MINERAL REPORT 16

Nickel — Canada and the World

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PREFACE

Nickel is essentially a 'space-age' metal although it was used in natural alloys from the dawn of civilization. Important uses began to be developed in the second half of the 19th century and since that time demand has increased at a rapid rate. Expansion of the world nickel industry has been particularly marked in the 1960s.

Canada has been the world's leading nickel producer for more than sixty years. Nickel developments in the Sudbury district, and more recently in northern Manitoba, have been important factors in the growth of the Canadian economy. Future expectations are for a continued and vigorous expansion of the nickel industry. Aggressive exploration, processing research, and market development have enabled the integrated Canadian producers to take a leading role in nickel industry developments around the world. Consequently, Canada's pre-eminent position in the world nickel industry is expected to be maintained for many years.

Much has been written on technical aspects of the nickel industry and in this respect attention is drawn to "The Winning of Nickel", a recent comprehensive and definitive study by Joseph R. Boldt, Jr. and Paul Queneau.

Although initial chapters of the present study briefly outline technical aspects of the nickel industry – geology, exploration, mining, and forward processing – primary emphasis is placed on what might be broadly described as economic aspects. Accordingly, attention is directed to the reserve and resource base; commercial forms and uses; corporate history, operations and developments in the Canadian and foreign nickel industries; the role of nickel in the Canadian economy, and world supply and demand conditions.

The Division gratefully acknowledges the information, comments, photographs and other help kindly provided by nickel-producing companies, a number of foreign governments, and overseas officials in the Canadian Department of Trade and Commerce. Particular acknowledgment is made for the assistance given by The International Nickel Company of Canada, Limited, Falconbridge Nickel Mines, Limited, and Sherritt Gordon Mines Limited.

W. Keith Buck,
Chief,
Mineral Resources Division.

Summer, 1967.

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EXPLANATORY NOTE

1. Short ton (2,000 lb) used except where otherwise noted.

2. Canadian dollars used except where otherwise noted.

3. International Nickel is used in this report as an abbreviation for the parent company formed in 1928 – The International Nickel Company of Canada, Limited – as well for the following corporate predecessors and wholly owned subsidiaries: International Nickel Company (New Jersey charter, formed 1902); The International Nickel Company (New Jersey charter, formed 1912); The International Nickel Company of Canada, Limited (Canadian subsidiary, formed 1916); The International Nickel Company, Incorporated (wholly owned United States subsidiary); International Nickel Limited (wholly owned British subsidiary).

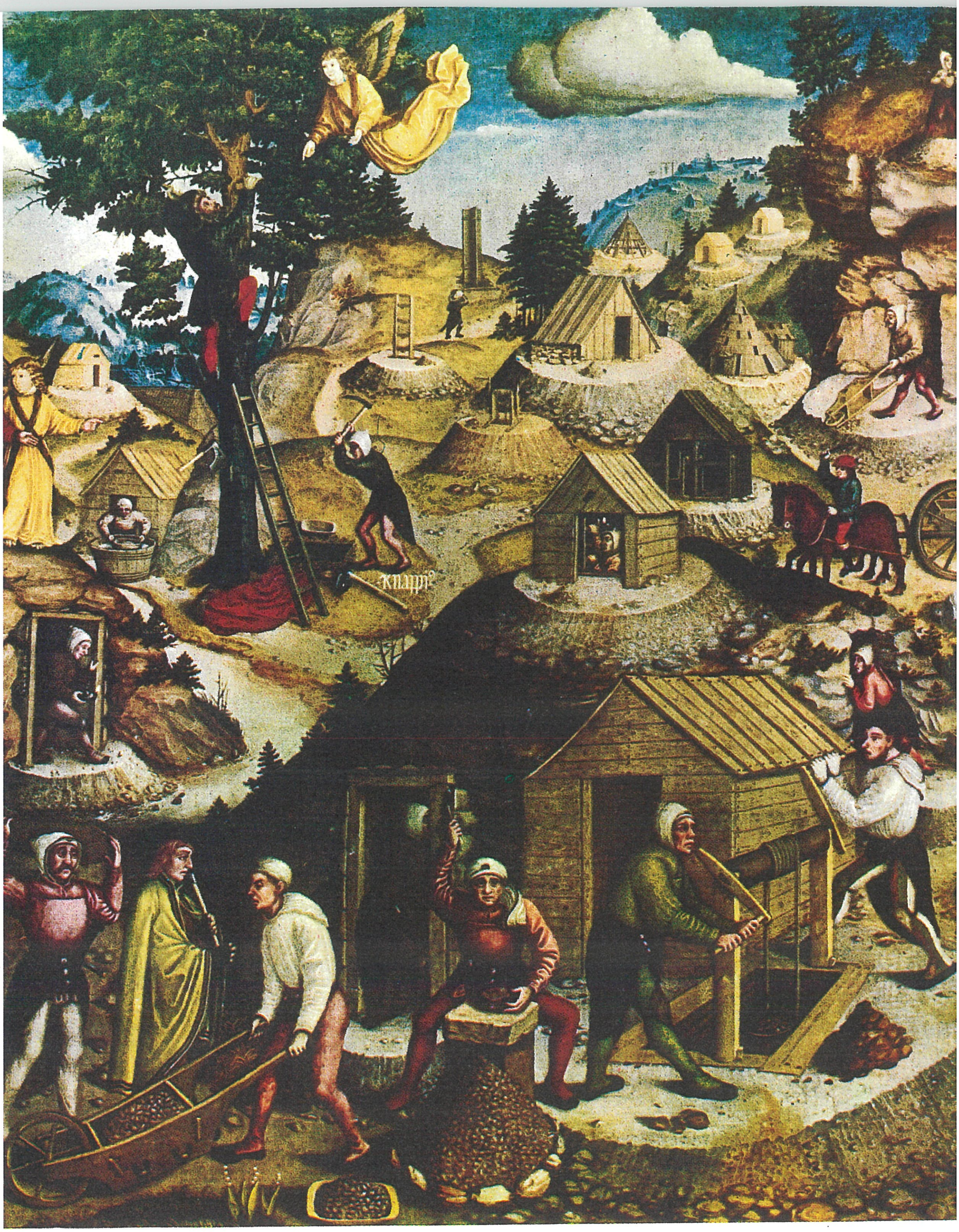

FIGURE 1. Altarpiece in St. Anne's Church, Annaberg, Saxony, painted by Hans Hesse in 1521, showing mediaeval mining in the Erzgebirge where kupfernickel was found in the silver-cobalt ores.

CHAPTER 1

HISTORY

EARLY HISTORY
(to 1864)

The derivation of the word nickel is generally credited to 'kupfernickel'. Mediaeval miners working the silver-cobalt ores of Saxony discovered a metallic mineral which, when melted, yielded no silver. The prevailing view at the end of the 17th century was that this material consisted of cobalt ore mixed with copper. When no copper could be extracted from it, the derogatory term 'kupfernickel' was applied meaning 'Old Nick's copper' or, perhaps, 'false copper'. This ore was later found to contain nickel (1, p.24).

Although nickel was not identified as an element until 1751 it has been used in natural alloys from the dawn of civilization. Meteorites, believed to have been man's earliest source of nickel, were used to forge implements that required strength and hardness properties. Some of the legendary sword blades of ancient warriors were no doubt fashioned from nickel-bearing meteorites(2, p.11).

Many of the bronzes produced by middle eastern civilizations from 4100 B.C. contain traces of nickel. The nickel content was probably an inadvertent impurity, present in the copper ores that were used. Chinese bronzes, dating from 770 B.C., also show traces of nickel(3).

The earliest known copper-nickel-alloy objects are coins minted about 170 B.C. in Bactria, a kingdom immediately north of present day Afghanistan. It is believed that these coins were derived from copper-nickel-sulphide deposits in southern China, the raw material being carried west through India by caravan(3).

A distinctive Chinese cupro-nickel alloy known as *paitung** was produced by smelting a mixture of copper-nickel ore and zinc ore. This malleable alloy, an inexpensive substitute for silver, was produced in Canton and was brought to Europe by the East India Company in the 17th century (2, p. 12). *Paitung* found a ready market in Europe but efforts to produce the alloy synthetically awaited the isolation of nickel as an element and the discovery of a reliable source of supply.

The Scandinavian countries and Germany were prominent in the early development of nickel metal. The element was first identified by Axel Cronstedt, a Swedish chemist, in 1751, but his work was not generally accepted until 1775 when Bergman first produced the metal in a fairly pure state while working on Swedish cobalt ores (1, p. 37). Later, it was learned that the speiss derived from the smelting of ores in Freiberg, Saxony, was

*Official Mandarin dialect meaning 'white-copper', also spelled *paktong* (Cantonese dialect) (3) and *pai-thung*(1).

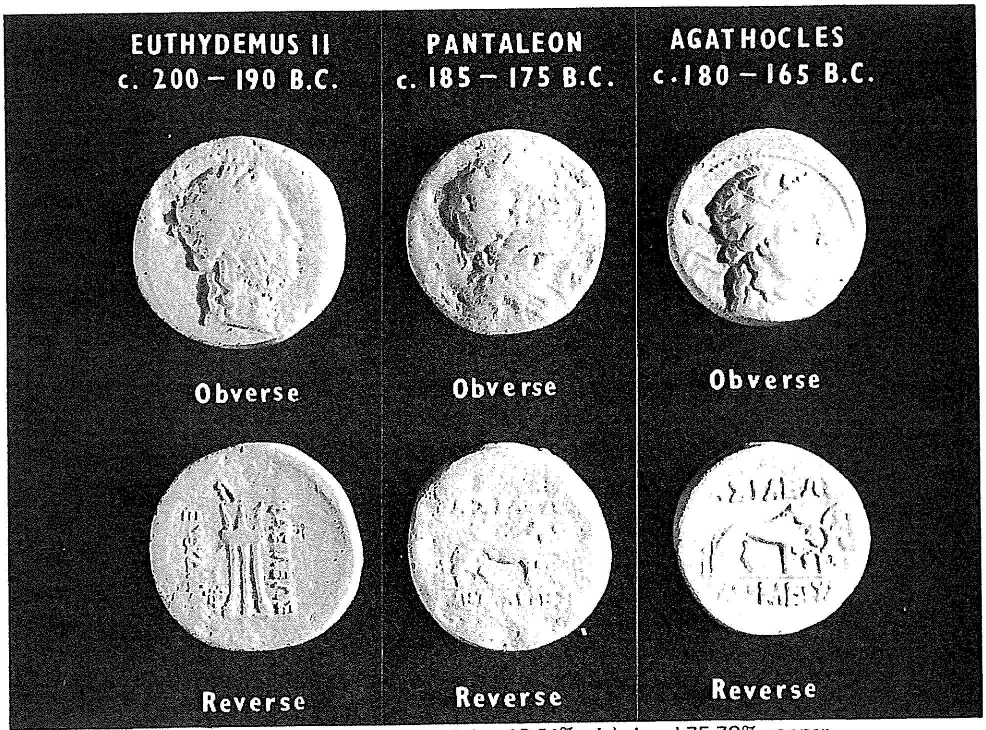

FIGURE 2. Bactrian coins containing 18-21% nickel and 75-78% copper.

largely composed of nickel. Subsequently, the Schneeberg mines of Saxony, rich silver and cobalt producers from the 15th century, were also worked for their nickel content (1, p. 50).

In 1776, von Engestrom discovered nickel in *paitung* but the development of a satisfactory substitute was difficult. The Henninger Brothers of Berlin placed the first imitation *paitung* on the market in 1824. Geitner of Saxony produced a similar alloy about the same time. Guiticks of Berlin introduced the alloy to England in 1830 where it became known as German silver and later nickel silver (2, p. 13). With the establishment of an electroplating industry in England in 1844, German-silver articles plated with either silver or nickel gained popularity. Switzerland introduced German-silver coins in 1850 and cupro-nickel coinage was adopted by Belgium in 1860 (4, p. 67). In the following years many other countries coined monies containing nickel. German silver, nickel plate and nickel coinage were the major uses of the small supply of nickel produced during the mid-19th century.

The first commercially refined nickel was probably produced at Schneeberg. However, as nickel markets began to expand with the development of German silver and the advent of electroplating, the search for nickel ore deposits was intensified. Nickel-bearing pyrrhotite ores in Norway and Sweden were mined and for several decades in the mid-19th century, Norway was the world's principal nickel producer. Maximum annual production from Norway amounted to 360 tons in 1876 (5, p. 100) with 15 mines and 7 smelters in operation(6).

The third quarter of the 19th century was a period of considerable growth for the nickel industry, world production increasing from 30 to approximately 550 tons a year. However, limited supply of the metal raised prices as high as U.S. $3.82/lb and restricted demand to a few specialized end-uses. The impending development of large sources of supply in the new world would drastically alter market conditions.

RECENT HISTORY
(1865 to Present)

The discovery of nickel deposits on the French island of New Caledonia in the South Pacific in 1865 and at Sudbury, Canada, in 1883, fore-shadowed the modern era of nickel production.

A French company, Société Anonyme Le Nickel, was formed by the Rothschilds in 1882 to take over the production, refining and marketing of the New Caledonian ores (7, p. 19). The largest and highest grade Sudbury deposits were secured by the Canadian Copper Company. This company, formed in 1886, contracted the smelting and marketing of the Sudbury ores to the Orford Copper Company of New Jersey. The increased supply and competition between the producers forced large price reductions, from a high of U.S. \$3.82/lb in 1873 to a low of U.S. \$0.28/lb in 1895.

A paper by J. Riley(8) on 'Alloys of Nickel and Steel' presented to the Iron and Steel Institute of Britain in 1889 had an important impact on nickel demand. The subsequent development of nickel-steel alloys for use in armaments brought about an enormous increase in the use of nickel and provided an outlet for the growing New Caledonian and Canadian production. This demand did not slacken until the end of World War I.

Traditionally, Société Anonyme Le Nickel exercised a monopoly control over the European nickel market. The Orford Copper Company supplied the United States market. However, by 1896, the Orford Copper Company had forced Le Nickel to share the European market which at this time absorbed most of the world's supply. Cost advantages resulting from the relatively large size of the Sudbury deposits and by-product recovery of copper and precious metals from the ore, facilitated this shift in market control, and as the change occurred, the scale of mining in the Sudbury district increased.

In 1902, the interests of the Canadian Copper Company and the Orford Copper Company were merged in the formation of the International Nickel Company, a New Jersey corporation. By this time, Canada was supplying 45% of the world nickel market and this increased to 70% by 1913. In 1916, The International Nickel Company of Canada, Limited, was incorporated for the purpose of consolidating the Canadian interests of the parent company.

With the completion of refinery facilities at Port Colborne, Ont., in 1918, International Nickel began to refine nickel in Canada. The Mond Nickel Company, Limited, a British firm that began mining in the Sudbury district in 1901 and operated a nickel refinery in Wales, merged with International Nickel in 1929.

Falconbridge Nickel Mines, Limited, began production in the Sudbury district in 1930 and in 1953, the third major Canadian nickel producer, Sherritt Gordon Mines Limited, began nickel mining and concentrating operations in Manitoba, bringing into production a nickel refinery in Alberta the following year.

World War I created an unprecedented demand for nickel but with the completion of war contracts in 1920 the demand plummeted. An intensive research and development program was implemented and by the mid-1920s new uses for nickel had offset the depressed armament demand. Nickel, however, also continued to be a strategic war metal and long-run production levels rose to meet a steadily increasing total demand.

World War II disrupted European nickel production but Canada expanded its nickel mining operations to satisfy the heavy Allied demand. As had happened 25 years earlier, peace brought a sharp decline in the use of nickel but the slump was not so prolonged as before, because nickel already had secured a sound position as a peacetime metal. As

FIGURE 3. Copper Cliff mine and smelter of the Canadian Copper Company, Sudbury district, about 1890.

demand increased through the forties and fifties new recovery processes were developed which facilitated the exploitation of new sources of laterite ores, primarily in the United States and Cuba.

GEOGRAPHIC DISTRIBUTION OF THE NICKEL INDUSTRY

In 1965, Canada accounted for 56% of the world's mine production of nickel. The other major producing countries were the USSR (19%) and New Caledonia (14%). World mine production of nickel from 1961 to 1965 is shown as Appendix H.

Canada is also the world's leading supplier of processed nickel; refined nickel, ferronickel or nickel oxide that is not processed further for industrial use. In 1965, Canada accounted for 39% of the world's output of processed nickel. The other major producing countries were the USSR (20%), Britain (10%), Norway (8%), and Japan (7%). World production of processed nickel from 1961 to 1965 is shown as Appendix I. An outline of world supply and demand for nickel is given in Chapter 9.

CHAPTER 2

ORE DEPOSITS AND RESOURCES

ORE DEPOSITS

Mason (1, p. 50) estimates that nickel is the fifth most common element of the earth, having an average bulk content of 2.7%. Most of this content is, however, concentrated within the inner core and mantle of the earth and thus cannot be directly utilized by man. Nickel is not as plentiful in the earth's crust. Estimates of the average crustal concentration range from .008 to .020% by weight; accepting the former estimate, nickel is the 24th most common element in the crust(2). Even so, the crustal abundance of nickel is greater than copper, lead or zinc, metals which are produced in substantially greater quantities. Exploration experience to date has shown that nickel is relatively evenly distributed in the crust and, therefore, does not occur as often in economic concentrations as do copper, lead or zinc.

Nickel deposits are almost always associated with mafic and ultramafic igneous rocks or their metamorphic alterations. This association is not surprising, for these rock types are believed to have been originally intruded from the inner regions of the earth where nickel is relatively abundant. There are two types of nickel deposit – sulphide and laterite. Although sulphide deposits have traditionally been the most important source of nickel, the supply obtained from laterite deposits is becoming increasingly important.

Nickel-Sulphide Deposits

Most nickel currently produced is obtained from nickel-copper-sulphide deposits. These include the deposits of Canada, Finland, South Africa and most of the USSR ores.

Nickel sulphides are usually associated with mafic to ultramafic intrusions, usually either perioditic or noritic. The ultramafic host rocks occur as integral parts of the lower, mafic portion of volcanic sequences, or, in younger Alpine-type intrusions of irregular distribution(3). Economic deposits occur as disseminations, replacements and fracture fillings within the intrusive or in the country rock nearby. Individual deposits are usually elongate, lenticular or sheet-like(4). Some deposits were formed later than the rocks that enclose them, mainly through the action of hydrothermal solutions, deposition being structurally controlled primarily by faults and shear zones. Many deposits, however, occur at or near the base of ultramafic intrusions. The origin of these deposits is uncertain but most geologists favour the theory that they were formed by magmatic segregation during crystallization rather than by hydrothermal solutions.

Ore generally consists of disseminated to massive sulphides with sulphide concentrations ranging from 15 to 100%. Pyrrhotite ($Fe_{1-x}S$) normally predominates but

FIGURE 4. Photomicrograph of massive nickel-sulphide ore. White: pentlandite. Gray: pyrrhotite. Black: magnetite, a common accessory mineral in some nickel-sulphide ores. Magnification: X50.

is associated with lesser concentrations of the valuable nickel and copper sulphides – pentlandite [$(Fe,Ni)_9S_8$] and chalcopyrite ($CuFeS_2$)(5). There also may be minor amounts of other iron-nickel sulphides, nickel sulphides and nickel-cobalt sulphide. In addition to nickel and copper sulphide, ores often contain recoverable quantities of cobalt, gold, silver, selenium, tellurium and platinum-group metals.

Nickeliferous-Laterite Deposits

A lateritic deposit is the product of weathering in a tropical climate. Alternate wet and dry seasons, and hot weather and warm acid groundwater throughout the year, are necessary conditions for the extensive leaching of silica from the surface rocks and, thus, for the formation of laterites (6, p. 203). Varying intensities of tropical weathering will produced a wide range of proportions in the laterite alteration products of the parent rock.

Olivine normally contains up to 0.3% nickel and, thus, olivine-rich rocks–peridotite, dunite and their metamorphic alteration, serpentinite–usually produce laterites rich in nickel when subjected to tropical weathering conditions for a long period (7, p. 10). Erosion is effected by groundwater that, acidified by the dissolution of carbon dioxide from the atmosphere and from decaying vegetation, decomposes the exposed rock. As the rock is leached, magnesium, iron and nickel enter into solution and silica forms a colloidal suspension. In solution the iron readily oxidizes and is precipitated as ferric hydroxide. On dehydration, a layer of goethite or hematite is formed. The nickel may be deposited from solution with the iron or it may be carried below the iron-rich zone and deposited as nickel silicate. Normally, some nickel is deposited in both zones but in widely varying proportions. Because an exploitable grade of nickel may be realized in either zone, there are two types of nickeliferous-laterite deposits: nickeliferous-iron laterites, and nickel-silicate laterites (7, p. 11).

In *nickeliferous-iron laterites,* nickel is deposited in the iron-rich zone and is concentrated to the extent that magnesium and silica are carried below in solution. The manner in which the nickel is deposited in this type of laterite is conjectural, but nickel probably is included in the dehydrated ferric hydroxide precipitate that is the major constituent of the iron-rich zone(4). The leaching process is continuous. As the surface is eroded, the precipitated minerals are dissolved by fresh acidic groundwater, the constituents being carried deeper and reprecipitated. The nickel content is normally concentrated by the process. A nickel deposit of exploitable grade results if the cyclical enrichment process acts over a sufficient length of time. Important deposits of nickeliferous-iron laterite occur in Cuba, the Philippines and Indonesia.

In *nickel-silicate laterites*, the groundwater solution is neutralized below the iron-rich zone and the nickel is precipitated with a portion of the magnesium at the base of the weathering zone. Nickel is less soluble than magnesium and is concentrated to the extent that magnesium and silica are carried by the groundwater below the zone of nickel deposition and to the extent that iron has been deposited above the nickel zone. In these deposits, the mineral of economic importance is garnierite, traditionally assigned the chemical formula $[(Ni, Mg)SiO_3 . nH_2O]$, but probably a mixture of two or more hydrous nickel-magnesium silicates (4). In a manner analogous to the nickeliferous-iron laterites, the cumulative enrichment process continues, and eventually an exploitable grade of nickel may be realized. Important deposits of nickel-silicate laterite occur in New Caledonia, Indonesia, the USSR and the United States.

There are two possible explanations for the formation of the two types of nickeliferous-laterite deposit. The one mentioned in the foregoing description is that the amount of nickel retained in the upper iron-rich zone is dependent on weathering factors. Because the complete separation of iron and nickel into distinct zones is never realized, in almost every nickeliferous-laterite occurrence both types of nickel deposit are present (7, p. 11). Another explanation is that the type of nickeliferous-laterite deposit formed depends on the primary source rock. Therefore, nickeliferous-iron laterites are the product of the tropical weathering of serpentinite while nickel-silicate laterites are formed by the tropical weathering of peridotite, dunite and, to a lesser degree, pyroxenite(4). Factors embodied in both explanations probably play an important role in the formation of nickeliferous-laterite deposits.

RESOURCES

To facilitate an estimate of world nickel resources, resources are subdivided into two categories: reserves and potential ore. *Reserves* applies to resources about which information provides sufficient economic justification for immediate development. *Potential ore* applies to resources that are not immediately exploitable, either because of marginal or submarginal grade, or because there exists critical uncertainties pertaining to geological, technological or other development factors. However, for classification as potential ore, available information must indicate that there are reasonable prospects of these problems being surmounted in the future.

The classification of most nickel-laterite resources as potential ore is dependent on a number of factors. Despite significant nickel production from lateritic deposits in New Caledonia, Cuba, the United States and the USSR, processing technology is not yet as fully developed for the lateritie ores as that for nickel-sulphide ores and, therefore, the cost of potential exploitation is more uncertain. The by-product recovery of such metals as cobalt and iron has not as yet been firmly established. Furthermore, most nickel-laterite deposits occur in developing nations where there may be difficulties in attracting the necessary development capital. Because the distance from these laterite deposits to the consumer is normally great, and because nickel laterites cannot at present be concentrated, it is probable that the entire treatment process from mining through refining will have to be carried out in the country of origin. However, these problems should not be overestimated. Technological advances have already gone a long way toward placing nickel laterites on a competitive footing and there is every reason to expect that this trend will continue. Also, the probability of discovering additional nickel-laterite deposits is good since the tropical and semitropical regions in which they occur have not been extensively explored (8, p. 442).

Estimation of world nickel resources is undervalued because the resource data for individual countries are either unavailable or underestimated. The most important factors in this respect are:

(i) A serious undervaluation of Canadian resource data for both reserves and potential ore. For the largest Canadian (and world) producer, the published reserve figure is a working inventory which has tended to increase with production. The ore reserves of developing mines are not usually included in published reserves. Therefore, reserves, as defined in this chapter for the purpose of resource estimation, are no doubt considerably larger. Also, there is little indication of the tonnage and grade of potential ore in the Sudbury district. It would be surprising if this figure were not very large.

(ii) Reserve tonnage estimates for the New Caledonian deposits are out of date. The lowering of the average grade of ore mined in recent years has been made possible by cost reductions. The large tonnages of potential ore that have thereby been drawn into reserves are not accounted for in available reserve estimates (9, 10).

(iii) No nickel resource data are available for the USSR.

Other significant deficiencies in nickel resource data are:

(i) No resource data are available for three by-product nickel producers – Burma, Morocco and Poland; two small producers – Korea and East Germany; or for the nickel resource potential of the British Solomon Islands and Botswana.

(ii) No quantitative data are available for South Africa and Albania.

(iii) Resource data between countries are not standardized.

Bearing in mind the above qualifications, the following table outlines world nickel resources, collected from various sources. The estimates of Canadian reserves and potential ore are referenced in Chapter 7. Their components are tabled as Appendices A and B. Estimates of foreign nickel resources are referenced in Chapter 8.

At 1965 world consumption levels, reserves represent approximately 28 years of production, and potential ore if utilized, would extend the resource base by an additional 127 years. Assuming a 5% annual compound growth rate in nickel demand, the corresponding figures would be 18 and 41 years. However, experience has shown that, while demand has accelerated in recent years, the ratio of reserves to annual consumption has been maintained.

World Nickel Resources*

Country	Reserves			Potential Ore			Type of resource
	Millions of tons	Nickel grade (%)	Nickel content (millions of tons)	Millions of tons	Nickel grade (%)	Nickel content (millions of tons)	
Albania	na	1.0	na	na	na	na	nl
Australia	2.4	4.3	0.10	65.3	1.3	0.85	ns & nl
Brazil	na	na	na	16.0	4.5	0.72	nl
Canada	414.2	1.5	6.30	na	na	4.97	ns
Cuba	356.0	1.3	4.63	1,653.0	0.8	13.22	nl
Dominican Republic	–	–	–	72.4	1.6	1.12	nl
Finland	7.0	0.8	0.06	na	na	na	ns
Greece	na	na	na	10.0	0.7	0.07	nl
Guatemala	30.0	1.5	0.45	na	na	na	nl
Indonesia	8.7	2.1	0.18	135.7	1.2	1.63	nl
New Caledonia	na	2.6-3.1	na	1,400.0	1.1	15.40	nl
Philippines**	62.8	1.3	0.84	2,676.6	0.7	19.84	nl
Rhodesia	7.0	1.0	0.07	16.0	0.8	0.13	ns
South Africa	na	0.3	na	na	na	na	ns
United States	16.2	1.5	0.24	na	0.25	na	ns & nl
Venezuela	–	–	–	58.4	1.1	0.63	nl
Yugoslavia	7.5	1.4	0.11	–	–	–	nl
Millions of tons	911.8		12.98	na		58.58	
Average grade		1.4			na		

*Some of the national resource estimates are significantly undervalued because of the lack of available information. Countries with no available data – notably the USSR – are excluded from the table. To this extent, totals do not reflect actual resources.

**Reserves: Nonac Island laterite and weathered serpentine.
Potential ore: all other indicated and inferred ore in Parcels I–IV (see Chapter 8).

ns nickel-sulphite resources.
nl nickeliferous-laterite resources.
na Not available.
– Nil.

For further detail and references, see Appendices A and B and Chapters 7 and 8.

CHAPTER 3

EXPLORATION

Virtually all nickel deposits, both sulphide and laterite, occur in or are associated with mafic and ultramafic intrusions. Exploration for nickel deposits is thus narrowed because acid and intermediate igneous rocks, and metamorphic and sedimentary rocks can be excluded from consideration except in the vicinity of ultramafic intrusions or where ultramafics have been metamorphosed.

NICKEL-SULPHIDE EXPLORATION*

Because exploration for nickel-sulphide deposits is both costly and uncertain it normally embraces a number of sequential 'information gathering' stages, a decision on whether or not to proceed being made on completion of each stage. The exploration process may be subdivided as follows:

(i) selection of geologically promising areas;
(ii) airborne geophysical surveys of promising areas;
(iii) ground geological and geophysical surveys of selected anomalies; and
(iv) diamond drilling.

Nickel-sulphide deposits have certain well defined characteristics and normally occur in a predictable geological environment. These factors, outlined in Chapter 2, guide the selection of geologically promising areas. One Canadian company has drawn up a set of flexible criteria for such a selection, a priority rating being assigned to each component(1). Consideration is given to rock types, rock mineralogy and texture, evidence of nickel-bearing sulphide, degree of differentiation, quantity of source rock, presence of major structures or lineaments, economics of location, etc. Areas with a relatively high over-all rating are selected for detailed investigation. The Thompson nickel belt was selected in 1947 by International Nickel as an area for major exploration, primarily because of structure and the presence of ultramafic rocks(1).

Magnetic sulphide deposits that are near the surface but not exposed can be detected by airborne geophysical methods. The properties of the country rock measured are magnetism and electrical conductivity. Pyrrhotite, whether nickel bearing or barren, is quite magnetic although not as magnetic as magnetite. While the latter is not a conductor, pyrrhotite is. Graphite and water-bearing shear zones are conductors but are non-magnetic as are sulphides of copper, lead and zinc unless magnetite or pyrrhotite is associated with them. An anomaly detected by the electromagnetic technique but not picked up by the magnetometer is not likely to be caused by nickeliferous sulphides(2). Magnetic and electromagnetic devices used together provide a reasonably confident indicator of

*Ref. (1-3).

FIGURE 5. Airborne geophysical survey, magnetometer suspended beneath aircraft.

sulphide mineralization. The airborne magnetometer is the product of World War II; the airborne electromagnetic device was developed as recently as 1951. When used together they enable rapid coverage of large areas and reduce the number of costly ground surveys.

Airborne magnetic and electromagnetic surveys find particular application on the Precambrian Shield and other areas of Canada and the world that are not deeply covered by overburden and that have not been subjected to deep weathering. Once promising anomalies have been located, ground geophysical surveys are conducted to delineate more precisely their location and limits. Drilling is necessary to determine whether the anomalies contain nickel-bearing deposits and, if so, to determine their economic potential. Airborne methods and ground follow-up in selected areas have been responsible for the discovery of the Thompson, Pipe, Moak Lake and Soab deposits in the Thompson nickel belt(1).

On the ground, an electromagnetic survey is normally conducted to verify the general anomaly parameters, and map the local geology. If the information is favourable, detailed geological and geophysical surveys are run. In certain cases a seismic survey may be carried out to check the depth of overburden. A gravity survey may be conducted to differentiate between sulphide or magnetite anomalies and anomalies caused by graphite or water-bearing shear zones. When results warrant, diamond drilling is carried out to determine economic potential. The experience of one integrated Canadian firm active in nickel exploration indicates that there is a reasonable certainty that sulphides cause nine out of ten of the anomalies that are selected by these exploratory methods for further testing by drilling, and that "at least 100 barren sulphide bodies occur in most Precambrian areas in Canada for every deposit containing economic values; (deposits which may or may not prove to be orebodies)"(1).

If diamond drilling results confirm the economic expectation, but the uncertainty with respect to one or more of the geological parameters (tonnage, grade, structure, *etc.*) remains prohibitive, an underground exploration program may be required before a 'development to production decision' can be considered.

NICKELIFEROUS-LATERITE EXPLORATION*

Nickel-laterite exploration is less complex and more predictable than nickel-sulphide exploration. The deposits normally cover large areas and lie close to the surface. Present geophysical methods are not suitable for directly detecting nickel-laterite deposits, so other exploratory techniques must be used.

The prerequisites for nickel-laterite formation are ultramafic rocks containing nickel, or their metamorphic alterations, and the exposure of these rocks to tropical weathering conditions for prolonged periods. These conditions indicate favourable regions for nickel-laterite exploration.

Regional exploration for nickel-laterite deposits is usually of a visual nature. The colour of the soil or the type of vegetation may serve as indicators (3, p. 29). Because nickel-laterite soils are deficient in elements important to normal plant life and, therefore, are only able to support certain types of growth, the vegetation over the deposits may contrast with the surrounding vegetation and, by doing so, indicate nickel potential. Such indicators find only local application for climatic variations alter the types of growth that lateritic soils will support.

Normal exploration procedure in areas expected to contain lateritic nickel ores involves either test-pitting or drilling on a grid basis. Since the high nickel values tend to be concentrated in the lower layers of the lateritic deposits, it is essential that sampling be carried down to the unaltered primary rock.

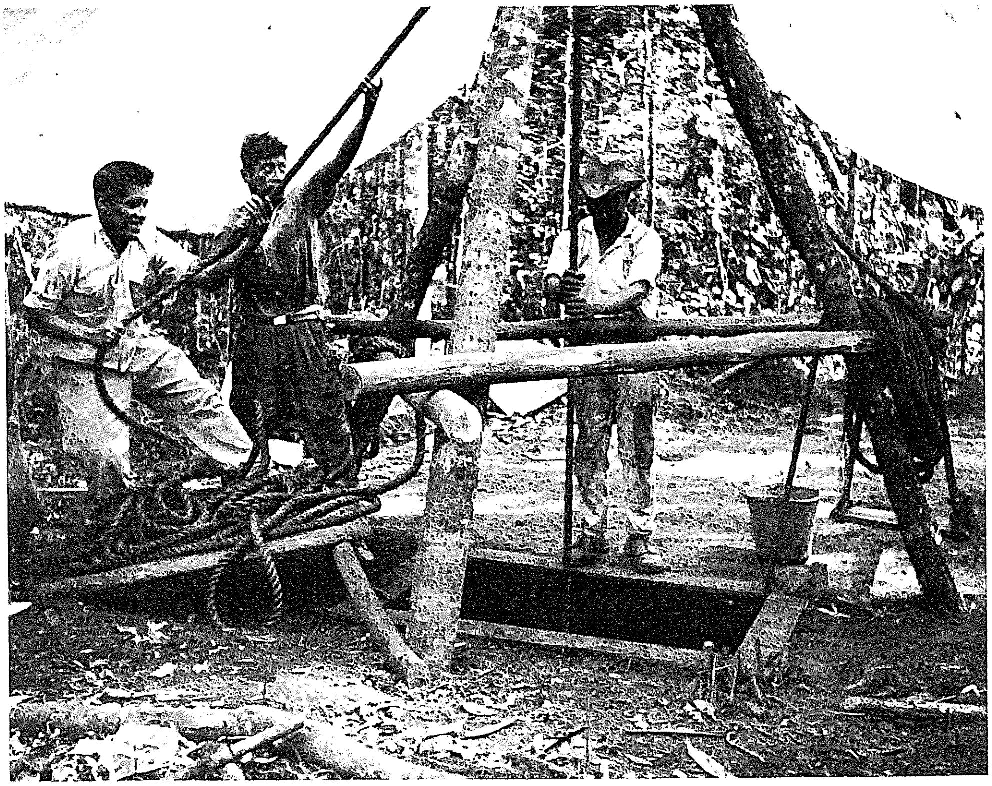

FIGURE 6. Test pit on nickeliferous-laterite deposit, Guatemala.

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*Ref. (3-5).

The deposits of Moa Bay, Cuba, provide a typical example of nickeliferous laterite exploration procedure(5). These lateritic deposits have been known since the end of the nineteenth century but their exploration awaited the development of an economic method of treatment. Exploration work began in 1952 with a reconnaissance program. Drill holes on 1,300-foot centres outlined several ore zones*. Within these zones, holes were drilled on 330-foot centres. Four years of drilling had proven ore reserves in excess of 50 million tons. In preparing the ore zones for mine development, drill holes were put down at 110-foot centres for grade control and intermediate holes, on 55-foot centres, were drilled to the top of the ore to establish the overburden cut-off.

*6-inch power-auger drills are commonly used in laterite exploration but hand-augers may be employed in difficult terrain.

CHAPTER 4

MINING

INTRODUCTION

Although the nickel industry has made important contributions to the evolution of mining, nickel mining methods are, in general, conventional. The objectives of this chapter are to outline the evolution of mining methods in the nickel industry, to detail some contributions to the development of mining methods in general, and to provide a general outline of the mining methods most widely used today in the nickel industry.

The primary factors that determine the mining method to be used are the physical characteristics of the deposit and its surroundings. These include the size and shape of the deposit, its depth and the type of overburden, the dip of the deposit, the strength of both the ore and the surrounding rock, and the grade of ore. While the mining method selected must function safely within these physical constraints, economic factors ultimately guide the decision.

Nickel-sulphide ores require hard-rock mining, primarily by underground methods. Nickeliferous laterites are almost always surface deposits, usually earth-like in consistency, and are mined by the open-pit method.

Canadian nickel-sulphide deposits are the most important source of nickel supply in the world today. Emphasis in this chapter is on the evolution and present state of mining methods in Canadian nickel mines. An outline is also given of the methods used to mine nickeliferous laterite ores.

MINING NICKEL-SULPHIDE ORES IN CANADA

Evolution*

In the Sudbury district, shallow high-grade sections of the nickel orebodies were the first to be mined, initially by random surface digging. By the turn of the century planned open pits were being developed. Mining was subsequently extended to a depth of about 200 feet by use of the glory-hole method. When all the ore that could be safely mined by these methods was removed, underground mining began. A floor was left below the glory

*Ref. (1)

holes and an overhand stoping method was adopted. Pillars were left where necessary. The mines at this stage of development were shallow, and artificial support was not required. There was considerable wastage. Usually only high-grade sections were mined. Lower-grade ores were left as pillars or unmined in the stope walls.

After the First World War, more orderly mining methods were introduced to meet the increasingly difficult conditions that resulted from mining at depth. Shrinkage stoping was adopted in the larger mines. By the end of the 1920s, controlled mining methods, giving greater artificial support and permitting a more complete recovery of orebodies, had been introduced. The cut-and-fill method or the square-set method were used depending primarily on the strength of both the ore and the wall rock. These methods, with modifications, have persisted. The undercut-and-fill method was developed by International Nickel in the early 1960s. It has partially replaced the square-set method for pillar recovery and is especially suited to deep-level mining.

