CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS
MINES BRANCH

NICKEL IN CANADA

WITH A SURVEY OF WORLD CONDITIONS

by

W. R. McCLELLAND
MINERAL RESOURCES DIVISION

Price 50 cents

Memorandum Series No. 130

1955

CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS
MINES BRANCH

NICKEL IN CANADA

WITH A SURVEY OF WORLD CONDITIONS

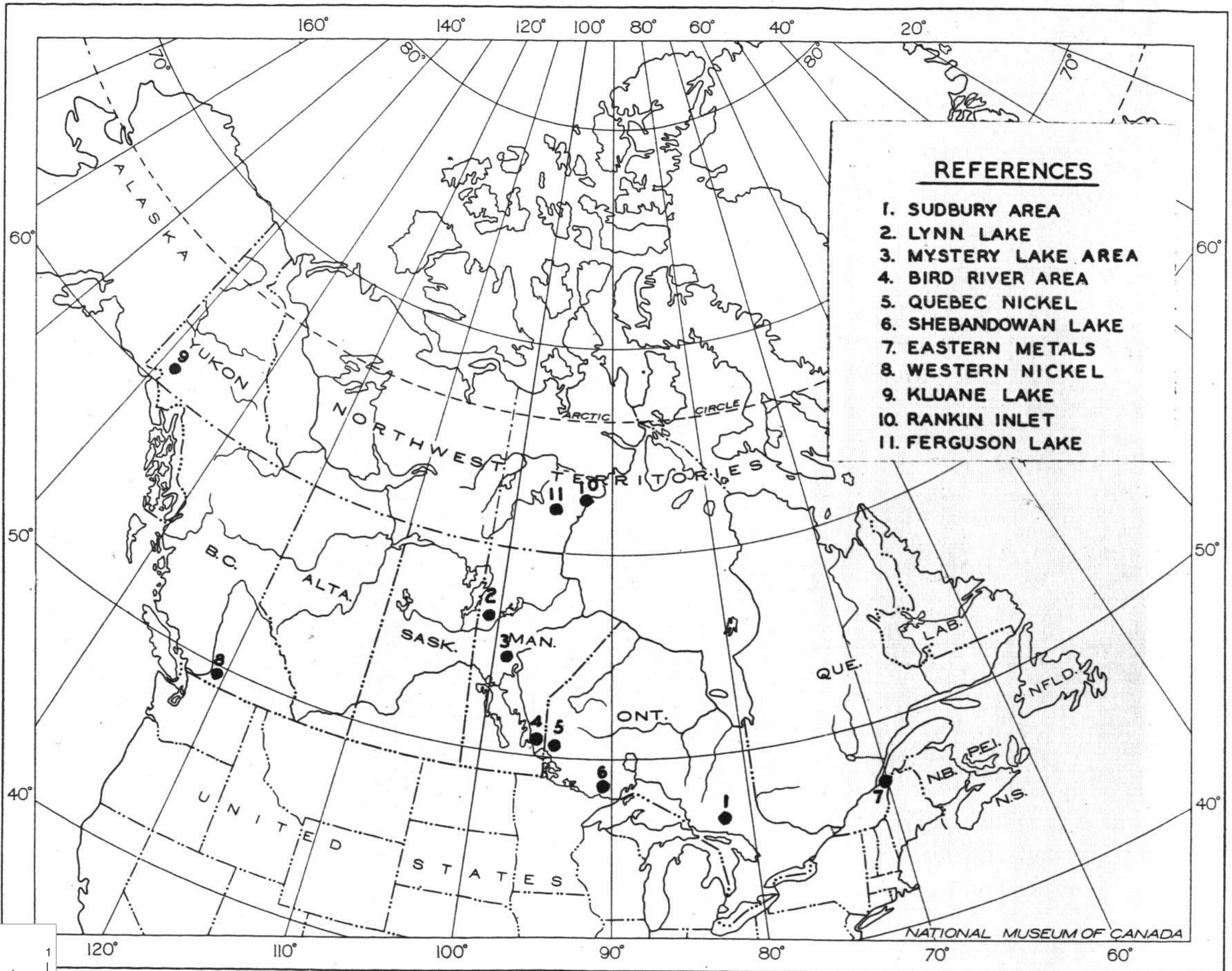
by

W. R. McCLELLAND
MINERAL RESOURCES DIVISION

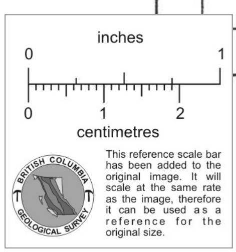
Price 50 cents

Memorandum Series No. 130

1955



MAP I. PRINCIPAL NICKEL OCCURRENCES IN CANADA.



CONTENTS

Illustrations

NICKEL IN CANADA WITH A SURVEY OF WORLD CONDITIONS

by

W.R. McClelland
Mineral Resources Division

CHAPTER I

INTRODUCTION

Nickel in point of value ranks first among the metals produced in Canada. In 1954 it represented almost 12.5 per cent of the total value of mineral production and was only exceeded by crude petroleum. Canada has been for many years the world's largest producer of the metal accounting for over 80 per cent of the entire output. The purpose of this review is to show the development and future potentialities of the Canadian nickel industry, whose importance in the national economy and paramount position as a world source of supply is unquestioned.

The Canadian nickel industry has grown steadily since the discovery of the nickel-copper deposits of the Sudbury basin of northern Ontario in 1883. During the past decade this growth has been greatly accelerated, and within the next few years Canada's output of nickel-- nearly 160,000 short tons in 1954 -- should be considerably increased.

The history of the industry in Canada provides one of the most fascinating stories in the annals of mineral discovery and development. In its early years, the industry was handicapped by technical difficulties, and it was only after many years of research that processes for the economic recovery of copper and nickel from the complex ores were developed. These have since been greatly improved, new methods have been developed, and a very high rate of recovery is now attained.

Nickel is a silvery white metal of atomic weight 59, specific gravity 8.9, and melting point of 1,453 C. In the chemically pure state, it has a tensile strength of 46,000 pounds per square inch. It possesses a wide range of valuable physical characteristics, namely strength, toughness, hardness, ductility, and resistance to corrosion and to change at high temperatures; these qualities are largely imparted to alloys containing nickel(1).

While nickel is a component of many alloys used in early days, it was unknown as a separate element until the middle of the eighteenth century. About this time, miners in Saxony found ores resembling those of copper, but which, on smelting, yielded a tough, hard, white metal that could not be hammered or worked into useful shapes. Because of its refractory behaviour, they called it 'kupfernickel', which in English means 'Old Nick's copper'.

In 1751, the Swedish chemist, Axel Cronstedt, while experimenting with ores similar to those found in Saxony, discovered the metal and named it 'nickel'.

There was little demand for nickel until near the end of the nineteenth century. Probably its first commercial use was in an alloy known as 'German silver' or nickel silver. Later it was used for coinage purposes. The United States issued the first copper-nickel coins in 1857, and was followed by Belgium in 1862; in 1881 Switzerland issued the first pure nickel coins. Nickel plating had been developed on a commercial basis in 1870.

Iron-nickel alloys were developed early and were followed later by the nickel steels. The significant merits of these alloys opened up a wide range of commercial applications. Demand for the metal began to increase after 1889 when James Riley of Glasgow published the results of his experiments on nickel steel. Tests proved this steel definitely superior to plain steel plate in withstanding armour-piercing shells, and nickel steel plate became the standard in naval and armament construction. A large proportion of nickel is still used in the ferro-alloy field, an estimated one-third of the output being consumed by the steel mills, including large quantities for stainless steel. Nickel plating and high nickel content rolling mill products account for about 40 per cent. The remaining quantities are used in a wide variety of application such as gray iron, steel and non-ferrous castings, heat-resistant and electrical-resistance alloys, magnets, batteries, chemical products, coinage, and in nickel-silver, cupro-nickel, and other miscellaneous alloys.

A few years prior to Riley's announcement, the Canadian nickel-copper deposits of the Sudbury Basin had been discovered, establishing large sources of supply coincident with the expanding markets for nickel. Production from these deposits rose rapidly and by 1911 was double the 1901 output of 4,594 tons. Output during World War I reached a maximum of 46,254 tons in 1918, only to be followed by a sharp drop during the post-war period. However, as a result of the development of new uses for the metal, demand steadily increased, and by 1929 production had risen to 55,137 tons. Output continued to expand, reaching a peak of 144,000 tons in 1943 during World War II. In the three-year period 1950-52, it has averaged 134,000 tons annually. Output in 1954 was nearly 160,000 tons (preliminary estimate). Current demand greatly exceeds this figure, however, and concerted efforts are being made to increase the sources of supply.

CHAPTER II

HISTORY OF NICKEL DEVELOPMENT IN CANADA

Canada, with its large reserves of ore, and with its producing mines, smelters, refineries, and research facilities, has played a foremost part in the development of nickel.

The first discovery of the metal in Canada was made in 1848 at the Wallace mine in northern Ontario, near the entrance of the Whitefish River into Lake Huron, by Alexander Murray of the Geological Survey of Canada, assistant to Sir William Logan, then Director of the Survey(2). A few years later T. Sterry Hunt, also of the Geological Survey, referred in the Geology of Canada, 1863, to an occurrence of nickel on Michipicoten Island. Neither of these occurrences proved to be commercial orebodies, and it was not until 1883, during the construction of the Canadian Pacific Railway, that the first deposit of nickel ore was discovered in the Sudbury area, although it was not recognized as such at the time.

This was the beginning of a series of nickel discoveries that has continued over the years. Up to 1886, eighteen deposits were found in rapid succession. Of these the Murray, Creighton, and Frood-Stobie mines are still in active production.

By 1890, three companies were operating in the Sudbury area: Canadian Copper Company Limited at Copper Cliff, Dominion Mineral Company at the Blezard and Worthington mines, and the English metallurgical firm of H.H. Vivian and Company, of Swansea, at the Murray mine. Canadian Copper Company had two furnaces in operation at Copper Cliff and similar furnaces were under erection by the other two companies.

Two grave difficulties beset the new industry. The first was the metallurgical problem of devising an economical method of treating the ores, and the second was the limited market for nickel, which at this period was controlled by interests in New Caledonia, the leading world source of nickel until 1905, when Canadian production took the lead. So serious did these difficulties become that two of the companies failed, and by 1894 Canadian Copper Company was the sole operator.

Meanwhile two processes had been developed which tests had proved could be used successfully in the economic treatment of the Sudbury ores. These were the Orford process to which the Orford Copper Company of New Jersey, incorporated in 1887, held the patent rights, and the Mond process developed and perfected by Dr. Ludwig Mond and his associates.

In 1902 Orford amalgamated with Canadian Copper and formed International Nickel Company. Other companies included in the merger were American Nickel Works, Société Minière Caledonienne, Nickel Corporation, Limited, Vermilion Mining Company of Ontario, Limited, and Anglo-American Iron Company.

Following the development of the nickel carbonyl or Mond process, Dr. Ludwig Mond and his associates acquired property in the Sudbury district in 1899 and the Mond Company Limited was incorporated under the Imperial Companies Act of Great Britain in September 1900. By 1901 the company had the Victoria mine ready for operation. The ore was smelted in Canada and refined at the company's plant at Clydach in Wales.

Several other companies were active in the area during this early period but they gradually disappeared, and by 1903 operations were confined to the International Nickel and the Mond Nickel companies. During the next 10 years both companies continued to expand operations. In 1912 reorganization of International Nickel Company resulted in a substantial increase in the authorized capital stock of the new company, which became known as The International Nickel Company, the prefix "The" being the only change in the title.

About this time a small Canadian-owned company, Alexo Mining Company, Limited, incorporated in 1913, opened up the Alexo mine in Dundonald township, Cochrane district, more than 100 miles from the nearest northern range of the Sudbury deposits. Between 1912-1919, a total of 51,860 tons of ore was mined and shipped to the Mond Nickel Company's smelter at Victoria Mines, The mine was closed in 1919, but was reopened during the period 1943-44 during World War II.

The outbreak of World War I in 1914 immediately focused attention on nickel. Its importance in making armour plate and munitions made it one of the most important of the strategic metals. Although Canada was the world's major source of nickel ore and matte, the metal was refined and produced only in United States, Great Britain, France, Norway, and Germany, and it was imperative that nickel be prevented from reaching the enemy. Production in Norway and Germany was small, but any leakage via the neutral United States would have proved serious. In September 1915, the Provincial Government of Ontario established a Commission, later known as the Royal Ontario Nickel Commission, to study every phase of the nickel industry relative to the best interests of the Province, Canada, and the Empire. The vast store of information contained in the report of the Commission, which was issued in 1917, makes it one of the important milestones in the history of the growth of the nickel industry in Canada. It is significant that, in 1917, the transfer of nickel refining facilities from United States to Canada was begun.

Early in 1917, British American Nickel Corporation Limited, which had been incorporated in 1913, and which owned approximately 17,600 acres in the Sudbury area, including the Murray, Elsie, and Lady Violet mines and several other mines and copper-nickel properties, began construction of large smelting and refining works at Nickleton, Ontario, and at Deschenes, Quebec, respectively. The company had acquired exclusive rights for North America to the Hybinette electrolytic process for producing refined metallic nickel. It commenced operations at Nickleton and Deschenes in 1919 but its timing was most unfortunate for, following World War I, there was an immediate drop in the demand for nickel.

A few years later the industrial depression of the early twenties added further difficulties. From an output of 92,500,000 pounds in 1918, Canadian nickel production dropped to a little over 17,597,000 pounds in 1922. Unable to meet these adverse conditions, British American went into liquidation in 1924.

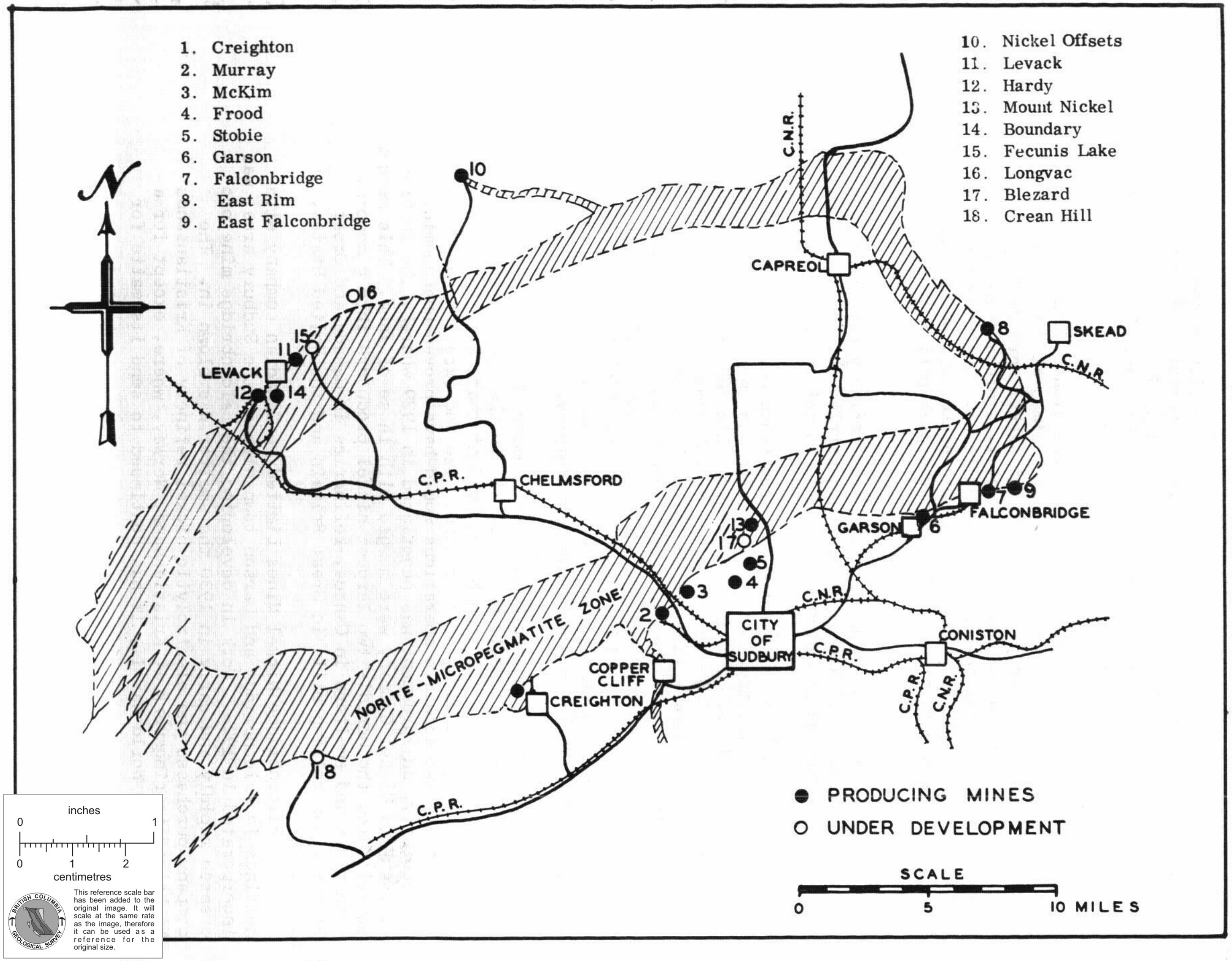
During the post-war years The International Nickel Company carried on an intensive program of research aimed at working out new peacetime uses for nickel. New alloys of nickel were developed, and extensive uses for one of these, Monel metal, a nickel-copper alloy produced directly from the matte, were built up. The demand for nickel increased steadily and by 1929 more nickel was being used for peacetime purposes than was used during the peak period of wartime production.

