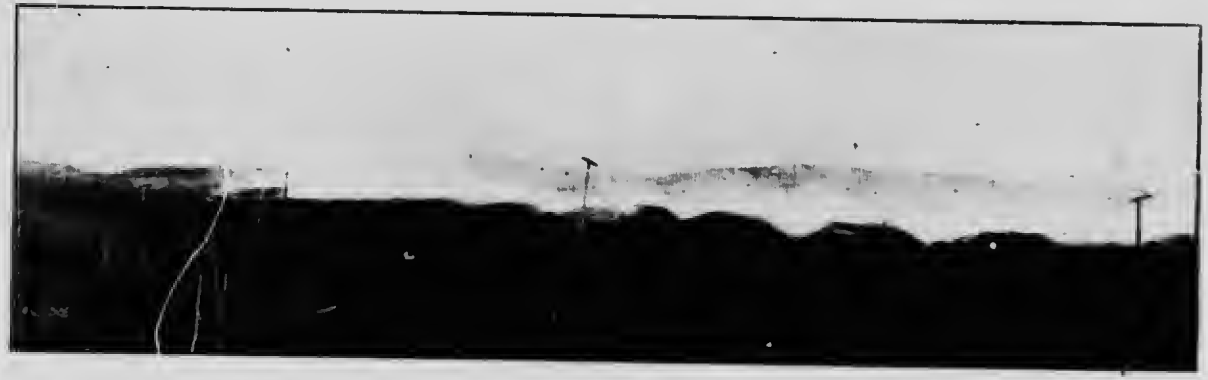


THE WEST SMELTER OF THE CANADIAN COPPER CO., AT COPPER CLIFF, ONT.

This view looking N.E. was obtained from the high trestle leading from the lower roast yard. The high dumps of granulated slag are prominent in the foreground.

Roast yard at Copper Cliff, Ont.
Showing temporary trestle and general method of building roast heaps.

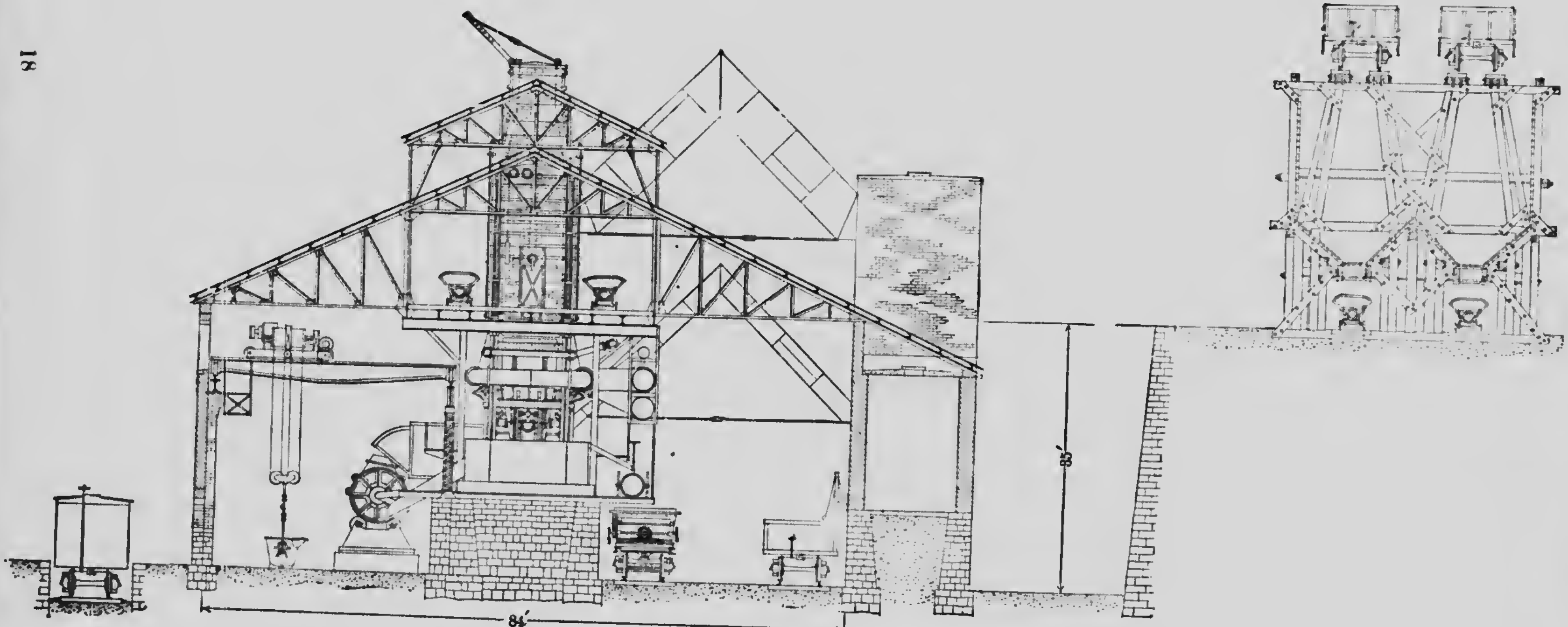
Roast yard of the Canadian Copper Co., at Copper Cliff, Ont.
In the foreground the ore is being removed from a pile that is roasted; the next pile shows the wood already laid to receive the ore, while in the background are similar ore piles in various stages of preparation for roasting. In the distance some of the piles are already fired with dense fumes arising from them, while to the right is the elevated railroad which runs the whole length of the yard.