As a result of advances in nickel processing technology over the past 30 years, large blocks of low-grade ore, previously marginal or subeconomic, have become economically attractive. Three low-cost mining methods have been applied to permit the mining of these leaner, disseminated ores.

(i) At mines where ore formation favoured bulk underground mining, the blast-hole method was developed. This method has, under such conditions, proven more economical than earlier types of shrinkage mining and has also, in certain cases, replaced the cut-and-fill method(2,3).

(ii) Reduced operating costs obtainable by the introduction of improved open-pit equipment and techniques, have encouraged a return to open-pit mining to recover low-grade disseminated deposits neglected in the initial operations(4,5).

(iii) A low-cost caving method was implemented in the 1950s at International Nickel's Creighton mine to recover caved material from completed shrinkage-stoping operations and other low-grade ore zones(6).

Outline of Present Practice*

Shrinkage Method

The economics of shrinkage stoping favour its application in relatively narrow, steeply dipping, low-grade deposits where both the ore and surrounding rock are strong. Since the ore must stand by itself during the whole mining process, it must be strong over the stope dimensions. The wall rock must not be excessively weak or it will slough off and dilute the ore as it is withdrawn. At depth, the shrinkage method does not usually offer sufficient support.

The distinctive feature of shrinkage stoping is that broken ore is left in the stope to support the walls while the remainder of the stope is mined. Mining is done on top of the broken ore. The volume of ore expands when it is broken and after each horizontal slice is mined, enough broken ore must be drawn off from below to provide working space between the top of the pile of broken ore and the back of the stope. The shrinkage method consists of a series of sequential stages: drilling, blasting and pulling broken ore until the floor pillar of the level above is reached. When mining is completed all the broken ore is drawn from below, leaving the stope empty. Later the stope may be filled

*Ref.(1)

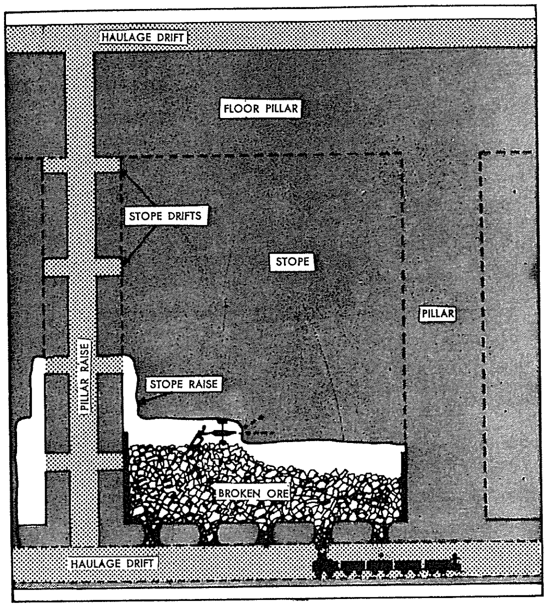

FIGURE 7. Generalized section of longitudinal shrinkage stope.

to prevent ground movement and subsidence or to facilitate the mining of pillars left between stopes during the initial mining stage. The use of cemented sand fill by International Nickel has extended the application of the shrinkage method to areas and at depths normally requiring cut-and-fill mining(7).

In shrinkage mining the bulk of broken ore is tied up in the stope until mining is completed and a time cost is incurred for this delayed recovery. The delayed recovery also encourages the oxidation of the sulphide minerals. This may result in metallurgical recovery problems.

Square-set Method

The square-set method(8) is the most selective and most costly underground method and, therefore, it finds application only in the mining of high-grade irregular orebodies where the ore is structurally weak. Although square-set mining is still important, particularly for pillar recovery, the method is used decreasingly because of both the declining average grade of ore reserves over time and the advances that have been made in cut-and-fill and undercut-and-fill methods.

In square-set mining, the walls and back of the stope are supported by a timber framework, fitted together in a cellular structure. The cells or sets, built up in a lattice framework, provide continuous lines of support in three directions at right angles to each other.*

Mining proceeds upward from the level in horizontal panels or floors. The ore is drilled, blasted and removed in small rectangular blocks, large enough to provide room for the installation of one square-set. The sets of each floor are locked into the sets below. Permanent support for the stope walls is supplied by filling. This is placed as soon as possible after a horizontal panel is worked out, especially if the ground is heavy.

*Although practice varies, 6 ft x 6 ft x 8 ft high would be a representative dimension of a square-set.

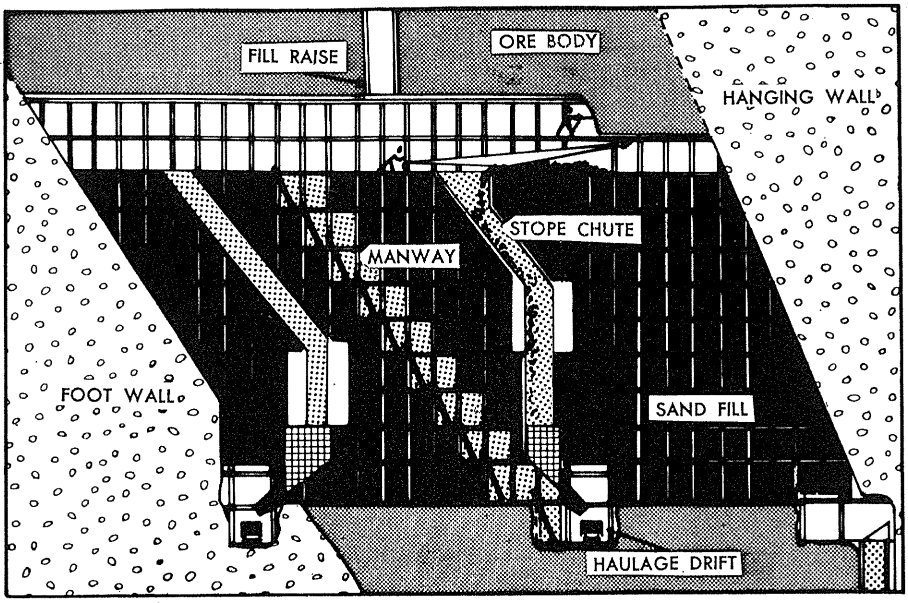

FIGURE 8. Generalized section of square-set stope.

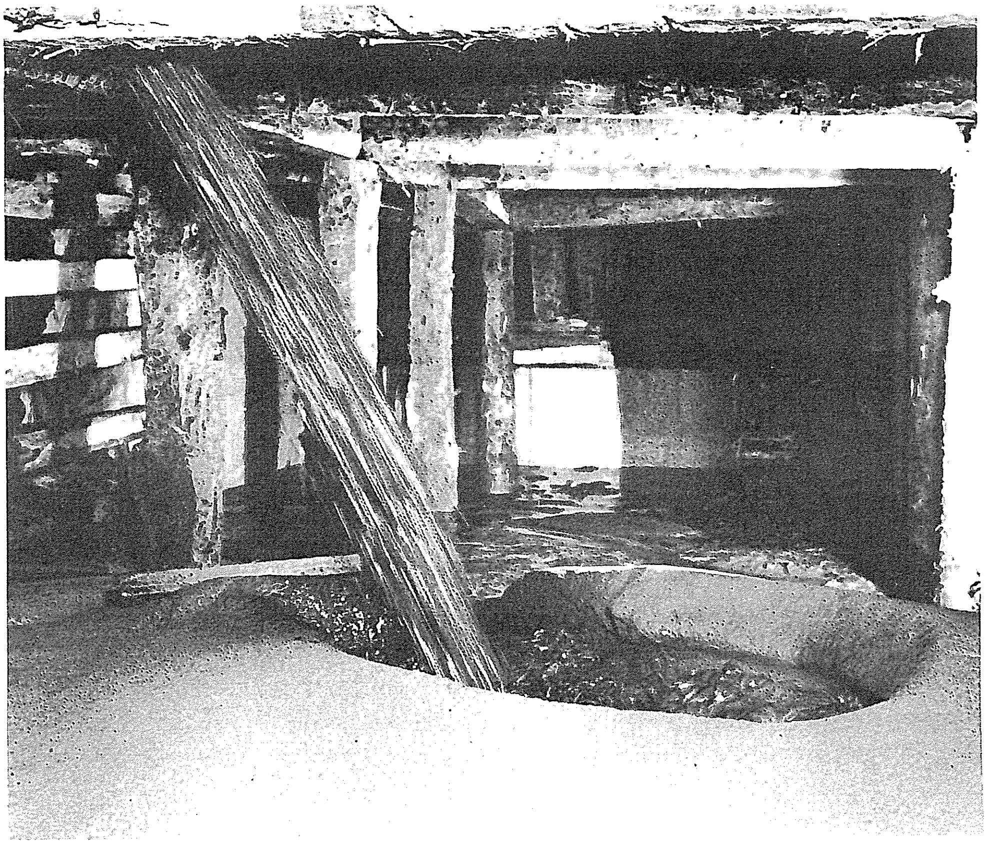

FIGURE 9. Water-borne sand fill flowing into square-set stope.

Cut-and-fill Method

Cut-and-fill mining(9,10) is the most widely used method in Canadian nickel mines. The method is applicable where ores are strong enough to permit safe working under the overhanging back, but the wall rock is weak enough to require the almost immediate support of fill. The development of rock bolts and the use of arched backs have extended the application of the cut-and-fill method to ore zones that previously required square-setting(11).

In cut-and-fill stoping, the ore is mined by successive horizontal slices, working upward as in shrinkage stoping. After each cut, the broken ore is removed and filling material is run up to within a few feet of the back, providing permanent support for the walls and a working floor for the next slice. The use of cemented sand fill has increased the recovery of ore with less wall rock dilution and has reduced timber consumption(7). Ore is scraped into chutes that are carried up through the fill.

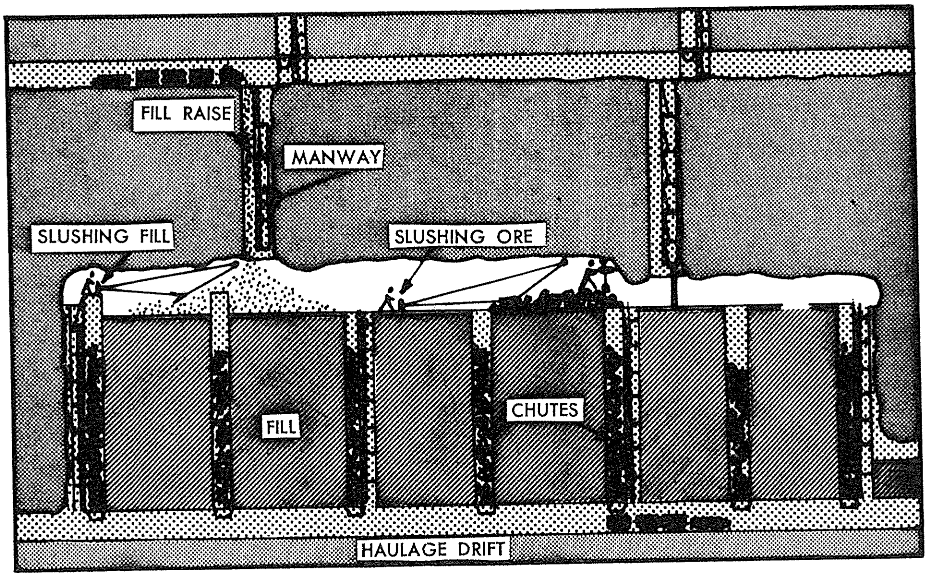

FIGURE 10. Generalized section of longitudinal cut-and-fill stope.

Improved ore-handling and waste-stowing have extended the use of cut-and-fill stoping. Increased productivity has also resulted from the use of wagon drills and prilled ammonium nitrate explosives.

Undercut-and-fill Method

International Nickel has pioneered the development of the undercut-and-fill method(10,12). It is now used for pillar recovery under normal mining conditions, where the ground renders square-set mining too costly. Its use in primary stoping operations is also being developed. Undercut-and-fill mining is expected in many cases to be an economical substitute for the square-set method, particularly at depth.

Undercut-and-fill mining extracts a block of ore by mining successive horizontal slices, from the top down. After a slice of ore is mined out, two laminated timber stringers are assembled to give continuous beam support along the stope length. They are

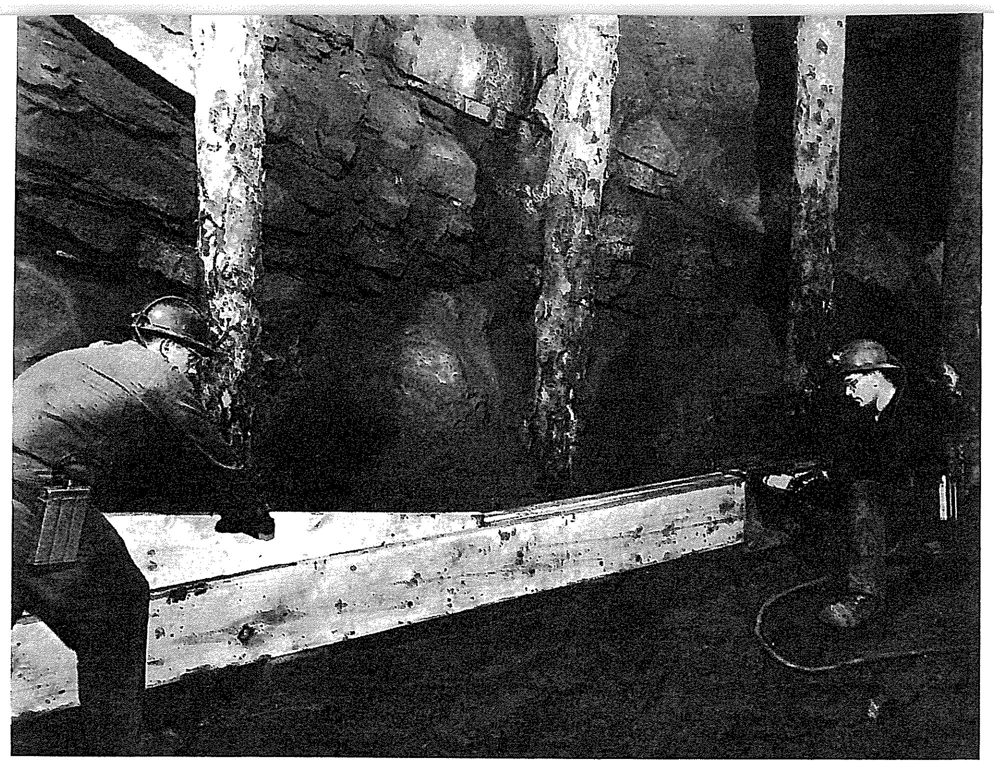

FIGURE 11. Constructing a laminated stringer in undercut-and-fill stope.

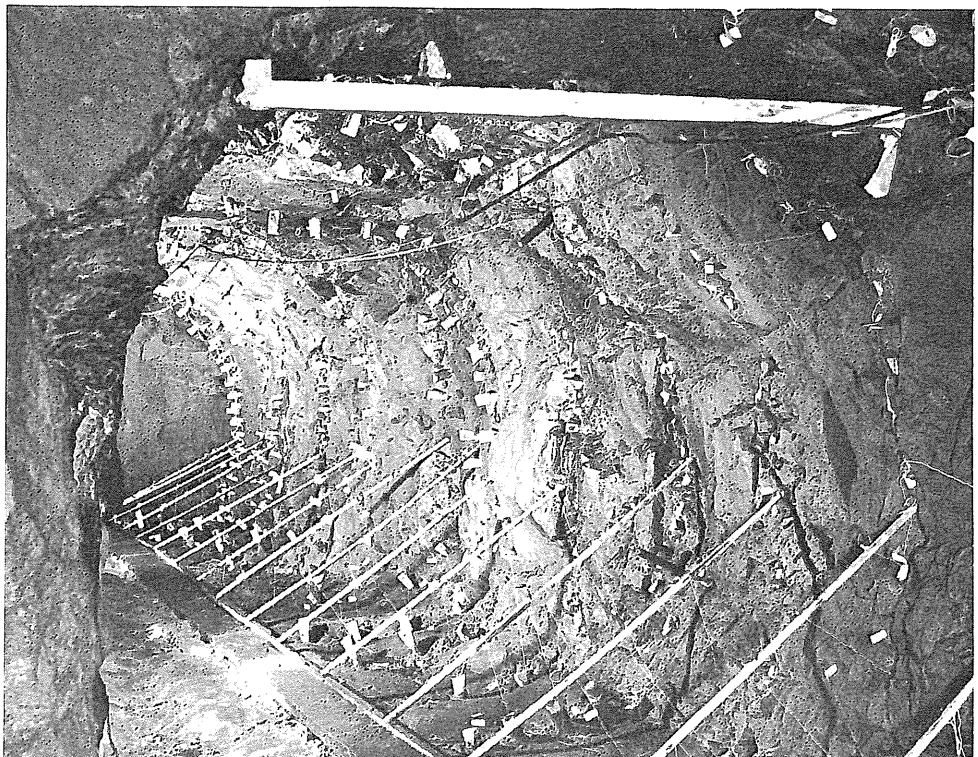

FIGURE 12. Blast-hole sub-level drill drift loaded and wired for blast.

joined to the bases of timber posts that are seated on the solid bottom to support the stringers above. Logs are laid across the stringers, forming a timber mat and the slice is filled. Cemented sand fill has been used. This provides good stability and permits the substitution of conventional timber stringers for the laminated stringers. Because this type of fill is cohesive, wire mesh may replace the timber mat. A second mat modification, known as a scissor mat, is rock-bolted to the pillar walls and eliminates the use of posts for support(7).

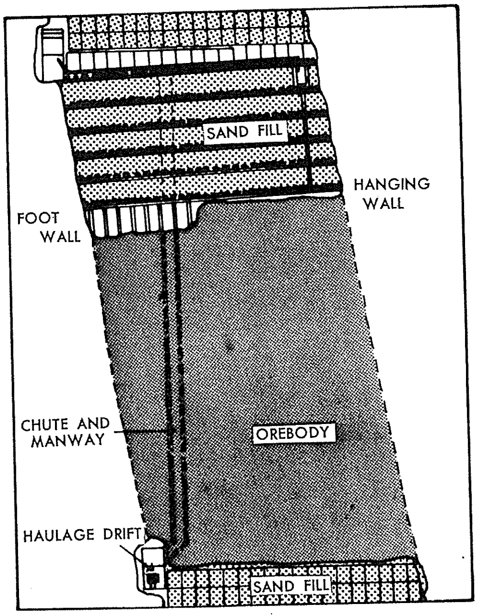

FIGURE 13. Generalized section of rib pillar mined by undercut-and-fill method.

Mining subsequently proceeds on the next slice below the fill. Drilling, blasting, scraping and timbering operations are repeated until all the ore in the slice has been removed. Ore is removed through a raise, developed through the block before mining commences. After a slice is completed, stringers and mat are laid, the slice is filled, and the mining cycle is repeated.

Timber consumption for undercut-and-fill mining is considerably lower than for square-set mining, particularly when cemented sand fill is used(7). Mining productivity is higher than in square-set mining.

Blast-hole Method

The blast-hole method is a Canadian contribution to mining methods; it involves longhole drilling and its development and use have not been confined to the nickel industry. This method is used to mine low-grade ore where both ore and wall rock are competent. Since it is a bulk method, some dilution results and it is not as selective as the four methods previously described. However, the stope walls do not have to be supported and there are important labour economies in longhole drilling. Thus the blast-hole method has, in many cases, proven to be more economical than shrinkage mining.

Each block of ore is developed by a series of drifts that run along the stope length at horizontal and vertical intervals, spaced so that diamond drill longholes from each drift can be interlaced with those of adjacent drifts. A system of boxholes is developed at the base of the block and is carried ahead of the face. Stoping commences with the blasting of a vertical slot at one end of the block.

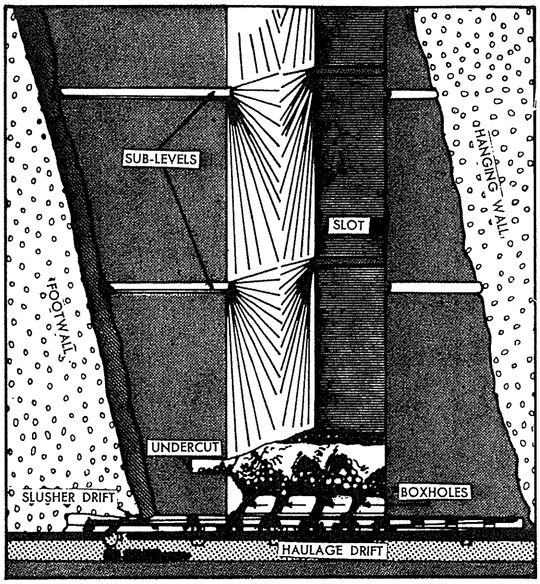

FIGURE 14. Generalized perspective view of blast-hole stope.

The drilling method is termed 'ring-drilling'. From each drift in the solid ore, rings of holes in a vertical plane are drilled at horizontal intervals of about six feet. All holes in each vertical plane are blasted simultaneously and vertical slices of ore are blasted in turn into the widening slot. The ore is pulled as it is blasted. The empty slot allows the broken ore to fall freely to the boxholes. Usually drilling is several slices in advance of the stope face so that slices can be blasted as the ore is required.

International Nickel has developed a modified mining method, block cut-and-fill, that combines the low-cost blast-hole method with cut-and-fill techniques, using cemented sand fill(7).

Caving Method

A low-cost caving method(6) was developed at the Creighton mine in the early 1950s for the mining of caved material from earlier shrinkage stoping and for the extraction of new low-grade ore. The caving method is applicable to homogeneous, weak orebodies that will cave under their own weight and crush into a manageable size for removal.

For the mining of new ore zones, the ore is undercut and the vertical sides of the ore block are so weakened that the block gradually collapses under its own weight. As the ore collapses, internal stresses provide crushing forces which break the ore as it moves downward. This eliminates drilling and blasting operations. The caving method is non-selective and some waste rock is broken up and drawn with the ore. The drawing of each block continues until a predetermined cut-off grade is reached.

Boxholes for the caving method are closely spaced under a block so that, as the bottom of the block caves and crushes, the broken ore may be drawn to provide room for the ore above to cave and crush. The rate of draw is a critical factor in the success of this mining method. If the ore is not drawn rapidly enough, the crushed ore will pack around the top of the boxholes, necessitating secondary blasting. If the ore is drawn too rapidly, voids will be created that allow large pieces to fall without crushing. To minimize dilution, it is necessary to draw each block evenly.

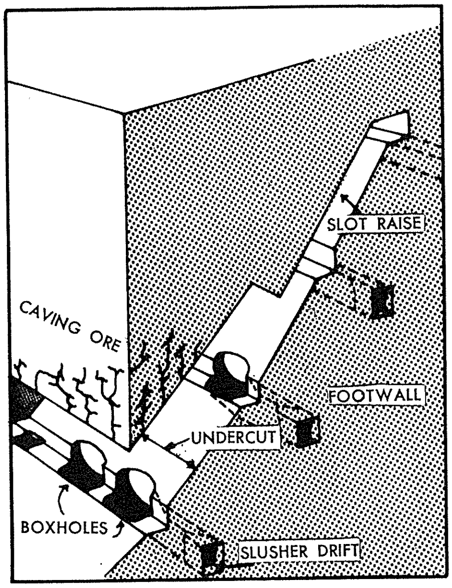

FIGURE 15. Generalized perspective view of caving method.

Open-pit Method

Although most Canadian nickel deposits are at depth, a few disseminated surface or near-surface deposits are being mined by the open-pit method(4). The use of this method has been stimulated by advances in open-pit technology, reducing the economic cut-off grade.

Important considerations in the choice between open-pit and underground methods for a given deposit arc the depth of overburden, the ore-to-waste ratio, and the size of the deposit. In Canada, climatic conditions give rise to special open-pit problems and techniques.

The mining cycle foı an open-pit operation consists of drilling, blasting, loading and transporting ore and waste. Primary drilling produces vertical or near-vertical blast-holes behind the open face of a solid bench. The height of the benches is selected to give maximum digging efficiency. The slope of the pit walls depends on the stability of the

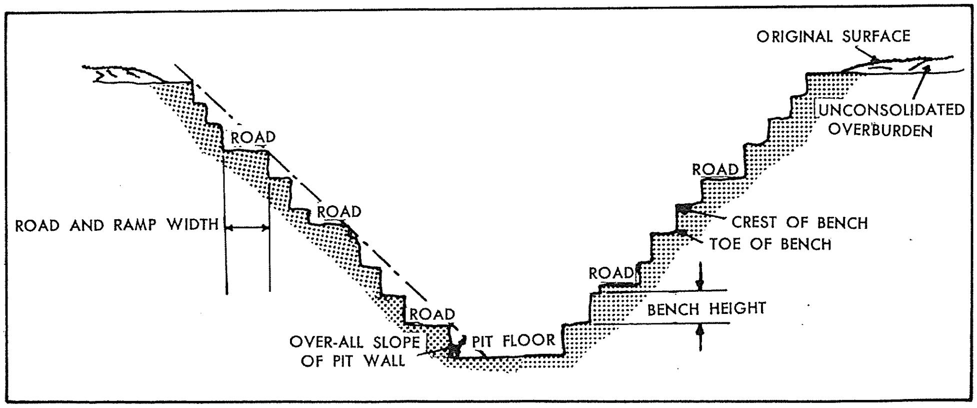

FIGURE 16. Generalized section of open-pit.

wall rock. Blasting is of primary importance. By 1963, a mixture of ammonium nitrate prills and fuel oil had replaced high explosives as a low-cost, efficient blasting agent. Secondary drilling and blasting are required to break boulders too large for the shovel to handle. Ore and waste are loaded by electric or diesel shovels with typical capacities of four to six cubic yards. Diesel trucks carry the broken rock up haulage roads out of the pit to the crushing station or waste dump.

One Canadian open-pit nickel mine started production in 1962 with a nominal annual production of two million tons of ore and a stripping ratio of 1:1. The bench height is 60 feet and the over-all slope of the pit walls is 55 degrees. The road and ramp width is 50 feet, carried at a maximum grade of 10 degrees.

MINING NICKELIFEROUS-LATERITE ORES*

The nickeliferous-laterite deposits in New Caledonia, Cuba, and the United States, are mined exclusively by open-pit methods. The deposits usually occur at a relatively shallow depth in layered form, with moderate overburden.

Mining practice is simple as the ores are typically soft and claylike and can be easily excavated. Blasting is not usually required. Overburden and ore are excavated by power shovels, scrapers, draglines or bulldozers. In the relatively small, independent New Caledonian operations, some work is done by pick-and-shovel.

Initially, the overburden is stripped to a cut-off point, usually predetermined by development drilling on a grid basis, sampling and assaying. Then the ore is excavated. Waste boulders may be sorted from the mined ore and discarded. Ore may be stockpiled or transported to the processing plant by truck, ship, aerial tramway or pipeline. The bottom cut-off of the ore is determined by assay or visual means. The final recovery of ore from bedrock pockets may require special techniques.

Grade control is important in nickeliferous-laterite mining. Nickel values are unevenly distributed in the deposits. A uniform feed is essential to maintain an adequate recovery of nickel in the processing plant. High mining selectivity and blending are required for grade control. Ore is usually mined at several locations within a deposit and brought to a central point for blending before being transported to the processing plant.

*Ref. (1, 13-16).

CHAPTER 5

PROCESSING

INTRODUCTION

This chapter describes the most important extraction processes used in the nickel industry. No attempt is made to outline the principles of mineral dressing and extractive metallurgy that underlie these processes.*

For sulphide ores, discussion is limited to those processes used by the three integrated Canadian producers: International Nickel, Falconbridge, and Sherritt Gordon. Outlines of processes used for treating nickeliferous laterites are confined to the operations of Le Nickel, Hanna Mining, and the Cuban producers prior to nationalization in 1960.

NICKEL-SULPHIDE ORES

In addition to the processing operations outlined below, nickel-sulphide ores are processed in the USSR and Finland.

Milling and Concentration**

Milling and concentration practices used by International Nickel, Falconbridge and Sherritt Gordon are described in generalized terms.

Primary crushing is usually done underground, followed by a secondary crushing on the surface. For high-grade ores, the product of the secondary crusher may be magnetically separated, the magnetic fraction being dispatched directly to the smelter. The secondary-crusher product, or its nonmagnetic fraction, is then ground in rod or ball mills. Where the pentlandite is finely disseminated in the pyrrhotite, the ground product may proceed to a wet magnetic separation, the pyrrhotite fraction of which is subsequently floated to produce a low-grade nickel concentrate. This concentrate goes to the smelter or refinery. The ground product, or its nonmagnetic fraction, is laundered to sumps for distribution to rougher flotation cells. Two products are recovered: a bulk nickel-copper concentrate and a tailings product.

The bulk nickel-copper concentrate may go directly to the smelter, or may first be separated by differential flotation into a high-grade nickel concentrate and a high-grade copper concentrate. The nickel concentrate is sent to a nickel smelter or refinery; the copper concentrate to a copper smelter.

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*The most comprehensive and up-to-date description of both nickel processing principles and the processes themselves is contained in reference 1.

**Ref. (2-6).

The tailings product from rougher flotation is laundered to scavenger flotation cells producing a low-grade concentrate that joins other concentrates for shipment to the nickel smelter or refinery, and a tailings product. The tailings are classified. The coarse fraction is usually used for mine backfill and the fine fraction discarded. A wet magnetic separation may be effected before or after scavenger flotation. The magnetic fraction is reground and floated, producing an additional low-grade nickel concentrate that is sent to the nickel smelter or refinery and a pyrrhotite concentrate that is subsequently treated to produce an iron concentrate.

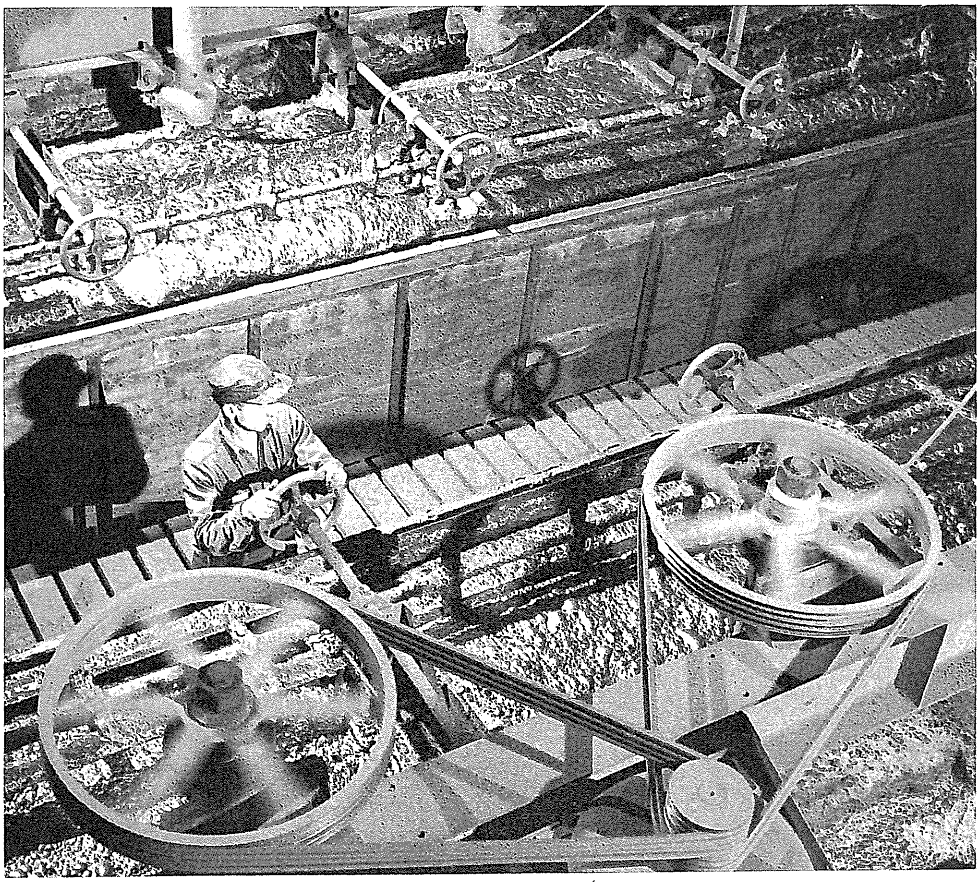

FIGURE 17. Flotation cells, Falconbridge Nickel Mines.

Pyrometallurgical Processes

The Orford process, the traditional method of separating nickel and copper sulphides, was used by International Nickel until 1948 when it was replaced by the matte flotation process. The Orford process carried out the separation by two 'top and bottom' meltings using coke and sodium sulphate. The final top contained copper sulphide and was smelted to yield blister copper. The final bottom, containing nickel sulphide, was roasted, sintered and reduced with coke to metallic form. With the application of electrolytic refining by International Nickel in the early years of the century, metal from the reduction furnaces was cast directly into anodes.

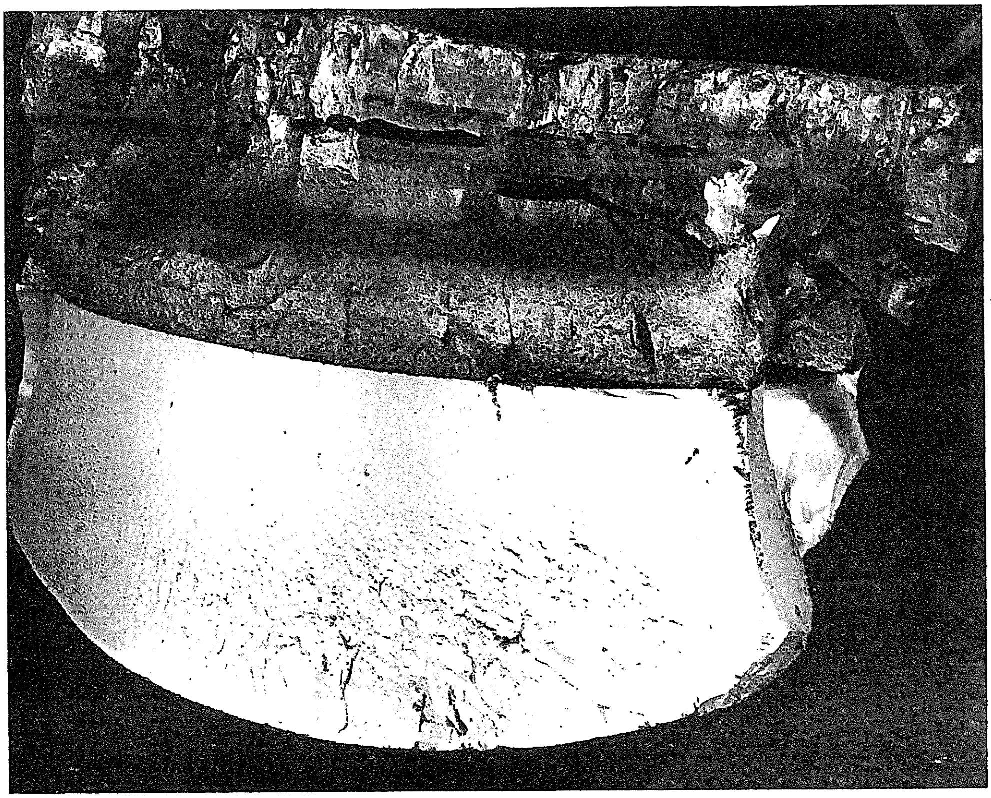

FIGURE 18. 'Tops' and 'Bottoms'. Top layer: copper sulphide. Bottom layer: nickel sulphide. (Approximately three feet high and five feet wide.)

*International Nickel, Copper Cliff Smelter**

Nickel-sulphide concentrate and sand flux are fed into multi-hearth roasters, producing a partially oxidized calcine for the reverberatory furnaces.** In the reverberatory furnaces, part of the iron is removed as a ferrous-silicate slag and the matte, containing about 15% nickel-copper, is tapped into ladles. Oxygen is used to enrich the combustion air, improving fuel efficiency and increasing furnace capacity.

The molten matte is transferred to converter furnaces. A silica flux, part of the matte product from the company's Coniston smelter, high-grade ore, and scrap, are added. Most of the remaining iron is skimmed as a ferrous-silicate melt and recycled through the reverberatory furnaces. The converter air blast is enriched with oxygen to improve efficiency, increase capacity and permit the smelting of a larger cold charge.

The converter matte product (Bessemer matte), containing about 77% nickel-copper and 22% sulphur, is poured into moulds for controlled cooling for about three days, producing grains that are separate and distinct chemical phases. This permits a clean separation of the three fractions: nickel sulphide, copper sulphide, and a nickel-copper alloy that contains most of the precious metals. The remainder of the matte product from the Coniston smelter is remelted in the slow-cooling moulds when the matte is cast.

* Ref. (7-11).

**The multi-hearth furnaces are being replaced by fluid-bed roasters.

The matte constituents are separated in the following manner. The 25-ton ingots are broken, crushed and ground. The nickel-copper alloy is separated magnetically and the magnetic fraction processed for precious-metal recovery. The nickel and copper sulphides are separated by differential flotation. The copper-sulphide concentrate is dispatched to the copper circuit.