Since 1918, when the Port Colborne refinery came into production, International Nickel Company has carried out all the stages of nickel production in Canada from mining to refined nickel.

Late in 1928 events of major importance occurred in the Canadian nickel industry. A reorganization was carried out whereby The International Nickel Company of Canada, Limited, hitherto a wholly owned subsidiary of The International Nickel Company of New Jersey, issued its stock direct in exchange for stock in the American Company. The operating assets of the New Jersey company were transferred to a new company, the International Nickel Company Inc., all of whose capital stock was acquired by The International Nickel Company of Canada, Limited, frequently referred to as 'Inco', which as a result of this reorganization became a Canadian company.

About this time the Mond Nickel Company began development of its Frood Extension property which lay within the Frood property of International Nickel. It soon became evident that these two properties embraced a single orebody of tremendous size and excellent grade. Mining this body by two separate operations would have proven uneconomic. Consequently, an agreement was negotiated in 1929 whereby the interests of the Mond Nickel Company were merged with those of Inco. This merger consolidated the world's two largest nickel producers into a company with mines and smelters in Canada, refineries in Canada and Great Britain, and rolling mills in Great Britain and the United States.

Falconbridge Nickel Mines Limited, a Canadian company with holdings in Falconbridge and Garson townships in the Sudbury area, was incorporated in 1928. Work in developing the Falconbridge mine progressed rapidly and early in 1930 the smelter was blown in. The company purchased the electrolytic nickel refinery of Kristiansands Nikkelraffineringsverk at Kristiansand, Norway, where, except for a period during World War II, it has continued to send its matte for refining.



MAP 2. - SUDBURY NICKEL DISTRICT

In 1923 a discovery of nickeliferous pyrrhotite was made south of Yale, 110 miles east of Vancouver, in the New Westminster mining division of British Columbia. Except for sample shipments of ore amounting to around 5,600 tons to Japan in 1936 and 1937, the mine was never brought into commercial production. Western Nickel Limited, which now owns the property, carried out an extensive program of exploration during 1953 and 1954.

Except for this limited development in British Columbia, the nickel industry of Canada until 1953 was confined to the relatively small area of the Sudbury basin of Ontario. Late that year Sherritt Gordon Mines Limited commenced operations at its Lynn Lake nickel-copper property in northern Manitoba, bringing a second important nickel area in Canada under development. The deposits were discovered in 1941 by a Sherritt Gordon Mines prospector almost 60 years after the finding of nickel near Sudbury.

The past decade has witnessed a tremendous expansion in both the mining and metallurgical phases of the Canadian nickel industry. In addition to developments at Lynn Lake several properties throughout Canada are being prepared for production. Important advances have been made metallurgically, one of the most outstanding being the development of the Forward Process. Exploration has resulted in a number of significant discoveries in various parts of Canada and renewed interest has been taken in several of the older known occurrences. Among the more recent discoveries under active development are deposits in the Eastern Townships about 65 miles southeast of Quebec City, in northwestern Ontario, in northern Manitoba, in the Keewatin District in Northwest Territories, and in the Kluane Lake area of southwestern Yukon.

CHAPTER III

CANADIAN NICKEL OCCURRENCES

Including the mines of the Sudbury area, Canada has over 75 known occurrences of nickel, which are found in seven of the ten provinces and in Yukon and the Northwest Territories(3).

ONTARIO

In addition to the Sudbury area, nickel is known to occur in the Parry Sound district, in Hastings county in eastern Ontario, in the Cochrane district and in the district of Nipissing in northern Ontario, and in the Algoma and Thunder Bay districts and other areas of northwestern Ontario. Nickel minerals are also found associated with many of the silver-cobalt ores of the Cobalt district of nothern Ontario, and a small tonnage is recovered in the treatment of these ores. These occurrences have little significance as sources of nickel.

Sudbury District

The largest reserves of developed sulphide ores of nickel in the world are those of the Sudbury Basin area(4). This basin, which is shaped like an elliptical trough approximately 37 miles long and 17 miles wide, is in rugged glaciated country, with rock ridges alternating with flat, drift-covered valleys. A series of volcanics, fragmental rocks, and sediments occupies the centre of the basin. The deposition of this series was followed by the intrusion of the nickel irruptive forming a great laccolithic mass of norite-micropegmatite, which constitutes the rim of the basin. The ore mineral occurring in the nickel irruptive rim, and certain "offsets" from it, is chiefly pyrrhotite, with which is associated pentlandite and chalcopyrite. While nickel and copper are the major metals of the Sudbury deposits, they also contain minor amounts of cobalt, gold, the platinum metals, selenium, silver, and tellurium. Metals of the platinum group (platinum, palladium, iridium, rhodium, ruthenium, osmium) occur in extremely small amounts, but the tonnages mined are so large, and the extraction processes so efficient, that Canada ranks as one of the largest producers of these metals.

The International Nickel Company of Canada, Limited

The numerous holdings of the company in the Sudbury district cover an area of 100,000 acres and include five producing mines, the Frood-Stobie, Creighton, Levack, Garson, and Murray mines. The combined underground development of these mines in 1954 amounted to over 375 miles(5).

The Frood-Stobie mine, in McKim township three miles north of Sudbury, consists of two principal sections: the Frood, which is one of the largest known nickel-copper deposits, and the Stobie. Since 1938 these deposits have been extensively mined by open-cut operations. The Stobie open-pit operation ceased in 1951 and work was concentrated entirely on underground development. A new shaft, No. 8, was completed to a depth of 1956 feet in 1952. The Frood open-pit, elliptical in shape, is over 500 feet deep, with benches at 60-foot heights. Large-scale expansion of the underground workings was started after the end of the war and within the next few years open-pit operations will be replaced by underground mining. The Frood has two main shafts, No. 4, sunk to a depth of 3,892 feet and No. 3 to a depth of slightly over 3,000 feet. The latter is equipped to lift 10,000 tons of ore per mining day.

The Creighton mine is in Creighton township, seven miles west of Copper Cliff. It is developed by four shafts, the deepest of which reaches 5,562 feet below the surface. The mine contains large tonnages of low-grade material which previously could not be mined economically by conventional mining methods. However, the development of a low-cost bulk mining technique known as induced caving, has now made possible the economic recovery of this lower-grade ore. By this method great masses of ore are caused to cave and disintegrate by their own weight. As a result of the caving project, production from the Creighton mine has been increased from 10,000 to 13,600 tons of ore per mining day.

The Levack, in Levack township, about 20 miles northwest of Copper Cliff, is the most distant of the operating mines. The main shaft was deepened and a new internal shaft completed in 1952 to the 2,650-foot level. Production is at the rate of 4,000 tons daily.

The Garson mine is in Garson township, 12 miles northeast of Copper Cliff. It is serviced by two shafts. The main shaft is being deepened to a depth of over 4,200 feet. Production is approximately 4,000 tons daily.

The Murray mine is four miles north of Copper Cliff in McKim township. The No. 2 shaft extends to the 3,300-foot level. Production is at the rate of 6,500 tons per mining day.

Exploratory work is being carried on in the Crean Hill mine in Denison township, 14 miles southwest of Copper Cliff.

To treat the enormous output of ore, which in 1954 exceeded 14,400,000 tons, the company employs two plants to provide the concentrates for the smelters. The original concentrator at Copper Cliff has a capacity of 30,000 tons of ore per day. In 1951 the company built a second concentrator at the Creighton mine to handle the increased tonnages resulting from the induced caving method of mining technique. This plant has a capacity of 12,000 tons of ore per day and produces a bulk sulphide flotation concentrate which is delivered via a $7\frac{1}{2}$-mile pipe line to the Copper Cliff concentrator where it enters the regular circuit for selective flotation.

The company operates two smelters, the main one being at Copper Cliff and the other, the former Mond Company's smelter, at Coniston, eight miles east of Sudbury. The latter is employed in producing copper-nickel Bessemer matte.

The Copper Cliff smelter is the largest of its kind in the world. The equipment includes roasting furnaces, reverberatory furnaces, blast furnaces, converters and a dust plant. The copper refinery, about a mile from the smelter, receives molten blister copper direct from the converters in "hot metal cars". Refining is carried out electrolytically. Construction of a $16,000,000 pyrrhotite treating plant that will employ an ammonia leaching process is under way.

The company's nickel refinery at Port Colborne, Ontario was built in 1918 and produces electrolytically refined nickel and nickel oxide. The capacity of the refinery is over 72,000 tons of electrolytic nickel a year. Smelting and refining operations will be dealt with in greater detail in a subsequent chapter on the metallurgy of nickel.

Through a wholly owned subsidiary, The Huronian Company, Limited, the company operates four hydro-electric plants in the Sudbury area, which have a total installed capacity of 70,000 horsepower. Power is furnished to the company's plants over its own power lines at 33,000 volts. Additional power requirements are met under contract with the Hydro Electric Power Commission of Ontario.

The ore reserves of International Nickel in the Sudbury area are of enormous size. At the end of 1954 measured ore reserves were estimated at 261,619,020 short tons with a combined nickel-copper content of 7,874,998 short tons.

Falconbridge Nickel Mines Limited

Falconbridge Nickel Mines owns a number of properties on the rim of the Sudbury Basin embracing approximately 53,000 acres. Of these the Falconbridge, McKim, Hardy, East, and Mount Nickel are producing mines. Active development is being carried out on the Fecunis Lake, Boundary, and Longvac deposits, all of which are expected to be in production by 1959(6).

The Falconbridge, the company's main producing mine, is in the township of that name, about 11 miles east of the city of Sudbury. It has two principal shafts, No. 1, a 3-compartment to a depth of 2,848 feet with 15 levels, and No. 5, a 5-compartment to a depth of over 4,000 feet. An internal shaft, No. 7, extends from the 2,450-foot level to 4,200 feet.

The McKim mine in McKim township adjacent to the International Nickel Company's Murray mine is developed by a single 1,421-foot shaft.

The East mine lies about a mile to the east of the Falconbridge and is opened up by a shaft to a depth of 2,800 feet.

Mount Nickel mine on the south half of lot 5, concession II, Blezard township, was discovered in 1885 and first operated between 1899 and 1901. It was worked again during 1915. The orebody is estimated to contain about 300,000 tons. A shaft to a depth of 800 feet was started in the spring of 1953 and mining is at the rate of 300 tons per day.

The Hardy mine in Levack township is on the northwestern rim of the Sudbury Basin. The main shaft extends to a depth of 1,427 feet. Production is at an annual rate of 300,000 tons. The Hardy mill of 1,500 tons daily capacity came into operation early in 1955.

The most important of the new developments is that of Fecunis Lake. This deposit, which lies beneath the lake a few miles northeast of Inco's Levack mine, is estimated to contain 10,000,000 tons of ore. The ground rises sharply from the southeast shore of the lake to a height of over 200 feet. At a point about 30 feet above the lake an adit is driven into the hill for a distance of 600 feet, where it intersects with No. 1 main shaft, which will be 4,000 feet. A second service shaft is being sunk near the shore of the lake. In addition to the mine buildings, plans call for a 2,000-ton concentrator, a railway spur to the main C.P.R. line, and a townsite.

The Boundary mine just east of the Hardy is being opened up by a drift from the 1,000-foot level of the Hardy mine and by a winze to a depth of 650 feet.

Longyac north of Fecunis Lake is being developed by an inclined shaft and the ore will be hoisted by a conveyor-belt system.

The concentrator at Falconbridge has a capacity of between 2,500 and 2,600 tons of ore per day. The smelter is equipped with three blast furnaces and four converters. Separation and refining of the metals in the nickel-copper matte is carried out at the company's refinery in Kristiansand, Norway. In order to meet the substantial increase in its output of ore arising from the new mine development under way, the company is making arrangements to expand its existing smelting and refining facilities.

The developed and indicated ore reserves of the Falconbridge mines and properties in the Sudbury area at the end of 1954 were 35,515,700 tons with an average grade of 1.59 per cent nickel and 0.82 per cent copper.

Nickel Rim Mines Limited

This property, comprising nine claims, is in MacLennan township, on the east rim of the Sudbury Basin. The mine is developed by a 3-compartment shaft to a depth of 700 feet. Shipments of development ore to the Falconbridge mill and smelter were started in October 1952. Construction of a 750-ton capacity mill was begun in 1953 and mill operations commenced late that year. Output is sold under contract to Falconbridge Nickel Mines. The estimated ore reserves are 1,393,000 tons with an average grade of 1.3 per cent nickel, and 0.49 per cent copper. Plans call for deepening the shaft and increasing the mill capacity.(7)

Milnet Mines Limited

The Milnet mine was located in Parkin township, 22 miles northeast of Sudbury, and was the most northerly of the operating mines in the Sudbury area. It consisted of a block of the Jonsmith property 500 feet wide, 1,000 feet long and 500 feet deep containing an orebody of approximately 200,000 tons with an average grade of 1.35 per cent nickel, 1.68 per cent copper, and 0.10 ounces per ton platinum metals. It was developed by a 3-compartment shaft to a depth of 475 feet with three levels. Production, which started in December 1952, was at the rate of 7,500 to 10,000 tons per month. The ore was crushed at the mine and trucked to Falconbridge for treatment. The mine closed down in 1954, when the orebody was mined out.(7)

Nickel Offsets Limited

The property, comprising 51 patented claims, is in Foy and Bowell townships, about 20 miles north of Chelmsford. The ore, which occurs in rich pockets, is in an offset extending out from the norite-micropegmatite rim of the Sudbury Basin. The mine is developed by two shafts about three-quarters of a mile apart. No. 1 is 1,550 feet and No. 2 is 1,106 feet deep. Production from a new 300-ton daily capacity mill started in September 1953. The company has a contract with Falconbridge Nickel Mines for the sale of concentrates containing at least 10,000,000 pounds of recoverable nickel up to September 1957. The mine was worked during 1943-44, when 10,311 tons of high grade nickel-copper was produced. The ore reserve is estimated to be in excess of 300,000 tons with an average grade of 1.77 per cent nickel, 1.31 per cent copper, 0.025 per cent cobalt, and $2.20 per ton in platinum metals.(7)

Cobalt District

A small amount of nickel is found in the silver-cobalt ores of the Cobalt area. This is recovered and marketed as nickel sulphate. In 1953 the ores and concentrates shipped from this region contained 526,400 pounds of nickel.

Other Properties and Occurrences

In addition to the properties described, there are a number of nickel-copper occurrences in Ontario, some of which have been partially developed. Many of them are being actively explored, and, in a few cases, some new discoveries have been made.

District of Sudbury

The Denison mine, on lot 12, concession II, Denison township, is owned by Pacolund Mines Ltd. Operations were begun in 1937 and a 3-compartment shaft has been sunk to a depth of 972 feet with six levels. There are two mineralized areas in norite dyke, known as the Worthington offset. Approximately 800 tons of ore was shipped from the Howland pit on the west boundary of the property in 1915-16 averaging from 6.5 to 7.0 per cent combined nickel and copper. No production has been reported from the shaft area. The ore reserve after 30 per cent sorting is estimated at 382,900 tons to 1,100 feet depth, averaging 1.0 per cent nickel and 0.93 per cent copper.(7)

The Dominion Nickel property of New Dominion Nickel Mines Limited, comprises three groups of five claims each in Norman township, Sudbury district. An adit was driven on the main group in 1947 and the deposit was diamond drilled. A sample taken 70 feet in from the mouth of the adit carried 2.52 per cent nickel and 0.05 per cent copper.

The Shakespeare property on the N.E. $\frac{1}{4}$ of lot 2, concession V, Shakespeare township, is owned by Falconbridge Nickel Mines Limited. The occurrence is a mineralized zone in quartz diorite in which mineralization consists of disseminated pyrrhotite, pentlandite, and chalcopyrite. It is undeveloped, but was diamond drilled in 1951. It is estimated to contain between 3,000,000 and 4,000,000 tons of material averaging 0.34 per cent nickel and 0.40 per cent copper.(8)

Northbridge Mines Limited, in which Falconbridge Nickel Mines has a controlling interest, is exploring a 28-claim property in Parkin township about two miles northeast of the Sudbury Basin. Sampling of outcrops has given copper from 0.18 to 0.95 per cent and nickel from a trace of 3.35 per cent. The deposit is of interest as it occurs north of the norite-micropegmatite contact.