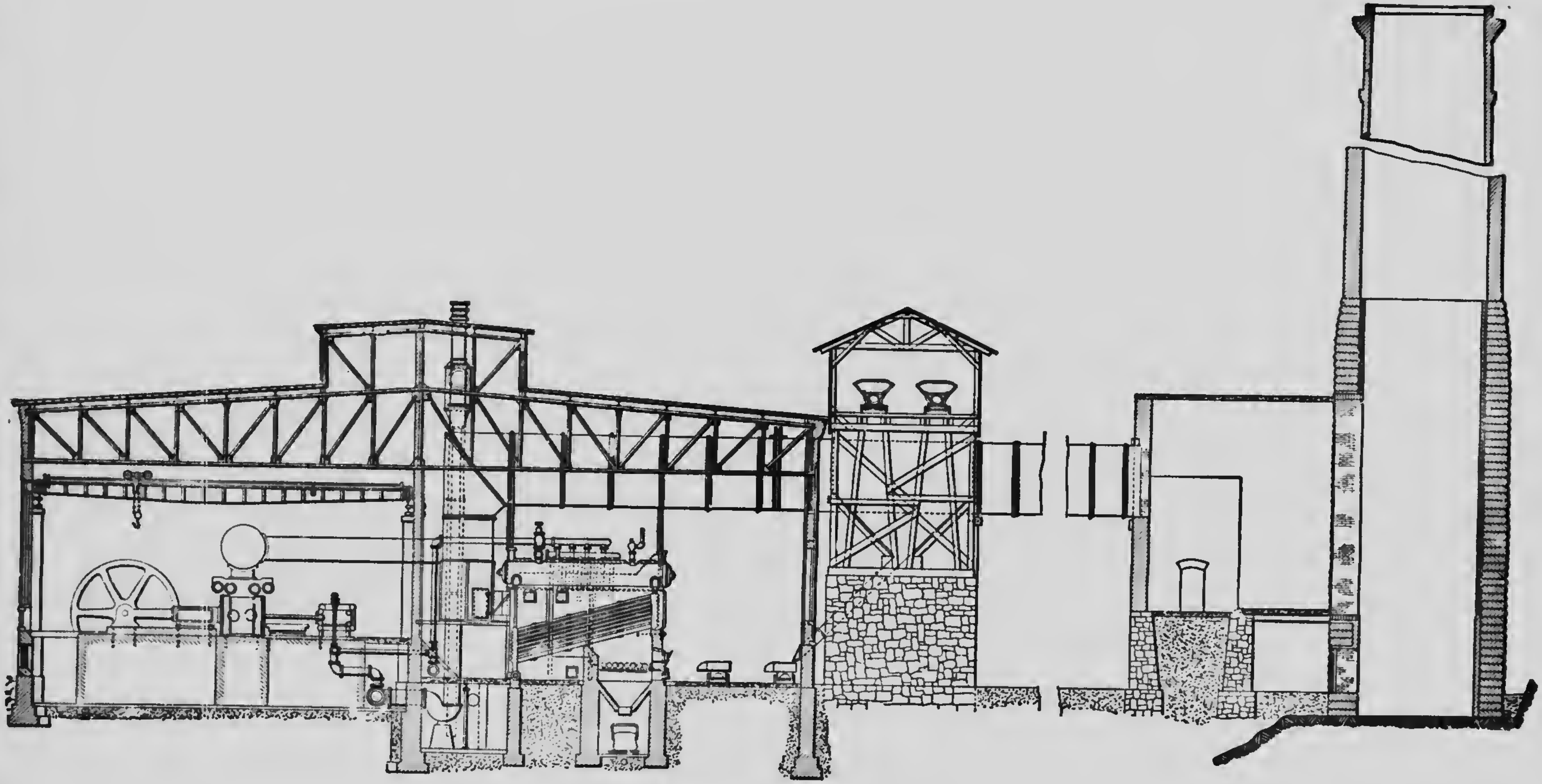
Roasting ore at main yard, Canadian Copper Co., at Copper Cliff, Ont.

Elsie Mine (Lake Superior Power Co.).