One part of the nickel-sulphide concentrate is sent directly to the Port Colborne refinery where it is cast into sulphide anodes. The remainder is pelletized and fluid-bed

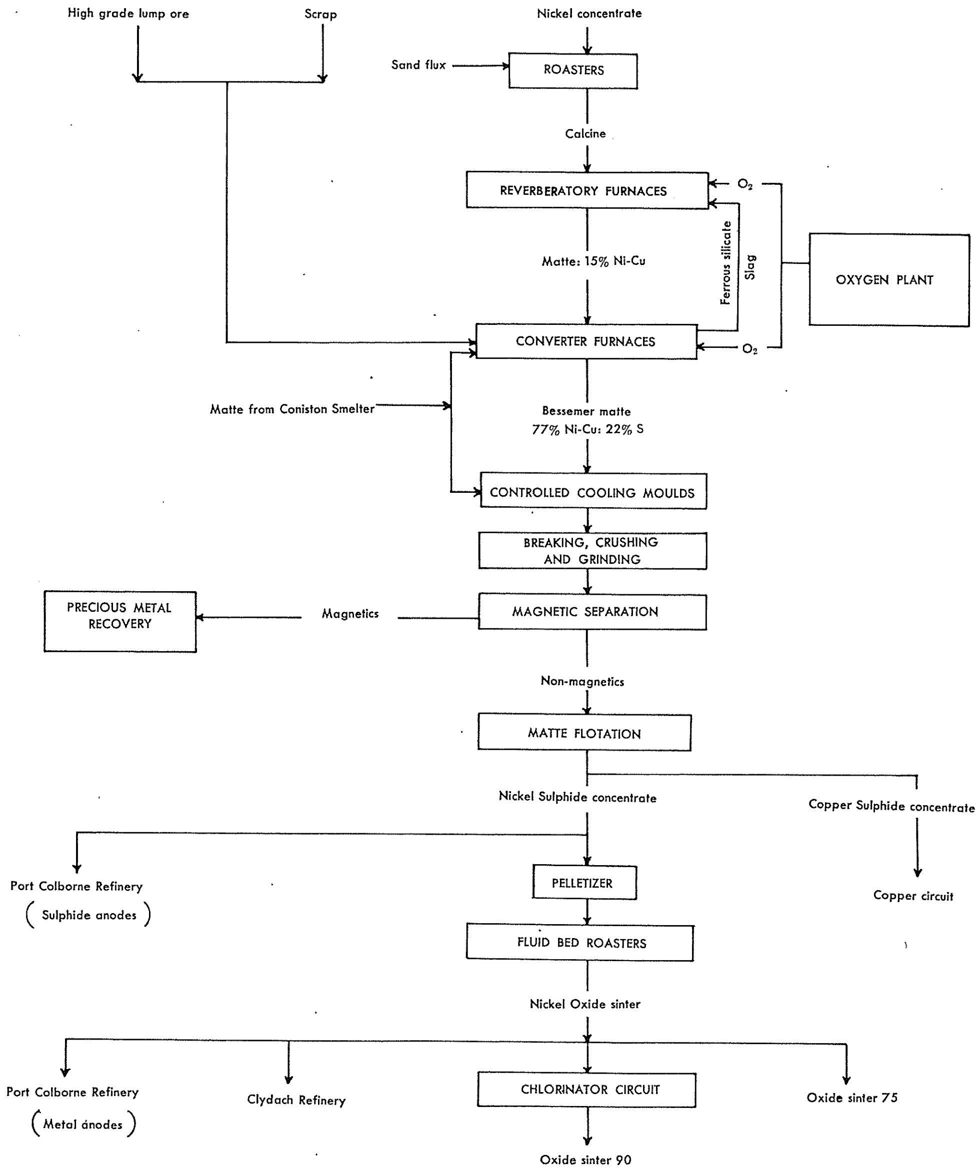

FIGURE 19. Generalized flowsheet, nickel circuit: Copper Cliff smelter.

FIGURE 20. Matte casting and cooling, Copper Cliff smelter.

roasted to produce nickel-oxide sinter. The nickel-oxide product, analyzing about 75% nickel, may be used in one of four ways:

(i) sent to Port Colborne refinery, where it is reduced to metal and cast into anodes for electrolytic refining.
(ii) marketed for direct use as a ferroalloy.
(iii) upgraded to a nickel-oxide product analyzing about 90% nickel, and marketed for direct use as a ferroalloy.
(iv) sent to Clydach for refining by the Mond Process.

International Nickel, Thompson Smelter

The Thompson smelter circuit(12) is similar to the initial phases of the nickel smelter at Copper Cliff but because the ore contains only a small amount of copper, the matte flotation process is eliminated.

Hot calcine and heated flux from fluid-bed roasters are recovered in cyclones and then fed into electric furnaces. Matte is tapped into ladles and transferred to converters. The molten nickel-sulphide Bessemer matte, containing about 75% nickel and 3% copper, is cast into anodes for electrolytic refining.

International Nickel, Coniston Smelter

This smelter was placed in operation in 1913 by The Mond Nickel Company.

The smelter feed consists primarily of high-grade ore that has been magnetically separated from the secondary-crusher product. Some concentrates are also used. The feed is sintered before proceeding through blast furnace and converter stages. The Bessemer matte produced is sent to the Copper Cliff smelter, where part of it is remelted in the converters and the remainder remelted in the slow-cooling moulds when the matte is cast.

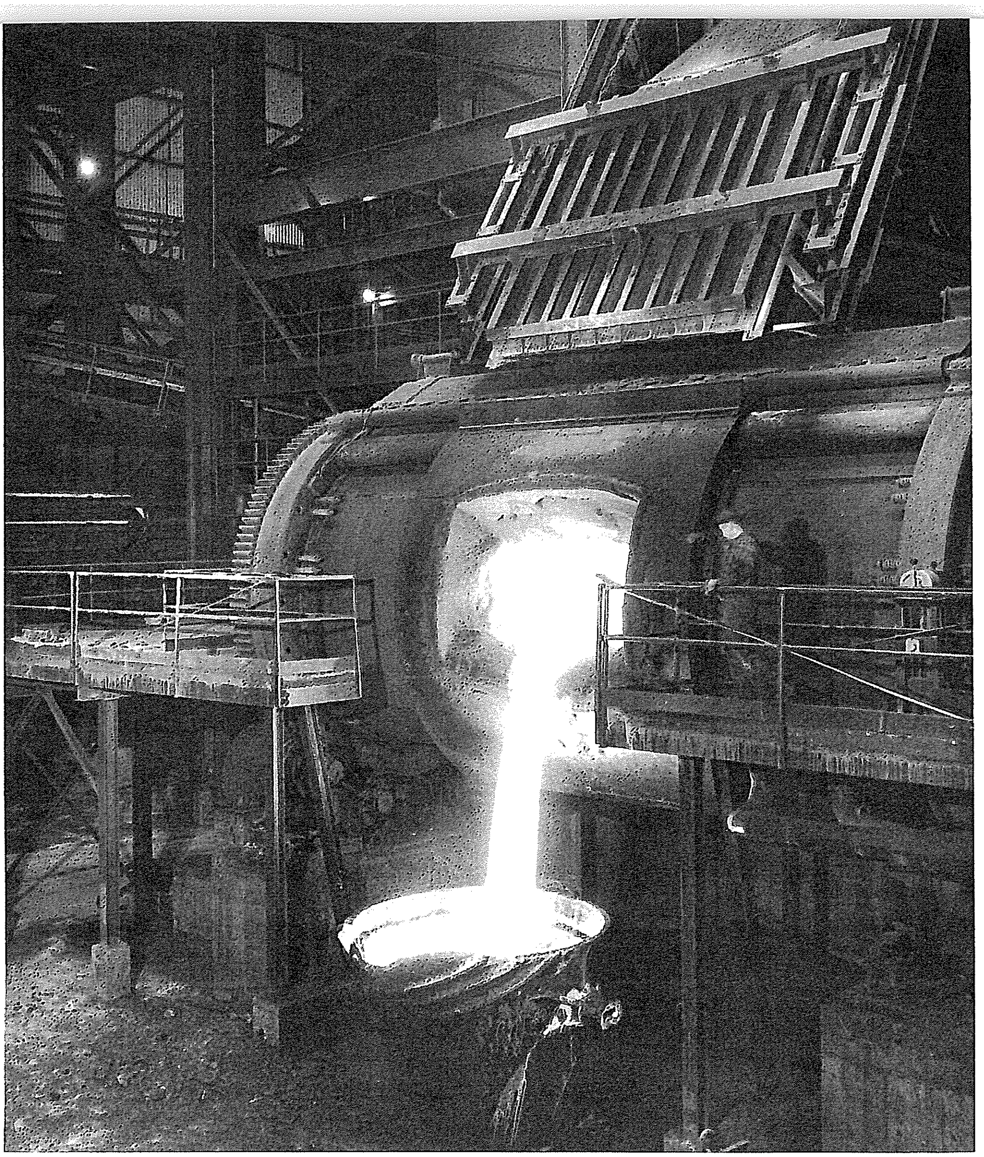

FIGURE 21. Pouring slag from converter furnace, Falconbridge smelter.

*Falconbridge Smelter**

The initial step in the smelter process is the agglomeration of the bulk nickel-copper concentrate from Falconbridge's three mills and from outside sources. The concentrate is blended with flue dust and pelletized. The pelletized product is sintered together with returned sinter fines and a flux of sand and limestone. Flue dust from sintering is recycled to the pelletizing stage. The minus-2-inch sinter product is returned for additional sintering.

The oversize sinter, together with coke, crushed converter slag, and lump ore from magnetic separation in the mill, is charged to blast furnaces. The mixture of slag and matte produced in the blast furnaces is fed continuously into settlers, and molten converter slag is added intermittently. Settler slag is dumped.

Settler matte is charged to converter furnaces. In the converters most of the remaining iron is oxidized and fluxed with silica. About three quarters of the converter slag is recycled to the blast furnace settlers. The remainder is cooled, crushed and resmelted in the blast furnaces.

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*Ref. (6).

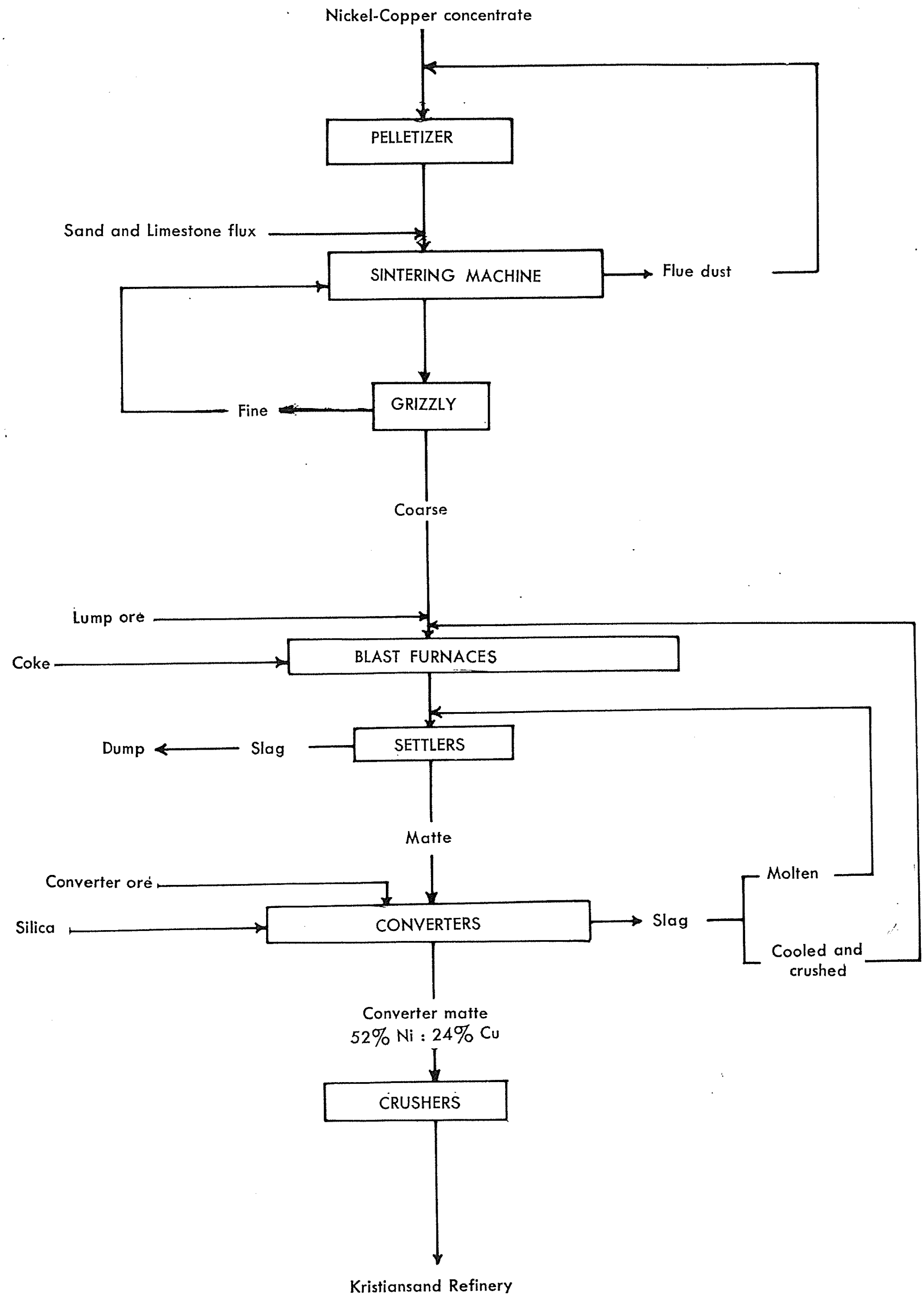

FIGURE 22. Generalized flowsheet, Falconbridge smelter.

The converter matte, containing about 52% nickel and 24% copper, is poured into moulds, cooled, broken, crushed, barrelled, and sent to the company's refinery in Norway.

Refining Processes

There are three basic commercial processes currently in use for the refining of metallic nickel from the matte or concentrate products of nickel-sulphide ores: the electrolytic process, and the Mond process, both in operation since the early years of the century; and the ammonia pressure leach process, developed in the late 1940s.

Electrolytic Refining, General

Electrolytic refining of nickel accomplishes two purposes: the deposition of high-purity nickel and the recovery of soluble and insoluble by-products, including precious metals. The process involves the transfer of nickel from an impure anode for deposition on a cathode of high-purity nickel by the circulation of an electrically conductive solution (the electrolyte). The anode and cathode are connected to a power source and an electrical circuit is formed by the anode, electrolyte and cathode (see Figure 24).

The anodes, consisting of impure nickel or nickel sulphides, are placed in tanks containing the electrolyte. Between each pair of anodes is a canvas-covered compartment in which a cathode is hung–the classical divided cell discovered by N.V. Hybinette about the turn of the century. This prevents the plating-out on the cathode and contamination of it by elements, such as copper, lower in the electromotive series than nickel. There is no direct transfer of ions from anode to cathode. Initially, the cathode consists of a thin starting sheet of pure nickel. Pure electrolyte, consisting primarily of ionized salts of nickel sulphate and nickel chloride, is fed into the top of the cathode compartment under a hydrostatic head, inducing an outward flow of electrolyte through the porous canvas walls. While passing through the compartment, nickel ions are transferred from the electrolyte to the cathode.

Outside the cathode the electrolyte picks up nickel, iron, cobalt, copper and other ions from the anode. The impure electrolyte is then removed for purification–the removal of iron, cobalt, copper and other impurities. The purified solution, containing a circulating load of nickel ions, is recycled to the cathode compartments.

Insoluble impurities, including precious metals, sulphur and selenium, collect as sludge at the bottom of the electrolytic tank as anode dissolution proceeds. The sludge is processed for the recovery of precious metals.

Where nickel-sulphide anodes are used, there may be additional steps in sludge processing to recover elemental sulphur. Also, the nickel content of the electrolyte has to be adjusted to compensate for the nickel imbalance between the cathode and anode reactions. Nevertheless, the electrolytic refining of metal anodes and sulphide anodes is basically the same. Important factors in the selection of sulphide-anode or metal-anode processes are the cost of power and the local market demand for by-products.

Most of the cathode product, usually more than 99.9% nickel, is sheared into squares and marketed.

*International Nickel, Port Colborne Refinery**

Before 1956, all electrolytic nickel refining at the Port Colborne refinery used metal anodes and most refined nickel is still produced by this method. However,

*Ref. (11, 13, 14).

FIGURE 23. Electrolytic nickel refining, Kristiansand refinery.

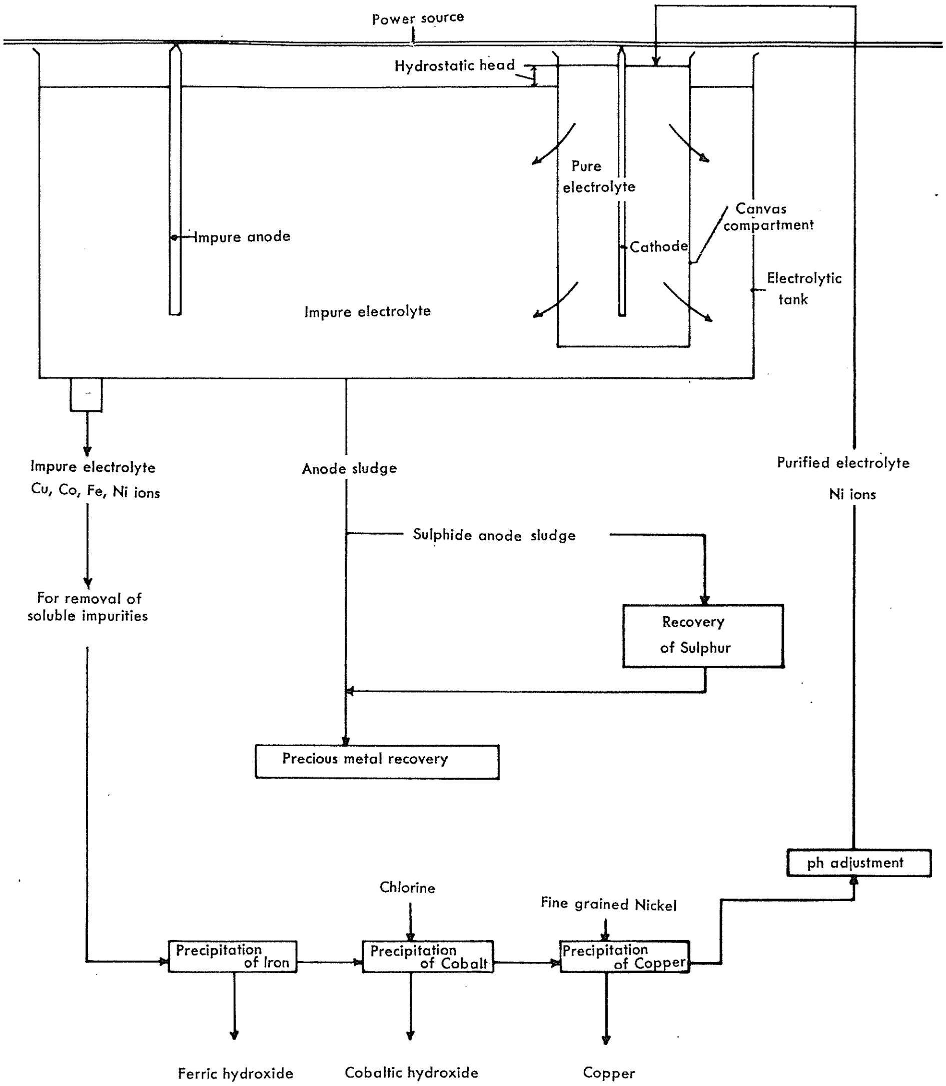

FIGURE 24. Generalized electrorefining flowsheet, The International Nickel Company of Canada, Limited.

with the advent of the matte-flotation process and the successful development of the sulphide-anode process it became advantageous to treat a minor part of the refinery feed by the direct electrolysis of artificial nickel-sulphide anodes. The electrorefining processes follow the general description.

The nickel-oxide sinter and the artificial sulphide concentrate required for the electrolytic circuits are derived from the Copper Cliff smelter. Nickel-oxide sinter is charged into anode furnaces with coke and reduced to metal, and nickel anodes are cast from the melt. Artificial nickel-sulphide concentrate is melted and cast into nickel-sulphide anodes.

International Nickel, Thompson Refinery

The Thompson refinery(15) processes nickel-sulphide anodes. The process used follows the general description given at the beginning of this section. Iron, arsenic, cobalt, copper and other elements are removed in the electrolyte purification process. In addition to cathode nickel, the refining plant products include cobalt oxide, sulphur and precious-metals concentrate derived from the treatment of anode sludge and slime.

*Falconbridge, Kristiansand Refinery**

The refinery raw material, crushed converter matte from the Falconbridge smelter, contains approximately 52% nickel and 24% copper. Nickel and copper are separated by roasting the matte to oxide and acid leaching the calcine to remove copper. The electrolytic refining process devised by Hybinette and commercially developed by him at Kristiansand, Norway, starting in 1910, still governs operations today although many improvements have been made.

The converter matte is crushed, ground and roasted to oxide and the calcine so produced is cooled and screened. The oversize product is reground and returned to the roasters. The undersize roaster product is continuously leached with acid-bearing spent electrolyte from the copper circuit. The free-copper oxide is readily dissolved by the acid and a minor fraction of the nickel also is taken up in solution. A minor fraction of the copper oxide, that has formed a solid solution with the nickel oxide during roasting, remains in the residue. Copper is electro-deposited from the pregnant solution and nickel sulphate is recovered from part of the solution.

The coarse portion of the leach residue pulp is hydrogen-reduced to impure active nickel for use in cementing out copper from the nickel electrolyte.

The fine portion of the leach residue is melted and reduced with coke in an electric furnace. Anode scrap is added and after skimming slag, the metal is tapped into anode moulds. The anodes are electrolytically refined following the general description given at the beginning of this section.

The primary refinery product is cathode nickel. Other commercial products are liquid sulphur dioxide, cathode copper, nickel-sulphate crystals, cathode cobalt, and precious metals.

International Nickel, Clydach Refinery

The Clydach refinery(13,17-19) uses the Mond, or Carbonyl, process, discovered by Ludwig Mond and Carl Langer in the nineteenth century. The process is based on the ability of carbon monoxide to transform nickel powder into nickel carbonyl gas at room temperature and atmospheric pressure. The refinery at Clydach, Wales, consists of an atmospheric carbonyl plant, and a pressure carbonyl plant, the former accounting for 95% of production. The refinery uses nickel oxide from the Copper Cliff smelter.

In the atmospheric carbonyl process the nickel oxide is ground, roasted and reduced to impure metallic powder with hydrogen and carbon monoxide in rotary reducer kilns. The impure nickel powder is fed into a rotary volatilizer kiln where nickel is separated from residue impurities. Carbon monoxide combines with the nickel to form nickel carbonyl gas that is sent to decomposer units. The volatilizer residue is leached to recover copper and nickel salts. The remaining material is processed for precious-metal recovery. In the decomposers, a column of nickel 'seed' pellets continuously circulates

*Ref. (6,16)

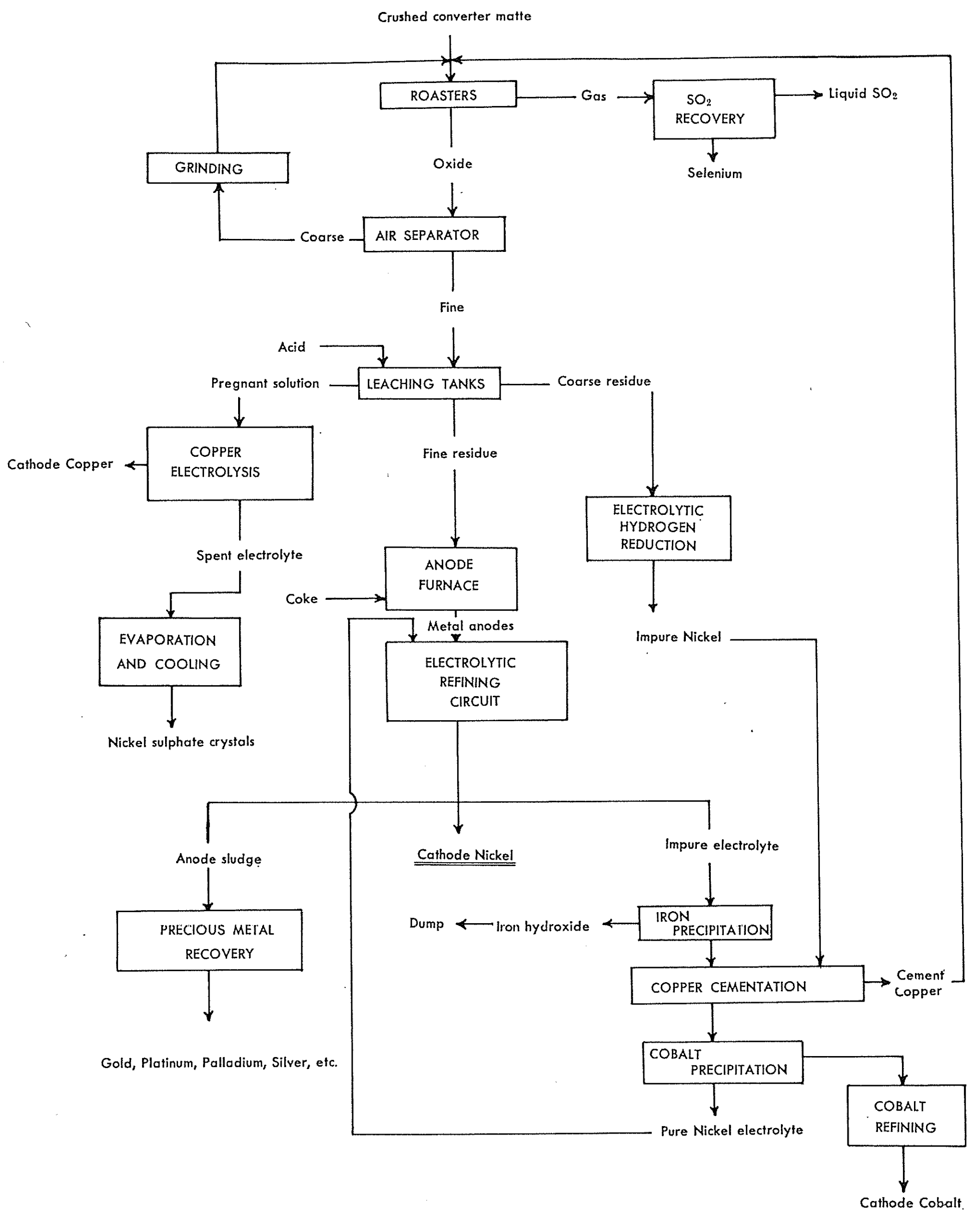

FIGURE 25. Generalized flowsheet, Kristiansand refinery.

through each unit. The nickel carbonyl gas from the volatilizers flows down and is distributed through the pellets. The gas is heated until it decomposes. Nickel deposits out as pure metal on the seed pellets and liberated carbon monoxide is returned to the volatilizers. The nickel pellets grow as they circulate in the decomposers. Overflow pellets are screened; undersize are recirculated, oversize are marketed.

The pressure carbonyl process is a batch method. Nickel oxide is reduced to impure metal in a reducer with hydrogen and carbon monoxide. The impure metallic residue is transferred to a volatilizer where carbon monoxide is introduced under pressure. The nickel-carbonyl gases produced are condensed to a liquid. Nickel carbonyl is separated by fractional distillation. In order to produce metal powder, the liquid nickel carbonyl is vaporized and then fed to a decomposer where nickel powder and carbon monoxide separate. The high-purity nickel powder produced has special chemical and metallurgical properties.

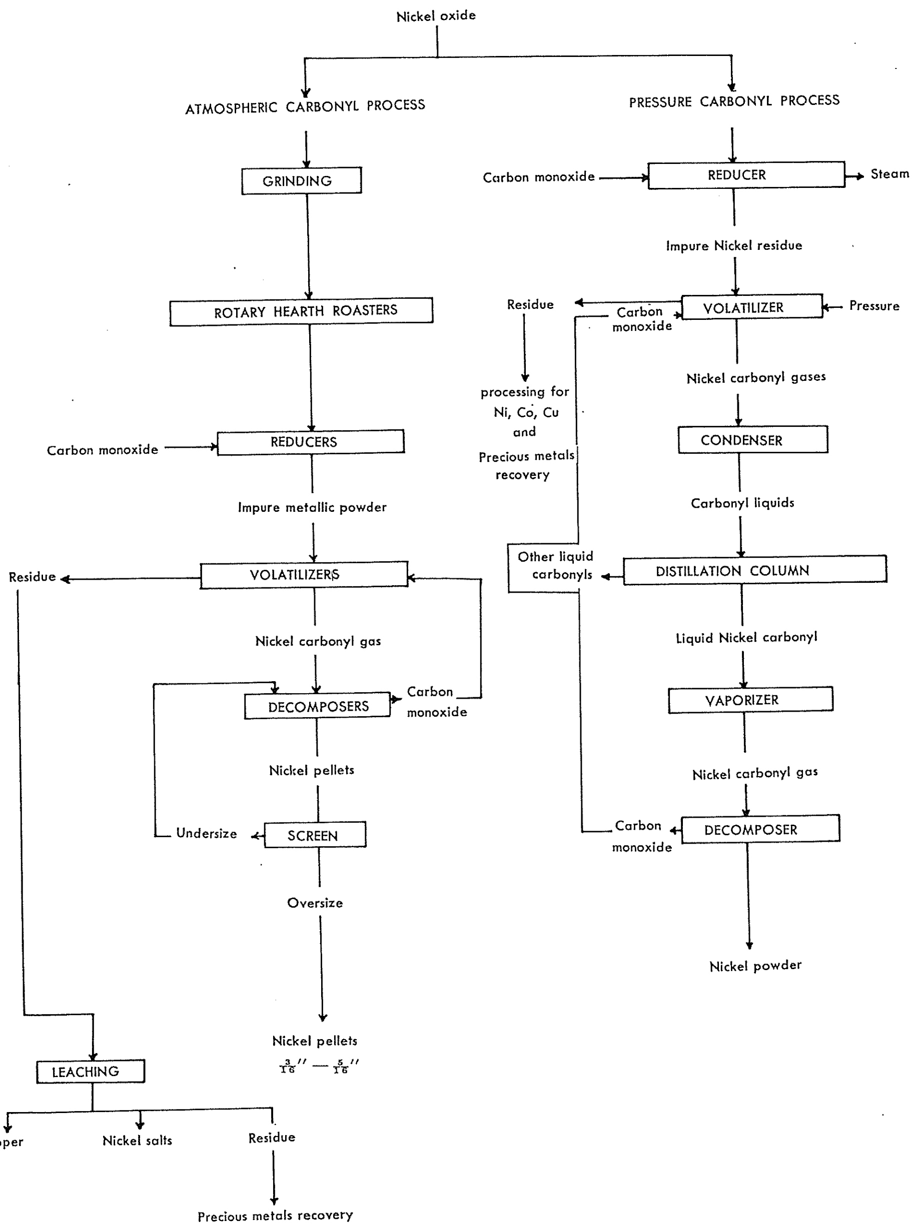

FIGURE 26. Generalized flowsheet, Clydach refinery.

Sherritt Gordon, Fort Saskatchewan Refinery

The refinery processes nickel concentrate from the company's Lynn Lake operation and matte from outside sources. The refinery uses the ammonia pressure leach process, developed and owned by Sherritt Gordon(20-23). The process is unique in that it recovers metallic nickel and cobalt from sulphide concentrate by hydrometallurgical methods. The conventional pyrometallurgical steps of roasting and smelting are eliminated. The process utilizes a low-pressure, low-temperature leaching followed by hydrogen reduction to obtain metallic nickel.

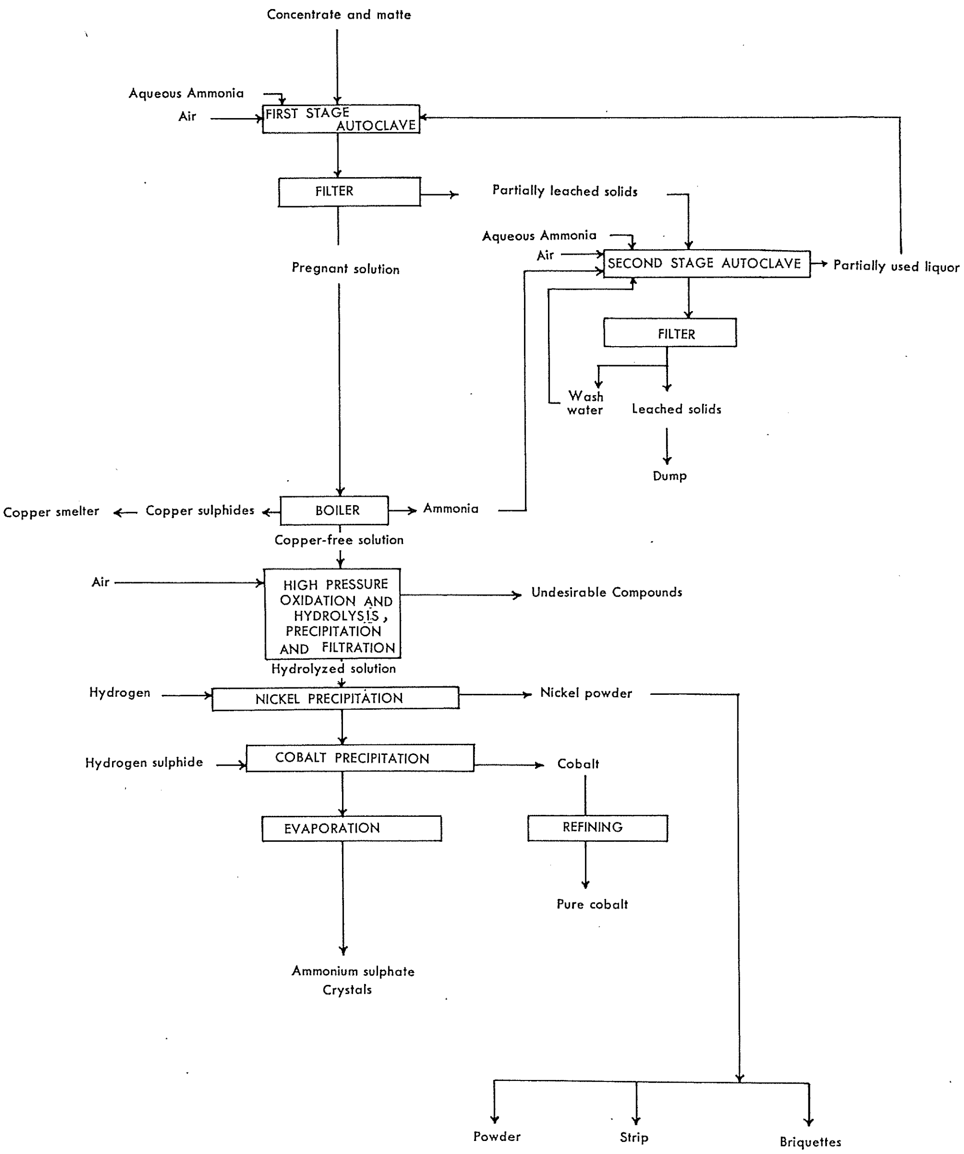

FIGURE 27. Generalized flowsheet, Fort Saskatchewan refinery.

The refinery feed is leached under pressure in autoclaves. Air and aqueous ammonia dissolve nickel, copper, cobalt and most of the sulphur, leaving iron and other impurities in the residue. Continuous operation is maintained by a two-stage countercurrent leach. The pregnant solution is filtered, then boiled to remove excess ammonia which is recirculated. As the free ammonia decreases, copper sulphide precipitates as a black sludge. The sludge is sent to a copper smelter.

The copper-free solution is filtered off and undesirable compounds are removed by high-pressure oxidation and hydrolysis, precipitation and filtration. The solution at this stage contains nickel, cobalt and ammonium sulphate. The recovery of nickel is carried out on a batch basis, in pressure tanks, by agitation with hydrogen. The nickel salt in solution is reduced to metallic nickel that deposits on nickel 'seed'. The cobalt is subsequently precipitated and refined to pure cobalt metal. The nickel powder is washed, dried and may be rolled into strip or briquetted before being marketed.

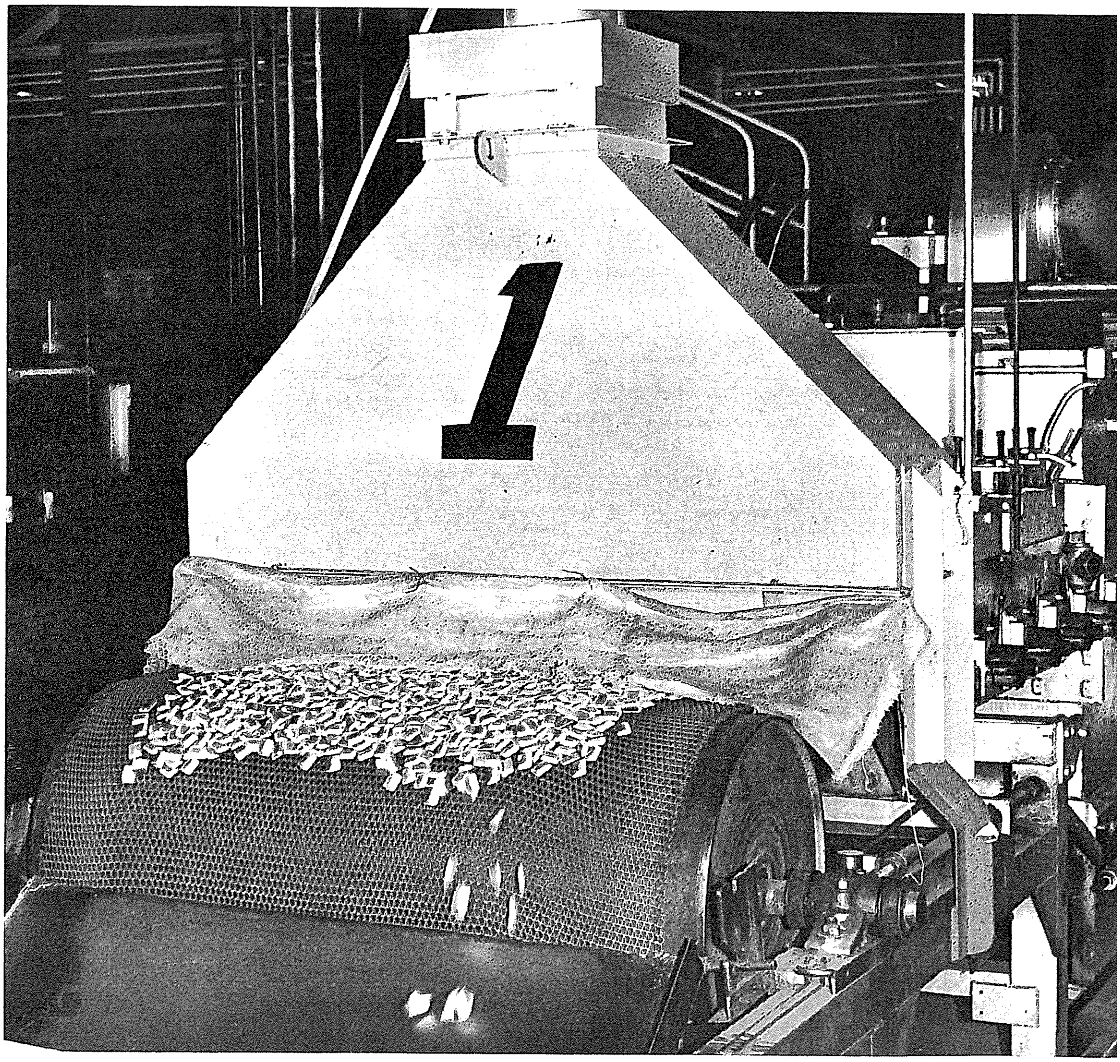

FIGURE 28. Sintering furnace for nickel briquettes, Fort Saskatchewan refinery.