The Gauthier property on parts of lots 7-10, concession I, Hyman township, and lots 9-10, concession VI, Nairn township, contains two small exposed sulphide zones in quartz-diabase less than half a mile apart. Selected grab samples contain up to 0.80 per cent nickel and 1.5 per cent copper.(7)

The Dunvegan property of Dunvegan Mines Limited comprises 129 claims in Kenogaming township, Sudbury district. The deposit was discovered in 1951. Pentlandite occurs disseminated in a serpentinized peridotite, close to the contact with volcanics. A geophysical survey and 5,000 feet of diamond drilling carried out in 1952 indicated 0.25 per cent nickel across widths up to 200 feet.

The property of Dominion Gulf Company in Sothman township comprises claims in the southeast corner of the township and a large group of claims in adjoining townships. Surface work, geological and geophysical surveys, and diamond drilling have disclosed lenses of disseminated nickeliferous pyrrhotite on the margin of a peridotite body and some narrow intersections of massive sulphides. The grade of the disseminated material averages 1.5 per cent nickel, while assays of the massive sulphides have been as high as 7.5 per cent nickel. Widths average 12.5 feet in the area drilled. No estimate of the tonnage has been reported.(7)

Southern Ontario

In Parry Sound district the Nickel Cliff mine on lot 17, concession VIII, Armour township, was developed in 1900 and 1901 by a shallow shaft 32 feet deep. Three drill holes were put down in 1903 and 1904. No recent activity has been reported. Grab samples taken from the dump in 1942 by J. Satterly, Ontario Department of Mines, analyzed 1.37 per cent copper and 1.40 per cent nickel.

The Bonter deposit on lot 27, concession V, Marmora township, Hastings county, occurs as disseminated chalcopyrite and pyrrhotite in a mass of igneous pyroxenite intruding greywacke. Some test pits were dug in 1925 and six diamond drill holes were put down in 1943. Two samples across 60 feet analyzed 1.34 per cent copper, 0.42 per cent nickel, and 2.39 per cent copper, 0.48 per cent nickel respectively.(9)

Northern and Northwestern Ontario

The Alexo mine, on lot 12, concession III, Clergue township and lot I, concession III, Dundonald township, Cochrane district, was discovered in 1908 and, during operations between 1912 and 1919 produced 2,213 tons of nickel and 240 tons of copper. Operations were resumed during the period 1943-44, when shipments totalling 2,846 tons were made to the Copper Cliff smelter. Nickeliferous pyrrhotite, pentlandite, and traces of chalcopyrite and pyrite occur as lenses at the contact of peridotite and Keewatin pillow lava. The mine is developed by a shaft to a depth of 265 feet with crosscuts and drifts on three levels.(10)

The Trebor mine (11), owned by Trebor Mines Limited, is in Strathy township, Nipissing district, about four miles northwest of Timagami on the Ontario Northland Railway. Sulphide mineralization occurs in a pitching basin-shaped body of peridotite disseminated throughout with chalcopyrite and pyrrhotite. Some massive sulphides occur in small veins. The ore zone is cut by two diabase dykes. The deposit was developed between 1932 and 1937 as the Cuniptau mine. During this period a 2-compartment shaft was sunk to 240 feet and a 50-ton pilot plant blast furnace, which was operated for a few months only, was erected. The matte produced contained 99,284 pounds of copper, 65,434 pounds of nickel, 37.0 ounces of gold, 910.0 ounces of silver, 82.7 ounces of platinum and 186.3 ounces of palladium. Exploration and development were resumed in 1948 and during 1949 over 38,000 feet of diamond drilling was carried out. In 1949, ore reserves northwest of the diabase were estimated at 369,000 tons, averaging 1.42 per cent combined nickel and copper, while southeast of the diabase over 2,500,000 tons of low-grade nickel-copper ore was reported. Consideration has been given to an open-pit operation.(11)

The Lakemount property, township 28, range 24, Algoma district, is a low-grade nickel-copper deposit in which disseminated chalcopyrite and pyrrhotite occur in the contact zone of a peridotite intrusive body. The deposit has been extensively diamond drilled. The results of drilling carried out in 1952 indicated 4,000 tons of ore per vertical foot to the 500-foot horizon. Sampling of 19 drill holes gave an average of 0.43 per cent nickel and 0.42 per cent copper.(12)

The Shebandowan Lake property on the southwest bay of lower Shebandowan Lake, Thunder Bay district, is owned by The International Nickel Company of Canada, Limited. It is composed of a series of sulphide lenses connected by very narrow widths of sulphides in sheared peridotite. The lenses vary in length from 800 to 1,600 feet and extend for a distance of about 4,000 feet. Ore widths vary from five feet to 10 feet. The ore minerals are pyrite, chalcopyrite, pyrrhotite, and polydymite. Surface sampling over the mining widths gives a nickel content rarely over 3.0 per cent and copper 2.0 per cent. Up until 1952 considerable surface work and diamond drilling were carried out on the property.(13)

The Pic Nickel property, also known as the Beggs-Currie property, east of Pic River, 17 miles north of Heron Bay Station, C.P.R., is owned by Pic Nickel Mines Limited. A body of disseminated sulphides in diorite makes up the low-grade nickel-copper deposit. Some surface work was done in 1930 and again in 1953.(14)

An occurrence of disseminated chalcopyrite and nickeliferous pyrrhotite was discovered in 1952 near Emo, 20 miles west of Fort Francis, Rainy River district. The property, comprising 200 claims was diamond drilled by Falconbridge Nickel Mines Limited and Ventures Limited. Results did not indicate deposits of economic grade.

Kenora District

The property of Kenora Nickel Mines Limited at Populus Lake, approximately 50 miles northwest of Kenora, embraces a body of nickel and copper-bearing sulphides in gabbro over a length of 1,000 feet, a width of 100 feet, and to a depth of 850 feet. Up to 1950, 22,000 feet of diamond drilling had been carried out. The over-all grade is reported to be around 0.75 per cent of combined nickel-copper.(7)

In the Werner Lake-Gordon Lake-Rex Lake area several lenticular bodies of nickel-copper mineralization occur with associated platinum-palladium values at intervals over a length of several miles. Quebec Nickel Corporation Limited has more than 200 claims in the area and has carried out extensive diamond drilling and surface exploration. Results of work done indicate the presence of substantial tonnages of sub-marginal and marginal ore. Three miles west of Werner Lake, Selco Exploration Company Limited has explored occurrences of mineralized peridotite discovered during the summer of 1953.(15)

NEWFOUNDLAND

Occurrences of nickel have been reported in several localities in the province. Between 1869 and 1876, a total of 411 tons of picked ore valued at $32,740 was shipped from a small deposit in the copper workings of West Mine at Tilt Cove on the west coast of Notre Dame Bay. This was apparently an isolated pocket, as no further shipments are recorded.(16)

Other occurrences have been found on the northwest side of Chapel Island in Notre Dame Bay; at Howe Harbour in Hare Bay on the northeast coast; and in the Blow-me-down massif of the Bay of Islands complex on the west coast. None of these occurrences appear to be of any economic value.

NEW BRUNSWICK

In St. Stephen parish, Charlotte county, a deposit of nickeliferous pyrrhotite and chalcopyrite occurs as pockety masses near the contact of altered slates and intruded masses of gabbro, Some 2,000 feet of trenching and 4,000 feet of diamond drilling carried out in 1929 indicated an ore body in the form of an inverted pyramid, 15,000 square feet at the surface and extending to a depth of 250 feet. The estimated tonnage is 150,000 tons averaging 1.5 per cent nickel and 0.9 per cent copper. In 1947, International Nickel leased this property and large areas in adjoining counties, and carried out extensive geological and geophysical surveys. The results, however, were not encouraging and the leases were relinquished.(17)

QUEBEC

The most important known occurrence of nickel is the property of Eastern Metals Corporation Limited in the eastern part of the province in the Township of Rolette, Montmagny county, about two miles west of the village of St. Fabien de Panet. Nickel was discovered on the property in 1951, and diamond drilling indicated two zones; the north, mineralized with nickel and zinc, and the south, approximately 300 feet to the southeast, containing copper minerals and low values in nickel. The zones occur in interbedded argillaceous slate, quartzites, and dolomites that have been highly fractured and altered. The nickel minerals of the north zone are polydymite and millerite associated with pyrite and a small amount of sphalerite. In the south zone chalcopyrite, malachite, and some native copper are found.(18)

Sinking of a 3-compartment shaft to a depth of 600 feet was begun in 1952. Exploration and development work on the 170-foot level in the north zone indicates that the full width of the ore zone is 30 to 35 feet with an average grade in excess of two per cent nickel. In 1952 the north zone was estimated to have in excess of 800,000 tons of ore averaging 0.81 per cent nickel and 1.32 per cent zinc. Metallurgical tests on the ore indicate satisfactory concentration and recovery of the nickel. The erection of a concentrator is planned.

In the south part of Calumet Island, Pontiac county, numerous narrow pyrrhotite and pyrite veins containing niccolite, nickeliferous pyrrhotite, chalcopyrite, and cobaltiferous gersdorffite are found on lot 11, range VIII, and lots 10, 11, and 30, range IX. Some work was carried out on the Ostram claims on lot 10, range IX, a number of years ago. Two or three shallow shafts were sunk and later 120 feet of trenching was done across the strike of the mineralized zone. A 5,830-pound sample submitted to the Ore Dressing Laboratory, Mines Branch, Ottawa, in 1933 analysed nickel, 0.88 per cent; cobalt, 0.17 per cent; iron, 18.8 per cent; insoluble, 54.9 per cent; and gold, 0.02 ounces per ton. No work on this occurrence has been reported in recent years.(19)

MANITOBA

Numerous nickel occurrences have been found in Manitoba in addition to the Lynn Lake deposit of Sherritt Gordon Mines Limited.(20)

Northern Manitoba

Sherritt Gordon Mines Limited

Sherritt Gordon Mines Limited began the production of nickel and copper concentrates from its Lynn Lake mine in October 1953 upon the completion of the 144-mile railway from Sherridon to Lynn Lake. The company's refinery at Fort Saskatchewan in Alberta was completed in June 1954. Scheduled annual output is as follows: 17,000,000 pounds of nickel, 9,000,000 pounds of copper, 300,000 pounds of cobalt, and 70,000 tons of by-product ammonium sulphate.(20)

The Lynn Lake property is in the Granville Lake area of northern Manitoba, 36 miles from the Manitoba-Saskatchewan border, and 120 air miles north of Sherridon. The deposit was discovered in 1941, but was not diamond drilled until 1945, when a substantial orebody was indicated. Subsequent magnetometer and electromagnetic surveys and extensive diamond drilling outlined seven main orebodies containing 14,055,000 tons of ore averaging 1.22 per cent nickel and 0.62 per cent copper.

The ore occurs as pipes of more or less massive sulphides in basic plugs. In cross-section, the pipes are generally elliptical and dip from 70° to vertical. The deposit is opened up by two shafts, the "A" mine 5-compartment shaft, completed to a depth of 1,627 feet, and the "EL" shaft, on which sinking was begun in July 1952, and at the end of 1953 had reached a depth of 1,000 feet.

The ore minerals are nickeliferous pyrrhotite and chalcopyrite, with minor amounts of cobalt.

The railway was built by the Canadian National Railways at an estimated cost of $14,725,000.

Power for the mine and mill and the townsite comes from a 7,000 h.p. hydro-electric power development constructed on the Laurie River, 44 miles south of Lynn Lake.

The initial capacity of the mill is 2,000 tons of ore per day; it produces a nickel concentrate and a copper concentrate. The former is hauled by rail to the company's refinery at Fort Saskatchewan, Alberta, for refining by the Forward ammonia pressure-leach process. The copper concentrate will be shipped initially to the Noranda smelter for treatment. Later it is planned to treat it at Fort Saskatchewan.

The Mystery Lake Deposits

These deposits are between the Manasan and Burntwood Rivers in Cross Lake Mining Division, some 35 air ailes north of Thicket Portage on the Hudson Bay Railway. Canadian Nickel Company, a subsidiary of International Nickel, is carrying on an extensive exploration and drilling program on its 91-claim property at Moak Lake. The deposits are of enormous size but the nickel content is low, ranging from 0.3 to 0.7 per cent. Technological advances in mining and metallurgy could readily make these deposits an important source of nickel. Adjacent to the Canadian Nickel property, Mystery Lake Mines Limited, in which Berens River Mines Limited holds an interest, is actively exploring and diamond drilling an interesting nickel-bearing serpentinized peridotite.(21)

Southeastern Manitoba

In the Maskwa River and Oiseau (Bird) River areas, Lac du Bonnet Mining Division, Southeastern Manitoba, occurrences of nickel have been known for many years. The deposits are replacement types in andesitic pillow lavas and beds of quartzose tuffs. The minerals are chalcopyrite, nickeliferous pyrrhotite, and pentlandite. Diamond drilling carried out prior to 1930 indicated 300,000 tons averaging 1.17 per cent nickel and 0.78 per cent copper on the Maskwa deposit, and 400,000 tons averaging 1.31 per cent nickel and 0.35 per cent copper on the Oiseau River deposit. Interest has been revived in these areas, and in 1951 Maskwa Nickel Chrome Mines Limited, a subsidiary of Falconbridge Nickel Mines Limited and

Ventures Limited, acquired a number of claims. The company has carried out electromagnetic and other geophysical surveys and diamond drilling, and plans further exploratory work, particularly in the Oiseau (Bird) River area. Some 1,350,000 tons of ore has been indicated.(22)

Other Occurrences

Other nickel occurrences are known in different sections of Manitoba. Some claims have been staked in the Clangula Lake-Bird River area, and showings of pyrrhotite, pentlandite, and chalcopyrite have been reported on English Brook, also in Rice Lake Mining Division. In the Lynn Lake area, God's Lake Gold Mines Limited is investigating a group of claims adjacent to the Sherritt Gordon property.

SASKATCHEWAN

Numerous nickel-copper occurrences have been reported in the northern part of the province and at least three have been investigated in the Lac la Ronge area. A magnetometer survey and diamond drilling program was carried out on the Hall property on the southeast shore of Rottenstone Lake by Cape Copper Mines Limited in 1952, and the Anglo-Rouyn Mines Limited is drilling the Maskwa group of claims, 15 miles northeast of Waden Bay. Several occurrences have been explored farther east near the Saskatchewan-Manitoba boundary. Among these, showings at Birch Lake indicate a mineralized zone of chalcopyrite and nickeliferous pyrrhotite 90 feet wide containing lenses of massive sulphides up to 10 feet in width. In the extreme north of the province, in the Goldfields area, the Achok group contains an elongated body of norite extending for at least 900 feet.(23) The norite has in part been brecciated and the sulphides, pyrrhotite, and minor amounts of chalcopyrite occur as cementing material in the breccia, as fracture fillings, and as disseminated replacements. The body is estimated to contain approximately 1,500,000 tons of low-grade ore with a nickel content varying up to 0.6 per cent.

BRITISH COLUMBIA

The B.C. Nickel Mines Ltd. property, now controlled by Western Nickel Limited, a jointly owned company of Pacific Nickel Mines Limited and Newmont Mining Corporation, New York, is between Stulkawhits and Emory creeks, seven miles by road from Choate on the Canadian Pacific Railway, about 100 miles east of Vancouver. (24)

The first discovery of nickeliferous pyrrhotite in this region was made in 1923. The deposits are found as masses of sulphides irregularly distributed in a hornblendite mass of late Mesozoic age. The massive bodies have up to 50 or 60 per cent sulphide and contain over 1.0 per cent nickel. The ore minerals are pyrrhotite, pentlandite, and chalcopyrite.

Up to 1931 active prospecting in the area resulted in the finding of a number of other showings. B.C. Nickel Mines Ltd., organized in 1929, carried out extensive development including some 94,000 feet of drilling. Up to 1936 two adits, No. 1 with a length of 4,629 feet and seven crosscuts totalling 7,145 feet, and No. 2 extending for 2,321 feet were driven into the mountain.

During 1936 and 1937, a total of 5,618 tons of development ore, including 475 tons of concentrate, was shipped to Japan. Operations ceased about this time and the mine never went into production. In 1938 Pacific Nickel Mines Limited acquired ownership of the property. In 1951, renewed interest was taken in the property and an exploratory program was inaugurated to locate additional ore reserves which in 1940 were estimated at over 1,000,000 tons averaging 1.39 per cent nickel and 0.5 per cent copper. Newmont Mining Corporation became associated with Pacific Nickel Mines Limited in this development, and the present company, Western Nickel Limited, was formed early in 1953.