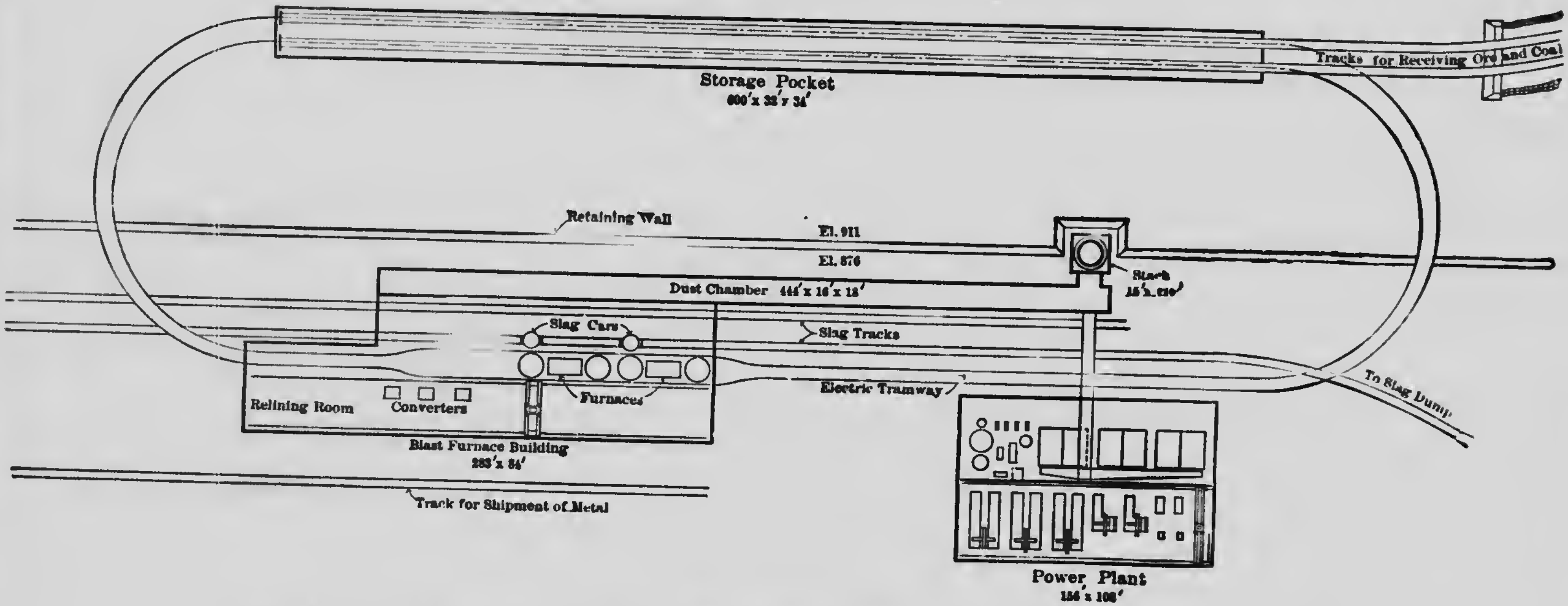
Interior of Smelter, Murray Mine, McKim Township.



Cross Section of New Smelter of Canadian Copper Co., at Copper Cliff, Ont.



Section of Works at Copper Cliff.



Ground Plan of the New Smelter and Works recently erected by the Canadian Copper Co., at Copper Cliff, Ont.

THE NEW SMELTER OF THE CANADIAN COPPER CO., AT COPPER CLIFF, ONT.
(Looking northwest.)

Interior of smelter in course of construction for the Canadian Copper Co., at Copper Cliff, Ont.
Showing the base of one of the new blast furnaces with forehearth partly completed.

Rock House and main open pit Creighton mine.

Creighton Mine, Canadian Copper Co.

This view was taken from the side of the main pit looking S.S.E. and shows the methods of handling the ore.

Main Pit of the Creighton Mine, Canadian Copper Co.

This illustrates methods of mining and the removal of the ore.

The General Offices and Smelter of the Mond Nickel Company, near Victoria Mines Station.

Rock house over main shaft at Victoria Mines, Mond Nickel Co.

The Smelter of the Mond Nickel Co. at Victoria Mines.
Slag dump in the foreground.

Roast yard at Victoria Mines, Mond Nickel Co., showing method of construction of roast heaps.

Roast Yard near Victoria Mines, Mond Nickel Co.

In the foreground is the weighhouse while in the distance can be seen the rock house over the main shaft.

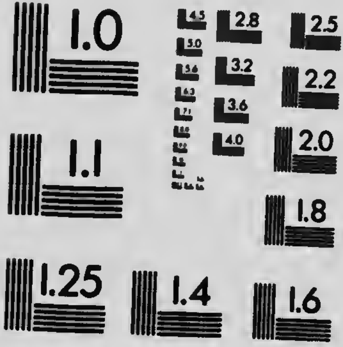
BRECCIA OF GRANITE AND HORNBLENDE SCHIST, OPPOSITE MANAGER'S HOUSE, MURRAY MINE.

Breccia of Granite and Hornblende Schist.

One quarter of a mile E. of Murray Mine, north of Canadian Pacific Railway.

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



Dyke of olivine-diabase cutting ore body at Murray Mine.
Showing basaltic or columnar structure.

PORTION OF A DYKE OF OLIVINE-DIABASE.
Showing boulder-like masses due to spheroidal weathering and disintegration.

Portion of Dyke of Olivine-diabase.
The concretionary structure and spheroidal weathering shown are characteristic of this rock.