NICKELIFEROUS-LATERITE ORES

In general, nickeliferous-laterite ores cannot be beneficiated by mineral dressing techniques; they must be directly processed by pyrometallurgical or hydrometallurgical means.

The nickeliferous-laterite processes presently in use produce a variety of intermediate and end products: nickel matte, nickel-sulphide concentrate, nickel-oxide powder, ferronickel and nickel metal.

In addition to the processing operations outlined below, nickel-laterite ores and/or their semiprocessed products, are treated in the USSR, Japan, Czechoslovakia and Brazil.

Pyrometallurgical Processes

Le Nickel, Ferronickel Process

One of the two processes in use at Le Nickel's Doniambo metallurgical plant in New Caledonia is an electro-metallurgical process for the production of ferronickel(24) (See figure 29). A new ferronickel smelter was completed in 1959.

The highly refractory New Caledonian nickel-silicate ore is dehydrated in rotary kilns and then fed into electric furnaces where it is reduced with coke breeze. Slag is tapped, granulated and dumped.

Crude ferronickel heats are tapped directly into a desulphurizing vessel. Sulphur is removed by means of sodium carbonate. The sodium carbonate decomposes and the sodium oxide that is liberated reacts with sulphur and silicon in the melt to form sodium sulphide and sodium silicate, which form a slag. The slag is added to the charge of the matte blast furnace (as noted in the description of the matte smelting process).

Desulphurized ferronickel is transferred to converters for the removal of chromium, silicon, carbon and phosphorus. Slag is tapped and dumped. The refined ferronickel, containing 24 to 29% nickel, is cast into 50-lb pigs for shipment to customers.

Le Nickel, Matte Smelting Process

The matte smelting process(1,25) has been in use at Le Nickel's Doniambo plant for many years. The facility is supported by a coke plant. The ore is screened, crushed, and sintered on travelling grates. The sinter thus obtained is smelted with coke, gypsum, limestone, and with ore pellets from the company's Poro plant, in low-shaft blast furnaces. Slag from the ferronickel desulphurizing furnaces is also added to the charge. Air blasts are preheated with coke gas. An iron-nickel sulphide containing about 25% nickel is produced. Slag is tapped and dumped.

The low-sulphur blast-furnace matte is then treated in horizontal Bessemer converters for the removal of iron. The iron is oxidized and, on the addition of silica, forms a ferrous-silicate slag that is skimmed. The nickel matte, containing about 78% nickel and 20% sulphur, is cooled, crushed and shipped to a refinery. Most of Le Nickel's matte is sent to the company's nickel refinery at Le Havre, France. Significant quantities are sold to refineries in Japan and Canada.

Le Nickel, Le Havre Refinery

At the Le Havre plant(1), New Caledonian matte is crushed, ground, and roasted to remove the sulphur. Roasting is carried out in two stages. In the first stage, the ground

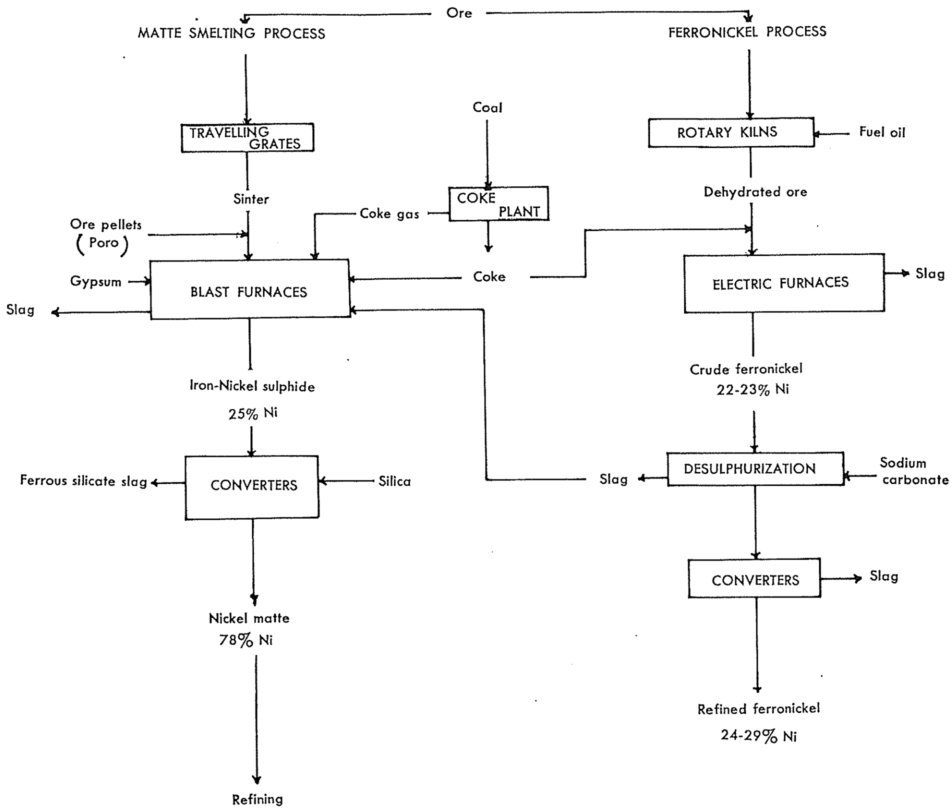

FIGURE 29. Generalized flowsheet, matte smelting and ferronickel processes, Doniambo smelter.

matte is processed in a fluid-bed furnace; then the calcine is roasted in a rotary kiln countercurrent to hot oxidizing gas. Roasting removes most of the sulphur and converts the matte into almost pure nickel oxide.

The nickel oxide is mixed with water and a binder and pressed into cylinders, called rondelles, 1 1/4 inches in diameter and 3/4 inch thick. Dried rondelles are mixed with charcoal and charged into the top of a reduction retort. In the reduction zone, nickel oxide is reduced to metal. Metal rondelles and excess charcoal are continuously discharged at the bottom of the retort. Rondelles, similar in shape and size to the original nickel-oxide cylinders, are separated from the charcoal by a magnetic pulley, and are cleaned, polished and marketed.

Hanna Mining, Riddle Smelter

The Ugine process is used for the production of ferronickel from nickel-silicate ores mined near Riddle, Oregon(26). The process involves the addition of a suitable reducing agent to a mixture of molten oxide ore in the presence of molten ferrous metal, using violent agitation for mixing the reducing agent and molten metals.

The ore is dried, screened, crushed and calcined in rotary kilns. The hot calcine produced is fed to electric melting furnaces. Molten ore from a furnace is poured into a reaction ladle. Molten ferronickel from an identical ladle is rapidly poured into the ladle containing molten ore. Ferrosilicon is added as a reductant. Agitation of reductant and

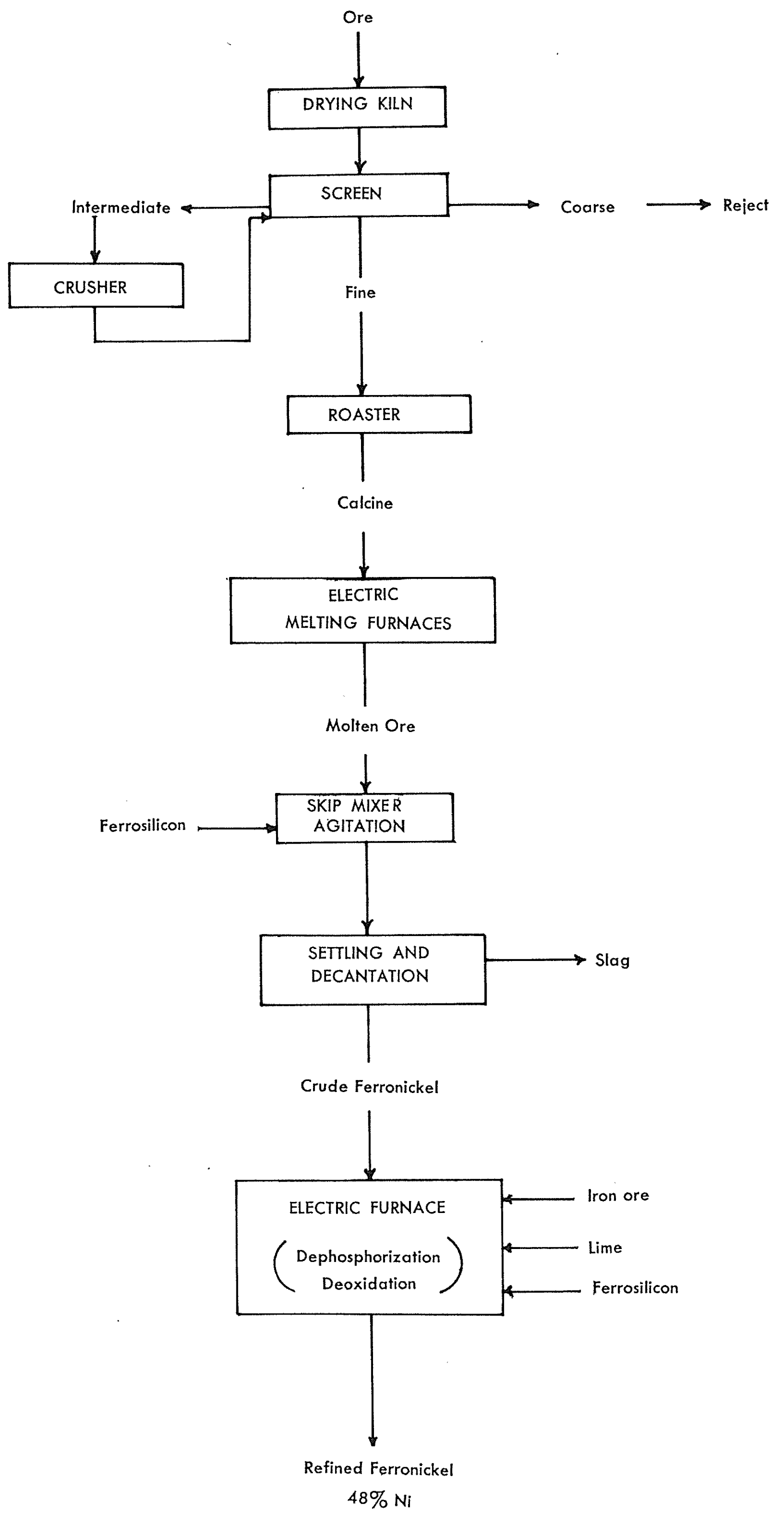

FIGURE 30. Generalized flowsheet, Riddle smelter.

molten ore is accomplished by pouring the material rapidly from ladle to ladle. After five pours the metal is allowed to settle and slag is decanted off the top of the ladle. The cycle is then repeated with a ladle of molten ore from another melting furnace. When sufficient ferronickel has accumulated, part is removed for refining.

Refining consists of dephosphorizing and deoxidizing the ferronickel in electric furnaces to meet market specifications. Iron ore is added to oxidize the phosphorus, and lime is added to convert the oxide to calcium phosphate, which is skimmed with the resulting slag. The ferronickel is deoxidized by the addition of coarse ferrosilicon. Refined ferronickel, averaging 48% nickel, is cast in 28-lb pigs and marketed.

Hydrometallurgical Processes

Caron Ammonia Leach Process

The Caron process(27,28) is based on the selective solvent power of ammonia for nickel and cobalt. The process finds application where the magnesia content of the ore is sufficiently high to preclude using the sulphuric acid process. The process is used to treat the ores of Nicaro, Cuba. The following outline describes the process as it was applied prior to nationalization in 1960.

The ore was dried, ground and roasted. The nickel and cobalt in the ore were reduced to metal. The reduced ore was cooled in a non-oxidizing atmosphere and quenched in ammonia liquor. The slurry was aerated in agitation tanks, oxidizing the nickel that was then leached by the liquor. The other metals formed insoluble oxides and remained in the pulp. The pregnant solution contained about 1% nickel.

The solution was reaerated to precipitate any remaining iron. The clarified solution was fed into an ammonia stripper where steam vapourized the ammonia. When the ammonia content in the solution fell below 2%, nickel precipitated as nickel carbonate.

The nickel carbonate solution was thickened and filtered. The filter cake was fed to an oxidizing kiln where free and contained moisture and carbon dioxide were driven off. Nickel-oxide powder, the final product, was bagged or canned for shipment.

Sulphuric Acid Leach Process

The pressure leaching of nickeliferous laterites to obtain a nickel-cobalt sulphide concentrate is the process that is used to treat the ores of Moa Bay, Cuba. The process uses sulphuric acid to extract nickel and cobalt from the ore. These metals are precipitated in sulphide form with hydrogen. Sulphuric acid leaching can only be applied to ores with a low magnesia content. The following outline describes the process as it was applied prior to nationalization in 1960 (29, 30) (See Figure 32).

The ore was slurried, wet screened and thickened to provide feed for the leaching operation. The critical step in the process is the selective leaching of nickel and cobalt from the gangue fraction. The slurry was heated to provide selectivity. Then it was fed through reaction vessels. Sulphuric acid was also fed into the first reaction vessel. Agitation was provided by high-pressure steam. The leached slurry was cooled, washed and separated by countercurrent decantation.

The pregnant solution was neutralized in agitation tanks. The neutralized liquor constituted the feed for sulphide precipitation in autoclaves at elevated temperature and pressure. High-purity hydrogen sulphide was injected, precipitating the nickel and cobalt. The precipitated slurry was blown into flash tanks where excess hydrogen sulphide separated. The flashed liquid carrying the suspended sulphide product was thickened and washed. The final sulphide slurry, containing 65% solids, was shipped to Freeport Sulphur's refinery at Port Nickel, Louisiana, for refining by a modification of Sherritt Gordon's ammonia pressure leach process.

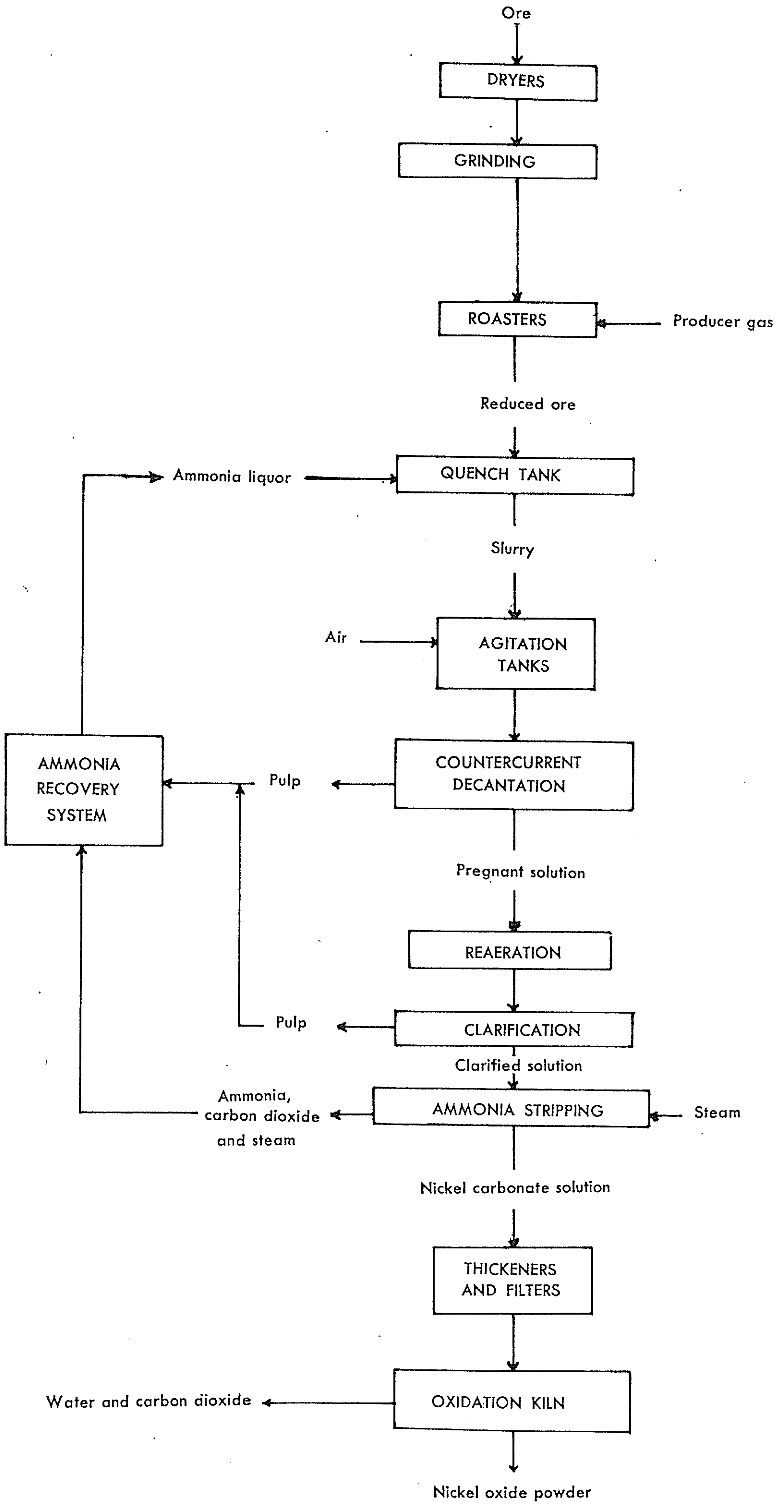

FIGURE 31. Generalized flowsheet, Caron ammonia leach process.

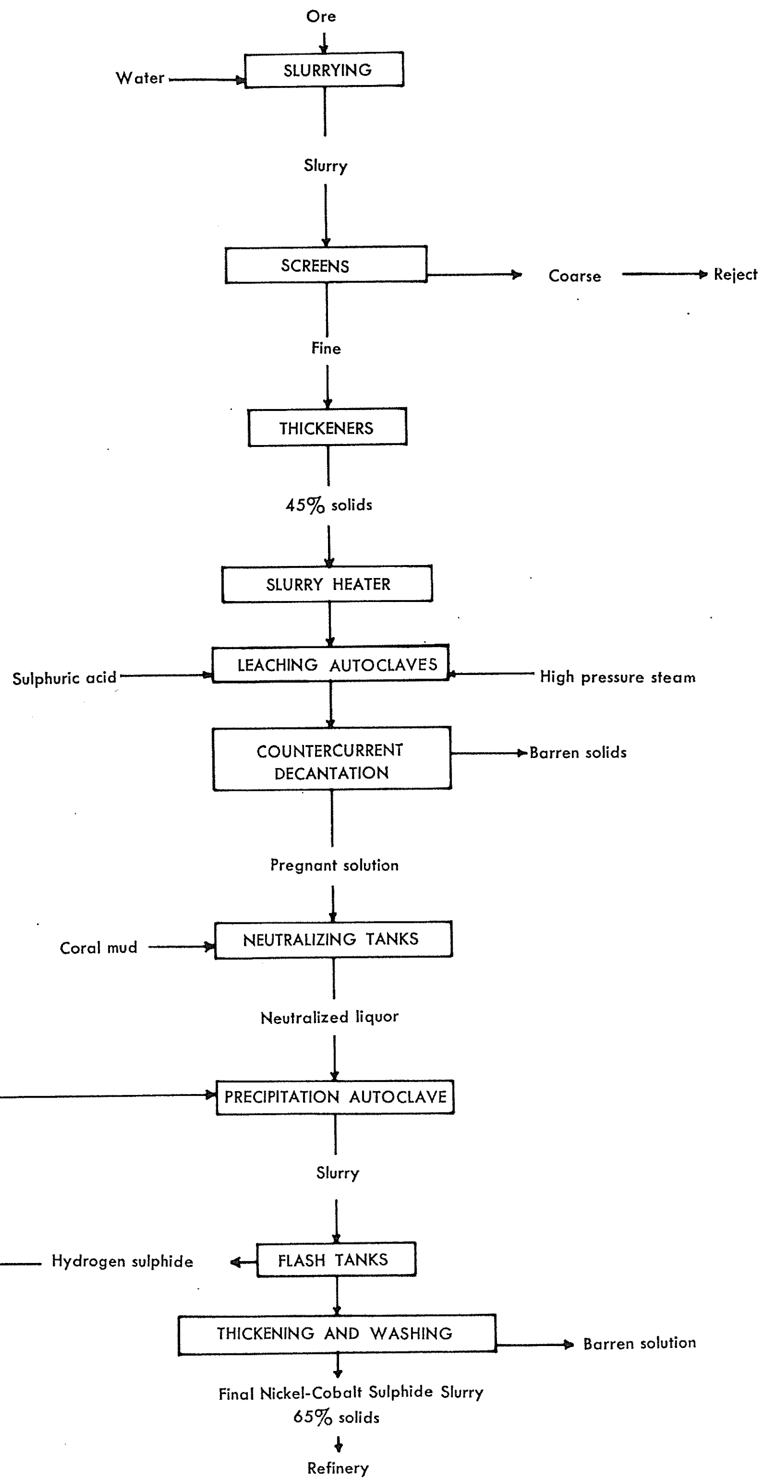

FIGURE 32. Generalized flowsheet, sulphuric acid leach process.

CHAPTER 6

COMMERCIAL FORMS AND USES

COMMERCIAL FORMS*

Most of the nickel delivered to industry is in a pure metallic form although the steel industry uses substantial quantities of nickel in oxide and ferronickel forms. Other nickel compounds are marketed in relatively small quantities, primarily to the chemical industry.

Electrolytic cathode nickel is the most important refined form. Nickel metal is also supplied in pellet, shot, ingot,briquette, rondelle and powder forms.

Electrolytic Cathode Squares

Cathode squares are the most widely used form since they are generally the most versatile for alloyers. Purity is usually about 99.95% nickel with 0.01% iron, 0.01% copper and traces of silicon, carbon and sulphur.

Electrolytic nickel is marketed in various sizes ranging from full-size cathodes, 28 1/2 inches by 38 inches, to one-inch squares. The intended use, the type of buyers equipment, and the processing procedures determine size.

A special grade of electrolytic nickel, termed 'SD' nickel by International Nickel, having the same grade as conventional cathodes and a small sulphur content, is sold for titanium-basket electroplating.

Nickel Shot

Nickel-alloy shot is used for ladle additions in cast iron foundries. International Nickel's 'F' shot has a typical composition of 92.00% nickel, 5.50% silicon, 1.65% iron, 0.55% carbon, 0.20% copper and 0.06% sulphur. Its melting point is lower than pure nickel. This assures rapid dissolution in molten iron. 'F' shot is marketed in a minus-1/4-inch size.

High-purity minus-one-inch steam-shattered shot, having a composition approximating that of its electrolytic base, has a limited use in the chemical industry.

Nickel Ingots

Ten-pound nickel ingots produced from and approximating the composition of electrolytic nickel are marketed to the low-alloy cast-iron industry. Five-pound ingots of 'F' nickel alloy are used for the production of nickel cast irons.

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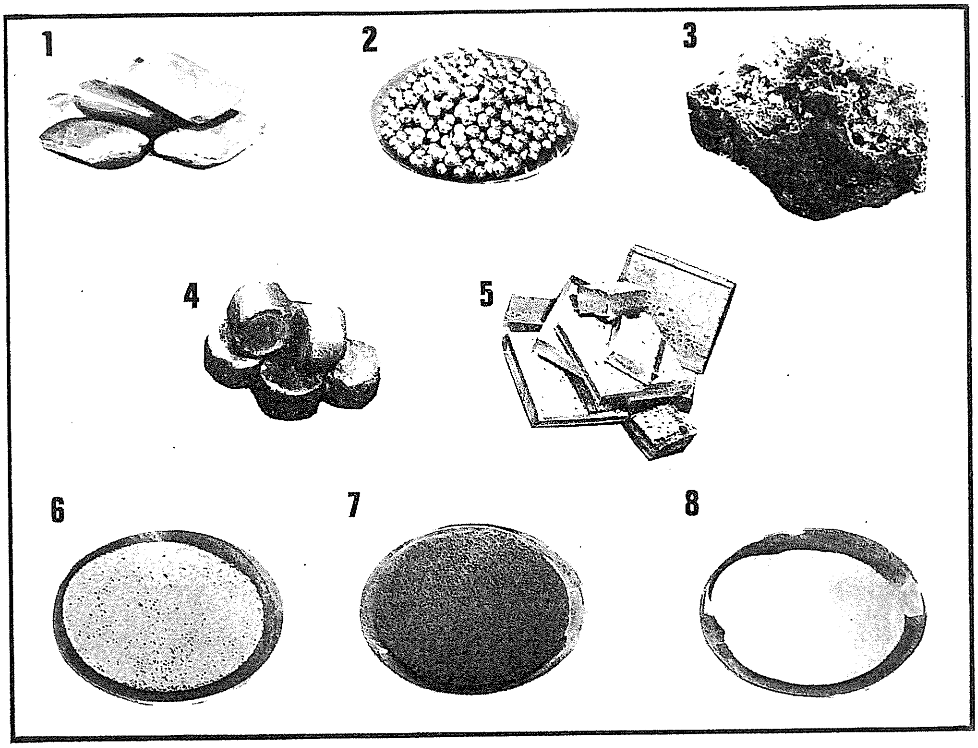
*Ref. (1,2).



1. Briquettes: Sherritt Gordon Mines Limited.
2. Pellets: The International Nickel Company of Canada, Limited.
3. Ferronickel: Société Anonyme Le Nickel.
4. Rondelles: Société Anonyme Le Nickel.
5. One-inch and two-inch electrolytic cathode squares: The International Nickel Company of Canada, Limited and Falconbridge Nickel Mines, Limited.
6. Oxide sinter 90: The International Nickel Company of Canada, Limited.
7. Oxide sinter 75: The International Nickel Company of Canada, Limited.
8. Powder: Sherritt Gordon Mines Limited.

FIGURE 33. Some important commercial forms of nickel.

Nickel Pellets

Pellets are produced in Britain by the Mond process and are sold in the European market where they are consumed in about the same volume, and for the same uses, as cathode squares. Price and purity of the two forms are essentially the same. Tradition and habit are the critical factors determining the preference for one over the other.

Nickel Powder

Pure nickel powder is produced by Sherritt Gordon's ammonia pressure leach process and International Nickel's pressure carbonyl process. It is competitive with other forms of refined nickel and has advantages in chemical industry applications where a large surface area permitting rapid dissolution is important. Nickel powder is also used for specialized applications such as coinage blanks, bearings, and fuel cells.

Special high-purity nickel powders command premium prices. Special grade powder is used for the manufacture of nickel-cadmium batteries.

Nickel Briquettes

Sherritt Gordon makes pillow-shaped briquettes from nickel powder by compaction followed by sintering at high temperature. Individual briquettes measure 1 1/2 inches by 1 1/4 inches by 3/4 inch and weigh 3 ounces.

Purity is essentially the same as that of electrolytic nickel, but briquettes have a lower sulphur content. This makes the product attractive for use in specialty alloys. Briquettes are also preferred for final addition to a melt because of ease of handling and a constant uniform weight that permits counted additions. Friability of the briquette form may result in excessive fines.

Nickel Rondelles

Nickel rondelles are the product of Le Nickel's Le Havre refinery. This cylindrical form, 1 1/4 inches long by 3/4 inch in diameter, is used in alloy manufacture and generally has similar applications to those of nickel briquettes. Purity is about the same as briquettes and electrolytic nickel.

Nickel Oxide

Nickel-oxide sinter is produced by International Nickel by pelletizing and roasting nickel-sulphide concentrates. A part is marketed as a product containing about 75% nickel. Another part is upgraded and sold as a product containing about 90% nickel. The two products are used in similar applications in the manufacture of alloys and stainless steels.

Nickel-oxide powder, containing about 76% nickel, is the final product of the Caron ammonia leach process used at Nicaro, Cuba.

Ferronickel

The nickel content of ferronickel varies from 24 to 28% (New Caledonia) to 48% (Riddle, USA). The main market for this form is the stainless steel industry. Ferronickel is produced in pigs weighing 25 to 60 lb.

Nickel-magnesium Additives

Nickel-magnesium alloys are used in the production of ductile iron. There are two commercial grades: 82% nickel, 15% magnesium; and 50% nickel, 15% magnesium. The additives are priced according to the price of their constituent metals plus a conversion cost.

Other Commercial Forms

Many nickel compounds are produced and the relatively small quantities marketed find a wide range of uses primarily in the chemical industry. Some of the more important of these forms are shown in the following table (3, p.289).

Compound	Nickel (%)	Applications
Acetate	24	colour fixative, catalyst
Ammonium sulphate	15	electroplating
Carbonate	45	catalyst, electroplating
Carbonyl	34	nickel refining
Chloride	25	electroplating, catalyst
Formate	31	catalyst, electroplating
Hydroxide	55–60	electroplating, storage batteries, catalyst
Nitrate	20	catalyst, electroplating
Oxide	76	enamelling, electronics
Sulphate	22	electroplating, enamelling, catalyst
Sulphide	91	catalyst

Nickel Scrap*

In the United States secondary nickel recovery satisfies about 10% of domestic consumption. The relatively low recovery factor is partly due to the lag in scrap recovery behind an accelerating demand for nickel and is partly due to the export of nickel scrap. However, the main reason is that much nickel is used as a minor constituent in alloying and its recovery is usually not economic. In addition, old scrap of the various nickel irons and steels is most difficult to segregate and becomes increasingly dispersed with reuse until the nickel content is lost.

The largest source of secondary nickel is stainless-steel scrap. The second largest source is nonferrous alloy scrap such as cupronickel, nickel-silver alloys and other nickel alloys. Spent catalysts and high temperature alloys are also important.

Nickel scrap includes both old scrap and the reverts (new scrap) from steel mills, foundries and other metallurgical plants.

Secondary nickel is an important factor in the manufacture of nickel bearing steel and other nickel alloys.

USES

Although the uses of nickel are varied, three quarters of the nickel consumed in the non-communist world is in alloy products. It has been estimated that there are over 3,000 alloys containing nickel in proportions that range from 99.0% in malleable nickel to

*Ref. (2, 4).

0.02% in a hardenable silver alloy(5). Ferrous alloys account for three quarters of nickel alloy demand, the remainder being used in alloys of nickel and copper or other nonferrous metals.

Important quantities of metallic nickel in the unalloyed state are used in electroplating. Significant amounts of nickel are used in coinage, clad steel, and as a catalyst.

Nickel compounds are used in electroplating, ceramics, catalysis and in the preparation of active materials for storage batteries.

Free World Nickel Consumption by Use, 1962–66
(%)

	1962	1963	1964	1965	1966
Stainless steels	30	31	34	33	33
Nickel plating	16	14	15	16	16
High-nickel alloys	16	17	13	14	15
Constructional alloy steels	13	13	13	12	12
Iron and steel castings	12	12	11	11	11
Copper and brass products	4	4	4	4	3
Other	9	9	10	10	10

Source: The International Nickel Company of Canada, Limited.

Ferrous Alloys*

Nickel oxide, pellets, ferronickel, cathode squares, and scrap are the most important nickel forms used in the ferrous metals industry.

Nickel-Alloy Steels

The strength, hardness and toughness properties that nickel imparts to steel was recognized toward the close of the nineteenth century. The demand for nickel-alloy steels has been a critical factor in the development of the nickel industry.

Nickel, in amounts up to 9%, is an important constituent of many alloy steels. It is frequently used with one or more other alloying elements such as chromium, molybdenum, copper and vanadium to develop optimum physical properties and processing characteristics. Nickel alloy steels are produced in bars, forgings, plate, tubing and structural shapes.

Low nickel steels containing 0.5 to 0.7% nickel, having high strength, ductility and toughness, are used in the motor industry, in railroad engineering, in power machinery and construction equipment.

High-strength age-hardening steels containing 1% nickel are used for structural applications in transportation, power and construction.

Nickel-chromium steels containing 1.5 to 3.5% nickel and 0.5 to 1.75% chromium are used primarily in armament.

Steels containing 3 to 4% nickel are characterized by a high tensile strength and elastic limit and are used in armament and a wide range of machine parts.

The ability of nickel to lower the temperature at which steel becomes brittle is useful in the expanding field of liquefied gas transportation and handling, and in machinery and structures subjected to low temperatures. A 9% nickel steel is suitable for these purposes.

*Ref. (3, 6-8).

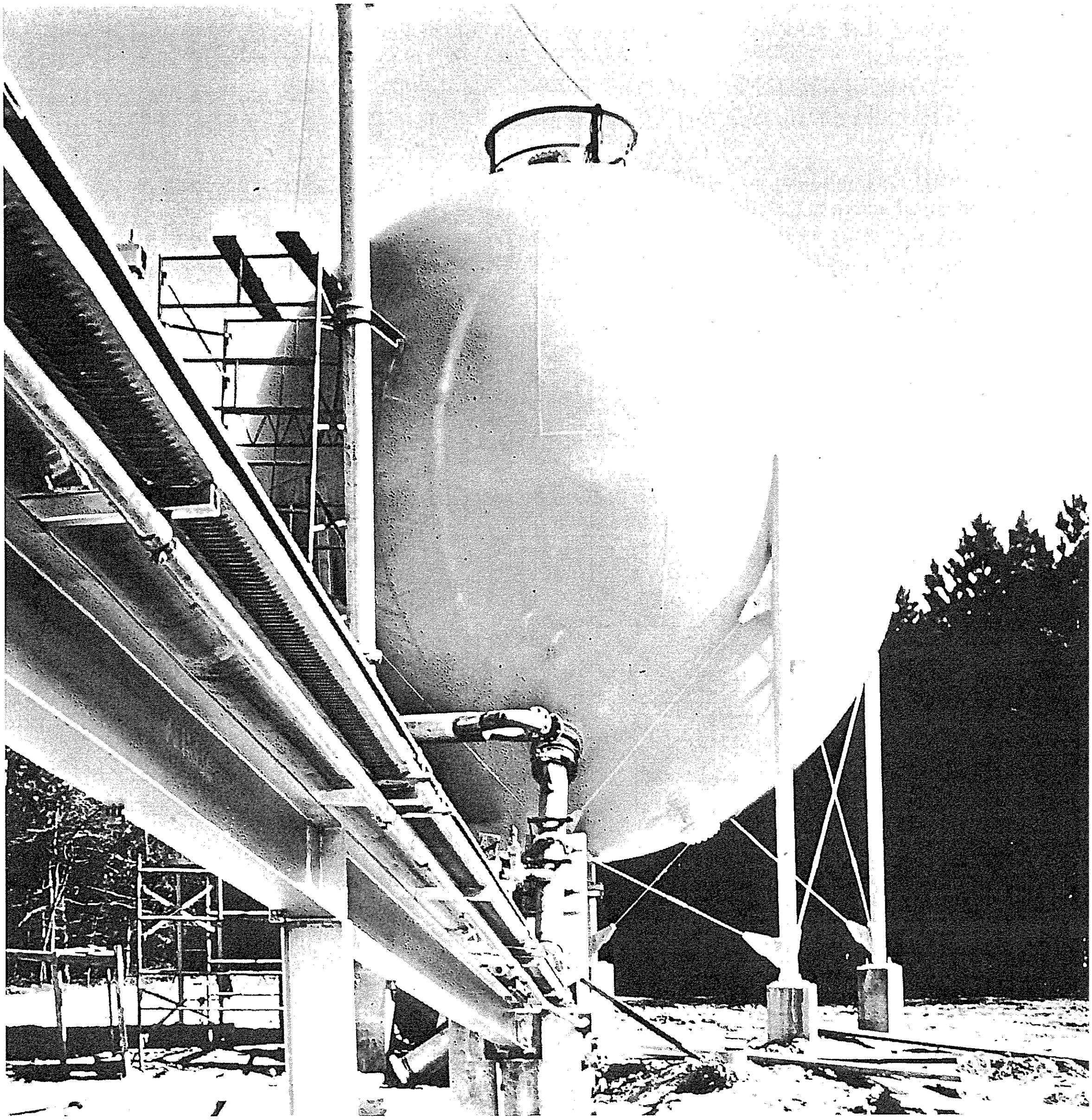


FIGURE 34. Nine per cent nickel-alloy steel storage tank for liquid gases at sub-zero temperatures.

Stainless Steels

The manufacture of stainless steel is the largest single use of nickel. It is produced in sheet, strip, rods, bars, forgings, wire and tube forms.

Chromium-nickel steels, known as stainless steels, are widely used because of their corrosion resistance, desirable mechanical properties, and ability to retain these properties through a wide temperature range.

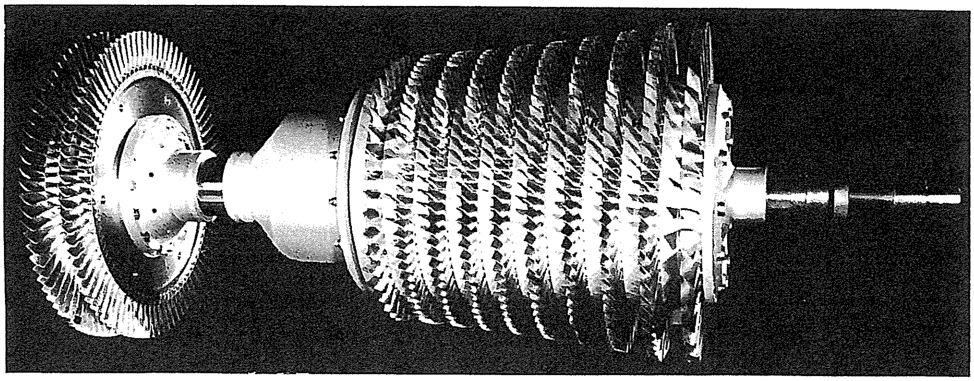


FIGURE 35. Stainless steel compressor blades.