Development work which was begun late in 1952 and which included the driving of a third adit, magnetometer surveys, and diamond drilling, revealed some additional ore. Continued exploration failed to disclose any further appreciable new ore, and work was discontinued in 1954.

YUKON

The first significant discovery of nickel in Yukon was made in 1952 in the Kluane Lake area in the southwestern portion of the Territory. The property, known as the Wellgreen is about 10 miles from the Alaska Highway at Mileage 1111.6 and is controlled by Hudson Bay Exploration and Development Company Limited. It comprises 538 mineral claims covering an area roughly three miles wide by 12 miles long. The deposits, which are of the replacement type, consist of massive sulphides in limestone and peridotite. The minerals are pyrrhotite, chalcopyrite, and pentlandite. By 1954, drilling had proved 500,000 tons of ore having an average grade of 2.14 per cent nickel, 1.34 per cent copper, 0.074 per cent cobalt, 0.049 ounces per ton of platinum, and 0.032 ounces per ton of palladium. The company is continuing to carry out exploratory work with encouraging results.(25)

Prospectors Airways Company, Limited holds a controlling interest in a nickel-copper prospect comprising 75 claims in the Quill Creek area, which adjoins the Hudson Bay property. The company also discovered a nickel-copper occurrence on White River, south of Lower Canyon on the Shakwak fault, about 40 miles from the Wellgreen property. The occurrence is in a sulphide zone, 500 feet wide, composed of disseminated sulphides with high-grade showings in pods of massive sulphides running up to widths of eight feet.

New Alger Mines Limited is exploring a 16-claim property adjacent to the Hudson Bay property in the Kluane Lake area.

NORTHWEST TERRITORIES

A deposit of nickel was discovered in 1928 on the western shore of Hudson Bay at Rankin Inlet.(26) The ore occurs as a body of massive and disseminated sulphides. Diamond drilling between 1930 and 1937 indicated some 150,000 tons of high-grade nickel ore but the deposit was considered too remote for commercial development. Rankin Inlet Nickel Mines Limited explored the deposit further in 1951 and staked additional claims. An extensive diamond drilling program carried out during 1952 brought the ore reserves up to 435,000 tons averaging 3.27 per cent nickel and 0.9 per cent copper, with values in platinum metals. Shaft sinking was commenced in 1952 and is to be continued to a depth of 300 feet with two levels. Complete mining equipment was delivered to the property during the summer of 1953.

Canadian Nickel Company Limited, a subsidiary of Inco, has made a discovery of nickel about 150 miles west of Rankin Inlet at Ferguson Lake.(27) The company holds an exploration concession covering 1,152 square miles and is carrying out diamond drilling and sampling operations to determine the extent and grade of the deposit.

Don Cameron Exploration Company Limited has done some exploratory work on nickel occurrence at Ennadai Lake in the Kazan River area, District of Keewatin.

An occurrence of nickel-cobalt-silver has been found on one of the Simpson Island Group, near the entrance to the east arm of Great Slave Lake. Goldcrest Mines Limited,which owns the property has diamond drilled the showing and carried out some surface exploration.

CHAPTER IV

MINING, MILLING, AND METALLURGY OF NICKEL IN CANADA

Mining

The methods employed in mining nickel ores in Canada range from open pit to practically all the accepted methods of underground mining. As the industry has grown and developed, mining methods have been adopted to meet changing conditions. The methods used by Inco have been written up in considerable detail (5) and various published articles provide a comprehensive picture of mining methods in the Sudbury area. Therefore, a brief outline only is given of mining practices followed in the Sudbury operations.

Open Pit - The first mining in the Sudbury district was done by open pit. The Frood open pit is now the only remaining operation of this type.

Shrinkage Stoping - This was adopted in most of the larger mines about 1917 and, with some modifications, is still in extensive use. It is the method used in the two independent mines, Nickel Offsets Limited, and East Rim Nickel Mines Limited.

Square-Set Mining - The square-set method is used in mining higher grade ore deposits where complete extraction of the ore is desirable; where the ore and walls require support during stoping; and where it is necessary to prevent caving and subsidence of the overlying ground.

Cut-and-Fill Mining - In this method, which is also used in mining higher grade ore, waste rock or other material is used to fill the excavated areas as stoping proceeds. The stoping varies little from the standard square-set-and-fill methods.

Induced Caving - This costs less than any other underground method, but is essentially applicable to large-scale operations only. The ore is undercut on the bottom of the stope area and the vertical sides of the stope block become so weakened that the mass of ore is caused to cave and to disintegrate by its own weight. The weight of the moving mass of ore provides the breaking force usually attained by the use of explosives.

Blast-Hole Mining - This also is a low-cost bulk method of mining, resembling induced caving, except that explosives are used to break the ore initially. It is used largely at the underground Frood section of the Frood-Stobie mine.

Milling

The milling and concentrating of sulphide nickel-copper ores generally follow the normal pattern for treating such ores. Various types of ore are found in the numerous mines of the Sudbury area, including disseminated ore, massive sulphides, breccia ore, and high-copper ore. In all, however, the principal minerals are pyrrhotite, chalcopyrite, and pentlandite (iron and nickel sulphide). Cubanite, bornite, nicolite, maucherite, sperrylite, gersdorffite, and violarite occur in minor amounts in certain of the deposits. The proportions of the principal minerals vary for the different types of ore and for each mine. As it is essential to maintain a fairly uniform mill feed, the selective mining of the different types of ore is an important consideration.

The maintenance of a reasonably close control on uniformity of mill feed, with an output of more than 40,000 tons of ore per day from a number of separate and distinct mines, as carried out by International Nickel Company, is an accomplishment requiring a high degree of co-ordinated control.

Some differences exist between the milling practices of Inco and Falconbridge Nickel Mines. These will be dealt with in the brief notes on the respective companies.

The daily milling capacity of Inco's mills and concentrators is about 42,000 tons, of which 30,000 tons is the capacity of the Copper Cliff mill and 12,000 tons of the Creighton.

The ore is crushed at the mines to a maximum size of six inches and conveyed by rail to Copper Cliff, except in the case of the Creighton mine, where the ore is milled in the new concentrator completed in 1951.

The ore is screened to give a coarse product for primary crusher feed and a fines product. The coarse product is fed to four seven-foot standard Symons cone crushers set at $\frac{3}{4}$-inch to 7/8-inch openings. The product from the crushers is delivered to surge bins above five seven-foot Symons shorthead cone crushers set at $\frac{1}{4}$-inch. The product from these intermediate crushers and the fines product are screened and the oversize is given a final crushing on five sets of 78 by 18-inch Traylor rolls. All crushing is carried out dry.

The crushed ore is conveyed to storage bins in the grinding section, which contains 34 Marcy mills. There are 17 grinding units, each consisting of a Marcy rod mill, a Marcy ball mill, and a Dorr FX classifier in closed circuit. The classifier overflow is laundered to sumps for distribution to the flotation circuits.

A bulk rougher concentrate and the final copper and nickel concentrates derived from it are made in 20-foot MacIntosh (Geco) pneumatic cells. The tailings receive a scavenger treatment in a bank of No. 30 Denver cells. The concentrates are thickened and filtered in one Oliver type and 11 Dorrco filters. The filtered concentrates are conveyed to the copper smelting and nickel smelting operations respectively. Treatment of these is discussed under the section on metallurgy.

Operations at the Creighton mill are similar to those at Copper Cliff except that in the flotation circuit a bulk concentrate only is made. This bulk concentrate is piped seven and one-half miles to Copper Cliff, where it joins the bulk concentrate from the primary flotation prior to the separation into copper and nickel concentrates.

The milling of Falconbridge ore includes an additional step in the crushing operation. The broken ore received from the mine is crushed, screened, and magnetically concentrated. The larger sizes of the magnetic concentrate go directly to the blast furnaces. The non-magnetic product is ground in a rod mill and five ball mills, each in closed circuit with classifiers. The final grind is approximately 70 per cent minus 200-mesh. The classifier overflow goes to the flotation section where a bulk concentrate is made. This concentrate, together with the magnetic fines, is conveyed to the roasting plant and subsequent smelting.

Metallurgy

In the early stages of nickel production the processes for separating the nickel from the copper were tedious and costly. It was not until 1890, when the Orford process was developed, followed a few years later by the Mond process, that economic methods of nickel production were established. Up to 1948 International Nickel Company employed the Orford process but since 1948 it has used a modification of this process. The Mond process is still employed in the United Kingdom. The Hybinette electrolytic process began commercial operation in 1910 in Norway. When Falconbridge Nickel Mines Limited was incorporated in 1928, the Hybinette plant was acquired and this process was adopted for the treatment of Falconbridge matte. The Sherritt Gordon operations employ the Forward ammonia leaching process. Although the Orford process has been replaced, a short description follows along with a brief account of the four processes used in producing Canadian nickel.

The International Nickel Company of Canada Limited

Orford Process(5)

The nickel concentrates, brought to a moisture content of not over 11 per cent, are conveyed to the roasting plant, where they are charged into 42 Nickols-Herreshoff roasting furnaces. These furnaces each have 10 internal hearths and one top drying hearth. The rabble arms are air-cooled. The maximum roasting temperature is 1440°F. The discharge from six roasting furnaces provides the charge for each of the seven reverberatory furnaces. The reverberatory furnaces have suspended unburned chemically bonded magnesite brick roofs and are fired with pulverized coal. The molten matte from the reverberatory furnaces is conveyed in ladles to the 19 Pierce-Smith converters, where it is blown to remove practically all the iron. The converter matte contains about 75 per cent combined nickel and copper, the balance being sulphur and less than one per cent iron.

The separation of the copper and nickel sulphides is based on treating the matte with sodium sulphide in a converter. At a temperature of 2000°F. copper sulphide is very soluble in sodium sulphide while nickel sulphide is only slightly soluble. When a molten mixture of the three sulphides is allowed to stand, a separation takes place owing to the difference in their specific gravities. As cooling proceeds, dissolved nickel sulphide separates out owing to its decreasing solubility in sodium sulphide. The material is cooled and allowed to solidify in large cast-iron pots; two layers are formed, the upper of copper-sodium sulphide, called "tops", and the lower of nickel sulphide, called "bottoms". Some copper sulphide remains in the first "bottoms" and a second treatment is necessary. The second treatment is carried out in cupolas, the charge consisting of first bottoms, sodium sulphate, coke, and limestone. The second tops and bottoms are separated after cooling as in the first treatment. The second bottoms, which contain 72 per cent nickel and from two to three per cent copper, are processed for the recovery of nickel either as oxide or metal. The nickel sulphide is roasted to remove sulphur, and the resultant oxide is reduced with coke in reverberatory-type anode furnaces. The cast anodes are then electrolytically refined.

The second tops, with about 20 per cent copper and four per cent nickel, are used as the fluxing agent for the first treatment.

The first tops are treated in converters to oxidize the sodium sulphide to sodium sulphate, which floats to the surface and is poured off and used in the second treatment, while the copper sulphide settles to the bottom of the converter. This is poured off and subsequently treated in acid converters to produce blister copper, which is transferred molten in "hot metal cars" to the copper refinery.

Modification of the Orford Process

The new process, which replaced the Orford process in 1948, differs very little up to the bessemerizing point.(28) From this stage, however, a very definite improvement in metallurgical practice has been achieved. Instead of bessemerizing to an all-sulphide matte, the charge is blown to a point where approximately 15 per cent is in the form of a copper-nickel alloy, and 85 per cent is present as combined nickel and copper sulphides. The combined alloy-matte is poured into moulds and allowed to cool slowly under carefully controlled conditions for a period of up to 15 days. During this cooling period the cast material crystallizes into three separate phases: a copper-nickel alloy containing approximately 95 per cent of the platinum metals, gold, etc.; copper sulphide containing about one per cent of nickel; and nickel sulphide containing about one per cent of copper. Each phase solidifies in crystals capable of separation. The cakes are removed from the moulds after cooling and broken up in a specially designed machine to a size suitable for crushing. The crushed material is ground to pass a 325-mesh screen. It is first treated by magnetic separation to remove the copper-nickel alloy. The magnetic material is dissolved and electrolyzed and the precious metals are recovered from the slimes. The non-magnetic copper and nickel sulphides are treated by flotation to separate the two sulphides. The copper product is filtered and then smelted in electric furnaces the molten sulphide from which is treated in three acid-lined converters. The blister copper is conveyed molten in "hot metal cars" by rail to the copper refinery.

The nickel product is conveyed as a pulp to the sinter building, where it is filtered, mixed with a small amount of coke, and roasted on five Dwight Lloyd sintering machines. The discharged sinter is cooled, crushed, and screened to the required size. A certain amount of the nickel oxide sinter is shipped directly to steel works where it may be added to the steel furnaces without further refining. The greater proportion is shipped to the Port Colborne refinery for conversion to nickel anodes which are refined electrolytically to high purity nickel.

Nickel Refining

Numerous changes have been effected in the refining process since the beginning of operations at the Port Colborne refinery in 1918.(5) The following is a brief description of the present process.

Nickel oxide sinter is received in box-cars from the Copper Cliff smelter. The sinter is stored in large bins from which it is conveyed by a belt to a mixing drum where the required amount of petroleum coke is added. The sinter-coke mixture is then charged to three reverberatory furnaces, two with a capacity of 200 tons and one of 175 tons. The furnaces are oil-fired and attain a temperature of about 2850°F. The reduced nickel is cast as anodes in copper moulds on circular casting machines. Each anode weighs about 500 pounds and has a nickel content of approximately 95 per cent.

The electrolytic tank house is divided into two sections, No. 1 containing 852 cells, and No. 2 containing 780 cells.

Electrolytic refining has two functions - the recovery of high-purity nickel and of the precious metals, platinum, gold, etc., as anode slimes. The fact that nickel occupies a relatively high position in the electromotive series, requiring a high cathode potential for electro-deposition, raises a number of problems in the refining operation. Cations of copper are more readily reduced at the cathode than nickel, and cations of elements such as iron and cobalt are readily deposited with nickel. To overcome these difficulties the cathode is suspended in a canvas-covered compartment into which purified nickel electrolyte is constantly flowing from a header along the side of each cell. The canvas is a tightly woven grade so that a hydrostatic head is maintained in the cathode compartments to ensure a constant flow of electrolyte through the canvas at a velocity sufficient to carry away the copper and iron ions released from the dissolving anode, thus preventing them from migrating to the cathode. The nickel ions set free at the anode also flow along with the copper and iron in the foul electrolyte which is piped from the bottom of the tanks to the purification system. When purified of copper, iron and cobalt, this solution is returned as the cathode compartment feed referred to above. This electrolyte is a mixture of nickel sulphate and nickel chloride containing 60 grams of nickel per litre. It is maintained at a pH of 4.0 and at a temperature of 132°F. The current density is 16 amperes per square foot at a voltage of 2.2 volts.

The anodes remain in the cells for 32 days. Cathodes are removed every 10 days and weigh about 135 pounds. The starting sheets are prepared by plating a thin sheet of nickel on stainless steel cathodes; about two days' deposition is required to give the required thickness.

The purification of the electrolyte consists in the removal of copper, iron, and cobalt. The first step is the removal of copper by cementation on fine grain nickel. The copper precipitates out in metallic form and the nickel goes into solution. This operation is carried out in a series of Pachuca tanks. The copper-free solution is vigorously aerated to oxidize the iron which is precipitated as a hydrate. After filtration the solution is treated with nickel carbonate and chlorine for the removal of cobalt in the form of a crude oxide. This is subsequently treated and refined to cobalt salts at the Mond refinery at Clydach, Wales. The purified solution is adjusted to the required nickel content and pH, and returned to the cathode compartments of the electro-refining cells.

The grain nickel used in the copper cementation is prepared from nickel sulphide concentrate which is remelted, cast, broken up, ground and roasted to oxide. The oxide is reduced with water gas at a

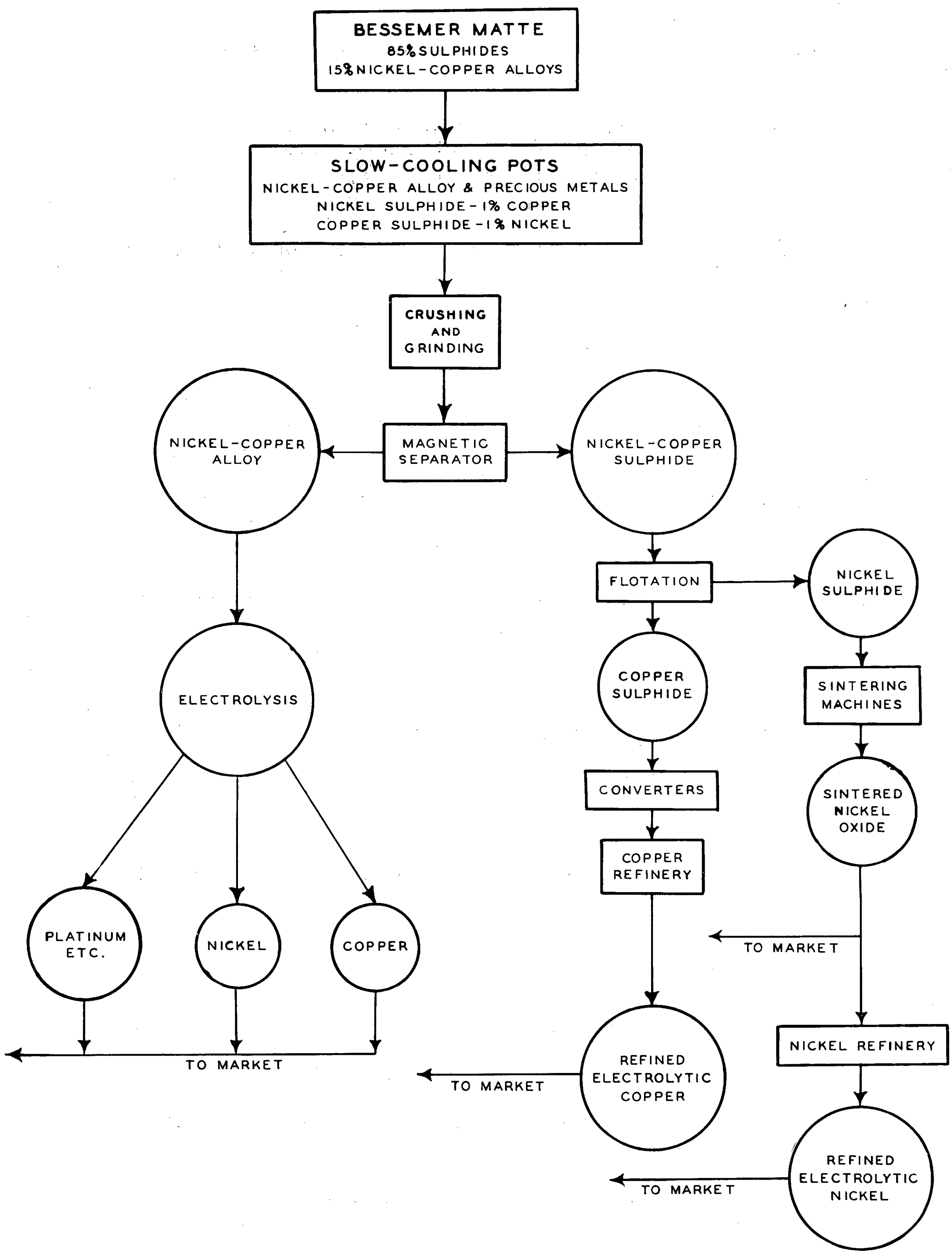


FIGURE I. MATTE FLOTATION PROCESS

temperature of about 750°F. in multiple deck furnaces. The oxide enters at the top and drops from hearth to hearth against a rising current of water gas which reduces the nickel oxide to metal.

The anode sludge, which contains the metals of the platinum group, gold, silver, and some nickel, copper, and iron, is removed from the spent anodes. At regular intervals the anode slimes are also cleaned out of the tanks. The sludge is roasted in a calcining furnace and smelted in an electric furnace. After fire-refining the metal is cast into anodes. The secondary anodes are returned to the tank house for electro-refining and the resulting anode sludge is the precious metals product which, after preliminary treatment at Copper Cliff, is shipped to International Nickel Company's precious metals refinery at Acton, England.

Mond Process(5)

The Mond process of separating nickel and copper and producing refined nickel is employed at the Mond Nickel plant of International Nickel Company at Clydach, Wales. It is based on the fact that nickel forms a gas, nickel carbonyl ($Ni(CO)_4$), with carbon monoxide at 50°C. to 80°C. At a temperature of 150°C. or higher, the gas is completely decomposed into nickel and carbon monoxide. The process has remained virtually unchanged since it was first devised. Basically, it comprises five steps:

Roasting to drive off the maximum amount of sulphur and fully oxidize the metallics in the matte or sinter.

Extraction of the major portion of copper by leaching with weak sulphuric acid.

Reduction of the oxides in the leached calcine to the metallic state.

Volatilization of the reduced nickel as nickel carbonyl.

Decomposition of nickel carbonyl to produce pure nickel and liberate the carbon monoxide.

The ground matte is roasted in single-deck, rotary-hearth, calciners at a working temperature of about 800°C. The discharged calcine has a sulphide content of 0.3 to 0.5 per cent.

The resulting calcines are leached with 10 per cent sulphuric acid, which removes up to 70 per cent of the copper. In current operations the matte is low in copper, around 2.5 per cent, and the leaching operation is not employed.

Reduction of the oxide is carried out in vertical towers provided with shelves. Mechanical rabbles stir the oxides and cause them to descend from shelf to shelf. The shelves are heated with hot flue gases to a temperature of from 380°C to 400°C. A rising current of water-gas containing approximately 52 per cent hydrogen effects the reduction of the nickel.

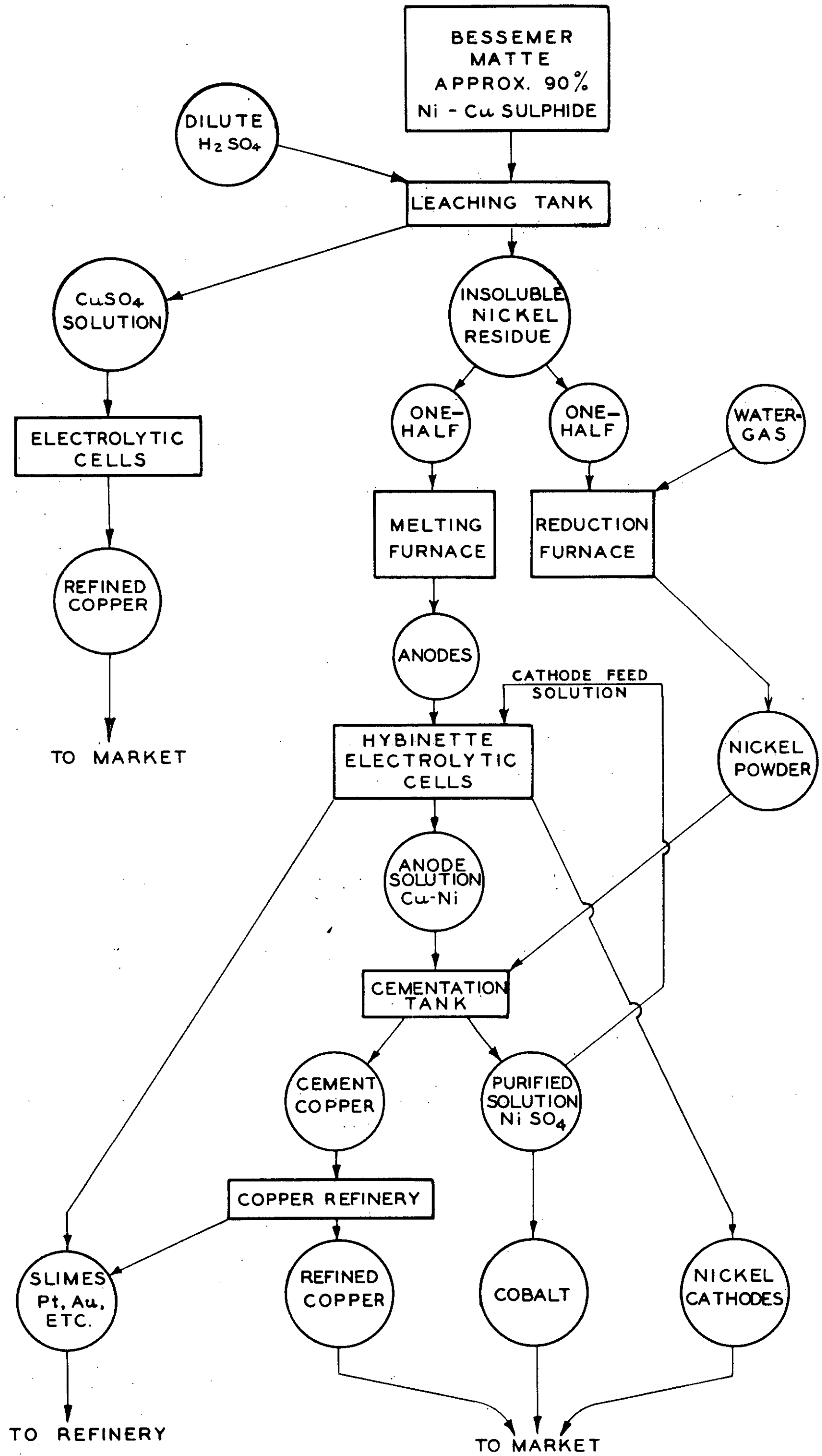


FIGURE 2. HYBINETTE PROCESS

The reduced nickel residue is conveyed by airtight conveyors to the top of the volatilization towers, which are similar to the reduction towers. The charge is rabbled from shelf to shelf against a rising current of producer gas (carbon monoxide). A temperature of 50°C to 80°C is maintained in the production of nickel carbonyl, which is blown to the decomposers as it is formed. The solid material is returned to the reducers and then again to the volatilizers, continuing to circulate between the two operations for from 7 to 15 days, until about 70 per cent of the nickel has been removed.

In the decomposing tower, the carbonyl gas comes into contact with nickel pellets at a temperature of 180°C. At this temperature the gas decomposes, the nickel is deposited on the pellets, and the carbon monoxide is liberated. The latter is returned to the volatilizer to form fresh nickel carbonyl. To prevent the granules from cohering they are kept slowly moving by withdrawing a small number from the bottom of the tower by means of a worm conveyor. The pellets are screened and the small pellets are returned to the top of the tower. It takes about two months to produce a pellet 1/8-inch in diameter.

Falconbridge Nickel Mines Limited

Hybinette Process

The smelting process employed by Falconbridge Nickel Mines differs somewhat from that of International Nickel Company.(28) The bulk concentrate is mixed with fine ore and roasted on Dwight Lloyd sintering machines. The resulting sinter is smelted in three blast furnaces. Molten blast furnace matte is transferred to four Pierce-Smith converters for removal of iron.

The Bessemer matte, containing about 50 per cent nickel and 30 per cent copper is shipped to the company's refinery at Kristiansand, Norway, for final treatment by a modified Hybinette process. The matte is crushed, ground, and roasted in Herreshoff furnaces, under such conditions as to minimize solubility of nickel and promote solubility of copper in acid electrolyte. Most of the copper is dissolved out in this way and the resulting solution is electrolyzed for the recovery of copper. Some nickel sulphate is recovered from the copper plant electrolyte by evaporation and crystallization.

The residue, which contains most of the nickel and analyzes about 12 per cent copper, is divided into two parts. The main part is melted and cast into anodes, the other is treated with water-gas in a muffle-type multiple hearth furnace to reduce the nickel to metallic form. The gas-reduced nickel is used to purify the solution of copper, and after removal of iron and other impurities, the purified nickel electrolyte is fed to the cathode compartments of the Hybinette cells. Electrolytic deposition of nickel is carried out in general as in the method already described under nickel refining, but recently the treatment was modified to provide for use of chloride electrolyte so that cobalt is now separated and produced in a further step as electrolyte cobalt.

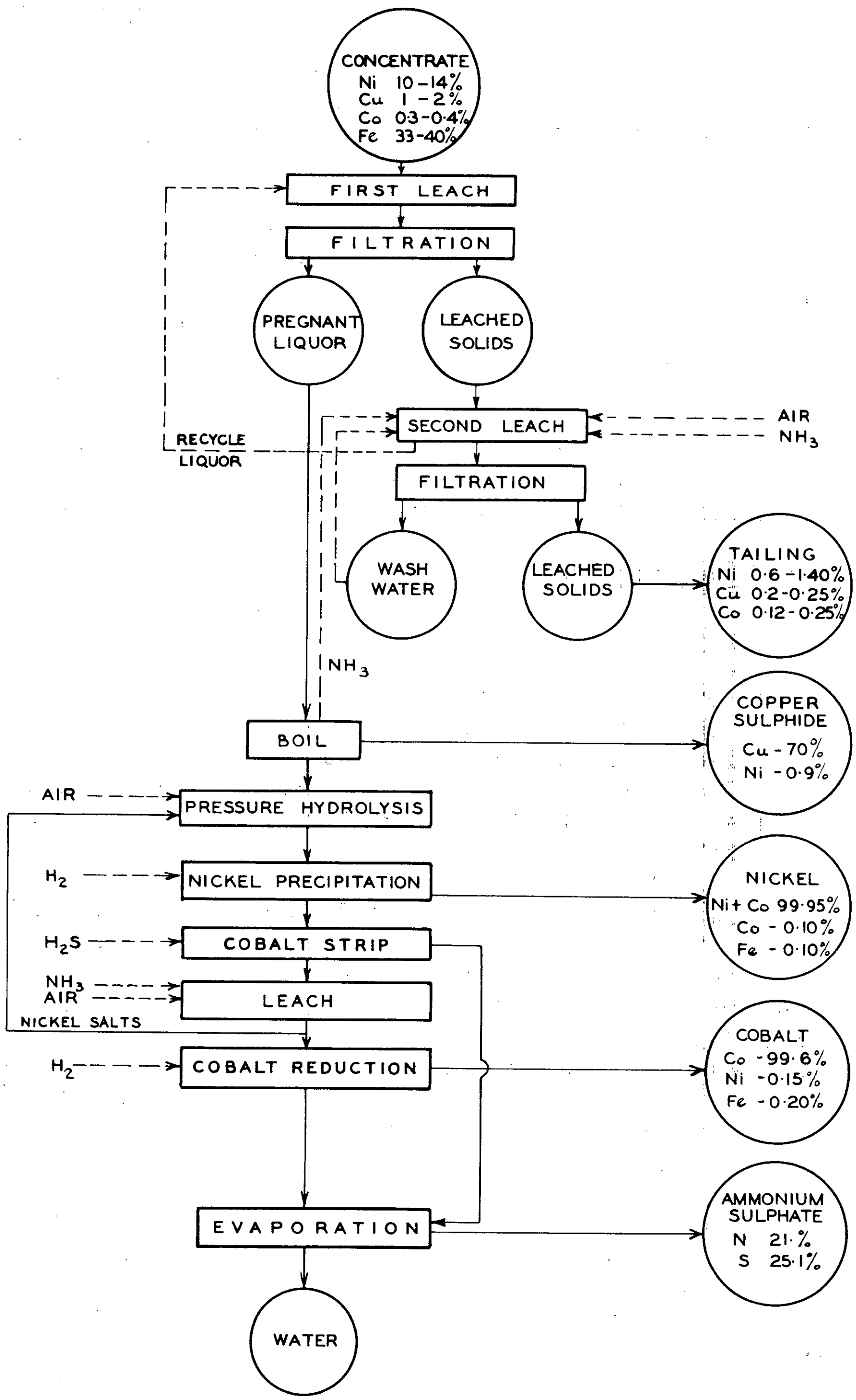


FIGURE 3. FLOW SHEET OF PROCESS USED BY SHERRITT GORDON MINES, LIMITED, FORT SASKATCHEWAN, ALBERTA.

Sherritt Gordon Mines Limited

Ammonia Pressure Leach Process(29)

The process used by Sherritt Gordon Mines in the treatment of its Lynn Lake nickel-copper ore for the concentration, extraction, and recovery of the metals is a radical departure from the usual practice of treating sulphide ores. After selective flotation of the ore to yield a copper-sulphide concentrate and a nickel-iron sulphide concentrate containing some copper and a small amount of cobalt, the process is basically chemical.

The nickel-copper-cobalt-iron sulphide concentrates are leached under pressure in stainless steel autoclaves with air and aqueous ammonia to dissolve the nickel, copper, cobalt, and most of the sulphur, leaving the iron and other impurities in the tailings. The copper is first removed from the solution as a sulphide by boiling, the nickel is then precipitated by hydrogen under pressure, the cobalt is then removed by treatment with hydrogen sulphide and the end solutions are evaporated to produce ammonium sulphate.(29)

Leaching

The operations are carried out at temperatures between 150°F and 220°F under total pressures of less than 125 pounds per square inch. A number of reactions take place in sequence and not necessarily at the same rate. The principal are presumed to be:

The sulphide mineral reacts with ammonia, oxygen, and water to produce metal ammines, hydrated ferric oxide, and ammonium thiosulphate:

Ammonium thiosulphate reacts with dissolved oxygen to produce ammonium sulphate and ammonium trithionate:

Ammonium trithionate is further oxidized by dissolved oxygen to produce additional ammonium sulphate and ammonium sulphamate.