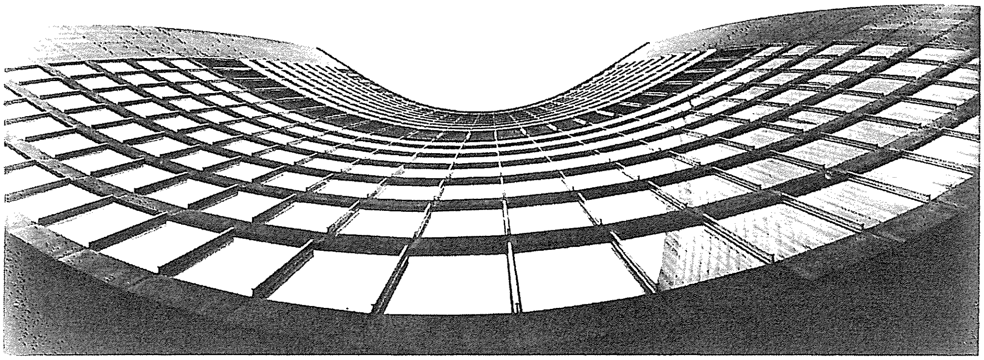


FIGURE 36. Stainless steel window frames, mullions and louvres, Toronto City Hall.

Austenitic stainless steel is the only type that contains nickel and it is the most widely used. Austenitic stainless steel contains from 3.5 to 22% nickel with a minimum chromium content of 4%. Occasionally other alloying elements are added. Chromium is the element primarily responsible for the corrosion resistance of the alloy. The nickel acts as an austenite stabilizer, lowers the tensile strength and hardness, and decreases the tendency of the material to harden with cold work.

The basic and most widely used grade of austenitic stainless steel contains 8 to 10% nickel and 17 to 19% chromium. It has excellent corrosion resistance and possesses very good ductility. The applications of this type are varied; they include kitchen equipment and utensils; dairy installations; transportation equipment; and oil, chemical, paper and food processing machinery.

Alloys with a lower nickel content than the basic grade are used for structural members where high strength is required.

The development of ferrous super-alloys to withstand increasingly severe operating requirements has mainly involved modifying the austenitic stainless steels. Among the modifications are precipitation-hardening steels and steels with nickel and chromium contents of 10 to 22% and 24 to 26% respectively. Also, appreciable amounts of tungsten, molybdenum, columbium and other elements may be added(6).

Maraging Steels

Maraging steels, containing 18 to 25% nickel, are used in high strength applications in the aircraft, missile and marine industries.

*Nickel-iron Alloys**

Low nickel grey cast irons, containing from 1.0 to 3.5% nickel, and often manganese or chromium, form castings with better wear resistance, strength and machinability than ordinary grey cast iron. They are used in various engineering applications.

High-nickel cast irons, containing from 10 to 15% nickel, are nonmagnetic, have high electrical resistance and are primarily used in castings for electrical machinery.

Corrosion-resistant cast irons, containing 12 to 30% nickel, can withstand atmospheric and chemical corrosion at elevated temperatures. They are used in petroleum plants, automotive parts and for varied chemical applications.

Ductile iron combines the strength properties of carbon steel with the processing advantages of grey iron. Nickel in amounts up to 3%, improves ductile iron's properties. The main use for ductile iron is the manufacture of cast automotive parts but increasing amounts are being marketed for other engineering applications. A special range of ductile irons, containing 20 to 35% nickel, combines excellent corrosion properties and heat resistance with strength and toughness.

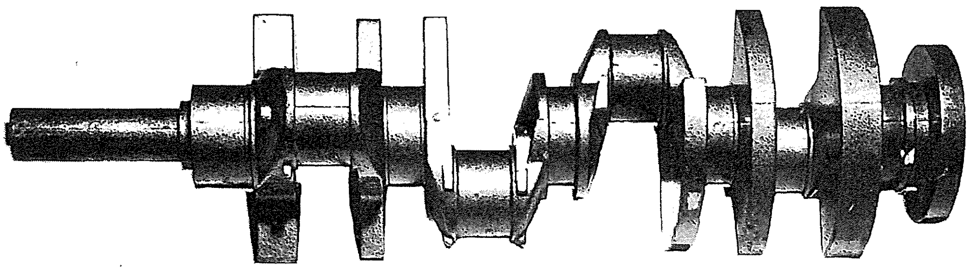


FIGURE 37. Ductile iron crankshaft.

Magnetic Alloys

Useful magnetic materials have either high permeability or are permanent magnets. Nickel is a major constituent of both magnetically soft and permanent magnet ferrous materials.

Nickel-iron alloys containing 35 to 90% nickel have high permeabilities at low field strengths. Improved properties may be obtained by the addition of chromium, copper, molybdenum or vanadium. These alloys are used in transformer, transmission, telephonic and other electrical applications.

Permanent magnets, containing 15 to 30% nickel, have excellent magnetic properties. Aluminum, copper, cobalt and titanium may also be added to the alloy. The primary use of permanent magnets is in loud-speakers; other applications include electrical measuring instruments, motors and generators.

*Ref. (9).

Thermal Expansion Alloys

Invar, an iron-nickel alloy containing about 36% nickel, has an extremely low coefficient of thermal expansion. Additions of small amounts of chromium and other metals secure specific expansivity values. Low-expansion alloys are used as length standards, compensating pendulums, balance wheels, tuning forks and glass to metal seals.

Nonferrous Alloys*

The distinctive and common properties of the various nonferrous nickel alloys are resistance to heat, abrasion and corrosive media.

Nickel-copper

Of the nonferrous alloys those of nickel-copper are the most important in terms of amount consumed. They range from Monel, which is two thirds nickel and one third copper, down to cupro-nickel, in which the proportions are reversed, and to high-tensile brasses in which the nickel content is only a few per cent.

Originally Monel was a natural alloy that resulted from the smelting of Sudbury nickel-copper sulphide ores in which the nickel-copper ratio was approximately 2:1. The composition of the Monel alloys currently marketed vary from 57% nickel – 40% copper, to 84% nickel – 14% copper. Monel has many industrial applications that utilize the alloy's strength, toughness, ductility and resistance to corrosion. Monel is used in food processing, in chemical plants and in the manufacture of turbine blades and fuel tanks. Its resistance to corrosion by sea water makes it valuable also for propeller shafts and ships' fittings.

A nickel-copper alloy containing 75% nickel and 25% copper, is extensively used for coinage in many countries.

Cupro-nickels, containing 1 to 50% nickel, have desirable physical and mechanical properties and are resistant to corrosion in many media. The most widely used cupro-nickel alloys are the 70:30, 80:20 and 90:10 groups. Cupro-nickels containing 10 to 30% nickel are resistant to sea water and are used in heat exchanger tubes, condensers and other marine applications. Small additions of iron and manganese are beneficial for these uses.

Cupro-nickel coinage, typically containing 75% copper and 25% nickel, is probably, in terms of monetary value, the most widely used of all base metal coinage materials. Most countries have one or more of their denominations in cupro-nickel (10-12).

Nickel-chromium

This group of alloys(13) contain 60 to 80% nickel, 13 to 20% chromium with the remainder mostly iron. The chromium gives these alloys corrosion resistance under oxidizing conditions and the high nickel content imparts a resistance to corrosion under reducing conditions. Inconel, 73% nickel and 15% chromium, because it is capable of withstanding very high temperatures, is used in furnace muffles, gas turbines, and jet and rocket engines. Illium, containing 64% nickel and 22% chromium, is resistant to corrosion by sulphuric and nitric acids over a wide range of concentrations and temperatures. Illium is used in pumps, valves, tubing and other equipment subject to severe acid corrosion.

*Ref. (3, 6-8).

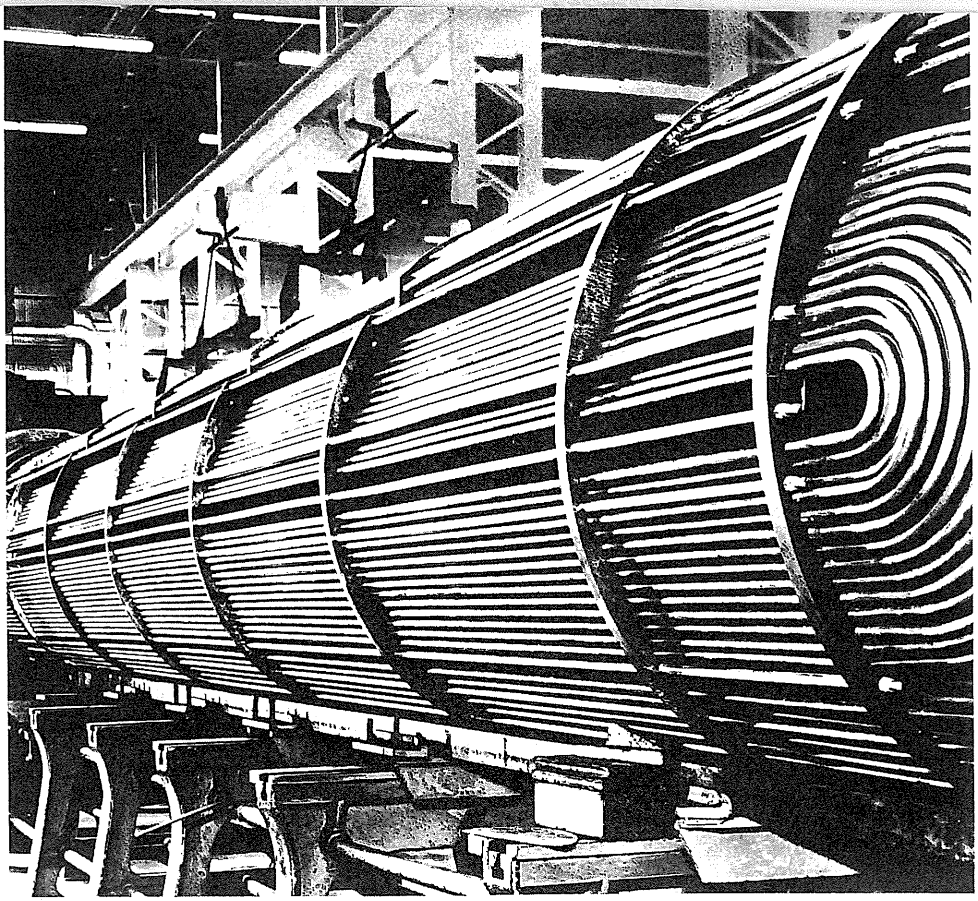


FIGURE 38. Copper-nickel alloy tubing for sea water desalinization plant.

Nickel-molybdenum

Nickel-molybdenum alloys, typically containing 65% nickel and 30% molybdenum, with the remainder iron, were developed to resist corrosion by hydrochloric acid; this is their most important property. Modifications in composition provide superior corrosion resistance to other mineral and organic compounds. Nickel-molybdenum alloys are used primarily in industrial equipment for handling acids and alkaline bleaching solutions.

Copper-nickel-zinc

This ternary alloy is probably the oldest of nickel alloys; known as *paitung* it was originally produced as a natural alloy in China. Nickel-copper-zinc alloys are commonly known as 'nickel silver'. Many compositions exist containing 10 to 30% nickel and 5 to 30% zinc with the remainder copper; the 18% nickel, 17% zinc and 65% copper composition is widely used because of appearance, good mechanical properties, and easy fabrication. The most important use for nickel silver is as a base for nickel plating. It is also used in food equipment, marine fittings, and musical and dental instruments.

Aluminum-nickel

The aluminum-nickel alloys, wrought and cast, combine light weight with strength, particularly at moderately elevated temperatures; they are therefore useful in the aviation and automotive industries. Nickel imparts increased strength. Aluminum-nickel alloys

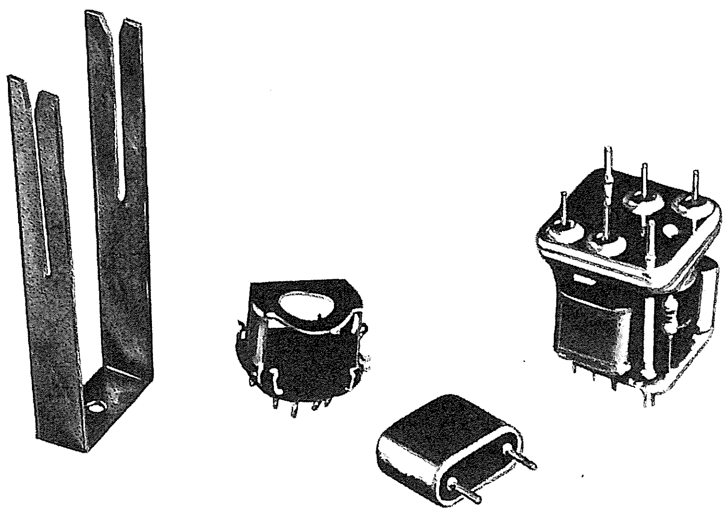


FIGURE 39. Nickel silver in the electronics field: diode cans, supports and spring clips.

may also contain small amounts of copper, magnesium, silicon and other metals. A typical range of compositions is 2 to 3% nickel, 1 to 4% copper, 1 to 2% magnesium, 0 to 14% silicon and 77 to 96% aluminum.

Super-alloys

The term 'super-alloys' refers to a group of high-temperature, high-strength alloys nearly all containing nickel. Many of the nonferrous super-alloys are modifications of existing nickel-chromium and nickel-molybdenum alloys. The addition of aluminum and titanium greatly strengthens the alloys by precipitation hardening. Most of these super-alloys are used below 2,000° F.

In 1962, DuPont developed an alloy containing 98% nickel and 2% thoria (TD-Nickel). The thoria is dispersed uniformly in submicron-size particles. The alloy is stronger than standard super-alloys at elevated temperatures and extends the temperature limit above 2,000° F in non-oxidizing atmospheres. Sherritt Gordon, since 1962, has also been carrying out research on the development of dispersion-strengthened nickel (DS-Nickel) and nickel alloys under contract with the Canadian Government(14). TD and DS super-alloys are produced in bar and strip forms.

Unalloyed Nickel

Although nickel is essentially an alloying element, it is also used in the unalloyed state. The metal is malleable, highly corrosion resistant in many media, and ferromagnetic; it has good thermal conductivity, moderate strength and hardness, high ductility and toughness, and fair electrical conductivity; it can be easily fabricated and will take and retain a high polish.

Electroplating

Nickel plating, the first important use for the metal, dates back to the 1840s. In 1966, 16% of the non-communist world's nickel consumption was for electroplating use. Nickel anodes provide most of the metal for this application.

Nickel is the most important metal applied by electroplating(15). Nickel electrodeposits provide a foundation for a lustrous finish on a wide range of manufactured metallic articles, particularly in the automotive and domestic appliance industries. Protection of the base metal (brass, zinc, aluminum, or other alloys) and permanence of a stain-free surface are the primary requisites of such coatings. These are obtained by an adequate thickness of nickel (usually less than 0.002 inch) covered by a relatively thin layer of chromium. Nickel coatings alone also are used in industry for the protection of the base metal from corrosion and contamination.

Because of favourable mechanical properties, electroplated nickel is also used in electroforming, a process by which a negative matrix is heavily coated to produce detailed features without the need of tooling. Some of the many uses of electroplated nickel are in electroforming printing plates, phonograph stampers, moulds, sheet and tube.

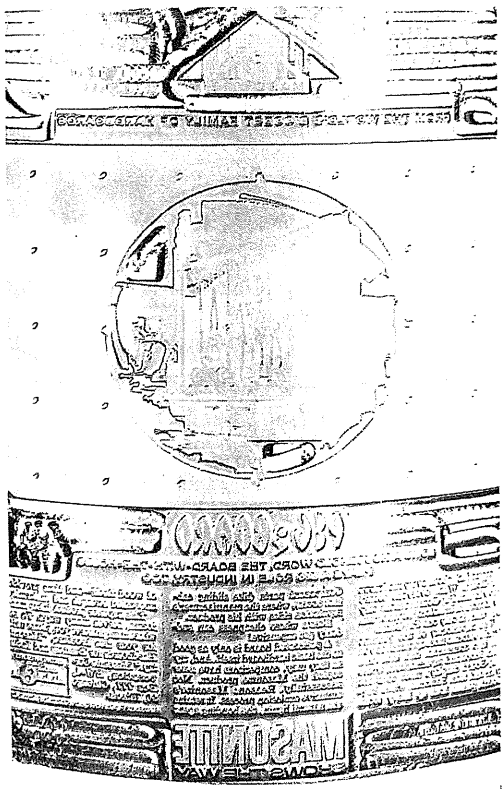


FIGURE 40. Vinyl mould used to produce electroformed nickel printing shell.

Nickel Clad Steel

Clad steels are composite products protected on one or both sides with nickel, a high-nickel alloy, or a stainless steel (3, p. 271). Their corrosion resistance is the same as the cladding material and in heavy sections they are cheaper than all-nickel or all-alloy materials. The cladding is bonded metallurgically to the steel base by hot working.

International Nickel has developed, to the pilot plant stage, a process for continuously coating steel with nickel. The nickel is applied in the form of a slurry containing nickel powder and is dried and sintered to the surface of steel sheet or strip(16).

*Coinage**

From 1881, when the first nickel coin was issued in Switzerland, until 1963, pure nickel coins had been issued by 45 countries in 134 denominations. Minting programs that attended economic reorganization following World War I resulted in the introduction of nickel coinage by a large number of countries. The Canadian 5-cent piece was first issued in pure nickel in 1922 and the 'beaver' design was adopted in 1937. The use of nickel for pure nickel coinage has substantially increased in the sixties primarily because of tightening silver supplies.

FIGURE 41. 1951 Canadian pure nickel five-cent piece commemorating the two hundredth anniversary of the discovery of nickel by Axel Cronstedt.

Catalysts

Metallic nickel is widely used as a catalyst for the hydrogenation of fats and oils, for the production of hydrogen from natural gas and waste gases from petroleum refining, for the manufacture of motor oils by cracking coal-tar or creosate oils, and for various other applications (8). Pure nickel is used in a finely divided form.

Nickel Compounds

Nickel compounds are widely used in the chemical and ceramic industries. The most important are the sulphate and the oxide compounds both of which are usually obtained as by-products during the refining of nickel (3, p. 289).

Electroplating

Although nickel anodes provide most of the metal for this application, significant amounts of nickel sulphate and nickel chloride and smaller quantities of other compounds are used in electroplating baths. Nickel formate and nickel nitrate are often added to plating solutions and nickel hydroxide and nickel carbonate are used to control the acidity of the electrolyte.

Important quantities of nickel salts are used in solution for the electrorefining of nickel.

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*Ref. (10-12).

Catalysts

Although metallic nickel is widely used as a catalyst, nickel compounds including sulphate, nitrate, chloride, formate and carbonate forms are also used in the preparation of nickel catalysts.

Ceramics

In the porcelain enamelling industry, nickel oxide insures the adhesion of the enamel to the metal. Nickel sulphate is used in the pickling process that precedes enamelling.

Nickel oxide is occasionally used for the decolourization of glass. Colours in glass, pottery and enamels are occasionally made from nickel oxide or other nickel salts.

Alkaline Storage Batteries

Nickel-iron and nickel-cadmium alkaline storage batteries are widely used. The active ingredient of the positive plates in both types of battery is nickel hydroxide that converts to higher hydrated oxides when charged.

With the advent of cordless electrical appliances the demand for nickel-cadmium batteries has grown. The long life of these batteries make them useful in solar cells for spacecraft and in aircraft and missiles.

CHAPTER 7

CANADIAN PRIMARY INDUSTRY

HISTORY*

Nickel was first discovered in Canada in 1848 at the Wallace mine near the mouth of the Whitefish River at Lake Huron by Alexander Murray, Assistant Director of the Geological Survey of Canada. The quantity of mineralization present was very low and the property did not develop beyond the prospect stage. In 1863 Hunt noted the presence of niccolite on Michipicoten Island. Canada's first nickel production came as a by-product of silver from the Silver Islet mine on an island in Lake Superior. This deposit was discovered in 1868 and by 1873 nickel was being extracted from the matte produced from these ores at the Wyandotte Smelting Works in Michigan.

The first reference to nickel in the Sudbury basin of Ontario was in 1856 when A.P. Salter, an Ontario provincial land surveyor, noted a strong magnetic attraction while surveying a meridian north of Whitefish Lake. Alexander Murray subsequently examined the area of magnetic attraction and noted a "magnetic trap" containing sulphides, which on assay gave low values in nickel and copper. His discovery was about 200 yards west of the Creighton mine, a mine that would become a pre-eminent nickel producer. However, the importance of the discovery was not apparent at that time and no further interest was shown until the construction of the Canadian Pacific Railway through the Sudbury area in the summer of 1883.

As the track for the new line was being cleared west of Sudbury a gossan was reputedly struck by one Thomas Flanagan, a blacksmith, while wielding a pick. A highly mineralized area was subsequently exposed which, in later years, became the Murray mine. After the initial discovery, prospecting activity increased and by the mid-1880s several other significant deposits, including the Frood, Crean Hill, and Stobie, were discovered.

Early development of the Sudbury district was slow. At first it was not realized that the ores contained nickel and the prospectors and speculators thought that they were dealing with essentially copper deposits. The market at that time was depressed by a 5-cent-a-pound duty on copper entering the United States and by the prohibitive freight rates to British smelters. Under these circumstances the considerable risk capital that would be necessary for the development of the deposits was not forthcoming.

By 1889, only two companies had incorporated to engage in mining activities in the Sudbury region. One of these, the Vermilion Mining Company, began operations on the basis of a gold discovery. When the deposit proved to be of nickel and copper, a majority interest in the company was sold to the Canadian Copper Company which then became the sole enterprise in the field.

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*Ref. (1-3).

Canadian Copper Company, Limited

The Canadian Copper Company entered the Sudbury district in 1886 to purchase lands and commence mining operations. The promoter of the enterprise, S.J. Ritchie of Akron, Ohio, was attempting to salvage the fortunes of unsuccessful efforts to exploit the iron ore fields of Hastings county in central Ontario. In this connection, Ritchie and his associates had built the Central Ontario Railroad for iron ore transportation. However, the iron ore proved to have too high a sulphur content to be marketable. Ritchie had strong financial support and included in his railroad charter was the authority to own and operate mines along the right-of-way. Presumably, his intention was to extend the Central Ontario Railway to Sudbury.

In the summer of 1885, Ritchie acquired several promising properties in the Sudbury area including the Copper Cliff, Stobie and Creighton deposits. The Canadian Copper Company was incorporated in 1886 to consolidate these interests. Ritchie and his associates in the Central Ontario Railway were the principal shareholders. Among other properties, the company later acquired the Evans and Frood deposits. Assays of the Sudbury ores indicated that in addition to copper, they contained 3 to 4% nickel. Since the price of nickel was at that time about 60 cents a pound, the potential profits of the properties appeared enormous and this accelerated their development.

The Copper Cliff mine began production in 1886 and it was quickly followed by the opening of the Stobie and Evans mines. These three mines were the only producers until 1898. The ore was concentrated by a heap roasting process which partially oxidized the iron and reduced the sulphur content. In order to concentrate the ores further for shipment, the roasted ores were mixed with coke and smelted in furnaces. The first furnace of the Canadian Copper Company was erected at Copper Cliff in 1888 and 80 to 100 tons of ore a day was treated, yielding a 35 to 50% nickel-copper matte. A Bessemer matte furnace was completed in 1889 giving the company an annual productive capacity of 9,000 tons of low-grade matte. Most of the matte was originally shipped to Europe for refining but, subsequently, shipments were made to the Orford Copper Company of New Jersey.

There were two problems associated with the exploitation of the Sudbury ores. One was the very small demand for nickel. World consumption of nickel in 1887 was about 1,000 tons. However, after 1889, with the development of nickel-steel alloys for armour plate, nickel demand increased tremendously. With a capacity for nickel matte equivalent to the world consumption in 1889, the Canadian Copper Company exerted every pressure to increase the demand for nickel. In 1890, Canadian Copper secured contracts with the United States Navy Department to supply matte containing 900 tons of nickel for armour-plate experiments.

The other problem was metallurgical. The existing methods for extracting nickel and copper from the Sudbury ores were slow and costly and could only be used on a small scale. In spite of their considerable efforts, the Canadian Copper Company was unable to find a satisfactory and profitable large-scale refining process. However, in the period 1890-1892 the Orford Copper Company developed a 'tops and bottoms' process that subsequently proved a commercial success.

Orford Copper Company

The Orford Copper Company, with a New Jersey charter, was incorporated in 1887. The company operated a copper refinery in New Jersey that was originally built to refine concentrates derived from mining properties near Orford in the Eastern Townships

FIGURE 42. General view of Canadian Copper's Murray mine about 1890 showing railway rock cut where nickel was first discovered in the Sudbury district.

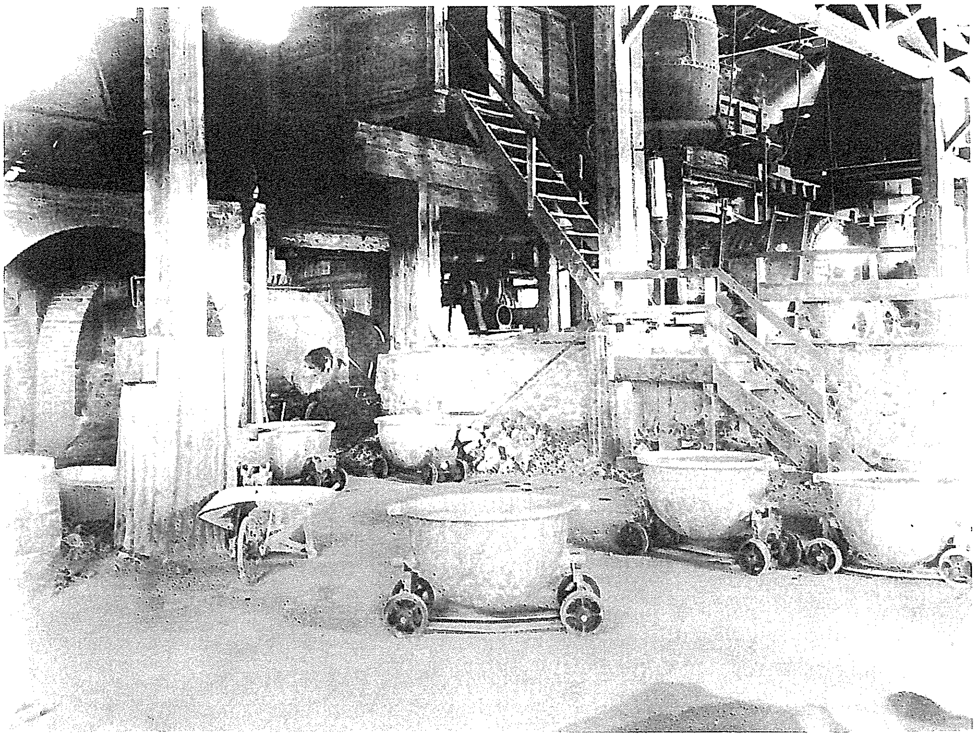


FIGURE 43. Interior of Murray smelter about 1890.

of Quebec. In 1887 the Orford Company began experimenting with matte from the Sudbury operations of the Canadian Copper Company. The manager of the refinery, R.M. Thompson, was endeavouring to develop an economical nickel refining process.

Little was known about the metallurgy of nickel at that time and processes were closely guarded secrets. The Orford Company undertook the refining of the copper-nickel matte that the United States Navy Department had purchased from the Canadian Copper Company. A nickel oxide of suitable purity was produced by a sulphuric acid process but the costs of this method proved prohibitive. However, in 1890-1892, Thompson developed the 'tops and bottoms' process that, by a series of 'top and bottom' meltings using coke and sodium sulphide, gave a copper-sulphide top and a nickel-sulphide bottom. This became the famous Orford process that remained part of standard nickel refining practice until 1948. The Orford Copper Company had an efficient process for refining nickel.

International Nickel Company

In the 1890s, it was easier for refining companies to acquire supplies of nickel ore than it was for mining companies to develop suitable refining and marketing outlets for their output. The Canadian Copper Company realized that it could not maintain control over the Sudbury district if other firms took advantage of the 'tops and bottoms' process by allying themselves with the Orford Company. Canadian Copper, therefore, entered into a contract with Orford whereby Canadian Copper would sell only to Orford, and Orford would buy only from Canadian Copper.

Large ore reserves coupled with a successful refining process supplied Canadian Copper and the Orford company with the means to gradually acquire control over the Canadian nickel industry. Market connections with the United States government and American armament producers enabled these two companies to invade the European market and reduce nickel prices to the point where other companies, which had commenced operations in the Sudbury district, were forced to shut down*. H.H. Vivian and Sons, a British nickel refining firm, and The Dominion Mineral Company, both of which acquired properties, erected smelters, and began production from the Sudbury district, failed to reopen after the winter shut-down of 1894-95. Canadian Copper was left once again in sole control of the district.

During these years the American armament manufacturers were finding it increasingly difficult to secure an adequate supply of nickel at favourable prices. European manufacturers controlled the New Caledonian nickel deposits. Eventually the Canadian Copper Company was forced into an amalgamation with American refining and consuming interests. The International Nickel Company, Limited, was incorporated in 1902 in the state of New Jersey. This company merged the Orford Copper Company and the Canadian Copper Company, under the control of the financial interests backing the United States Steel Corporation. The Orford Copper Company ceased to exist but the Canadian Copper Company continued to operate as a subsidiary.

The period from 1902 to 1918 was a time of rapid development in the nickel industry, based on pre-war armour-plate demands and the military needs of World War I. By 1905, the Sudbury district had become the world's chief supplier of nickel and Canadian Copper was the dominant producer. The main demand for nickel continued to

*Depressed prices compounded the management, grade and processing problems of these firms.

be in Europe where International Nickel gradually obtained a larger share of the market. Canadian nickel production increased from just over 5,000 tons in 1902 to about 46,000 tons in 1918 (Appendix C).

There were also indications that the peacetime markets for nickel were broadening. Industrial uses for nickel in the United States had risen to 3,000 tons per year by 1913. International Nickel began to develop new uses for nickel; in 1906 Monel metal was introduced—a natural alloy of copper and nickel produced from Sudbury ores without separation.

In 1900, Canadian Copper began production from the Creighton mine which in time became the most important nickel mine in the world and supplied all the ore smelted by International Nickel from 1919 to 1929. The company began developing the Frood mine in 1912 but it was later shut down and didn't become an important producer until the thirties. To cope with the increasing mine production, new blast furnaces and basic converters were installed at the Copper Cliff smelter, and in New Jersey, International Nickel's refining facilities were enlarged in 1913 producing just under 20,000 tons of nickel.

During these years there was a growing public demand in Canada for the domestic refining of nickel. 'The Nickel Question' as it was known continued to be a matter of public controversy until the pressure of World War I made it possible for the Ontario and Federal governments to compel International Nickel to establish nickel refining facilities in Canada. The development of an electrolytic refining process and the resulting attractiveness of Niagara Falls' hydroelectric power encouraged International Nickel in 1916 to build its first Canadian refinery at Port Colborne, Ontario.

Before the end of World War I several other companies endeavoured to become producers in the Sudbury district. Only one company succeeded and there was one notable failure.

Mond Nickel Company, Limited

The successful entrant in the Sudbury district was the Mond Nickel Company, incorporated in England in 1900. Earlier, Ludwig Mond, the founder of the company, had developed a carbonyl process for refining nickel. After trying unsuccessfully to sell this process to the Canadian Copper Company, Mond decided to obtain his own nickel supply.

In 1899, the Mond group purchased the Victoria mine in the Sudbury district. Production began in 1901 and the ore, after heap roasting, was smelted at the Victoria mine. The matte produced was sent to Clydach, Wales, for refining. Mond Nickel subsequently purchased the Garson, Worthington, Levack, Frood-Extension and North Star properties. In 1913, the Victoria plant was closed and a new smelter was erected at Coniston more central to the ore supplies.

Several reasons may be inferred for Mond's relatively easy entrance into the nickel industry at a time when other companies were meeting with failure. One was that Mond had a successful refining process that produced a superior product. Also, it may be surmised that Canadian Copper was not unwilling to have a competitor in the district at a time when it was being attacked by the government as a foreign monopolist. Mond's small size, British charter and willingness to co-operate with Canadian Copper made that company a useful ally rather than a competitor and facilitated its admission to the industry.

Nickel production from the Clydach refinery increased steadily through the war years to a peak of 5,000 tons in 1918. With the depressed armament demand, production declined to 2,000 tons per year in the early twenties and the Mond Company embarked on a program of product research and market development in the hope of finding new outlets for nickel. New nickel alloys were developed and the company began to prosper once again. Increases in the demand for pellet nickel necessitated expansion of the Clydach refinery and production rose to over 10,000 tons in 1928.

To supply its expanding markets, Mond Nickel was developing new properties in the Sudbury district for production. One of these, the Frood-Extension, was subsequently found to be the centre part of the most important ore deposit in the Sudbury area. However, both ends of the deposit were owned by International Nickel and it was decided that single ownership was the only economical way to exploit this major orebody.

There were other reasons for a merger as well. The Mond family, who closely controlled Mond Nickel, was at this time deeply involved with establishing Imperial Chemical Industries. A merger with International Nickel would permit the Mond family to continue to share in the profits of the nickel industry without having to be concerned with the direct control and management of a company. From International Nickel's point of view there were economies to be gained by technical reorganization, the elimination of duplicate services and the centralization of selling operations. Finally, there were considerable profits to be made from the financial transactions relating to the merger. The merger took place in December 1928 with Mond acquiring stock in International Nickel and the Mond Company becoming a subsidiary(4).

British America Nickel Corporation, Limited

The British America Nickel Corporation, incorporated in 1913, acquired the Murray, Elsie, Lady Violet, Gertrude, Whistle and Wildcat properties in the Sudbury district. The company also acquired North American rights to the Hybinette refining process.

Because the grade of ore was relatively low it was difficult for the company to secure markets. The necessary financing was not obtained until 1916 when the British government purchased $3 million in corporate bonds and contracted to buy 6,000 tons of nickel annually for ten years. In 1918, British America started to erect a smelter at Sudbury and a refinery at Deschênes, Que. However, the company was unable to complete its construction program before the war ended, and in 1920 the British government cancelled the contract.

British America finally reached the production stage in 1921, in a period of rapidly falling demand. Nevertheless, by aggressive action in the United States market, British America posed a threat to International Nickel and forced that company into a price war. Despite the price cuts, British America expanded operations and by 1924 was producing about 400 tons of nickel per month. Later in the same year, demands by bond holders who held a high proportion of the capitalization of the company, forced British America into liquidation. In 1925 the assets of the company were sold to International Nickel.

The International Nickel Company of Canada, Limited

In 1916, The International Nickel Company of Canada, Limited, was formed by Dominion incorporation to consolidate the subsidiaries of The International Nickel Company (N.J.) in Canada, the latter company owning all the issued stock.

The post World War I period for the nickel industry was one of transition from a dependence on the armament market to the development of peacetime uses for the metal. Initially production was sharply reduced. Because of the United States recession in late 1920, International Nickel was forced to close operations completely for part of 1921 and 1922. At this time it was decided that great savings could be realized by concentrating nickel refining at Port Colborne and during 1921 the Orford nickel refinery in New Jersey was closed permanently.

An intensive product research and market development program by International Nickel during the early twenties brought an increasing demand for nickel in such products as corrosion resistant alloys, cast irons, structural steels and stainless steels. To promote the growth of these new uses, International Nickel erected a plant at Huntington, West Virginia, and in 1922 began producing a wide range of semifabricated shapes. By the late 1920s, International Nickel was undergoing a tremendous expansion and by 1929 mine production had risen to over 58,000 tons annually.

In 1928, before the Mond merger, shares of the International Nickel Company were exchanged for shares of The International Nickel Company of Canada, Limited. Thus the former Canadian subsidiary now became the operating, holding and parent company with subsidiaries in the United States and Britain(4).

By the end of 1928 there was only one nickel company producing in Canada–International Nickel. However, this absolute control was short-lived as in 1930 Falconbridge Nickel Mines began production in the Sudbury district. In 1953, the third major nickel producing company, Sherritt Gordon Mines, began production in Manitoba.

International Nickel's mine production decreased sharply in the early 1930s and in 1932 only 17,000 tons were delivered. All mines except the Frood were closed down during the depression. The Creighton mine was reopened in 1933, Garson in 1936 and Levack in 1937. Before World War II further advances in product research and market development were made and deliveries of nickel by International Nickel increased to 82,000 tons in 1938.

Because of disruptions in European production facilities, the brunt of the allied wartime nickel demand was placed on Canada, and consequently on International Nickel. International Nickel's development work at Petsamo, Finland, was halted by the Russian invasion. The Germans took over Falconbridge's Norwegian refinery and Le Nickel's Le Havre refinery. To meet wartime requirements mine production in the Sudbury district was greatly expanded and additional refining facilities were installed at Port Colborne. International Nickel also undertook to process Falconbridge matte. During the war years International Nickel produced 750,000 tons of nickel as well as considerable quantities of copper and platinum metals(5). The amount of ore mined was equal to its own output, and that of its predecessors during the preceding 64 years of their existence.

In 1944, the Petsamo territory, in which International Nickel's Finnish holdings were located, was ceded to the USSR under the terms of an armistice between the USSR and Finland. The company received a settlement of $20 million from the Soviet government(6, p.244).

Peace once more brought a sharp decline in demand. The slump, however, was not as extreme or prolonged as that following the end of World War I. Nickel had already developed a sound position as a peace-time metal. Deliveries of nickel by International Nickel which had fallen to 100,000 tons in 1946, recovered to 128,000 tons in 1950. The Korean War and consequent defence build-ups accelerated demand.

International Nickel began exploration in northern Manitoba in 1946. Initial work was centred about the Mystery-Moak Lakes region and although large deposits were discovered, they were only of marginal grade. The Thompson orebody, discovered in 1956, proved to be of much higher grade. By 1961, a fully integrated nickel operation was completed at Thompson with an annual production capacity of 37,000 tons of refined nickel.

With its new facilities in Manitoba, and expanded operations in Ontario and Britain, International Nickel had, by 1966, a total annual production capacity of 225,000 tons.

Falconbridge Nickel Mines, Limited

Falconbridge Nickel Mines, Limited, was incorporated in 1928 and subsequently acquired a group of mineral claims on the southeast side of the Sudbury basin. These claims developed into the Falconbridge mine.