The end products are a solid residue that includes hydrated iron oxide and a solution that contains dissolved metal ammines, ammonium sulphate, and ammonium sulphamate. Continuous operation is carried out by a two-stage counter-current leach. In the first stage fresh concentrate and recycle liquor are fed to a compartmented autoclave. After sufficient retention time the pulp is filtered and the partly leached solids are mixed with fresh ammonia solution and charged to a second autoclave. Here the reactions proceed until leaching is complete. The pulp is thickened and the ferric hydrate and insoluble tailings are removed by filtration.

Copper Recovery

The pregnant solution is boiled in a continuous still to remove some of the excess ammonia, which is recovered as high-strength aqua ammonia, and returned to the leaching circuit. As the free ammonia decreases, the thiosulphate and trithionate compounds decompose, resulting in the precipitation of copper sulphide.

Pressure Hydrolysis

The solution left after filtering off the copper sulphide contains small amounts of thionate, thiosulphate, and sulphamate compounds that must be removed before the nickel is recovered. This is effected by heating the solution under pressure in the presence of air, which oxidizes the thionate and thiosulphate to sulphate and at the elevated temperature hydrolyzes the sulphamate to ammonium sulphate. Trace impurities are also hydrolyzed and removed by filtration.

Hydrogen Reduction

The precipitation of the nickel is carried out in pressure tanks by agitating the solution with hydrogen within a temperature range of 200°F to 400°F, and at pressures as high as 900 pounds per square inch. As nickel salts react with hydrogen more readily and under more moderate conditions than cobalt salts, it is possible to precipitate the nickel and leave the cobalt in the solution for subsequent hydrogen treatment and recovery.

The nickel is precipitated as spherical particles ranging between 50 and 80 microns in diameter.

Ammonium Sulphate

The final solution is evaporated to produce high-purity ammonium sulphate.

General

The total leaching time is less than 24 hours, while the subsequent operations take from one to two hours each.

In the investigations carried out on the process a concentrate of the following composition appears to give the best economic returns:

Nickel	10-14 per cent
Copper	1-2 " "
Cobalt	0.3-0.4 " "
Iron	33-40 " "
Sulphur	28-34 " "
Insoluble	8-14 " "
Precious metals - less than	.02 ounces per ton

From such a nickel concentrate the following recoveries are made:

Nickel	90-95 per cent
Copper	88-92 " "
Cobalt	50-75 " "
Sulphur	60-75 " "

The nickel powder has a purity of 99.95 per cent with an iron, sulphur, and copper content of 0.01 per cent each.

CHAPTER V

WORLD RESOURCES

The nickel ores that constitute the major sources of the metal fall into three principal classes: sulphide ores, silicates or oxidized ores, and nickeliferous iron ores. Arsenical ores, usually containing both nickel and cobalt, account for only a small production.

Nickel occurs in greater amount than copper as a constituent of the earth's crust, the proportions being approximately 0.020 and 0.010 respectively. It is less amenable, however, than copper to the action of the natural agencies that tend to concentrate the element into workable deposits, and consequently economic deposits of nickel are far less numerous than those of copper.

Sulphide Ores

The largest reserves of developed sulphide ores of nickel are those of the Sudbury district of Ontario. Next in relative importance are the Lynn Lake deposits of Manitoba, the Karelo-Finnish Petsamo deposits of Russia and the Merensky Reef deposits (30) of South Africa. Potential sulphide deposits in Canada have been covered in Chapter III - Canadian Nickel Occurrences. World potential reserves of sulphide ores apart from the developed deposits are not large, but the possibility of new discoveries of ore of economic grade in Canada and South Africa is favourable.

Alaska

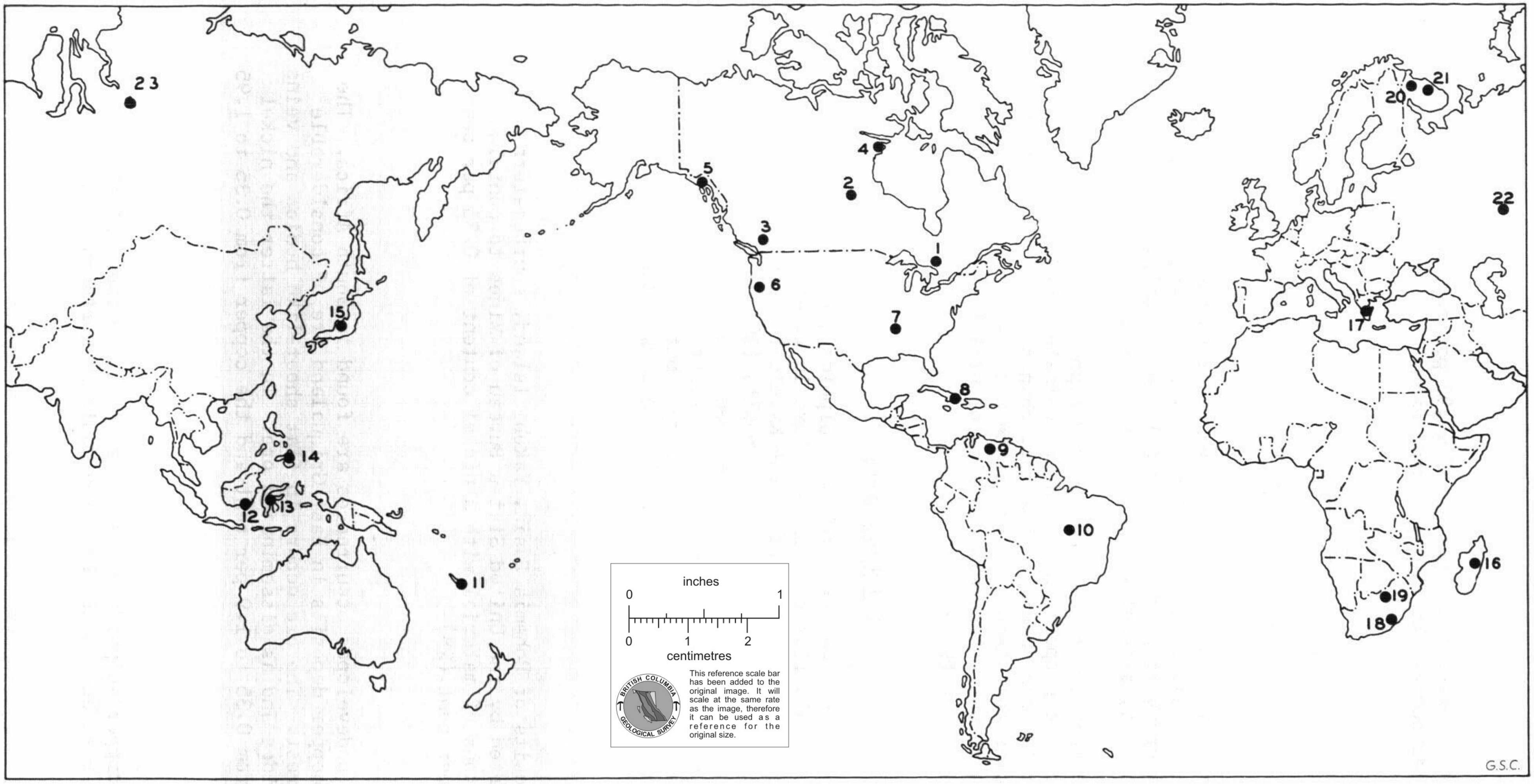
The deposits of Bohemia Basin, Yakobi Island, southeastern Alaska, are reported by the United States Bureau of Mines to contain over 10,000,000 tons of material with a nickel content of 0.36 per cent and copper 0.27 per cent.(28)

South Africa

Several undeveloped occurrences are found in South Africa. The magmatic nickel-copper deposits in East Griqualand are of considerable prospective interest. The ore occurs in flat sheet-like bodies and veins of massive sulphides and as disseminated ore. In the latter the nickel content ranges from 0.35 to 1.9 per cent and the copper from 0.35 to 1.95 per cent.(31)

Russia

Nickel-copper sulphide deposits are known in the Norilsk area of northwestern Siberia, and in the Kola Peninsula in northern Russia.(28)



1. CANADA - SUDBURY AREA.
2. CANADA - LYNN LAKE.
3. CANADA - WESTERN NICKEL.
4. CANADA - RANKIN INLET.
5. ALASKA - YAKOBI ISLAND.
6. UNITED STATES - RIDDLE, OREGON.
7. UNITED STATES - FREDERICKTOWN, MISSOURI.
8. CUBA - LEVISA BAY AND MOA BAY.
9. VENEZUELA - LOMA DE HIERRO.
10. BRAZIL - SAO JOSE DO TOCANTINS.
11. NEW CALEDONIA.
12. BORNEO - SELUKU.
13. CELEBES - LARONA.
14. PHILIPPINES - SURIGAO.
15. JAPAN - HONSHU ISLAND.
16. MADAGASCAR - NICKELVILLE.
17. GREECE - ATALANTE - LARYMNA.
18. UNION OF SOUTH AFRICA - MERENSKY REEF.
19. UNION OF SOUTH AFRICA - GRIQUALAND EAST.
20. RUSSIA - PETSAMO.
21. RUSSIA - KOLA PENINSULA.
22. RUSSIA - CENTRAL AND SOUTHERN URALS.
23. RUSSIA - NORILSK

MAP 3. PRINCIPAL WORLD OCCURRENCES OF NICKEL

Norway

A number of relatively small, low-grade deposits have been explored and worked in Norway. Norway controlled the nickel market during the period 1870-77, prior to the development of the New Caledonia deposits.(28)

Philippines

A nickel-platinum deposit has been discovered in west-central Luzon, Philippine Islands, on which drilling has indicated a reserve of from 200,000 tons to 250,000 tons averaging 1.5 per cent nickel.(28)

United States

A complex lead-copper-nickel-cobalt deposit occurs at Fredericktown, in the lead district of southeastern Missouri. A plant has been erected to treat the ore, and an annual output of about 900 tons of nickel is expected. Measured and indicated ore reserves are reported as 1,775,000 tons averaging 2.3 per cent lead, 1.4 copper, 0.28 cobalt, and 0.46 nickel.(28)

Nickel Silicate and Oxidized Ores

Prior to 1905, nickel silicate ores were the world's principal source of nickel, the deposits of New Caledonia containing the largest known reserves. The figures for silicate ore reserves are in general less accurate than those available for the larger sulphide deposits, but the nickel content of the world reserves of these ores, grading about three per cent nickel in selected and sorted ore, is estimated to equal or exceed that of the larger, developed sulphide deposits.

New Caledonia

Nickel was discovered in New Caledonia in 1865, but the economic development of the deposits did not begin until 1875. New Caledonia was the leading producer of nickel until 1905, when Canadian production took the lead. La Societe le Nickel controls the principal deposits of the island. The ore, garnierite, occurs as a hydrated silicate of nickel and magnesia. The sorted or selected ore is currently maintained at a grade of about 3.5 per cent. Mining is by open-pit methods. Production of ore increased from 138,000 metric tons in 1950 to 373,000 metric tons in 1952. Published figures on reserves or grade are not available but the company reports that the reserves are adequate to maintain an annual output of 12,000 metric tons of metallic nickel for 80 years.(32)

United States

A nickel silicate deposit is under development by the M.A. Hanna Company at Riddle, Douglas county, Oregon. The deposit occurs in flat-lying beds under a layer of topsoil. Drilling has indicated beds containing over 6,000,000 tons of ore grading one to two per cent nickel. Plans call for a minimum production of 95,000,000 pounds of nickel in the form of a ferro-nickel alloy with a 25 per cent nickel content. Open-pit mining will be employed. (28)

Brazil

A number of nickel silicate deposits are found in Brazil. In the State of Goias, some 50 deposits occur in a 14-square-mile-area north of Sao Jose do Tocantins. The district as a whole is estimated to contain as much as 16,000,000 tons of ore averaging between one and three per cent nickel. The ore beds are from 10 to 60 feet deep with an overburden ranging from a few feet to 15 or 20 feet. The deposits are discontinuous.

Small deposits have been mined and smelted in the Minas Geraes region. At Livramento there is a probable reserve of 250,000 tons and a possible reserve of 2,000,000 tons with a nickel content of 1.5 per cent. In the same region at Ipanema, deposits contain about 200,000 tons of ore grading one to two per cent nickel, and 2,000,000 tons of possible ore of the same grade.(28)

Venezuela

Large low-grade nickel silicate deposits have been explored at Loma de Hierro. International Nickel Company has sampled an area 10 to 12 miles long and more than half a mile wide. Details of ore reserves have not been published, but it is reported that reserves exceed 30,000,000 tons containing about 1.75 per cent nickel. The deposits lie in beds of clayey weathered material 30 to 100 feet thick. The material is reported to carry a little cobalt and manganese. The beds lend themselves to mechanized mining by open-pit methods but ore is too low grade to be treated economically by current smelting practices.(28)

Russia

The reserves of nickel silicate ore in the central and southern Urals are extensive and comprise a large part of Russia's nickel reserves. The deposits are associated with weathered peridotite and serpentine. The Khalilovo deposit in the southern Urals was reported in 1933 to have a reserve of 15,600,000 metric tons containing 1.54 per cent nickel. The neighbouring Aktyubinsk deposit is smaller and of lower grade, containing 14,000,000 metric tons with 0.72 per cent nickel. The deposits in the central Urals are considerably smaller.(28)

Greece

Garnierite deposits, from which some production has been obtained at different periods, occur in the Atalante-Larymna district of Greece. Deposits of nickeliferous iron also occur in the same region. The German firm of Krupp has recently constructed ore dressing and metallurgical plants capable of treating 130,000 tons of nickel ore annually and operations were resumed in 1955. The reserve of silicate ore is reported to be 500,000 tons averaging 2.5 per cent nickel.(28)

Celebes

Several deposits of nickel silicate ore occur on the island of Celebes, the two principal regions both being on the eastern side of the Gulf of Bone in the southeastern part of the island. Geological conditions indicate a probable reserve of about 2,000,000 tons containing three per cent nickel, and a possible reserve in excess of 10,000,000 tons grading between one and three per cent. The ore bodies are irregular, occurring locally as earthy masses. Other favourable prospects are known in the districts of Soroaka and Balang.(28)

Madagascar

Small deposits of garnierite ore of fair grade are found in the Nickelville district, Alaotra region of Madagascar. The ores are associated with partly serpentinized rocks. Reserves are estimated at 900,000 tons containing 4.2 to 8.5 per cent nickel. The nickel in the serpentine and talc material is not considered recoverable, although the content is fairly high.(28)

Tanganyika

A deposit of garnierite and nepouite at Kabulwanyele, Tanganyika, is reported to contain about 5,000,000 inferred tons of nickel ore carrying up to 0.72 per cent nickel. Investigations aimed at developing the deposits were carried out shortly after the end of World War II, but the results do not appear to have been favourable.(33, 34)

Nickeliferous Iron Ores

Nickeliferous iron ores constitute the world's largest potential source of nickel, but the low nickel content and the refractory nature of the ores has limited their development to a few isolated cases. The average nickel content ranges from a little above to a little below 1.0 per cent. Treatment methods to recover the nickel are relatively costly.

Some of the largest deposits of this type of ore are found in Cuba, while immense deposits comprising hundreds of millions of tons are known to occur in the Philippines, Celebes, and parts of Borneo. Smaller and lower-grade deposits are found in Greece, U.S.S.R., Japan, and several other localities.

Cuba

Extensive deposits of low-grade nickeliferous iron ore occur in Oriente and Camaguey provinces on the northeastern coast of Cuba. The ores have been formed through the weathering of basic rock, now represented by serpentine. The Nicaro deposits, Mayari district, consist of three indistinct layers. The upper or surface layer, four to eight feet thick, is a red hematitic ore containing an average of about 0.8 per cent nickel and 49 per cent iron. The middle layer, eight to twelve feet thick, consists of yellow to yellowish brown limonitic ore containing about 1.3 per cent nickel and a little over 50 per cent iron. The bottom layer is composed of disintegrated serpentine and has a thickness of from two to ten feet. It contains about 1.6 per cent nickel and 22 per cent iron. This mode of occurrence is typical of the deposits found in the three major districts Mayari, Moa, and San Felipe. The total reserves of nickeliferous iron ore in these districts are estimated at about 3,000,000,000 tons, but no estimates of recoverable nickel have yet been made.

The Nicaro Nickel Company developed the deposits in the vicinity of Levisa Bay during World War II. About 31,000,000 tons of lateritic ore containing 1.45 per cent nickel was outlined. Production in the form of nickel oxide began in 1943 and continued until 1947, during which period 34,463 tons of nickel was produced. Difficulty was encountered in treating the serpentine ore and it was necessary to use a proportion of the middle layer ore. As a result the over-all reserves were reduced to 24,000,000 tons grading 1.45 per cent nickel. Operations were resumed in 1952 with a projected annual output of 30,000,000 pounds of contained nickel.

In April, 1953 Freeport Sulphur Company announced the location of a large nickeliferous iron orebody amenable to treatment in the vicinity of Moa Bay. Extensive exploration has indicated 40,000,000 tons of ore averaging 1.35 per cent nickel and 0.14 per cent cobalt. The company proposes to erect a plant with an initial output of 30,000,000 pounds of nickel annually.(28)

Greece

A reserve of nearly 10,000,000 tons of lateritic iron ore reported to contain about one per cent nickel is found in the Atalante-Larymna district. Renewed activity in this area has already been referred to in the section under silicate ores.(28)

Russia

Complex ferro-nickel and iron-nickel-cobalt ores which appear to correspond to low-grade nickeliferous iron deposits elsewhere are found in the central and southern Ural Mountains. No estimate of the reserves is available.(28)

Celebes and Borneo

Large deposits of nickeliferous iron ores have been prospected in these islands. In Celebes about 10 ore fields have been discovered in the mountainous country in the southeastern interior part of the island. The most important field is the Larona, where proved ore reserves amount to 370,000,000 tons averaging 49 per cent iron with an indicated nickel content of about 0.9 per cent.

Southeastern Borneo has large deposits of lateritic nickeliferous iron ore, the largest of these being on the Island of Seluku. Reserves have been estimated at about 500,000,000 tons with a nickel content reportedly averaging 0.66 per cent.(28)

Japan

The nickeliferous iron ore deposits on Honshu Island in Japan yielded a small output of nickel-bearing pig-iron during World War II. The ores are residual lateritic clays containing from 0.3 to 0.8 per cent nickel and from 20 to 25 per cent iron. Reserves are estimated at about 63,000,000 tons with an average grade of 0.5 per cent nickel.(28)

Philippine Islands

The deposits of nickeliferous iron ore found in the Philippines are very similar to those of Cuba. The occurrences in the Province of Surigao, Mindanao, have been prospected and reserves of 550,000,000 tons have been blocked out, with potential reserves of over 1,000,000,000 tons indicated. The ore beds range from a few feet to nearly 100 feet in thickness. The iron content is 47 per cent with nickel averaging almost 0.8 per cent. The deposits cover an area about seven by thirteen miles on the northeast coast of Mindanao. Only a part of the area, that comprising the Peninsula of Dahican, has been drilled and sampled.(28)

Table 1

Estimated Nickel Reserves of the World[4]

(Metal Content in Short Tons)

Country	Operating or Under Development	Undeveloped
Canada	4,822,000(1)	500,000(1)
Cuba	1,413,000(2)	16,457,000(2)
United States (including	257,000(3)	153,000(2)
Alaska)	N.A. (1)	140,000(1)
Brazil	-	200,000-400,000(3)
Venezuela	-	450,000-875,000(3)
Celebes, Borneo	-	4,000,000-7,000,000(2)
		80 000(3)
Philippines	-	4,500,000(3)
Japan	-	315,000(2)
Madagascar	-	45,000(3)
New Caledonia	464,000-514,000(3)	16,000,000(3)
Greece	12,500(3)	50,000-100,000(2)
Union of South Africa	N.A.(1)	N.A.(1)
U.S.S.R.	N.A.(1)(2)(3)	N.A.(1)(2)(3)

(1) Sulphide ores.

(2) Nickeliferous iron ores.

(3) Silicate ores.

(4) Sources of information, U.S. Bureau of Mines, Materials Survey - Nickel, 1952 and U.S. Bureau of Mines, Report of Investigations 5099, February, 1955.

N.A. Information not available.

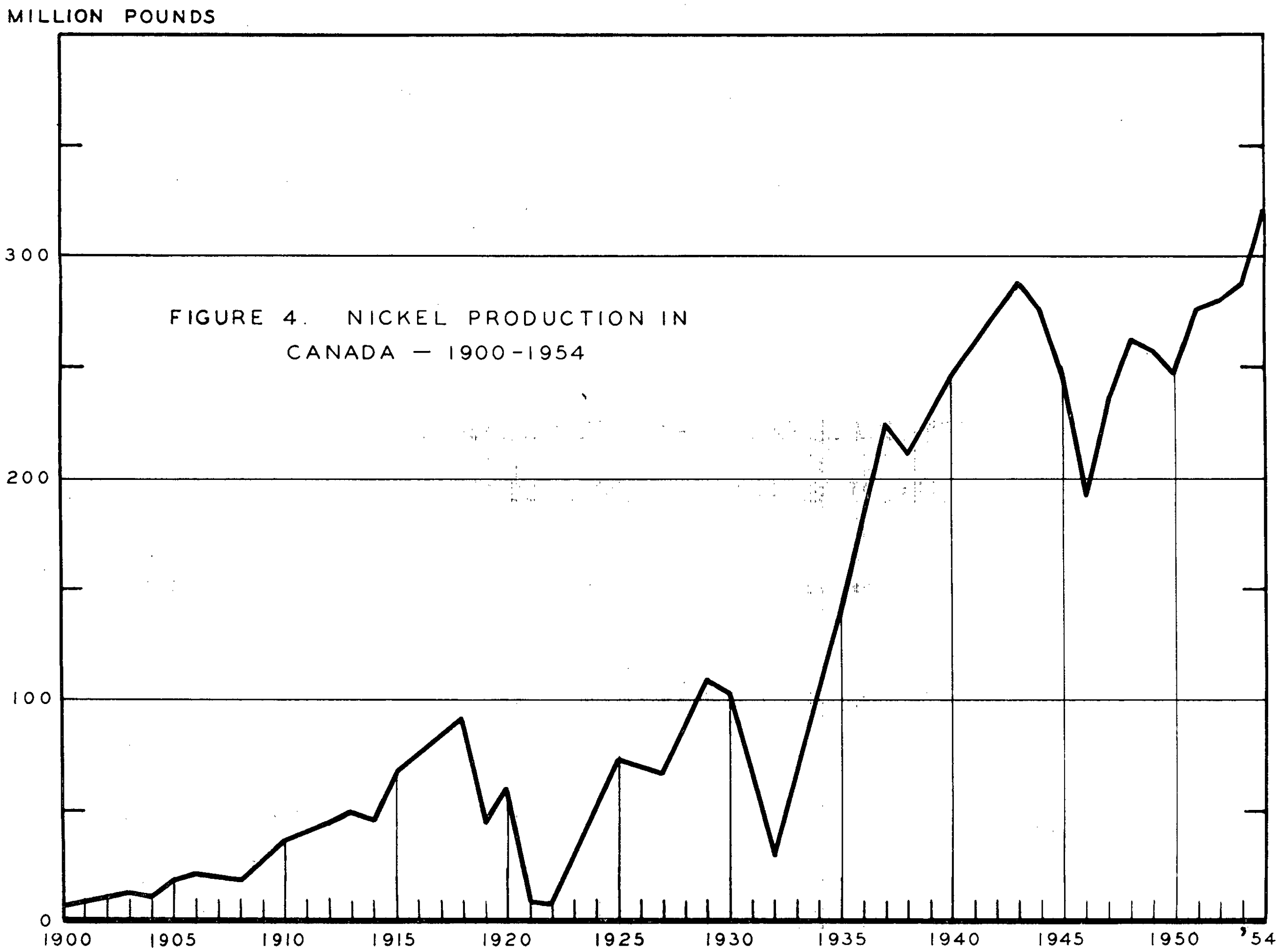


FIGURE 4. NICKEL PRODUCTION IN CANADA — 1900-1954

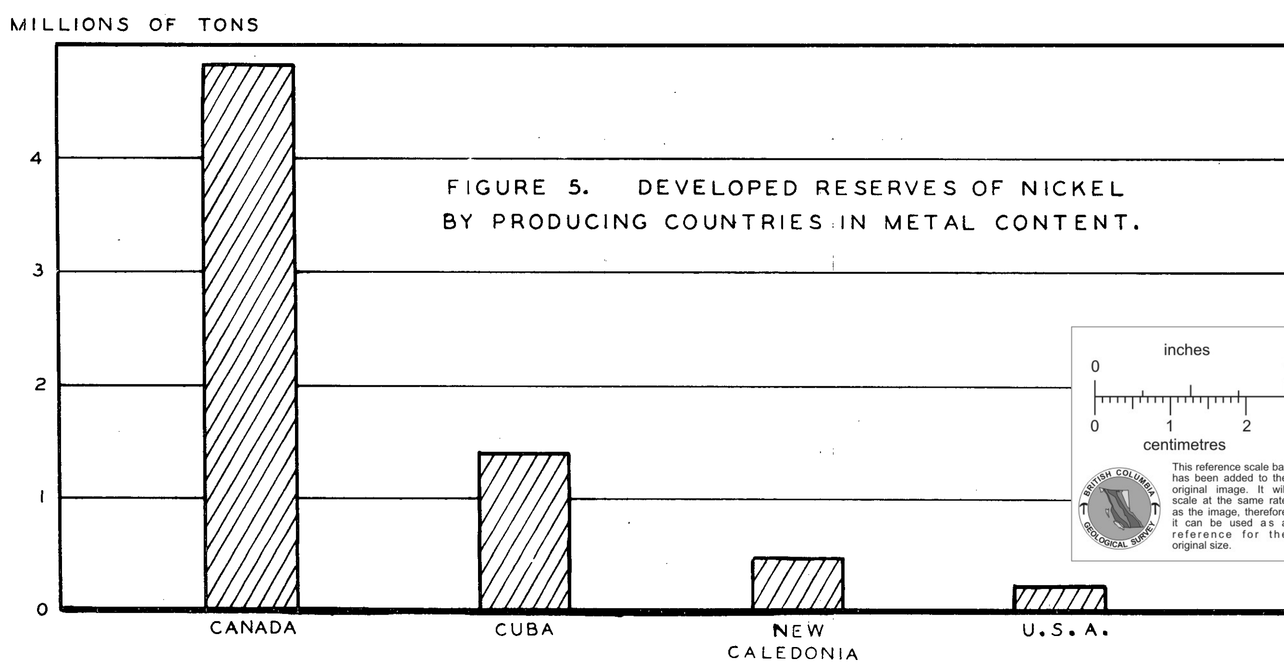


FIGURE 5. DEVELOPED RESERVES OF NICKEL BY PRODUCING COUNTRIES IN METAL CONTENT.

CHAPTER VI

ECONOMICS OF NICKEL

Production

Canada produces about 80 per cent of the world output of nickel, and as the projected increase from the various developments under way throughout the country more than counterbalances that from other world developments, it would appear that Canada will continue to maintain its present position for many years to come.

The first recorded production of Canadian nickel was for 1889, when an output of 415 short tons was reported, and from then to the end of 1952 Canadian production totalled 3,090,264 short tons. In the 25-year period, 1926-50 inclusive, Canada accounted for slightly over 80 per cent of the total world production of nickel.

Table 2

Production of Canadian Nickel*

Period or Year	Production (Short tons)	Period or Year	Production (Short tons)
1889-1898	17,203	1935	69,253
1899-1908	68,230	1936	84,869
1909-1918	282,897	1937	112,452
1919	22,272	1938	105,286
1920	30,668	1939	113,053
1921	9,646	1940	122,778
1922	8,798	1941	141,129
1923	31,227	1942	142,605
1924	34,768	1943	144,009
1925	36,928	1944	137,200
1926	32,857	1945	122,565
1927	33,399	1946	96,062
1928	48,378	1947	118,626
1929	55,138	1948	131,740
1930	51,884	1949	128,690
1931	32,833	1950	123,659
1932	15,164	1951	137,903
1933	41,632	1952	140,007
1934	64,343	1953	143,693
		1954	159,992e

* Dominion Bureau of Statistics.

e Preliminary estimate.

Of all the base metals, nickel is probably the most sensitive to the influence of world economic and political conditions. This is clearly evident from the curve shown in Figure 4 illustrating Canadian nickel production from 1898 to 1952.

The growth in the output of nickel during World War I was followed by a decline in demand and consequently of output until 1923, when economic conditions began to improve. Production continued to increase until the early 30's when it fell to a low of 30,000,000 pounds in 1932 from a high of 110,276,000 pounds in 1929. During World War II output climbed to a record 288,000,000 pounds in 1943. Following the outbreak of the Korean war in 1950 and the resultant increase in demand for the metal for defence requirements, production again moved upwards. Most of the restrictions on the use of nickel were removed during 1952. Demand for the metal has remained at a high level owing chiefly to continued defence needs and to industrial requirements.

In the recovery of Canadian nickel, the other metals associated in the ore constitute an important segment of the industry. Almost 50 per cent of Canada's copper production is from the nickel-copper ores of the Sudbury district. Gold, silver, cobalt, selenium, platinum, and the platinum metals are important by-products, adding materially to the value of Canada's mineral production.

New development and expansion will, within the next five years, result in an increase in output of from 30,000 to 35,000 tons of nickel annually. This will be produced mainly by the three major companies - Inco, Falconbridge, and Sherritt Gordon. A further increase is possible, as several smaller operations are expected to be producing within the next few years.

Reserves

The reserves of nickel in Canada are large, the great bulk of the ore being confined to the Sudbury area. The extensive exploratory and development work being carried out on nickel occurrences in many widely separated areas of Canada are adding appreciably to these reserves.

A conservative estimate of known nickel reserves based on available information is shown in the following table. There exist, in addition, significant amounts of nickel-bearing material that at present is considered to be too low in grade to be classed as ore, or by reason of its location cannot be mined economically under existing conditions.

Table 3

Canadian Reserves of Nickel Ore

(short tons)

	Ore	Nickel Content
Measured	318,391,000	4,844,000
Indicated	58,136,000	395,000
Inferred	1,500,000	9,000

It is significant that the proved ore reserves of Inco have continued to rise since 1950 despite substantial increases in ore mined.(34)

Table 4

Proven Ore Reserves of
The International Nickel Company of Canada, Limited

(short tons)

Year	Proved Ore Reserves	Total Ore Mined
1950	252,859,725	9,849,024
1951	253,704,771	11,799,320
1952	256,355,903	13,248,593
1953	261,541,259	13,667,000
1954	261,619,020	14,456,254

World Production

Russia has ranked second in nickel production since 1941. Actual production figures are not available, but the estimated output is based on the figures given in the Minerals Yearbook published by the United States Bureau of Mines. New Caledonia, which had held second place from 1905 to 1941, is now the world's third largest producer. Its mines have been in continuous production since 1875. Although there has been no recent production from Norway, Burma, and Greece, these countries were consistent minor producers for a number of years.

The existing demand for nickel has also stimulated the development of deposits in several widely separated areas of the world. In addition to the Nicaro development mentioned above, the Moa Bay deposits of Cuba are being prepared for production. This will place Cuba in a

Table 5

World Production of Nickel by Countries 1926-1951[1]

(Short Tons of Contained Nickel)

Year	World	Canada (2)	Cuba (3)	Brazil	U.S.A. (4)	French Morocco	Rhodesia	South Africa	Finland	Germany	Greece	Italy	Norway	Sweden	U.S.S.R. (5)	Burma	Japan	Australia	Indonesia	New Caledonia
1926	37,370	32,850			322															4,189
1927	38,030	33,400			858						110		110							3,527
1928	55,400	48,378			522						726		451			813				4,480
1929	62,100	55,138			340						284		483			930		95		4,816
1930	59,800	51,884			308								965			1,065		132		5,376
1931	40,000	32,833			373						715		586			899				4,600
1932	24,040	15,163			195						1,050		1,075			1,042		1		5,512
1933	51,000	41,632		33	126						1,518		1,068			1,090		10		5,512
1934	78,900	64,342		43	157						1,172		1,470		950	1,354				9,480
1935	85,300	69,258		6	160	229	13			300	1,222		1,361		2,020	1,640	4			9,072
1936	102,950	84,868		527	107	94	15			728	1,383		1,400		2,200	1,446	26			10,141
1937	132,400	112,451		117	219	146	4			981	1,055	75	967		2,200	1,359				12,787
1938	127,300	105,285		413	416	180	84	49		606	1,330	165	1,372		2,750	1,057		22	551	12,897
1939	134,500	113,051		28	394		540	439		551	1,473	110	1,219			1,015	966		830	11,712
1940	154,300	122,777			554			459		804	634	96	1,110		9,530	821	909		2,449	11,613
1941	178,600	141,126			660			588	107	743	204	100	1,000	111	15,000	519	2,547		1,323	11,458
1942	174,200	142,603		1	612			593	1,797	636	778	82	1,004	416	12,130		1,380		1,323	10,378
1943	184,100	144,007	2,679		642	50		544	9,888	1,048	546	47	636	774	12,300		1,778		1,323	8,128
1944	173,100	137,297	5,158	7	988	52		593	345			15	583	769	14,330		1,896			6,945
1945	159,800	122,564	12,015	66	1,155			554	992			13	569	430	14,770		716			4,771
1946	135,600	96,061	12,391		352			548	686				61		22,000					3,063
1947	154,300	118,625	2,220		646			583	595						27,550					3,687
1948	166,500	131,738			883			505							27,550					5,381
1949	160,900	128,688			790			625							27,550					3,716
1950	160,000	123,055			913			929							27,550					6,945
1951	176,100	137,903			755			1,252							27,550					10,120

(1) Materials Survey-Nickel and Minerals Year Book, 1951.
(2) Dominion Bureau of Statistics, Ottawa.
(3) Nickel content of produced oxide.
(4) By-product in electrolytic refining of copper.
(5) Estimated figures only.

significant position among the minor producers of nickel. The Greek deposits are also to be reopened and at least two projects, one in Oregon and one at Fredericktown, Missouri, are under development in United States. Indications are that the combined annual output of nickel from these new sources will amount to about 30,000 tons.