The history of the Falconbridge claims goes back to 1901 when Thomas Edison made a dip needle survey on the projected norite contact eastward from Garson township. The anomaly encountered was diamond drilled in 1916 by the E.J. Longyear Company and some six million tons of ore were proven to the 500-foot level. The property then remained idle until acquired in 1928 by Ventures Limited, with Sudbury Basin Mines, Limited, participating. These two companies capitalized Falconbridge Nickel Mines and turned their claims over to it for development.

In 1929, Falconbridge purchased a refinery in Norway and arrangements were made to use the Hybinette process. In 1929, a smelter was erected at the minesite and smelting and refining operations began the following year.

Falconbridge entered the nickel industry at a time of declining demand and it had difficulty establishing markets. After it weathered the depression years the company began to prosper; production reached 10,000 tons in 1939. The company embarked on an aggressive exploration program, particularly on the northern rim of the Sudbury basin, and by the late thirties had absorbed most of the active smaller developments in the Sudbury district. However, the company remained small in comparison to International Nickel averaging only about 5% of the total Canadian production during these years.

Although Falconbridge used International Nickel's refinery during the war years, smelter production had risen by 1945 to 12,500 tons of nickel. Important expansion of mine and processing facilities has been in progress since the end of World War II. During the 1950s, agreements between Falconbridge and the United States government provided a guaranteed market for some 112,000 tons of nickel and stimulated growth. During these years, the Hardy, Onaping and Fecunis Lake mines were brought to production and refinery capacity expanded in 1966 to an annual rate of about 40,000 tons.

Sherritt Gordon Mines Limited

Sherritt Gordon Mines Limited was incorporated by Ontario in 1927. The company originally mined a copper-zinc deposit at Sherridon, Man. which remained in production until 1951.

Nickel-copper mineralization was discovered by Sherritt Gordon prospectors at Lynn Lake, Man. in 1941. Exploration and development work was curtailed by the war and diamond drilling did not start until 1945. The several orebodies discovered were developed when the necessary financing had been arranged and a suitable milling and refining process had been developed. Mine production started at Lynn Lake in 1953 using the mining plant, concentrator and houses of the old Sherridon mine(4).

A hydrometallurgical process was developed in the early 1950s for the treatment of the nickel-copper sulphide concentrate. A refinery designed to make use of the ammonia pressure leach process was erected at Fort Saskatchewan, Alta. It started production in 1954 with a designed capacity of 8,500 tons of nickel per year in powder and briquette forms. The United States government contracted to purchase 5,000 tons of nickel per year for a five-year period. Under this agreement, the company supplied approximately 18,500 tons of nickel to the US government. The balance of the contract was sold to International Nickel. Refinery capacity had increased to 15,000 tons per year in 1966.

GEOLOGY OF MAJOR NICKEL AREAS

The Sudbury Basin, Ont. *

The Sudbury nickel-sulphide deposits are associated in place, and presumably in origin, with a body of norite and micropegmatite, the 'nickel eruptive', that outcrops as an oval ring with axes of 37 and 17 miles and a width that varies from one to four miles. The depth and form of the bottom of the intrusive is unknown. The outer part of the ring is norite and the inner part micropegmatite, with a fairly rapid graduational change from one to the other. Inside the intrusive are Precambrian rocks of the Whitewater series. Dyke-like or irregular bodies of the intrusive, known locally as offsets, radiate out from the ring's outer margin into the footwall rocks for distances up to 25 miles.

The Sudbury basin has been studied geologically for more than 60 years and although much is known about it there are still many points of dissension concerning its origin(10). The open synclinal structure of the Whitewater series, the annular shape of the norite-micropegmatite mass, and the symmetrical disposition of these acid and basic phases together suggest that the igneous mass is a thick sheet intruded along the contact between the Whitewater series and older rocks. However, there is also evidence that the irruptive is a ring dyke and, therefore, a composite intrusion, with the Whitewater series actually a part of the presumed older rocks outside the ring.

The primary structure of sulphide localization is a quartz diorite phase in the footwall contact of the norite. Sparse mineralization is present for most of its perimeter and it is only where one or more secondary structures have been superimposed on the primary one that sulphide mineralization may be extensive enough to make quantities and grades of economic importance. These secondary geological features are penetrations of norite or its contact phase into the footwall rocks, and shearing and brecciation along or adjacent to the base of the intrusive.

Ore occurs in massive, disseminated, stringer and breccia forms. Gradations exist from one type to another. Ore differs somewhat from mine to mine in the Sudbury basin but, in general, is composed of 15 to 100% sulphide. Massive ore generally occurs along fault or breccia zones. Disseminated ore is found almost entirely in the quartz diorite, a contact phase of the norite. Stringer ore occurs in narrow fractures which may be irregular or have an echelon pattern. Breccia ore contains rock fragments such as schist, quartz, norite, granite, gneiss, quartz diorite, and gabbro or greenstone.

The principal ore minerals are pyrrhotite, pentlandite and chalcopyrite. Nickel is primarily present in the mineral pentlandite and platinum in the mineral sperrylite. The metal content and sulphide mineral proportions vary widely between deposits.

The grade of ore is variable and the average grade of reserves has steadily fallen over the years. In 1955, the average grade of reserves was about 2% nickel and slightly less than that amount of copper(7,p.73). In 1966, average grade of proven reserves was about 1.5% nickel with a similar amount of copper.

Over the years approximately 34 nickel-copper mines have been operated in the Sudbury district(8, p.39). Early in 1967, 16 mines were in operation and another five were in the development stage.

*Ref. (7-11).

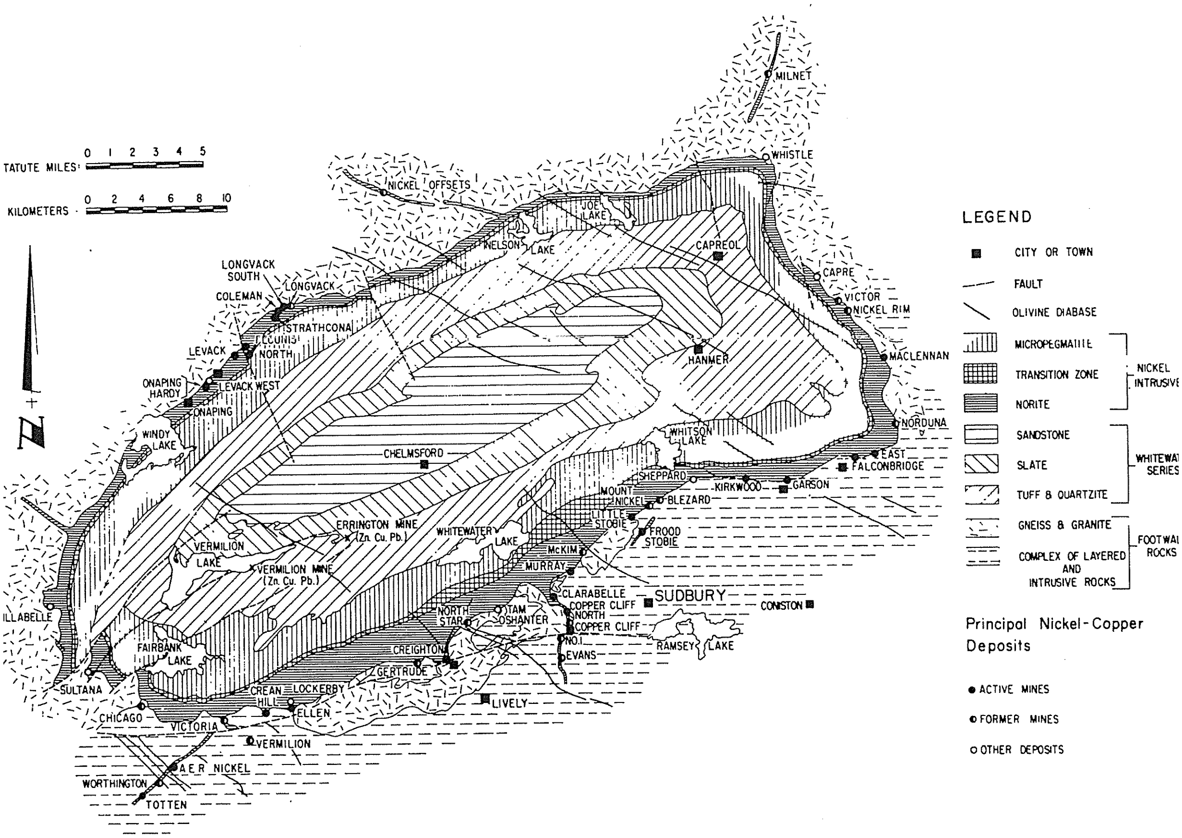


FIGURE 44. Geological map of the Sudbury district.

Lynn Lake, Man.

At Sherritt Gordon's Lynn Lake mine, the ore occurs in several orebodies that have been found in two basic plugs that intrude into Precambrian sediments and volcanics (7). Ore occurs as massive sulphides, disseminated sulphides, or stockworks of sulphide stringers where faulting has fractured the intrusions. The sulphides are pyrrhotite, pentlandite, chalcopyrite and pyrite. Cobalt occurs in small amounts. The orebodies are cut by post-mineral faults. Blocks of ore occur between the faults.

The A plug is the largest, 12,000 feet long and 5,000 feet wide, and is known to contain ten orebodies. The ore zones occur where the basic rock has been most brecciated by pre-ore faults. The ore itself appears to be displaced by these west-dipping thrust faults but actually the amount of post-ore movement on the faults is small. The EL plug contained the richest orebody, which occurred within its inner core.

The average grade of the ore is about 0.8% nickel and 0.5% copper. Proven ore reserves at the end of 1966 were about 11 million tons.

Thompson Nickel Belt, Man.

The nickel deposits of the Thompson belt(12-14) occur in the zone marking the boundary between the Superior and Churchill geological provinces. The most favourable areas lie along a narrow, one-hundred-mile-long strip of intensely deformed, metamorphosed, and granitized rocks enclosing remnants of less-altered sediments, and all intruded by lenticular serpentinite bodies. The deposits are associated with these serpentinite bodies.

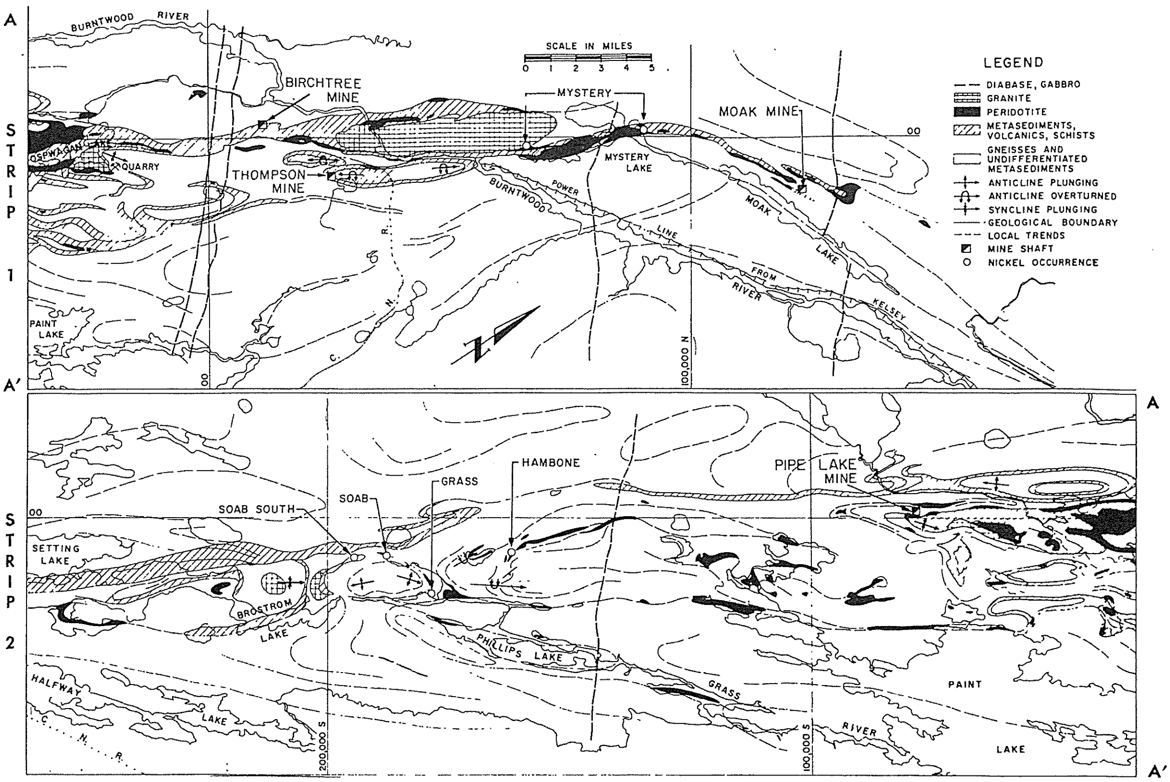


FIGURE 45. Geological map of the Thompson nickel belt.

The nickel deposits are of two types; low-grade deposits that occur within the serpentinite bodies, and at least one high-grade deposit that is found mainly in sedimentary rock and gneisses. The high-grade Thompson deposit (average grade of ore is almost 3% nickel) is associated with a small serpentinite intrusion and part of the ore is found in this rock; however, most of the sulphides occur in the adjacent sediments and schists.

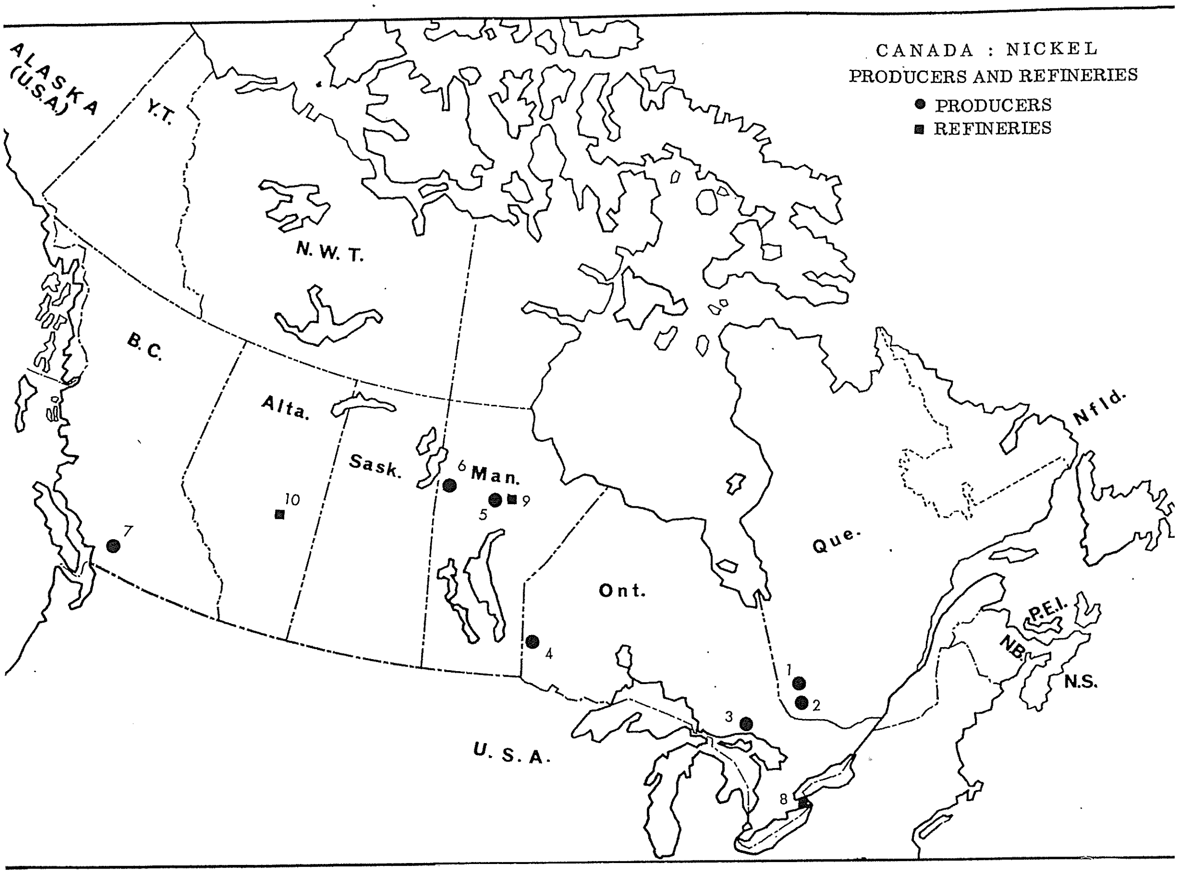
In most deposits, sulphides occur as disseminations although massive sulphides are found in places. Pyrrhotite, pentlandite and chalcopyrite are the primary sulphide minerals but the copper-nickel ratio of 1:5 is notably lower than in deposits associated with norite or gabbro.

In early 1967, the Thompson mine was the only producer in the district, with reserves believed to be in excess of 25 million tons(12,p.107). However, three deposits are in the development stage and several others are being actively explored.

PRODUCERS

The International Nickel Company of Canada, Limited

The International Nickel Company of Canada, Limited, with its subsidiaries, operates as a fully integrated producer of nickel, copper, platinum and other metals. Operations centre around mines and smelters at Sudbury, Ont. and Thompson, Man. Refining and processing plants, as well as research laboratories, are operated in Canada, the United States and Britain. The company is the largest producer of nickel in the world and ranks among the major producers of copper and platinum. Other elements recovered are gold, silver, palladium, iridium, rhodium, ruthenium, selenium, tellurium, osmium, cobalt, iron and sulphur.



PRODUCERS

1. Marbridge Mines Limited
2. Lorraine Mining Company Limited
3. Sudbury area: Falconbridge Nickel Mines, Limited (6 mines, 1 smelter) The International Nickel Company of Canada, Limited (9 mines, 2 smelters)
4. Metal Mines Limited
5. The International Nickel Company of Canada, Limited (Thompson mine and smelter)
6. Sherritt Gordon Mines Limited
7. Giant Mascot Mines Limited

REFINERIES

8. The International Nickel Company of Canada, Limited (Port Colborne)
9. The International Nickel Company of Canada, Limited (Thompson)
10. Sherritt Gordon Mines Limited (Fort Saskatchewan).

FIGURE 46. Canada, nickel producers and refineries.

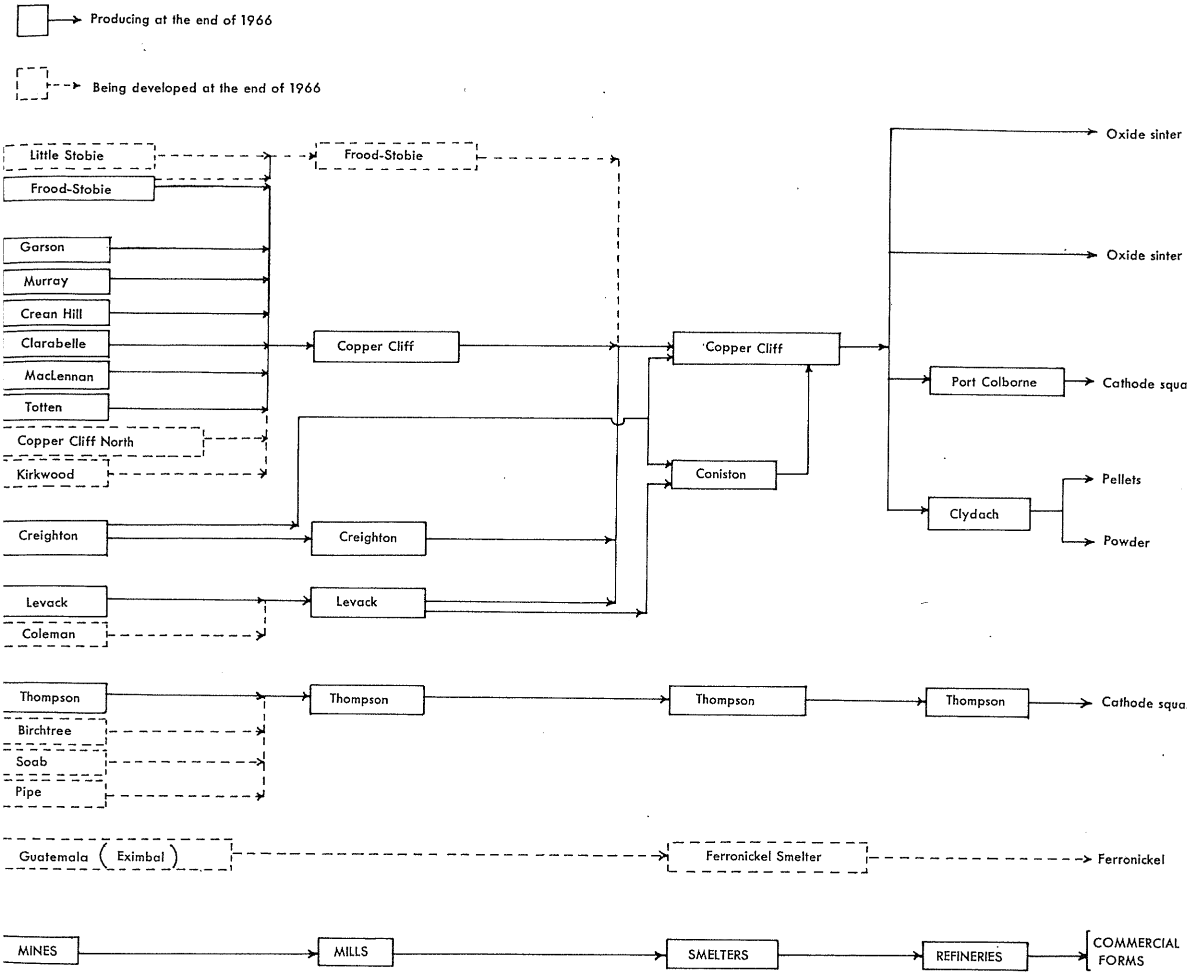


FIGURE 47. Generalized nickel processing flowsheet, The International Nickel Company of Canada, Limited.

The International Nickel Company, Incorporated, is a wholly-owned subsidiary of The International Nickel Company of Canada, Limited, and holds title to the various United States plants owned by the company. In 1965 the name of International Nickel's British subsidiary was changed to International Nickel Limited from The International Nickel Company (Mond) Limited. This subsidiary holds the title to British plants operated by the parent company.

International Nickel spent almost $84 million in 1966 on capital expenditures and exploration. Capital expenditures for 1967 were expected to approximate $125 million(15).

Mines

In early 1967, International Nickel was operating eight mines and one open pit in the Sudbury district. They are the Frood-Stobie, Creighton, Levack, Garson, Murray, Crean Hill, MacLennan and Totten mines, and the Clarabelle open pit. Four deposits are in the development stage. The Copper Cliff North mine was expected to start production in 1967; the Kirkwood mine in 1968; the Little Stobie and Coleman mines in 1969(16).

In Manitoba the company operates the Thompson mine. The Soab mine was scheduled for production in late 1967 and the Birchtree mine in 1968. In 1966 plans were announced for the open-pit development of the Pipe deposit.

In 1967, the International Nickel's majority-owned subsidiary in Guatemala was developing an integrated nickel mining and processing operation.

In 1966, International Nickel mined 17.5 million tons of ore. At the end of 1966, proven ore reserves at the company's Sudbury and Manitoba producing mines were estimated at 324.9 million tons with a nickel-copper content of 9.5 million tons(15).

The flow of products between the company's mines and processing facilities is shown in Figure 47.

Frood-Stobie Mine – This mine is located in McKim township, three miles north of Sudbury. The north section of the mine was formerly owned by the Mond Nickel Company.

The Frood-Stobie deposit lies in a large dyke-like zone of quartz diorite, separated from the norite footwall by more than a mile of granite. The quartz diorite contains numerous inclusions which tend to dilute the ore. The quartz diorite matrix contains blebs of sulphide. It has been possible to mine most of this disseminated mineralization. Non-disseminated ore occurs in massive, breccia and stringer forms. The greatest massive sulphide accumulations are near the bottom of the quartz diorite body and along the lower part of both walls(8,17).

The Frood-Stobie mine is the largest producer in the Sudbury district and is the richest in precious metal content. The mine had produced over 190 million tons through 1966. Production at the end of 1966 was at a rate of 20,000 tons per day(18). Substantial progress was made in 1966 on a major mine expansion program.

Creighton Mine – This mine is located in Creighton township, seven miles west of Copper Cliff.

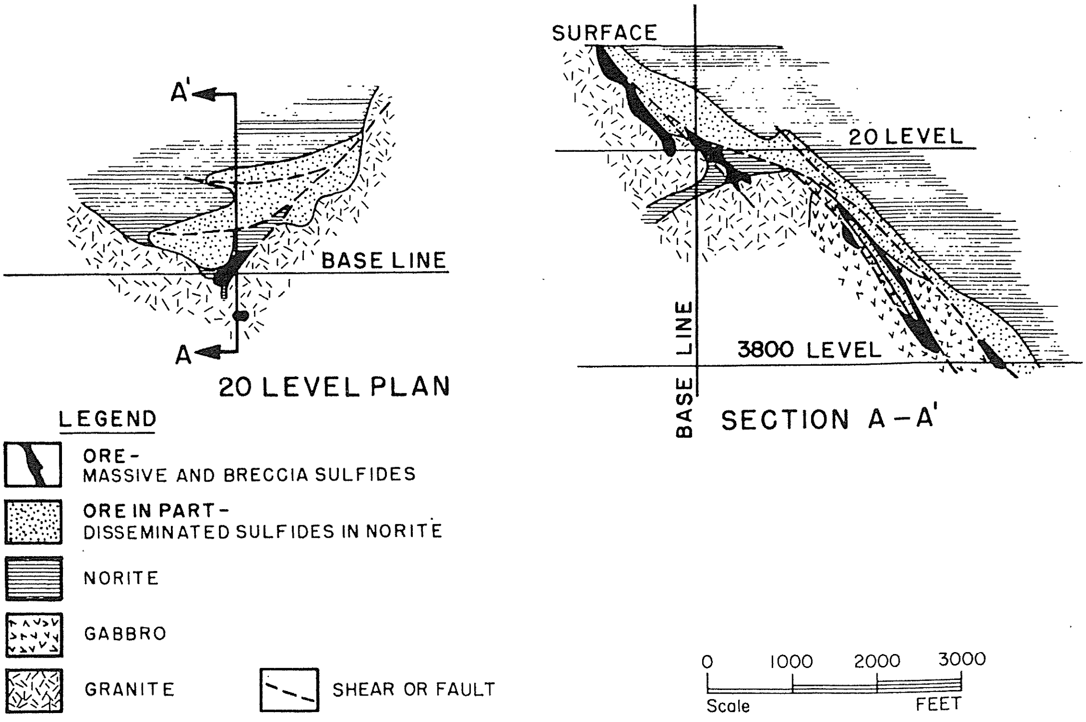


FIGURE 48. Generalized geological plan and section, Creighton mine.

The Creighton orebodies occur in a depression at the base of the intrusive where shearing and associated breccia coincide roughly with the contact. The deposits occur along parallel shears in a large slab of quartz diorite and in shattered footwall rocks. Disseminated sulphides typically occur in the upper quartz diorite zone. Massive or breccia sulphide occurs in the footwall(8).

In 1967, the lower section of the mine, below the 5,400-foot level, was being developed for production. The 7,150-foot No. 9 production shaft had been sunk to 2,300 feet at the end of 1966. Production at the end of 1966 was at a rate of 20,000 tons per day(18).

Garson Mine – This mine is located in Garson township, 12 miles northeast of Copper Cliff. It was formerly owned by the Mond Nickel Company.

The Garson deposit is similar to the Creighton deposit in that it is associated with quartz diorite and a series of shears. The main orebody lies along and between two faults. The faults converge at depth, forming a steeply dipping trough-like orebody. Ore consists of both disseminated and massive sulphides(11).

Production from this mine at the end of 1966 was 4,500 tons per day.

Levack Mine – This mine is located in Levack township on the north rim of the Sudbury basin, 20 miles northwest of Copper Cliff. It was formerly owned by the Mond Nickel Company.

The ore occurs within a very irregular body of granite breccia along the norite contact, as narrow dykes extending into the norite, and in brecciated and shattered zones in the underlying granite gneiss. Within the granite gneiss the ore is mainly in stringer and lense forms. In the granite breccia the ore is mainly of the disseminated type. Mineralization is extensive where the breccia occurs as tongues in the norite(11).

Production from Falconbridge's Fecunis mine is operated in conjunction with International Nickel's own operation at Levack. Production from the Levack mine was 7,000 tons per day at the end of 1966.

Murray Mine – This mine is located in McKim township, four miles north of Copper Cliff.

The Murray orebody is related to an extensive lenticular body of contact breccia that occurs at the base of the intrusive. The ore occurs both in the noritic matrix of the breccia and in the underlying greenstone and granite of the footwall complex. The breccia ore and the underlying high-grade sulphide form a continuous ore unit where present. The main orebody extends to 3,000 feet, averaging 1,500 feet in length with a maximum thickness of 500 feet(8).

Production from this mine at the end of 1965 was 7,500 tons per day.

Crean Hill Mine – This mine is located in Denison township, 14 miles southwest of Copper Cliff. The orebody consists primarily of copper-nickel-iron sulphides cementing a breccia of greenstone and quartz at the contact of the intrusive. The orebody dips about 60° to the east. The Crean Hill mine, dormant since 1918, was reopened early in 1964. Production averaged 3,000 per day in 1965.

Totten Mine – The mine is located 20 miles southwest of Copper Cliff. Ore shipments began early in 1966 and production was 1,000 tons per day at year-end(18).

MacLennan Mine – The mine is located on the west rim of the Sudbury basin, 18 miles northeast of Copper Cliff. Development and production from the deposit are contracted. Production, which began in 1966, was 600 tons per day at year-end.

Clarabelle Pit – This open pit is located southwest of the Murray mine. The deposit, occurring in what is referred to as the 'Copper Cliff offset', consists of massive and disseminated sulphides composed of pyrrhotite, pentlandite and chalcopyrite. The mineralization occurs in an inclusion bearing zone at the norite contact. Ore production was about 8,000 tons per day at the end of 1966.

Copper Cliff North Mine – This mine, which is presently being developed by a contractor for production in 1967, consists of the underground portion of the Clarabelle orebody. Level development, underground construction, and the sinking of a second shaft were in progress at the end of 1966(18).

Kirkwood Mine – The Kirkwood deposit is located about two miles west of the Garson mine. The deposit occurs near the contact of greenstone and norite, both of which have been sheared and altered. Previous production from this property was suspended in 1916. The deposit is being developed by a contractor for production in 1968. Shaft sinking was in progress at the end of 1966.

Coleman Mine – The Coleman deposit is situated on the northwest rim of the Sudbury basin, several miles east of the Levack mine and not far from Falconbridge's Strathcona mine. The deposit is being developed by a contractor for production in 1969. Shaft sinking was in progress at the end of 1966(18).

Little Stobie Mine – The Little Stobie deposit is one mile north of the Frood. The sinking of two shafts started in 1966. The deposit is being developed by a contractor and is scheduled for production in 1969.

Thompson Mine – International Nickel has acquired extensive holdings in the Thompson nickel belt of northern Manitoba. Long term rights to these properties, which cover an area 80 miles long and up to 10 miles wide, have been assured by agreement with the Province of Manitoba. Included in the area is the Thompson mine which is located 400 miles north of Winnipeg and 950 miles northwest of Sudbury.

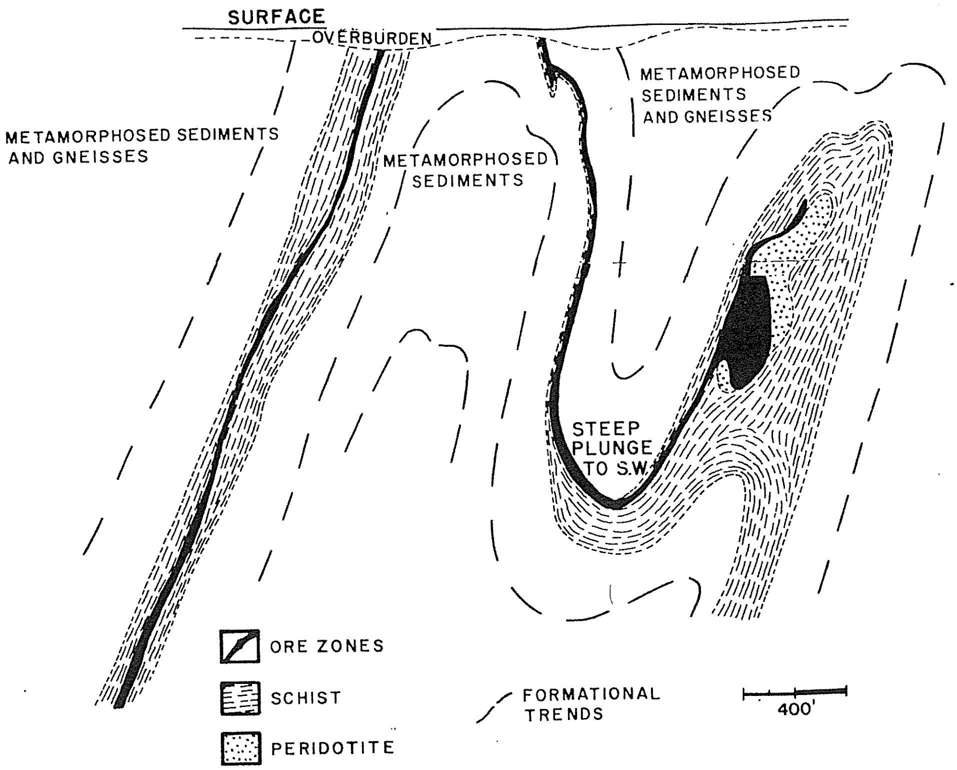


FIGURE 49. Geological section of Thompson mine.

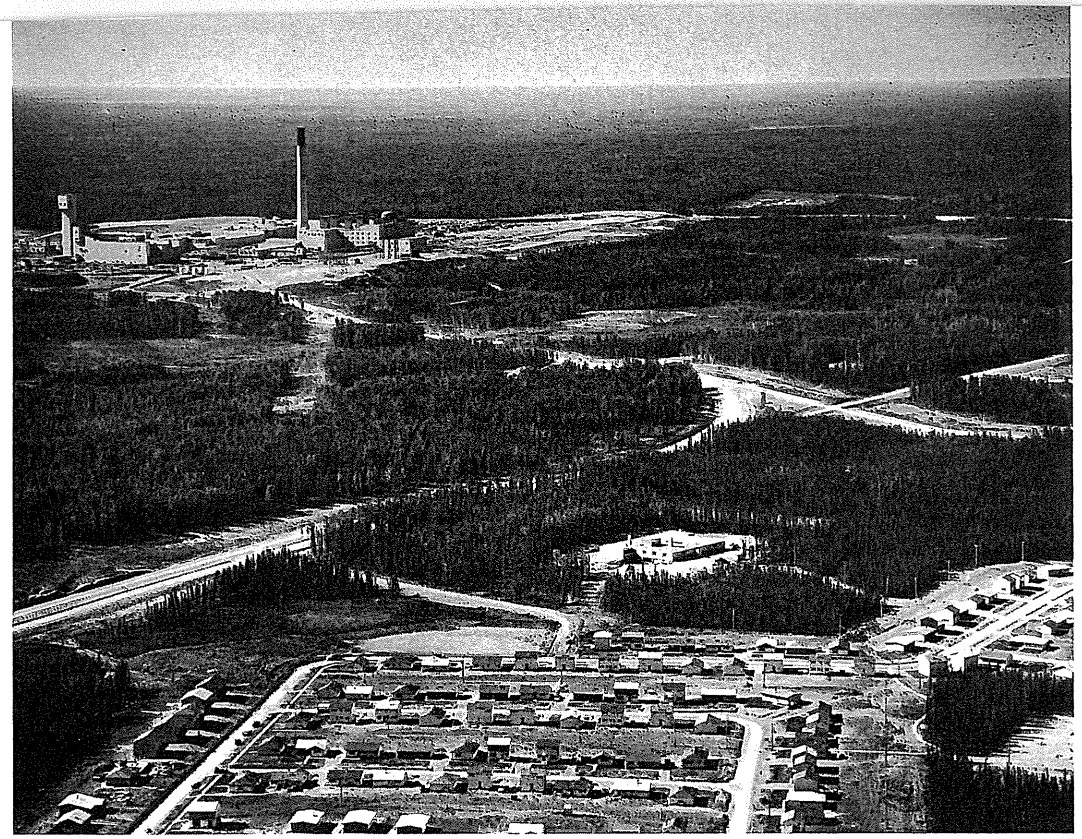


FIGURE 50. Thompson, Man. Townsite in foreground, International Nickel's mine, mill, smelter and refinery in background.

The Thompson deposit lies within a band of biotite schist bounded on the south by quartzite and arkose and on the north by a band of sedimentary-iron formation. The orebody dips 65 to 75° southeast, conformable with the enclosing sediments. The ore consists primarily of coarse-grained pyrrhotite and pentlandite containing fragments of rock and small flakes of biotite. Although most of the ore lies within the biotite schist band, some massive and disseminated sulphides occur within a serpentinite body at one end of the deposit(12).

Production from the Thompson mine started in 1961 and at the end of 1966 was at a rate of about 8,000 tons of ore per day. Mining is primarily by the cut-and-fill method.

Birchtree Mine – The Birchtree deposit is located four miles southwest of Thompson, Man.

The Birchtree deposit appears to be similar to the Thompson orebody. Pyrrhotite and pentlandite occur as bands and streaks of massive sulphides and disseminated within a biotite schist that is interbanded with quartzite. Narrow lenses of peridotite and talc schist occur in the biotite schist. Grades range up to 2.5% nickel. Estimated nickel content is greater than one million tons(44).*

Plans to develop the Birchtree deposit were announced early in 1964. At the end of 1966 the sinking of a production shaft and underground lateral development were in progress. Production is scheduled to start by late 1968. Ore from the mine will be treated at Thompson.

Soab Mine – This deposit is located west of the Grass River, 42 miles southwest of Thompson, Man.

*Including material not economically mineable at present but which may reasonably be economical in the future.

There are apparently three ore zones. The longest has a length of 4,000 feet and is a breccia sulphide that occurs in a shear zone. The second sulphide zone, having a width of over 50 feet, is located on an iron formation-skarn contact. The third lies at a low angle to a granodiorite-gneiss and hornblende-gneiss contact. Grades range up to 1.5% nickel. Estimated nickel content is between 100,000 and one million tons(44).*

Production is expected by 1968. Two shafts were being sunk at the end of 1966.

Pipe Pit – In 1966, plans were announced to develop the Pipe deposit some 20 miles south of Thompson.

The orebody consists of disseminated sulphides in serpentinite with some massive and sulphide breccia. Estimated nickel content is greater than one million tons(44).*

The ore will be mined by open pit and will require the removal of 100 feet of clay overburden. Production is expected by 1970. Capital investment will be about $100 million.

Guatemala – A majority-owned subsidiary, Eximbal, is developing nickel-laterite deposits in the Lake Izabal area of Guatemala. In 1966 important development work was carried out. Plans are to mine and smelt 1.2 million tons of lateritic nickel ore annually, producing 12,500 tons of nickel in ferronickel form.

Other Interests – In 1967, International Nickel was carrying out exploration and development work on various other properties in the Sudbury and Thompson districts, at Shebandowan Lake and near Timmins, Ont., and in Australia, the United States and the British Solomon Islands. To determine the feasibility of developing large low-grade deposits northwest of Garson in the Sudbury district, the sinking of an exploration shaft began early in 1967.

Concentrators

At the end of 1966, International Nickel operated four concentrators: three in the Sudbury area at Copper Cliff (30,000 tpd), Creighton (12,000 tpd) and Levack (6,000 tpd); and a fourth at Thompson, Man. (6,000 tpd). The flow of products from mines to concentrators to smelters is shown in Figure 47. The production from several developing mines in the Sudbury area has necessitated the construction of a fifth concentrator at Frood-Stobie (22,500 tpd) scheduled to be completed in 1967. The Thompson concentrator will be expanded to process ore from the company's three developing mines in Manitoba.

Smelters

International Nickel operates two nickel smelters in the Sudbury district and one at Thompson.

The Copper Cliff nickel smelter has a capacity of about 8,000 tons of nickel-sulphide concentrates per day and 2,750 tons of high-grade ore per day. The flow of products from concentrators to smelters to refineries is shown in Figure 47. External sources of concentrate supply for the smelter are obtained from the operations of Metal Mines and Lorraine Mining. The increased smelter capacity resulting from the use of oxygen to enrich the combustion air will enable the smelter to treat the concentrates from the Frood-Stobie concentrator after certain plant modifications have been made.

*Including material not economically mineable at present but which may reasonably be economical in the future.

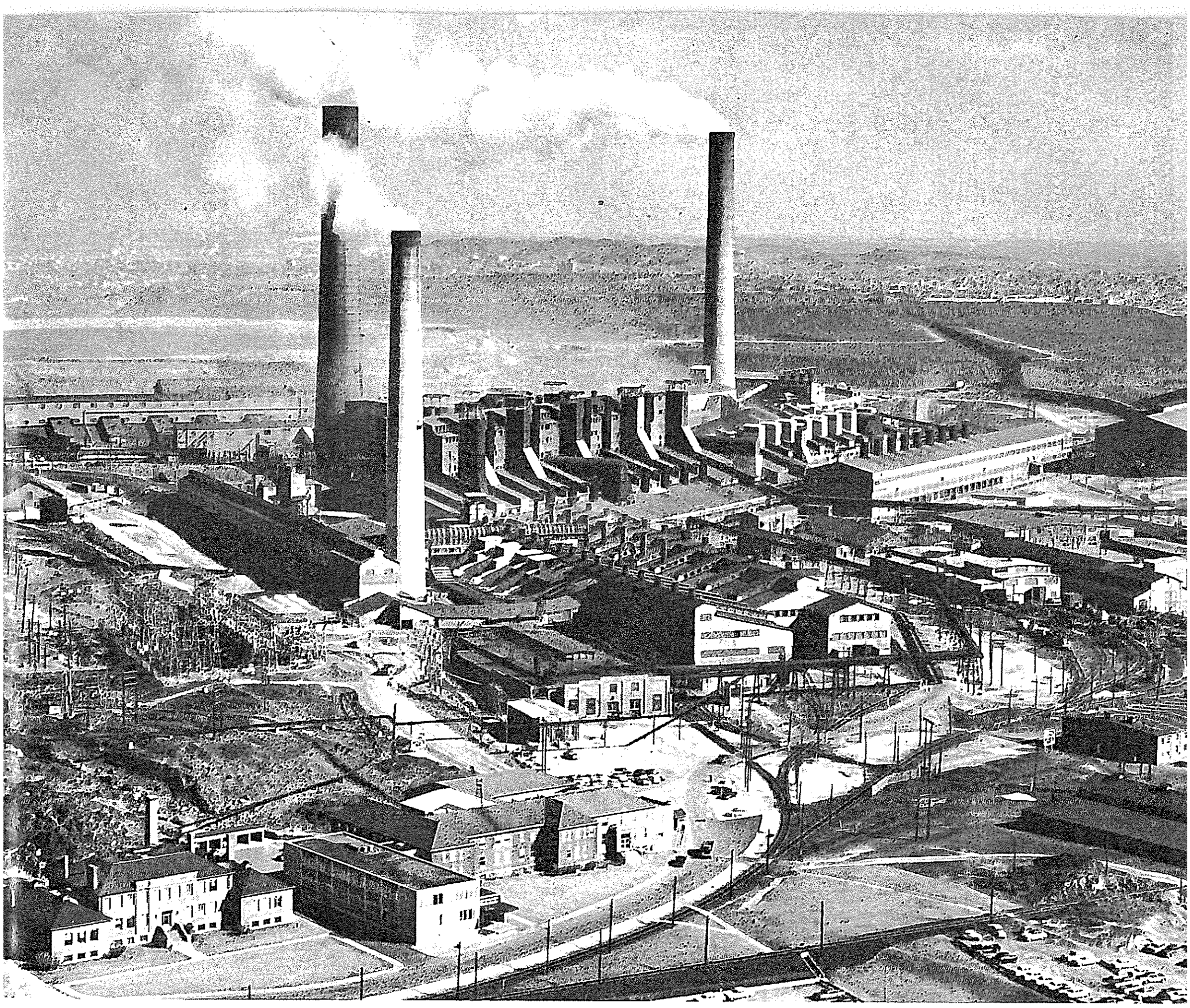


FIGURE 51. International Nickel's mill and smelter at Copper Cliff, Ont.

In early 1967, the Coniston smelter, located eight miles east of Sudbury, was producing at 50% of its 2,500 tpd capacity. The Bessemer matte product is sent to Copper Cliff for further processing.

The nickel smelter at Thompson produces a Bessemer matte that is cast directly into anodes for electrolytic refining. The Thompson smelter will be expanded to treat output from the company's three developing Manitoba mines.

Refineries

International Nickel operates nickel refineries at Port Colborne, Ont.; Clydach, Wales; and Thompson, Man.

The Port Colborne refinery recovers nickel by the electrolysis of both nickel-metal and nickel-sulphide anodes. By-products of the process include cobalt and elemental sulphur.

The nickel refinery at Clydach, Wales produces nickel pellets and powder by the carbonyl process. Production capacity is 40,000 tons of refined nickel per year. An important modernization scheme was completed in 1967.

Nickel is recovered at Thompson by the direct electrolysis of nickel matte. Plant capacity in early 1967 was 50,000 tons of nickel per year. The Thompson refinery will be expanded to treat output from the company's three developing Manitoba mines.

Rolling Mills

A rolling mill is operated by International Nickel at Huntington, West Virginia. The plant produces nickel and nickel alloy sheets, wire, seamless tubing, round ingots, cold drawn rods and other rolled products. Installation of a large new rolling mill unit and a forging press was completed in 1964. A new strip facility was installed in 1966.

Henry Wiggin and Company, Limited, a subsidiary of International Nickel, operates a rolling mill, extrusion plant, specialized high-nickel alloy fabrication plant and research laboratory at Hereford, England.

Market Outlets

Henry Gardner and Company, Limited, London, is the sole distributor of International Nickel primary nickel products in Britain. Elsewhere among the major consuming nations, International Nickel maintains a large number of sales and technical service offices.

Research Laboratories

Product research laboratories are operated in the United States at Sterling Forest, New York and Harbor Island, North Carolina and in Britain at Birmingham and Acton.

Process research laboratories and pilot plants are operated at Copper Cliff and Port Colborne, Ont. and at Clydach, Wales. The plant at Port Colborne contains pyrometallurgical, hydrometallurgical and vapometallurgical facilities for developing extraction and refining processes for both sulphide and laterite nickel ores.

A research facility at Sheridan Park, Ont. began operating at the end of 1966. It will be primarily concerned with extractive metallurgy and the development of improved methods for processing metallurgically complex ores. Geophysical and geological research, as well as product research, will also be carried on(15).

Financial and Operating Results – The International Nickel Company of Canada, Limited(19)*
(U.S. dollars)

	1951	1956	1961	1966
Share capital	149,012,000	156,545,000	130,150,000	147,342,000
Retained earnings	159,413,000	286,926,000	439,613,000	661,049,000
Net sales	286,785,000	444,740,000	517,226,000	694,122,000
Net earnings after tax	62,900,000	96,300,000	88,800,000	118,200,000
Depreciation and depletion	9,100,000	19,900,000	19,900,000	26,200,000
Income taxes	48,100,000	61,000,000	60,900,000	69,000,000
Dividends	37,900,000	54,700,000	46,900,000	83,100,000
Capital expenditures	23,700,000	23,000,000	46,000,000	73,000,000
Exploration expenditures	2,600,000	8,200,000	7,400,000	11,700,000
Ore reserves (tons)**	253,704,771	264,223,823	297,419,000	324,870,000
Ore mined (tons)	11,800,000	15,500,000	17,500,000	17,600,000
Nickel deliveries (tons)	121,950	143,050	186,250	250,100

*For all the company's operations.

**Proven.

Falconbridge Nickel Mines, Limited

Falconbridge Nickel Mines owns and operates six nickel-copper mines, three concentrators and a nickel smelter in the Sudbury district. In early 1967, the company was also developing the Strathcona and Longvac South mines and building a 6,000-ton-per-day mill for production by early 1968. The nickel-copper matte is processed in the refinery of the company's subsidiary in Norway. The products of the company include nickel, copper, cobalt, gold, silver, platinum, palladium, liquid sulphur dioxide, selenium residues and iron oxide. These products are marketed chiefly in Europe and the United States by the company and by various sales agents.

A controlling interest in several important producing and non-producing mining properties is held by the company because of its acquisition of Ventures, Limited in 1962.

Nickel production capacity at the end of 1966 was about 37,500 tons per year. This is to be raised to 50,000 tons by 1968.

Mines

Falconbridge Nickel Mines operates six mines in the Sudbury district: the Falconbridge, East, Hardy, Onaping, Fecunis Lake and North mines. The Fecunis Lake mine is operated jointly by Falconbridge and International Nickel. In addition, the Strathcona and Longvac South mines are currently under development and the Lockerby property is being extensively explored.

In 1966, Falconbridge mined 2.1 million tons of ore. At the year-end, proven and probable reserves were calculated to be 74.9 million tons grading about 2.0% combined nickel-copper.

Falconbridge Mine – This mine is located in Falconbridge township, about 10 miles northeast of Sudbury. It is the original producing property of Falconbridge Nickel Mines.

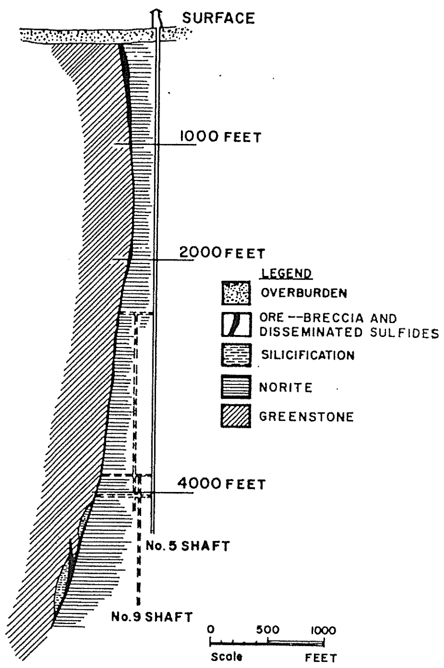


FIGURE 52. Geological section of Falconbridge mine.

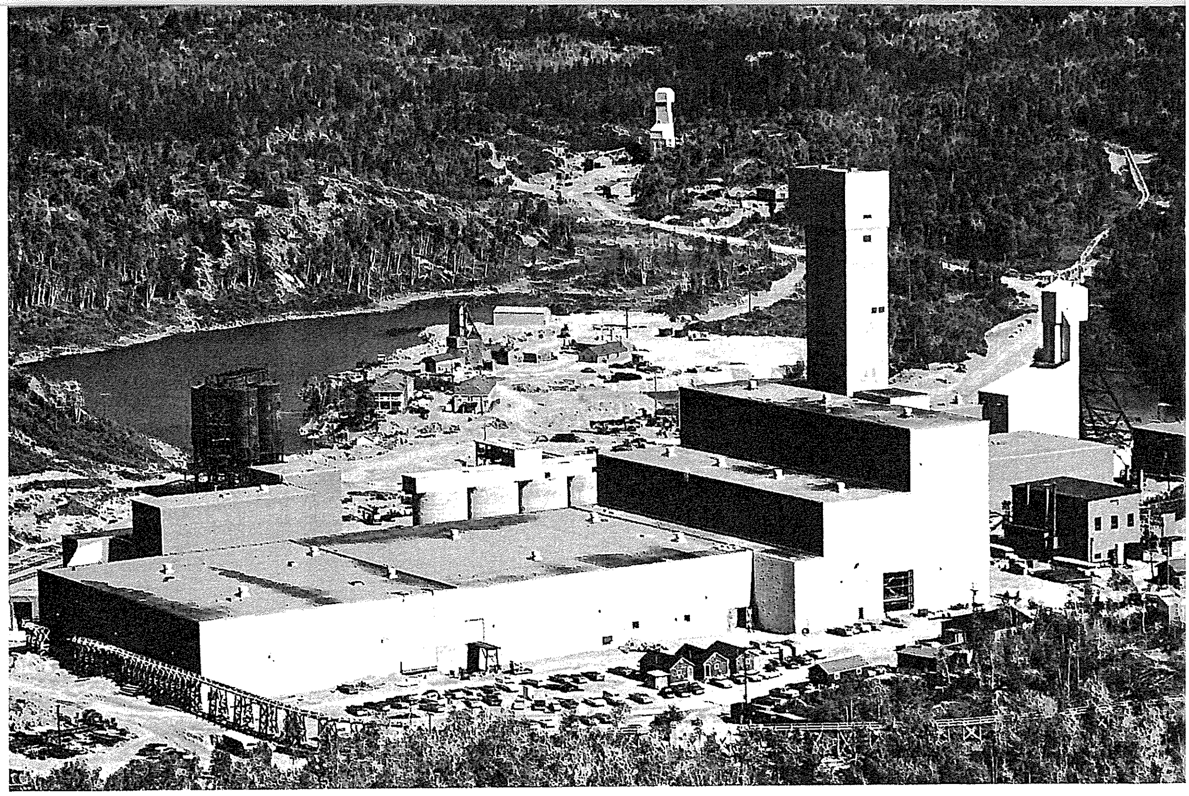


FIGURE 53. Falconbridge's Strathcona nickel project, fall 1967.

The Falconbridge orebody is a steeply dipping, nearly continuous sheet of sulphide breccia up to 120 feet wide but averaging 15 feet. The strike is east-west. The sulphides occur between norite on the north and greenstone on the south. The contact between the ore zone and the norite coincides with a shear zone that is the controlling feature of the ore. Two sets of cross faults displace the main shear zone and the ore. The ore is a breccia type similar to the Murray deposit(20).

In 1966, production at the Falconbridge mine averaged about 3,000 tons per day. The stoping methods used are cut-and-fill, square-set and undercut-and-fill.

East Mine – This mine, located about one-half mile east of the Falconbridge orebody, has been in production since 1954.

The East mine orebody is located on the norite-greenstone contact, separated from the Falconbridge deposit by a 2,000-foot barren zone. The ore zone is localized by a strong shear similar to that of the Falconbridge mine. The breccia ore is generally bordered by zones of disseminated sulphides up to 50 feet wide. The contact of the breccia and the disseminated ore is usually abrupt and sheared. A common feature of the East and Falconbridge mines is the steep south dip of the norite-greenstone contact at depth. This is one of the few locations where the edge of the Sudbury Basin dips away from its centre(21).

In 1966, production averaged about 1,200 tons of ore per day. The cut-and-fill method is used. The main workings of the mine connect with the Falconbridge mine and the ore is trammed to the Falconbridge ore pass for hoisting to the surface(18).

Hardy Mine – This mine is the most westerly of the group of producing mines on the northwest rim of the Sudbury basin.

In the vicinity of the mine the footwall contact of the norite strikes northeast and dips to the southeast at about 35 degrees. The footwall rocks are highly metamorphosed granite and granite gneiss cut by later breccias. The orebodies, following an echelon pattern, are located in the footwall rocks as massive lenses and irregular stringer zones near and parallel to the base of the norite(22).

The Hardy mine produces about 500 tons of ore per day. The under-cut-and-fill method is used in pillar recovery.

Onaping Mine – This mine is located east of the Hardy mine and includes the former Boundary mine. The property was brought into production in 1961.

The orebody consists of two parts: the Boundary section extends down from the 1,000-foot horizon, the Onaping section is a down-dip extension and extends down from the 3,050-foot horizon. The orebody consists of massive lenses and stringers of sulphides replacing and cementing granite breccia, parallel and close to the norite contact. The nickel-copper ratio of the ore varies from 2:1 in the upper levels of the Boundary section to 8:1 in the Onaping section.

The Onaping mine produces about 1,300 tons of ore per day. Cut-and-fill stoping is used. Stoping efficiencies are hindered by a flat dip. Ore from the Boundary section of the mine is hoisted through the Hardy mine shaft. Ore from the Onaping section is hoisted through the Onaping shaft.

Fecunis Lake Mine – The Fecunis Lake property adjoins the east boundary of International Nickel's Levack mine.

Sulphide mineralization occurs in a granite breccia along the footwall contact of the norite intrusive. The ore has a strike length of several hundred feet and bulges into the underlying granite, attaining thicknesses of up to 500 feet. Mineralization is disseminated near the norite contact increasing in amount toward the centre of the orebody where the sulphides form very heavy, coarse disseminations and massive stringers, some of which extend well out into the footwall rocks.

During 1966, production averaged about 2,000 tons of ore per day. Mining is carried out by International Nickel and hoisting and milling is done by Falconbridge. Mining is by either cut-and-fill or square-set methods, depending on the ground conditions. Cemented sand fill is used.

North Mine – This mine adjoins the east side of the Fecunis Lake mine. The orebody, which is of good grade but moderate size, was discovered late in 1964 and was developed from two levels of the Fecunis Lake mine. Production started in 1965 and averaged about 600 tons per day in 1966.

Strathcona Mine – This deposit is on the northwest rim of the Sudbury basin between the Fecunis Lake mine and the dormant Longvac mine.

The orebody has a strike length of one half mile and dips vary from 20 to 60 degrees south, in response to rolls in the norite contact. Irregular disseminated ore zones occur in the norite at the base of the intrusive. Most of the ore occurs in a granite breccia zone between the norite and the footwall gneiss complex. The breccia averages 75 feet in width. Lenticular en echelon ore lenses occur in the granite breccia and sulphides commonly replace the breccia matrix. In addition, lenses of massive sulphides occur as much as 600 feet below the base of the intrusive in the footwall gneiss complex(23).

Two shafts have been completed to a depth of 3,200 feet. Stope preparation and excavation of ore handling facilities and ventilation raises were in progress during 1966. The mine was scheduled to go into production by early 1968 at a rate of about 7,000 tons of ore per day.

Longvac South Mine – This deposit is located north of the Strathcona mine. The company began shaft sinking on this orebody in 1966 and plans were to bring it into production by early 1968.

Lockerby Property – This property is about two miles east of International Nickel's Crean Hill mine and 20 miles west of Sudbury. Falconbridge has been carrying out deep drilling on a large orebody. Collaring of a shaft was expected to begin in mid-1967.

Other Interests – Marbridge Mines, 50% owned and managed by Falconbridge, operates a nickel mine in La Motte township, Quebec. In 1967 Bowden Lake Nickel Mines, another subsidiary, was actively exploring its holdings in the Thompson nickel belt. Falconbridge has a controlling interest in New Quebec Raglan Mines, which is exploring high-grade nickel-copper-sulphide deposits in Ungava. In the Dominican Republic a majority-owned subsidiary has explored extensive nickel-laterite deposits. An enlarged ferronickel pilot plant began operating in 1967.

Concentrators

Falconbridge currently operates three concentrators. The Falconbridge mill which serves the Falconbridge and East mines, has a daily capacity of 3,000 tons. The mill at the Hardy mine has a daily capacity of 1,500 tons and processes ore from the Hardy and Onaping mines. The 2,300-ton-per-day Fecunis mill began operations in 1957 and serves the Fecunis Lake and North mines. A fourth concentrator is under construction at the Strathcona mine. Scheduled for production in early 1967, it will have a capacity of 6,000 tons of ore per day.

Smelter

The company's smelter is located at the Falconbridge mine. In 1967, the rated capacity was 1,600 tons of concentrates per day. External sources of concentrate supply for the smelter are obtained from the operations of Marbridge Mines and Kidd Copper Mines. Construction of the present smelter and associated plant additions were completed in 1957 and a second furnace was installed early in 1965. The matte product is shipped to the refinery of the company's wholly-owned subsidiary at Kristiansand, Norway.

Refinery

Falconbridge's wholly-owned subsidiary, Falconbridge Nikkelverk A/S, operates a refinery at Kristiansand, Norway, which has an annual capacity of 37,500 tons of refined nickel. The electrolytic refining method devised by N.V. Hybinette about the turn of the century and commercially developed by him at Kristiansand from 1910, still governs operations today although many improvements in detail have been made.

Foundry

The Company's only fabricating is done by its subsidiary, Fahralloy Canada Limited at Orillia, Ontario, where a large foundry produces steel alloy castings for heat, abrasion and corrosion resisting applications.

Market Outlets

Falconbridge nickel is sold in more than 25 countries throughout the non-communist world. North American markets are serviced directly from the company's head office in Toronto, Ont. Sales on other continents are handled by company representatives, located with respect to the important nickel consuming markets(4).

Research Laboratories

The company operates a research laboratory at Thornhill, Ont. which was expanded in 1962-63. A large chemical and metallurgical research laboratory is operated at Falconbridge, Ont. Research is also carried out by the company's subsidiaries in Norway and the Dominican Republic and by Lakefield Research of Canada, another subsidiary.

Financial and Operating Results – Falconbridge Nickel Mines, Limited(24)*
(dollars)

	1951	1956	1961	1966
Share capital	7,306,000	12,214,000	12,837,000	79,215,000
Retained earnings	9,970,000	22,565,000	55,467,000	107,942,000
Net sales	20,783,000	49,869,000	76,312,000	92,495,000
Net earnings after tax	3,011,000	7,164,000	16,968,000	27,725,000
Depreciation and depletion	1,087,000	5,134,000	9,811,000	3,304,000
Income tax	2,400,000	302,000	2,200,000	6,175,000
Dividends	1,705,000	4,508,000	6,420,000	17,129,000
Capital expenditures**	3,381,000	11,435,000	6,308,664	27,619,000
Exploration expenditures	474,000	2,286,000	2,982,000	6,967,000
Ore reserves (tons)**	19,116,500	45,259,450	46,247,200	74,860,700
Ore mined (tons)**	1,084,000	1,850,000	2,532,000	2,101,000
Nickel deliveries (tons)	na	21,692	32,773	39,482

*For all the company's operations except where noted.
**Nickel operations.

na Not available.

Sherritt Gordon Mines Limited

Sherritt Gordon owns and operates a nickel-copper-cobalt mine and concentrator at Lynn Lake, Man. for the production of nickel and copper concentrates, and a chemical metallurgical plant at Fort Saskatchewan, Alta. for the production of refined nickel, cobalt, and substantial amounts of fertilizers. Refined nickel capacity in 1967 was 15,000 tons per year. Other metal products produced at Fort Saskatchewan include nickel coinage blanks, metal strip and special metal powders.

Newmont Mining Corporation has a 37.4% interest in and effective control of Sherritt Gordon.

Mines

Lynn Lake – This property is situated in the Granville Lake district of northern Manitoba. The nickel-copper deposits occur in two basic intrusive plugs, the A and the EL. Production from the EL mine terminated in 1964 and the mine has been stripped and abandoned.

The A plug is about 12,000 feet long and 5,000 feet wide and the contained orebodies are worked by two mines. The A mine is composed of the A,C,D,E, and J orebodies and the Farley mine contains the B and K orebodies. The Farley shaft is 3,700

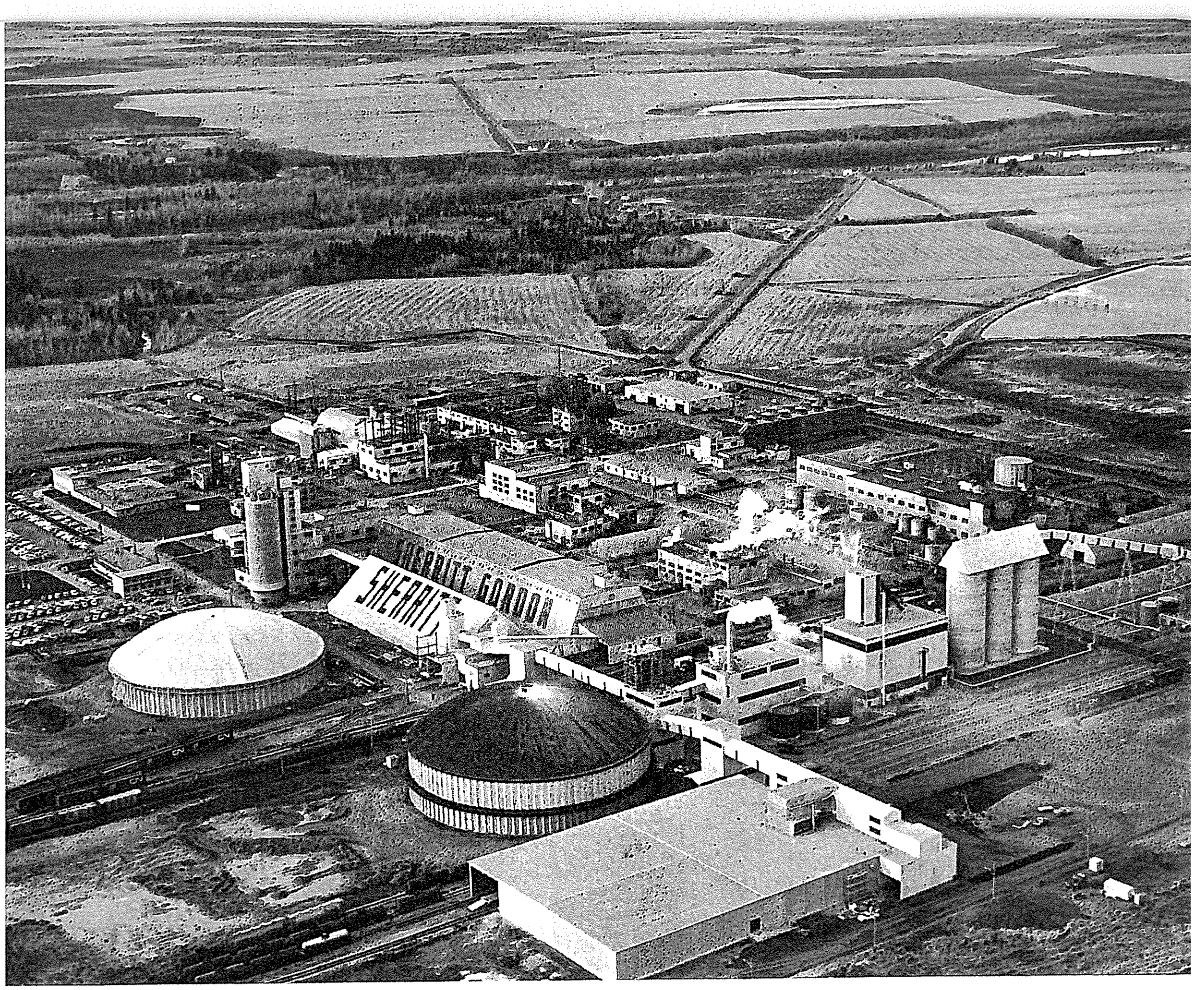


FIGURE 54. Fort Saskatchewan plant, Sherritt Gordon Mines Limited.

feet south of the A shaft and the mines are connected on the 1,000-foot and 2,000-foot levels. Mining is by the blast-hole method. Extraction from the A zone is nearing completion. Increasing amounts are derived from the lower grade C,D,E,B and K orebodies.

In 1966, mining was at a rate of about 3,300 tons of ore per day compared with 3,700 tons per day in 1965. It is unlikely that the mine will again be able to maintain the annual tonnages mined and milled during the 1960-66 period. A total of 1.2 million tons of ore was mined and milled in 1966. Ore reserves during 1966 fell 1.2 million tons to 11.4 million tons averaging 0.84% nickel and 0.47% copper at year-end.

Underground exploration in recent years has resulted in the discovery of the N and O ore zones some 3,000 feet south of the Farley shaft. A substantial amount of low-grade ore has been indicated between 1,800-foot and 2,800-foot horizons in the N zone, and between the 1,900-foot and 3,500-foot horizons in the O zone. The long-run future of the mine, beyond the 10-year ore reserve in sight, appears to depend upon finding additional ore in the south end of the A plug, below the 3,000-foot level. Mine exploration is concentrated in this area.

Other Interests – Since 1959, Sherritt Gordon and Marinduque Mining and Industrial Corporation, a Philippine company, have been jointly studying the application of Sherritt Gordon's processes and experience in nickel extraction to the recovery of nickel and cobalt from the Nonoc Island nickeliferous laterites. Early in 1967, Marinduque made a submission to the Philippine government covering proposals for the exploitation and development of the laterites with Sherritt Gordon supplying the refinery process and engineering skill to build and manage the nickel refinery that would be built in the Philippines.

Concentrator

The concentrator has a capacity of 3,900 tons of ore per day and produces nickel and copper concentrates using conventional milling methods. The nickel concentrate is dispatched to Fort Saskatchewan for refining.

Refinery

The Fort Saskatchewan complex comprises a nickel refinery, a cobalt refinery, an ammonia plant, an ammonium sulphate plant, an ammonium phosphate plant, a urea plant, and ancillary facilities.

The nickel refinery has a capacity of 15,000 tons of nickel per year and in addition to the Lynn Lake nickel concentrate, treats nickel concentrates and matte from outside sources. The refinery uses the ammonia pressure leach process which is owned by Sherritt Gordon (described in Chapter 5). Some of the nickel powder produced is rolled directly into nickel strip for electronic and coinage use; some is sold to the chemical industry and the remainder is produced as pure nickel briquettes for sale to the alloy and steel industries.

Sherritt Gordon has contracted with Société Le Nickel for the purchase, on a long-term basis, of an annual supply of 3,000 tons of nickel contained in matte. This will permit the refinery to operate at its rated capacity.

Rolling Mill

A rolling mill at Fort Saskatchewan produces strip directly from metal powders. A coinage plant at the same location is capable of producing coinage blanks, minted coins and medallions.

Market Outlets

In continental Europe the marketing of Sherritt Gordon's nickel and cobalt products is handled by Klockner and Company, Germany; in Asia, Africa, Britain and South America by the British Metals Corporation; and in Canada and the United States by the Company's own marketing division.

Research Laboratories

The company's research and development division is located at Fort Saskatchewan. The objectives of the company's research work are: development of new and more economic metallurgical extraction processes; improvement in quality of present metal and fertilizer products; development of new products; and technical assistance in licensing company's processes to interested parties.

Over the last fifteen years this division was successful in the development of an ammonia leach nickel reduction process presently in use for production of nickel at Fort Saskatchewan; development of a process for the production of cobalt at Fort Saskatchewan; development of a process for the production of nickel strip and nickel coinage from powders in use in the rolling mill; development of a process, presently in use, for the recovery of nickel and cobalt from high temperature alloy scrap.

In 1966, an extensive program was under way to develop a process for the extraction of nickel and cobalt from lateritic nickel ores and to find a solution to production of dispersion strengthened nickel and its alloys. (This work is being assisted by grants from the Department of Defence Production in Canada and the United States Air Force.)

Financial and Operating Results – Sherritt Gordon Mines Limited(25)*
(dollars)

	1956	1961	1966
Share capital	21,767,000	21,767,000	21,902,000
Retained earnings	16,778,000	27,677,000	32,826,000
Net sales	19,802,000	23,947,000	44,307,000
Net earnings after tax	5,610,000	3,907,000	3,760,000
Depreciation and depletion	2,825,000	3,452,000	4,261,000
Income tax	125,000	140,000	120,000
Dividends	–	3,400,000	2,273,000
Capital expenditures	6,213,000	2,217,000	6,419,000
Exploration expenditures	na	274,000	338,000
Ore reserves (tons)**	13,070,000	14,000,000	11,400,000
Ore mined (tons)**	749,506	1,219,157	1,205,318
Nickel production (tons)	9,620	13,240	14,761

* For all the company's operations except where noted; nickel operations began in 1953.
** Nickel operations.
na Not available.
– Nil.

Giant Mascot Mines Limited

Giant Mascot Mines owns and operates the Giant Nickel mine, a nickel-copper producer 15 miles north of Hope, B.C. Production began in 1959.

Sulphide ore occurs in an ultrabasic stock having a cross-sectional area of about 1.5 square miles. The stock has a peridotite core surrounded by proxenite and is intruded into diorite. Only the southwest part of the peridotite is altered and all known orebodies occur on the contact zone there. The orebodies, steeply plunging pipe-like deposits, are both disseminated and massive, the disseminated deposits suggesting hydrothermal replacement and the massive ores indicating magmatic sulphide injection. The predominant sulphide minerals are pyrrhotite, pentlandite, and chalcopyrite(26).

The mine has been developed by two adits that are connected by an inclined shaft. During the fiscal year ending September 1966, mine production was at a rate of about 1,350 tons per day, obtained from ten orebodies. Ore is mined by the blast-hole method. The development during 1966 of a new high-grade orebody, the '1500', made an important contribution to ore reserves. Ore reserves at September 1966 were 830,000 tons grading 0.92% nickel and 0.30% copper (27).

Early in 1965, the capacity of the concentrating plant was raised from 1,250 tons per day to 1,325 tons per day and in 1966 the daily operating input averaged 1,312 tons. During the year ended September 1966, concentrate containing 1;738 tons of nickel was produced (27). Bulk concentrate is shipped to Sumitomo Metal Manufacturing Limited in Japan under a contract that became effective in March 1966.

Metal Mines Limited

Metal Mines owns and operates a nickel-copper mine at Gordon Lake, 55 miles northwest of Kenora, Ont. Production began in 1962.

Mineralization consists of pyrrhotite, pentlandite and chalcopyrite. There are a number of orebodies. The B deposit, a narrow irregular vein, occurs in an east-west trending regional fault zone. A similar deposit held by Norpax Nickel Mines is in the same structure, three miles distant. The other deposits (A,F,G and D) are within peridotite masses that are adjacent to the fault zone. Mineralization in the peridotite masses takes the form of disseminations (weak to almost complete replacement), lenses and fracture fillings.

In 1966, production was obtained from all five orebodies. The peridotite deposits are mined by cut-and-fill and blast-hole methods. Cut-and-fill is to be replaced as much as possible, but is still used in both types of ore. Early in 1967, the narrow but high-grade B deposit was being reconverted from cut-and-fill to shrinkage stoping.

The D zone, a downward extension of the G deposit, was discovered by exploratory drilling in 1964. Since that time this deposit has made important contributions to ore reserves and production. Early in 1967 an exploratory drift was advancing west from the A deposit. Since the main peridotite masses are widely separated and somewhat erratic in distribution, exploration is intensive.

During 1965, the mill treated 184,000 tons of ore, producing bulk concentrate containing 1,857 tons of recoverable nickel. Total ore reserves (proven, probable and indicated) at year-end stood at a little over one million tons grading 1.38% nickel and 0.56% copper(28). The deposit also contains small but economically significant quantities of platinum and palladium.

Early in 1967, the mill was handling about 650 tons of ore daily. The bulk concentrate is trucked 70 miles to Lac du Bonnet, Man. and is then shipped by rail to International Nickel's smelter at Copper Cliff. International Nickel has a contract with Metal Mines to purchase concentrate for a five-year period beginning October 1962.

Marbridge Mines Limited

Marbridge Mines owns a producing nickel property in La Motte township, northwestern Quebec. The company is a joint operation of Falconbridge Nickel Mines and Marchant Mining Company, Limited. Production began in 1962.

Mineralization, consisting of massive sulphides, pyrite, pentlandite and small amounts of pyrrhotite and chalcopyrite, is at the contact of a highly serpentinized talcose peridotite and an assemblage of metamorphosed volcanic-sedimentary rocks.

The No. 1 orebody is about 400 feet long and dips at 50 degrees to the northeast. It consists of a core of massive sulphides ranging up to 7 feet thick surrounded by a mantle of disseminated sulphides. Deep drilling has indicated the downward extension of the orebody. In 1966, work was under way to sink a winze below the bottom 1,350-foot level, to establish a new level at 1,500 feet. In December 1966, developed and indicated ore reserves in No. 1 mine were 36,850 tons averaging 1.52% nickel.

A new ore structure, the No. 2 orebody, was discovered by surface drilling during 1964 about 3,000 feet southeast of the No. 1 deposit. In this deposit the most important mineral is millerite, a nickel mineral not ordinarily found in commercial quantities(29). During 1966, the No. 2 mine shaft was deepened from 650 to 750 feet, to provide a fifth working level. In December 1966, developed and indicated ore reserves in No. 2 mine were 26,000 tons averaging 2.67% nickel.