Consumption

Domestic consumption of metallic nickel is not quite three per cent of the refined nickel produced in Canada. The development of foreign markets is therefore an important consideration in the distribution of Canadian production. The United States is the largest market, accounting for about 67 per cent of the exports in 1952. The United Kingdom provides the second largest market, absorbing almost 22 per cent of the exports.

Substitutes for nickel were developed during the period of controlled use. Some of these may continue in use even though restrictions on the use of the metal have been lifted. Competition from this source, however, should not prove serious as the peculiar advantages and characteristics of nickel have been well established through the years of effort spent in developing and promoting its use in commercial applications. Moreover, the great industrial expansion under way in United States and elsewhere has brought nickel into increasingly high demand for peacetime commercial use, and there is every reason to expect a strong and expanding commercial demand for nickel as defence requirements become less. Meanwhile, up to the end of 1967, the United States Government has contracted for the purchase of some 253,000 tons of Canadian nickel, or approximately 11 per cent of the production during this period, largely to meet stockpiling requirements.

Prices

Between 1830 and 1876 the price of metallic nickel ranged from a low of $1.00 per pound to 1840 to a high of $3.50 per pound in 1873. Since 1875 the price has remained under a dollar per pound. The highest price between 1890 and 1926 was $0.92 a pound in 1892 and the lowest was $0.21 a pound in 1895. Prices varied up until the amalgamation of the two major Canadian producers, the yearly average for the period 1913-1928 inclusive being $0.387 per pound. From 1929 to 1941 the price of nickel remained constant at $0.35. In 1942 it was lowered to $0.31-1/2 where it remained until during 1946, when it was raised to $0.35. With the exception of a drop to $0.33¾ in 1948, prices have risen sharply in recent years. The current (1955) price is $0.645 per pound. All prices since 1928 are in United States dollars, f.o.b. Port Colborne, Ontario, in carload lots.

CHAPTER VII

PRINCIPAL USES OF NICKEL

With its wide range of applications, nickel has become one of the most essential metals. By far the greater amount is used as an alloying element in stainless and other steels, cast-iron, and non-ferrous alloys. When it is alloyed with other metals its many valuable qualities are largely imparted to the resulting alloy. In its application in highly specialized alloys, nickel has made possible the commercial development of a large number of new chemical products as well as of electrical and electronic equipment.

The use of the metal alone, except in electroplating, is limited and represents only a small fraction of the total used in industry.

The percentage of nickel consumed in the principal industrial applications is shown in Table 6. As the United States is the largest consumer, the percentages have been calculated from information contained in the United States Minerals Yearbook, 1951, on nickel consumed by uses. The calculations are based on the figures for 1950, a year in which the use of nickel was unrestricted for at least 11 months.

Comparable percentages for Canadian use are shown in Table 7. With the exception of cast-iron and non-ferrous alloys, they follow closely those in the United States.

Table 6

Percentage of Nickel Consumed in 1950 in the United States by Uses

Use	Per Cent
Stainless steels	21.2
Other steels	17.9
Cast-iron	4.9
Non-ferrous alloys[(1)]	28.4
High.temp. and electrical resistance alloys	5.7
Electroplating	18.3
Catalysts	1.1
Ceramics	0.3
Magnets	1.0
Other	1.2

[(1)] Comprise copper-nickel alloys, nickel-silver, brass, bronze, beryllium alloys, magnesium and aluminum alloys, monel, inconel, and malleable nickel.

Table 7

Percentage of Nickel Used in Canada

Use	Per Cent
Steel	37.3
Cast-iron	16.6
Non-ferrous alloys	22.6
Heat-and corrosion-resistant alloys	13.4
Electroplating	5.7
Other	4.4

Nickel is marketed in three principal forms: as metallic nickel and nickel alloys, as rolling mill and foundry products, and as nickel compounds.

Metallic Nickel

The usual forms in which metallic nickel is available include cathodes (cut to convenient sizes), ingots, shot, malleable nickel, pellets, rondelles, grains, and powder.

Table 8

Nominal Percentage Composition of Commercial Forms of Metallic Nickel(1)

Form	Nickel and Cobalt	Copper	Iron	Carbon	Silicon	Sulphur	Other Metals
Cathodes	99.90-99.95	.01-.03	.01-.04	Trace	Trace	Trace	-
Ingot & shot	92.0 -99.6	.04-.20	.15-1.65	.02-.55	.01-5.5	.01-.04	-
Cubes, rondelles, grains	99.2 -99.5	-	-	-	-	-	-
Powder(2)	98.7 -99.0	-	-	-	-	-	-
Pellets(2)	99.5 -99.9	-	-	-	-	-	-
Malleable Nickel(3)							
"A"	99.4	0.10	0.15	0.10	0.05	0.005	.2 Manganese
"D"	95.2	0.05	0.15	0.10	0.05	0.005	4.5 Manganese
"Z"(4)	94.0	0.05	0.25	0.16	0.41	0.005	4.3 Aluminum

(1) The International Nickel Company of Canada Limited and Metals Handbook 1948.
(2) Made from nickel carbonyl; cobalt-free.
(3) Produced in various grades.
(4) Trade name - Duranickel.

The principal industries using metallic forms of nickel are listed below, along with the most important nickel-bearing alloys produced, and examples of the types of equipment into which they are fabricated.

Steel Mills

Nickel steels, nickel chromium steels, nickel molybdenum steels, nickel copper steels, etc., having a nickel content from 0.5 to 10 per cent, are used in transportation and agricultural equipment, armaments, machine tools, mining and road building machinery, oil well drilling and refinery equipment, steel mill machinery, power generating equipment, and steel construction.

Stainless steels containing from 2 to 26 per cent nickel produced in sheet, strip, rods, bars, forgings, wire, and tubes are used in a wide variety of applications, such as architectural trim, airplane engines, truck tanks and bodies, kitchen and pantry equipment, hospital and laundry equipment, dairy and food handling machinery, and in chemical and processing industries.

Heat-resisting steels containing from two to twenty-six per cent nickel are used in furnace and other equipment for glass, ceramic, metal, and chemical manufacture.

Steel Foundries

Castings of nickel steel, nickel chromium steel, nickel vanadium steel, nickel manganese steel, nickel molybdenum steel, and nickel chromium molybdenum steel, with a nickel content from 0.75 to 5 per cent, are used largely in railway locomotives, cars, and track work; in steel mill, mining, and oil-well drilling equipment; and in machine tools, gears, pumps, valves, and fittings.

Iron Foundries

Nickel cast-irons containing one to five per cent nickel are used in automobile, tractor, marine, railway, and stationary engines for cylinders, pistons, rings, camshafts, crankshafts, etc.; in gears, cams, and brake drums; in dies, pots, molds, grate bars, stokers, and household furnace castings; and in valves, pumps, and compressors.

Ni-Tensyliron with a nickel content of from one to three per cent is a processed iron for high-strength castings.

Ni-Hard, containing from four to six per cent nickel is used for castings in heavy-duty equipment.

Ni-Resist, 14 to 36 per cent nickel, is used for corrosion resistance in chemical, paper, textile, and food-handling industries, and in castings for high-temperature service.

Copper and Brass Mills: Brass and Bronze Foundries

Copper-nickel alloys containing 15-50 per cent nickel are used for white metal fixtures, valves, and condenser tubes. Nickel-silver (German silver) containing 10-20 per cent nickel is used as a base for plated ware and for plumbing fixtures, marine hardware, slide fasteners, and springs. Other 'white' alloys containing 15-30 per cent nickel are used in castings for such items as plumbing fixtures and food and dairy equipment.

Brasses and bronzes containing 1-10 per cent nickel are used for pressure castings, gears, bushings, and many other purposes where high strength is required. Nickel-aluminum alloys containing up to five per cent nickel are used for pistons, connecting-rods, cylinder heads, crank-cases, and die castings.

Special Alloy Manufactures

Heat-resisting alloys containing up to 85 per cent nickel are used to make carburizing and annealing containers, chemical retorts, and furnace parts.

Electrical-resistance alloys containing 65 to 85 per cent nickel are used for domestic heating and cooking appliances, industrial heating elements, pyrometers, and electrical control equipment.

Corrosion-resisting alloy castings containing 2 to 36 per cent nickel are used for pumps, valves and fittings, retorts, etc., for the chemical and processing industries.

Magnetic alloys (29 to 90 per cent nickel), non-magnetic alloys (8 to 27 per cent nickel), permanent magnet alloys (14 to 32 per cent nickel), and controlled expansion type alloys (30 to 60 per cent nickel) are used in radio, radar, television, telephone, and telegraphic equipment and for meters, instruments, controls, switches, motors, magnetos, gauges, generators, clocks, and compasses.

Elinvar-type alloys containing 36 to 42 per cent nickel are used for balances, scales, and instruments.

Miscellaneous alloys with molybdenum, cobalt, titanium, gold, etc., containing from 5 to 80 per cent nickel are used for a number of specific industrial purposes. Widely used coinage alloys contain 25 per cent nickel and 75 per cent copper.

Electroplating and Chemical Industries

Nickel as cast and rolled anodes is used in electroplating of household appliances, plumbing fixtures, automobile trim and general commercial and industrial equipment, and in alkaline storage batteries.

Nickel is used as a catalyst in soap and edible oil production, in gas purification, and in the production of high-octane motor fuels.

Rolling Mill and Foundry Products

International Nickel, in its mills and foundries in Great Britain and the United States, manufactures a number of products in rolled or cast form. In normal years these products represent approximately 10 to 15 per cent of the company's total sales. The principal mill forms are rods, sheets, strips, tubes, and wire, as well as special forgings and shapes.

The mill and foundry products are classified under metal groups.

Monel

This alloy, containing approximately two-thirds nickel and one-third copper, is prepared in both rolled and cast form and is used in the aircraft, building, chemical, dry-cleaning, electrical, food processing, household appliances, hospital equipment, marine construction, petroleum, power, pulp and paper, and textile industries.

"K" Monel and "KR" Monel

These alloys are age-hardening varieties of standard monel metal and have a composition of 66 per cent nickel, 29 per cent copper, 2.75 per cent aluminum and less than one per cent each of iron, manganese, silicon, and carbon. "KR" monel is free-machining. These alloys are available in rolled and forged form and are used in instrument parts, control mechanisms, and springs in aircraft; high-strength propeller shafts in marine construction; varied equipment in the petroleum industry; and in the manufacture of safety tools, wrenches, pliers, screwdrivers, etc.

Rolled or Cast Nickel

Rolled nickel contains approximately 99.5 per cent nickel, and cast nickel 97 per cent nickel and 1.5 per cent silicon. These forms are used in the automotive, chemical, electrical, electronic, and radio industries in such applications as spark plug electrodes; in tanks and vessels used to make rayon, soaps, caustic soda, plastics, and gelatin; and in tube screens, grids, etc. Rolled nickel is used for coinage; Canadian five-cent coins have been made from high-purity rolled metal since 1922, except for a few years when a strategic shortage existed.

Inconel

The composition of inconel is 80 per cent nickel, 14 per cent chromium and six per cent iron. Its typical uses are for industrial applications that demand high strength together with a high degree of resistance to corrosion to oxidation at high temperatures.

Special Alloys

There are a number of other alloys covered under trade names that have specialized uses. Their specifications and particular applications are covered in the publications issued by International Nickel.

Nickel Compounds

The third form in which nickel is put on the market is as oxides and salts. Since the matte flotation process replaced the Orford process, nickel oxide sinter has been used to an appreciable extent directly in the making of special steels in place of metallic nickel. The oxides are also used for ceramic enamels and colours. Nickel salts are used in electroplating baths and as catalysts.

CHAPTER VIII

REFERENCES AND BIBLIOGRAPHY

References

1. Metals Handbook, Am.Soc. for Metals, 1948 edition, pp.1025-1062.
2. Report of Royal Ontario Nickel Commission, 1917, p. 24.
3. Mineral Index, Mineral Resources Division, Mines Branch, Ottawa.
4. Ontario Bur. of Mines, Vol. XIV - Part III, (1904).
   Ontario Dept. of Mines, Vol. XLIII - Part II, (1934).
5. The Operations and Plants of International Nickel Company of Canada Limited. Can.Min.Jour., Vol. 67, No. 5, 1946.
6. Falconbridge Nickel Mines, Ltd., Ann. Rept. 1952.
7. Ontario Dept. of Mines, P.R.1952-4. Prelim.Rep. on Copper, Nickel, Lead, and Zinc Deposits of Ontario.
8. Ontario Dept. of Mines, Vol. XXXVIII, Pt.7, 1929, pp.25-26.
9. Ontario Dept. of Mines, Vol. LII, Pt. 3, 1943, p.17.
10. Report of Royal Ontario Nickel Commission, 1917, pp.229-32.
11. Ontario Dept. of Mines, Vol. LI, Pt. 6, 1942, p. 24.
12. Ontario Dept. of Mines, Vol. LV, Pt. 4, 1946, pp.119-121.
13. Ontario Dept. of Mines, Vol. XXXVII, Pt.4, 1928, pp.128-48.
14. Ontario Dept. of Mines, Vol. XL, Pt.2, 1931, p.33.
15. Ontario Dept. of Mines Press Release, Oct. 29, 1953.
16. Nfld. Geol. Survey, Inform. Circular No. 4, 1938, p.101.
17. N.B. Dept. of Lands & Mines, Ann.Repts. 1893, 1928, 1929, 1930, 1938, 1947.
18. Que. Dept. of Mines, Prelim. Rept. 279, 1952.
19. G.S.C. Summ. Rept. 1925, Pt. C.pp. 105C-124C.
20. Sherritt Gordon Mines Ltd., Ann. Repts.
21. Man. Dept. of Mines & Nat. Resour. Pub. 41-1 (1952), Geol. of the Partridge Crop Lake Area.
22. G.S.C. Mem. 169, 1932, pp. 91-98.
23. G.S.C. Paper 52-1, 1952. Nevin Lake Map Area.
24. G.S.C. Mem. 190, Geol. & Min. Deposits at the Mine of B.C. Nickel Mines Ltd.
25. Hudson Bay Min. & Smelt. Co. Ltd. Ann. Rept. 1952.
26. Trans. C.I.M., Vol. 34, 1931.
27. G.S.C. Paper 53-22 Geol. Notes on Southern Dist. of Keewatin, N.W.T. 1953.
28. Materials Survey Nickel 1950, National Security Resources Board, U.S.A.
29. F.A. Forward, Ammonia Pressure Leach Process for Recovering Nickel, Copper, and Cobalt from Sherritt Gordon Nickel Sulphide Concentrate 1953.
30. Union of S.Africa, Dept. of Mines, The Min. Resources of the Union of S. Africa, 1940, p.282.
31. The Mineral Resources of the Union of S.Africa, 1940, p.283-285.
32. Report of Royal Ontario Nickel Commission 1917, pp.234-264.
33. British Commonwealth Geological Liaison Office.
34. The International Nickel Co. of Canada Ltd. Ann. Rept. 1952.

Bibliography

Report of Royal Ontario Nickel Commission 1917.
Materials Survey Nickel 1950, National Security Resources Board, U.S.A.
The Operations and Plants of International Nickel Company of Canada Limited by the Executive and Operating Staff, Canadian Mining Journal, Vol. 67, No. 5, 1946.
Underground Mining Methods at International Nickel Company by H.J. Mutz, A.F. Brock, and W.J. Taylor, AIME Trans. Vol. 196.
Shaft Sinking Practice at Inco by A.F. Brock and W.J. Taylor C.I.M. Trans. Vol. LIII, 1950.
Metals Handbook, 1948, Edition A.S.M. pp. 1025-1062.
The International Nickel Co. of Canada Ltd., Ann. Repts. and Company Publications on Nickel Alloys, etc.
Falconbridge Nickel Mines Ltd., Ann. Repts.
Sherritt Gordon Mines Ltd., Ann. Repts.

EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1955