During 1966, two oreshoots within the shaft areas were discovered. At year-end ore reserves in No. 3 oreshoot were 33,250 tons averaging 1.90% nickel, with 49,100 tons grading 1.58% nickel in No. 4 oreshoot(30).

Ore is mined by the shrinkage method. During 1966, No. 2 mine contributed about 80% of the production.

Ore is trucked to the mill of Canadian Malartic Gold Mines where a part of the mill has been converted to handle nickel ore and an addition constructed to house flotation equipment. During 1966, Marbridge treated 129,000 tons of ore, an average of about 350 tons daily. Concentrate for the period, sold to Falconbridge Nickel Mines, contained 3,591 tons of nickel(30).

Lorraine Mining Company Limited

Lorraine Mining Company owns a producing copper-nickel property in the Belleterre area of northwestern Quebec. McIntyre Porcupine Mines holds an 80% interest in the company.

The orebody of massive and disseminated sulphides occurs within basic lava, lying along shears at or near the contact with a metagabbro stock. The deposit is tabular, steeply dipping and has been traced to a depth of about 700 feet(31).

Production began early in 1965 at a mill rate of 400 tons per day. At the end of 1966 ore reserves were 210,383 tons grading 1.32% copper, 0.57% nickel and minor amounts of precious metals. The orebody has not been delimited and there are possibilities of extensions and parallel occurrences. The shaft bottoms at 1,080 feet and six levels have been established. Ore is mined by the blast-hole method.

The mill has a capacity of 500 tons per day. During 1966 the mill treated 186,000 tons producing concentrate containing 927 tons of nickel(32). Concentrate is trucked to Laverlochère on the CPR line, some 26 miles from the property and from there it is transported by rail to International Nickel's smelter at Copper Cliff.

Kidd Copper Mines Limited

Aer Nickel Corporation, which is 87% controlled by Associated Arcadia Nickel Corporation, owns a copper-nickel property in Denison and Worthington townships in the Sudbury district(33).

The property lies along the Worthington offset of the Sudbury intrusive. Four lenticular mineralized zones have been outlined. The ore is typical Sudbury mineralization of the breccia type. Sulphides occur as small veins or disseminated masses within a brecciated actinolite alteration zone(34).

The property has been developed by two shafts sunk to 980 and 1,080 feet, connected on three levels, with lateral work on six levels. Underground exploration has indicated 772,000 tons averaging 0.71% copper and 0.62% nickel in two zones(33).

Kidd Copper Mines Limited leased the property for a ten-year period in 1965. The mill started production late in 1966 at a rate of 1,000 tons per day. Mining is by the shrinkage method. Nickel concentrate is shipped to Sudbury for smelting by Falconbridge Nickel Mines.

FORMER PRODUCERS

About 42 nickel and nickel-copper mines have operated in Canada; 22 were in production at the end of 1966. All but two of the former producers were in the Sudbury district. These two properties will be briefly described.

Alexo Nickel Mine

The Alexo mine was immediately south of Porquis Junction, Dundonald township, northern Ontario. The deposit was discovered in 1908 and produced about 2,400 tons of nickel during the periods 1912-19 and 1943-44. The mine was developed by a 265-foot shaft with crosscuts and drifts on three levels. In 1952, Noranda Mines Limited purchased the mine. Subsequent drilling and geophysical work failed to locate additional ore(34).

The Alexo deposit was a tabular sulphide body at the contact of serpentinized peridotite and pillow lava. Massive and disseminated sulphides consisted of pyrrhotite and pentlandite with minor amounts of pyrite and chalcopyrite. The deposit was proven for a length of 700 feet with widths ranging from 3 to 40 feet and averaging 10 feet(1, p.228). The ore mined averaged 4.2% nickel and 0.5% copper.

North Rankin Nickel Mines Limited

North Rankin Nickel Mines Limited operated a nickel mine at Rankin Inlet, on the west side of Hudson Bay, NWT from 1957 until it closed in the fall of 1962.

The ore was associated with a serpentinized peridotite sill on the north limb of a syncline. The ore, consisting of approximately 8 feet of massive sulphide and 18 feet of disseminated sulphide, occurred at the base of the sill and appeared to be localized by a dragfold. Mineralization consisted of pyrrhotite, pentlandite and chalcopyrite with minor amounts of magnetite, pyrite and violarite(35). The ore mined averaged 3.1% nickel and 0.9% copper(36). Platinum metals content was relatively high for a nickel-copper ore.

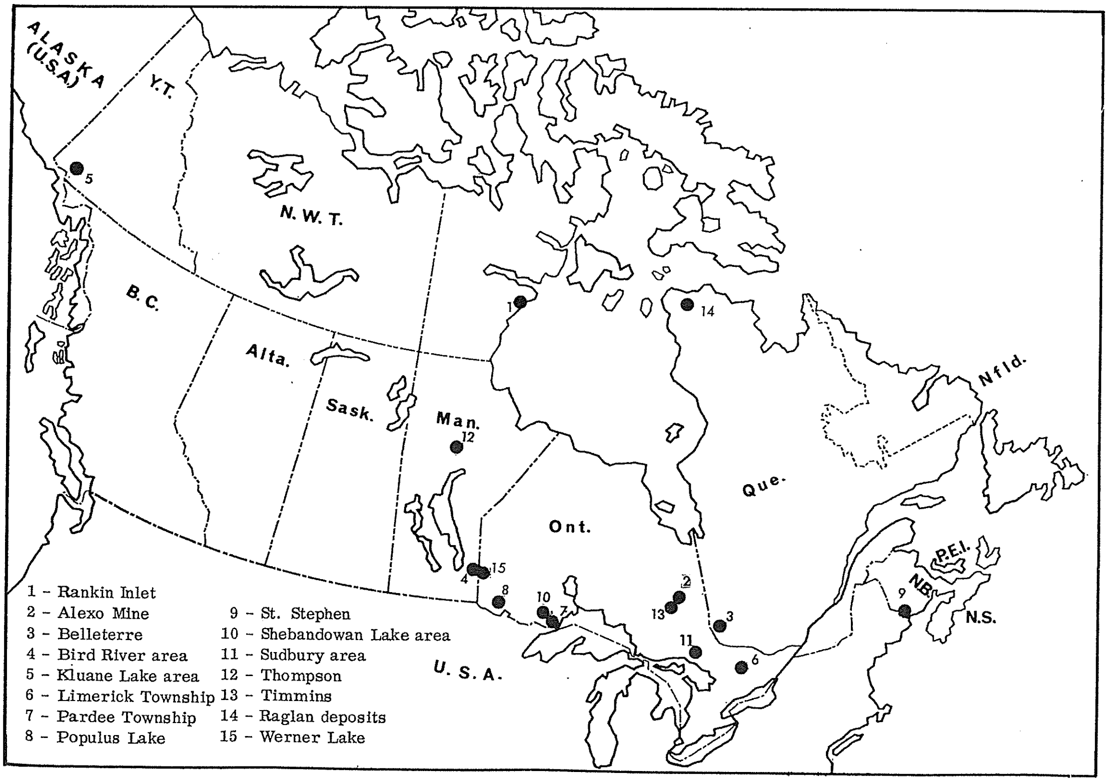


FIGURE 55. Canada, nickel — former producers and other occurrences.

The mining operation illustrated some unique problems associated with subarctic mineral development. Mine workings were entirely in the permafrost zone. Water for drilling was salined and heated. Eskimo labour was used wherever possible(37).

Mill capacity was 250 tons per day. Concentrates were shipped by coastal steamer to Churchill, Man. and thence by train to the Fort Saskatchewan refinery of Sherritt Gordon Mines Limited. The mine produced approximately 10,000 tons of nickel in concentrate form(36).

OTHER OCCURRENCES

The following descriptions of nickel occurrences represent a small sampling from the total number of known nickel occurrences in Canada. Occurrences included have a history of active exploration and reasonable economic potential. The selection of occurrences represents a measure of subjective judgment. Published information is biased toward the inclusion of relatively small deposits controlled by relatively small mining and exploration companies. There is little information available on a number of deposits of apparent potential owned by the integrated nickel producers. Furthermore, the occurrences considered in themselves represent a wide range of economic potentials.

Belleterre, Que.

Consolidated Regcourt Mines, through a subsidiary Conrego Nickel Mines, has a controlling interest in a nickel-copper property near Belleterre, northwestern Quebec(33). The property was drilled in the mid-1950s. In 1964 an independent consultant estimated reserves to be 2.2 million tons averaging 0.67% nickel and 0.73% copper. Consolidated Regcourt acquired new management in 1964 but no further exploration work has been reported.

Bird River, Man.

Maskwa Nickel Chrome Mines holds 98 claims in two groups in the Bird River area of southeastern Manitoba. The company is controlled by Falconbridge Nickel Mines Limited.

Precambrian sedimentary and volcanic rocks in the area contain tabular masses of banded igneous rock that range in composition from gabbro to peridotite. The whole assemblage has been intruded by granite. Copper-nickel mineralization occurs along peridotite-granite contacts(8).

At the end of 1953, drilling had indicated 1.2 million tons averaging 1.23% nickel and 0.68% copper in two lenses. The property was idle from 1954 until Falconbridge resumed diamond drilling and metallurgical testing during the latter part of 1965(33).

Kluane Lake, Yukon

The Hudson-Yukon Mining Company, a subsidiary of Hudson Bay Mining and Smelting Company, holds a controlling interest in a nickel-copper prospect near Quill Creek and White River in the Kluane Lake area of the Yukon.

The sulphide deposits occur in a serpentinized peridotite sill near its contact. Mineralization is controlled by shears and fractures in the peridotite(38,39).

In the early 1950s, Hudson-Yukon carried out diamond drilling and lateral development from two winzes that extended 600 feet below the adit level. This work indicated 737,600 tons averaging 2.04% nickel and 1.42% copper(33). A new feasibility study and property evaluation was undertaken and completed early in 1966. No further steps were taken during the year. It was tentatively planned to bring fresh ore to the metallurgical plant of the Hudson Bay Mining and Smelting Company for further flotation testing in 1967.

In 1967, it was announced that Discovery Mines Limited, along with two other unnamed companies, had optioned the former Canalask Nickel Mines' nickel-copper property on White River. Indicated ore reserves of 550,000 tons averaging 1.68% nickel were reported by the original company (Canalask) following underground exploration from 1954 to 1957.

Limerick Township, Ont.

Macassa Gold Mines owns a nickel-copper prospect in Limerick township, 14 miles south of Bancroft, southeastern Ontario. Nickel-copper mineralization occurs on the edge of a gabbro intrusion. The deposit was discovered by geophysical survey. Diamond drilling in 1962-63 indicated 2.0 million tons averaging 1.0% nickel and 0.25% copper. The property was idle in 1966(33).

Pardee Township, Ont.

Great Lakes Nickel Corporation Limited owns a copper-nickel prospect comprising 29 claims in Pardee township, 40 miles southwest of Port Arthur, northwestern Ontario.

Copper and nickel bearing sulphides occur at the base of a diabase sill in a coarse grained anorthositic gabbro near its contact with a hard argillite. The mineralization appears to have separated into layers in the sill. The nickel occurs as pentlandite. Surface diamond drilling by early 1967 had indicated 40 million tons averaging 0.40% copper and 0.20% nickel(40). The material contains a small but significant precious metals content. In 1967, the company was seeking production financing. A diamond drilling program and mill testing were in progress.

Thunder Bay Nickel Mines, an associated company, has been drilling the ground it holds on the eastern extension of the regional sill structure.

Populus Lake, Ont.

Kenbridge Nickel Mines Limited, a subsidiary of Falconbridge Nickel Mines, owns a nickel-copper prospect at Populus Lake, 43 miles southeast of Kenora, northwestern Ontario.

The ore occurs as disseminated and massive sulphides in a basic intrusive that varies in composition from gabbro to peridotite, and intrudes greenstone and contains fragments of it. The intrusive is about 2,500 feet long by 200 feet wide and is associated with a major northeast-striking fault zone. The mineralization is concentrated within linear shear zones which generally parallel the contact of the intrusive complex. The zone plunges steeply to the northeast.

In the 1950s, exploration work, including a shaft and extensive diamond drilling, indicated 3.5 million tons averaging 1.06% nickel and 0.54% copper. The exploration program was suspended in 1957.

St. Stephen, N.B.

Small lenses of nickel and copper sulphides have been intermittently explored for many years at St. Stephen in southwestern New Brunswick. These deposits are associated with a differentiated gabbro-anorthosite-peridotite intrusive(41). The mineralization, essentially pyrrhotite with pentlandite and chalcopyrite, occurs primarily in the gabbro as disseminations or as massive sulphide lenses, most of which are related to altered zones of breccia along the contacts between gabbro and meta-sedimentary country rocks.

Atlantic Nickel Mines, on incorporation in 1963, acquired the St. Stephen nickel-copper property and mining plant from St. Stephen Nickel Mines Limited. Atlantic Nickel is controlled by Mount Pleasant Mines Limited. Prior to acquisition, drilling outlined five mineralized zones containing a drill-indicated reserve estimated at 3.5 million tons averaging 0.70% nickel and 0.36% copper. In one zone, underground openings to a depth of 280 feet have developed a probable reserve of 333,000 tons averaging 1.27% nickel and 0.69% copper in a steeply plunging pipe of massive sulphides(42). Metallurgical research and market studies were reported in progress during 1966.

Shebandowan Lake, Ont.

The International Nickel Company of Canada holds a group of 75 patented claims in the Shebandowan Lake area of northwestern Ontario, 60 miles west of Port Arthur.

Surface diamond drilling was carried out in 1951-52. Drilling results indicated a series of replacement sulphide lenses, connected by very narrow widths of sulphides in sheared peridotite. The lenses appear to vary from 800 to 1,600 feet in length with widths ranging from 5 to 10 feet. The mineralized zone was traced for about 4,000 feet and attains widths up to 100 feet. The largest of the lenses occurs under a lake(34). The lenses contain pyrrhotite, pyrite, chalcopyrite and pentlandite, in massive and disseminated forms. The deposits have an appreciable platinum content.

In September 1965, it was reported that International Nickel had been carrying out a heavy diamond drilling program on the property since the beginning of the year. The company recorded an additional 107 claims surrounding its original holding. International Nickel began shaft sinking preparatory to underground development in 1966(15).

Sudbury Area, Ont.

Nickel Rim Mine

The mine is located on the east margin of the Sudbury intrusive. Sulphides occur in a zone of quartz diorite and quartz diorite breccia that lies between the norite and footwall granite. The deposits contain massive, disseminated and breccia-type ore. Reserves averaged 0.7% nickel and 0.3% copper(34).

The mine is developed by two shafts with levels opened to the 1,300-foot horizon. The deposit was brought into production by Nickel Rim Mines Limited in 1952. A mill of 500 tons capacity began production in 1953 and was expanded to 1,500 tons per day in 1956. Operations were discontinued in May 1958. During its life the mine produced approximately 7,100 tons of nickel in ore and concentrate forms. An estimate of material remaining in the mine as of January 1959 showed 747,624 tons averaging 0.90% nickel and 0.35% copper(43).

In 1964, the property was sold to Falconbridge Nickel Mines Limited for $200,000.

Thompson Nickel Belt, Man.

The nickel deposits of the Thompson district occur as nickeliferous sulphides associated with bodies of serpentinized peridotite. In most deposits sulphides are disseminated through the peridotite although in places massive bodies and sulphide stringers occur in gneiss near the peridotite (11,12). It has been hypothesized that the nickel belt, known to extend for some 100 miles, lies along the axis of a Precambrian mountain range and that this belt coincides with the northeast-trending boundary between the Superior and Churchill provinces of the Precambrian Shield(13). The geology of the district and outlines of International Nickel's producing mine at Thompson and developing Birchtree, Soab and Pipe mines have been described earlier in the chapter. Other important occurrences in the district are described below. The estimated nickel contents of these deposits are taken from the "Metallogenic Map of Manitoba"(44). These estimates include material not economically mineable at present but which may reasonably be economical in the future.

The International Nickel Company of Canada, Limited

International Nickel owns and has explored the following deposits:

Moak Lake: Disseminated sulphides in serpentinized peridotite, some massive and sulphide breccia; underground exploratory development; estimated nickel content is greater than one million tons.

Mystery Lake: Similar geology to the Moak Lake deposit; surface exploration and drilling; estimated nickel content is greater than one million tons.

Hambone: Sulphide breccia in gneiss and serpentinized peridotite; estimated nickel content between 100,000 and one million tons.

Grass River: Estimated nickel content less than 100,000 tons.

Falconbridge Nickel Mines Limited

Bowden Lake Nickel Mines, controlled by Falconbridge Nickel Mines, has been exploring a number of nickel occurrences near Wabowden Lake at the southern end of the nickel belt. A surface diamond drilling program was completed in April 1966. The following deposits, believed to be of marginal grade, have been outlined:

	Estimated Nickel Content
Halfway Lake:	less than 100,000 tons.
Bowden Lake:	between 100,000 and 1,000,000 tons.
Bucko:	between 100,000 and 1,000,000 tons.
Wabowden:	less than 100,000 tons.

A drilling program carried out in the winter of 1966-67 gave indications of substantial tonnages at depth in the Bucko deposit(45).

Timmins, Ont.

McWatters Gold Mines Limited

McWatters Gold Mines holds a controlling interest in a nickel prospect of 55 claims in Langmuir township, 25 miles southeast of Timmins. Surface diamond drilling during

1964 indicated 643,560 tons averaging 1.07% nickel in two zones. Evaluation by an independent consultant in 1965 concluded that the deposit was presently uneconomic. In 1967 arrangements were being made to lease the property(46).

Texmont Mines Limited

Texmont Mines Limited, formerly Fatima Mining, holds a nickel prospect consisting of 26 patented claims in Bartlett and Geikie townships, 20 miles southwest of Timmins. Sulphide mineralization, consisting primarily of fine grained disseminated pentlandite, occurs in a serpentinized peridotite sill that strikes north-south and dips about 70 degrees to the east(8).

Before 1960, work on the property consisted of surface diamond drilling, shaft sinking to 790 feet, and lateral development on two levels. The property was idle from 1960 to late 1964 when surface drilling resumed. In June 1966, reserves were estimated at 5.3 million tons averaging 1.0% nickel to a depth of 2,000 feet.

In 1966, Texmont entered into an agreement with the Canadian Nickel Company, a subsidiary of International Nickel, for further development of the nickel property. Canadian Nickel was to pay Texmont $450,000 in three annual instalments in return for a 15% interest in the property, the right to continue with exploration and an option until June 1967, to elect to bring the property into production in which case it would receive a further 35% interest in the property. Canadian Nickel would manage the property if it was brought to production(47).

Ungava, Que.

Until 1965, both Falconbridge Nickel Mines and Raglan Nickel Mines carried on nickel exploration activities on adjoining properties in the Cape Smith-Wakeham Bay area of Ungava. In 1965, their respective subsidiaries were merged, forming New Quebec Raglan Mines Limited. Under terms of the merger Falconbridge was required to spend about $2.1 million on the properties over a period extending through to September 1971. This commitment was met by the end of 1966. Falconbridge acquired a 59% interest in the reorganized company(24).

The nickel-copper sulphide deposits occur in an east-west trending belt of folded Precambrian sediments, volcanics and related mafic and ultramafic intrusives extending from Wakeham Bay on Hudson Strait to Hudson Bay. The host rock for the deposits are serpentinized gabbro sills that lie within a series of volcanics. The sulphides are related to the lower contacts of the sills and are locally controlled by shears, cross joints and minor faults(8).

Major diamond drilling programs have been carried out since the late 1950s. There are several orebodies. The four main areas of interest are Cross Lake, Katiniq, Raglan West and Raglan East. Drilling on the Cross Lake tract to the end of 1964 indicated 10 million tons averaging 1.55% nickel and 0.78% copper. No further exploration is presently planned for this area. Preliminary drilling in the Katiniq area indicated, by the end of 1965, 2 million tons of somewhat better grade than Cross Lake reserves(49). Drilling in this area during 1966 confirmed previous results and extended the mineralized zone. By the end of 1965, drilling in the Raglan West area had indicated 3.5 million tons averaging 2.59% nickel and 0.48% copper(49). Results during 1966 substantiated the drilling done in previous years. Also, the Raglan East deposit was discovered southeast of the Raglan West area. Drilling results to the end of 1966 were inconclusive (48). Another drilling program was in progress in 1967.

Werner Lake, Ont.

Norpax Nickel Mines holds a 46-claim nickel-copper prospect two miles west of Werner Lake, northwestern Ontario. Disseminated and massive sulphide mineralization is closely associated with a regional fault zone in peridotite. A similar deposit is mined by Metal Mines in the same structure at Gordon Lake, three miles distant.

Exploratory work has consisted of surface drilling, shaft sinking to 400 feet and lateral development on two levels. Development indicated one million tons averaging 1.2% nickel and 0.5% copper. The ore zone averages 19 feet in width and a downward continuity of at least 700 feet has been indicated by drilling. It was reported in 1966 that there were no immediate plans for proceeding with the next development stage which would involve deepening the workings in order to increase reserves to a total that would justify production planning(50).

POSITION IN THE ECONOMY*
1955-65

Production

In terms of dollar value, nickel has traditionally been the most important metallic mineral produced in Canada and second to crude petroleum among all mineral commodities. In 1965, nickel production was valued at $440 million, accounting for over 11% of the mineral value produced in the country. During the 1955-65 period, the growth in the value of nickel produced has enabled the nickel industry to maintain a relatively constant share of the expanding Canadian mineral output.

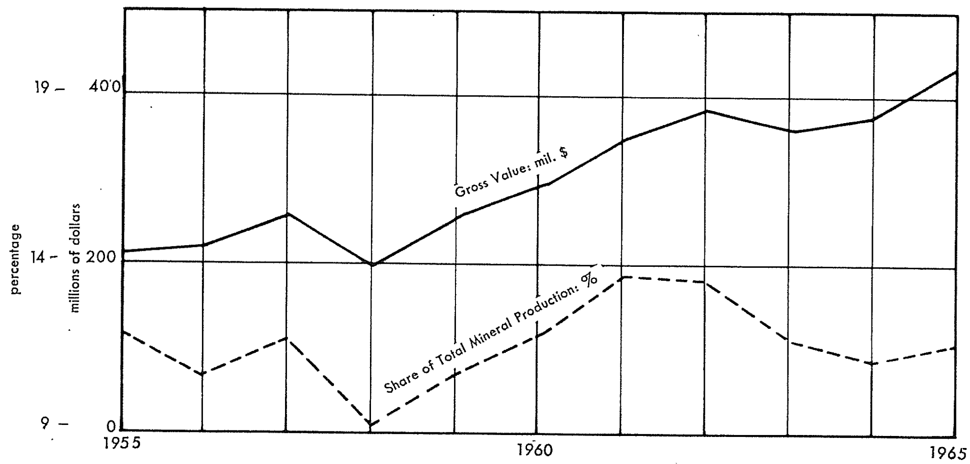


FIGURE 56. Canada — nickel production and total mineral production.

*Ref.(51-56)

Canada has been the world's leading producer of nickel since 1905. During that period growth has been sustained by the exploration for and discovery of large reserves, metallurgical innovation, and vigorous market development. The growth of the Canadian nickel industry has been particularly rapid during the 15-year period 1951-65; volume of output has doubled and value has quadrupled.

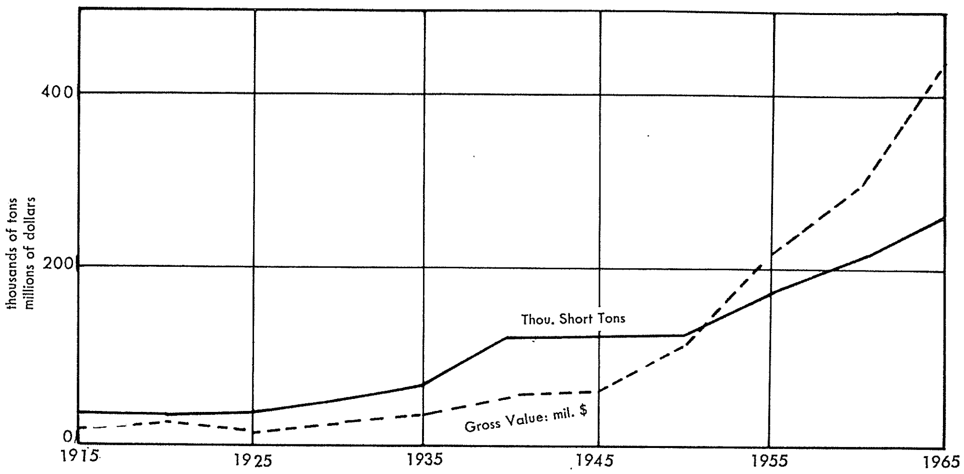


FIGURE 57. Canada — nickel production.

Nickel production has become increasingly diversified with time. As recently as 1950, the Sudbury basin was the sole source of Canadian production and accounted for 75% of world production, and International Nickel produced 90% of the nation's nickel output. In 1965, the Sudbury basin accounted for 74% of Canadian nickel production and 58% of world production; International Nickel produced 80% of Canada's nickel output.

Diversification of production away from the traditional supply centre, the Sudbury basin, has been the natural result of growing demand, and declining economic ore grades. The accelerating demand for nickel in the post-war period has generated important technological advances within the industry, particularly in exploration and metallurgical activities. Declining unit costs of production and favourable prices have stimulated exploration on a global basis and the discovery of large low-grade deposits has eased nickel supply conditions. The extension of the resource base has resulted in geographical and corporate diversification in output and has also provided the foundation for continued long-run growth.

Canada continues to maintain its traditional position as the world's major source of nickel, and has been the primary factor in the growth of world nickel production during the 1955-65 period. In 1965, Canada accounted for approximately 58% of world nickel output, a decline of 10% over the decade. The production share of the rest of the world has correspondingly expanded.

From 1955 to 1965, Canadian nickel production has shown an average annual compound growth rate of 5.4% This compares with 9.1% for the rest of the world and a global average of 6.6%.

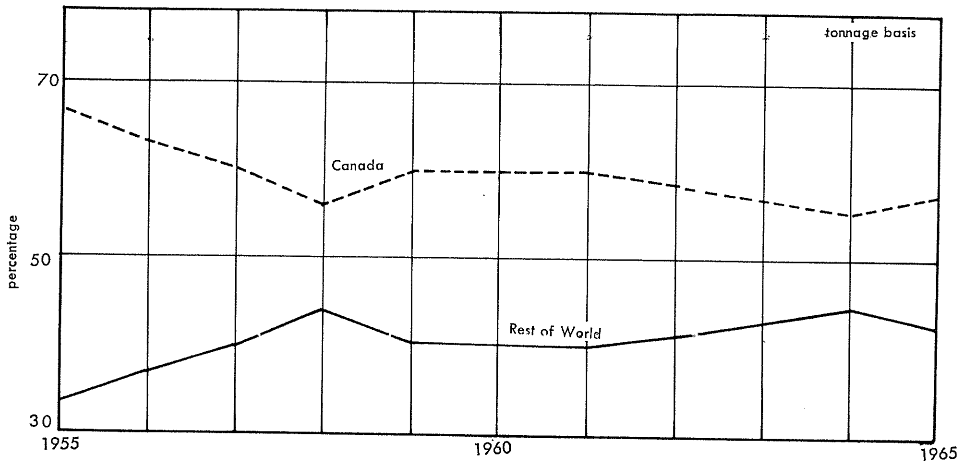


FIGURE 58. Canada and Rest of World — nickel production shares.

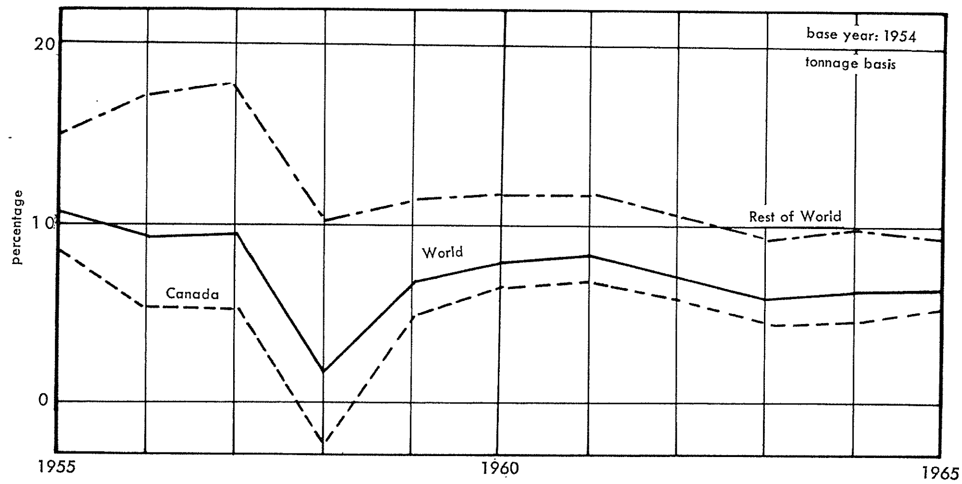


FIGURE 59. Canada and Rest of World — average annual compound growth rates of nickel production.

Traditionally, Canadian production has been derived from the Sudbury basin. During the period 1955-65 important amounts have also been produced at Lynn Lake, and later from the integrated operation at Thompson, both situated in Manitoba. Announced development plans indicate that most of the growth in Canadian nickel production for some years to come will be in Ontario and Manitoba. A table of Canadian nickel production by province for the 1889-1966 period is given as Appendix C.

International Nickel, the dominant Canadian producer, accounted for approximately 80% of the nation's output in 1965. Since the end of World War II, Falconbridge and Sherritt Gordon have also established major integrated nickel operations. The development programs presently being pursued by International Nickel and Falconbridge should at least be sufficient to maintain their present production shares. In 1965 there were four other independent nickel mining operations in Canada, mining relatively small deposits of average grade, and generally marketing concentrates to one of the integrated producers.

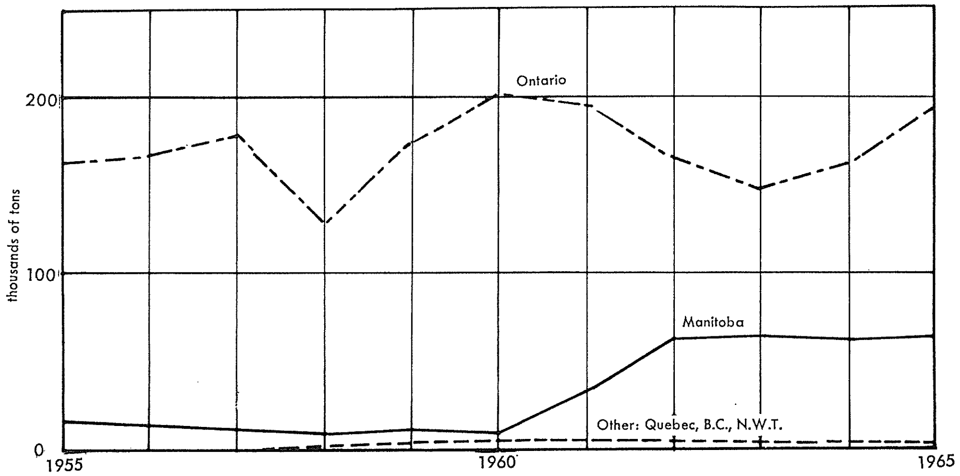


FIGURE 60. Canada — nickel production by province.

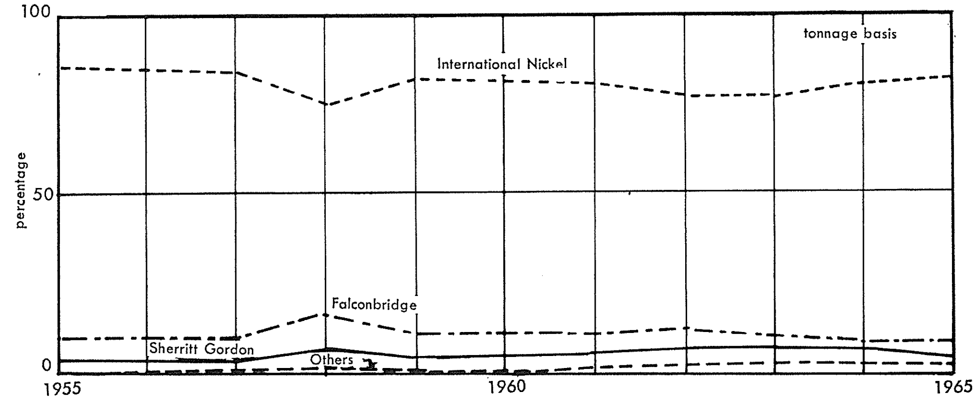


FIGURE 61. Nickel production shares — Canadian producers.

International Nickel and Falconbridge are the world's largest nickel producers and both companies are internationally active in nickel exploration and development. Together with Sherritt Gordon, these firms actively pursue metallurgical research and market development activities. All three companies are integrated from mining through refining.

Of the three integrated Canadian producers, International Nickel is perhaps the most heavily committed to the nickel industry. All productive operations are concerned with nickel and related by-products. Falconbridge, although primarily a nickel producer, has horizontally diversified, through subsidiary and associated companies, into copper, gold iron, lead and zinc mining operations. The emphasis placed by Sherritt Gordon on process innovation and market development has established a technological base which has allowed the company to diversify into the production of fertilizers and other chemical products.

Although no fabrication of refined nickel takes place in Canada, most domestic output is in refined metal form. There appears to be a potential for further domestic nickel refining and fabricating. Foreign refining of Canadian smelter products is carried out primarily by subsidiaries of International Nickel and Falconbridge in Britain and Norway respectively.

A comparison between ore mined and ore reserves indicates a strong and growing resource base for the Canadian nickel industry. From 1955 to 1965, while mining depleted 208 million tons of ore, new discoveries and extensions of developed deposits were sufficient to realize a net increase in published reserves of 56 million tons. Declared reserves are generally proven and thus should be regarded as a working inventory rather than a supply limit. The extension of the resource base indicates an increasing growth potential for the Canadian nickel industry.

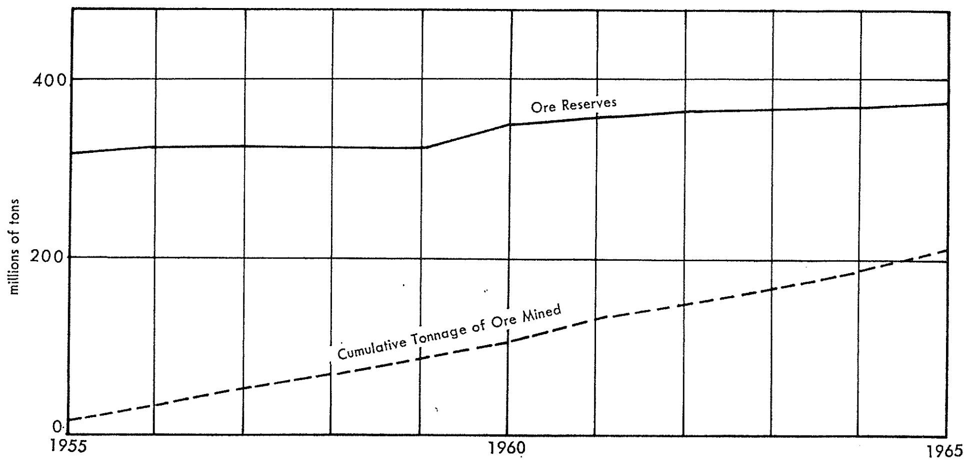


FIGURE 62. Canada – nickel-copper ore reserves and tonnage mined.

Increasing reserves have been partially offset by declining ore reserve grades. From 1955 to 1965, the combined nickel-copper ore reserve content has been relatively stable, declining from 2.9 to 2.8%. As technological advances proceed in the exploration, mining and processing of nickel ores, the trend of increasing reserves and declining grade can be expected to continue. If, on the other hand, unit costs rise, increasing competition can be expected from the development of extensive laterite deposits in other countries and from mineral and nonmineral substitutes.

An important economic consideration in the Canadian nickel industry is by-product recovery. The quantity of copper recovered from nickel ores is not much less than that of nickel and such recovery accounts for more than one third of Canada's copper production. The recovery of platinum group metals is also important and as a result, Canada is a major producer. The recovery of cobalt, iron concentrates, selenium and sulphur from nickel ores is becoming increasingly important. By-product recovery permits the mining of material that would be uneconomic on the basis of nickel content alone.

At certain times the amount of Canadian nickel produced and the amount sold differ markedly. Differences indicate changes in inventory level. The periods 1955 to 1958 and 1961 to 1963 were periods of inventory build-up; 1958 to 1961 and 1963 to 1965 were periods of inventory depletion.

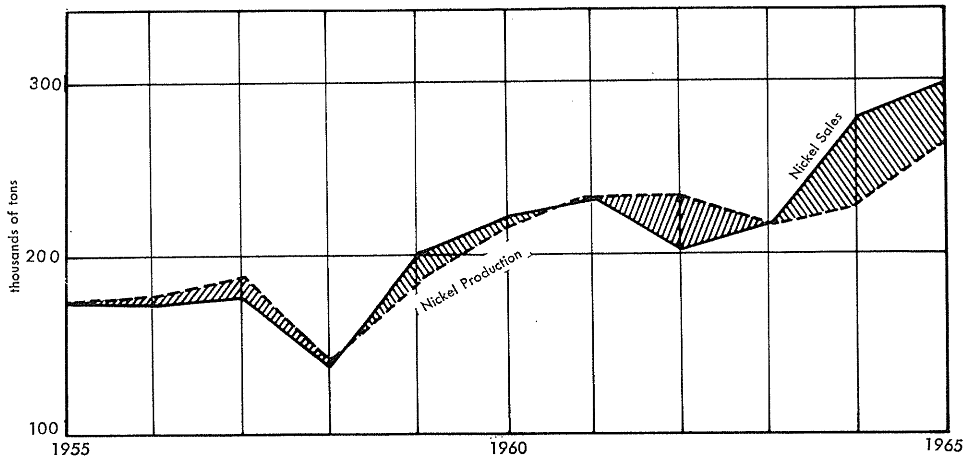


FIGURE 63. Canada — nickel production and nickel sales.

Inventories are useful for the short run stabilization of the effects of irregularities in supply or demand. Such irregularities are common for mineral commodities and in the nickel industry may be caused by such factors as labour problems, discontinuities in developing productive capacity, changes in government stockpiling strategy or the erratic nature of durable goods demand.

Exports

Almost all nickel produced is exported. Imports and domestic consumption though small, are growing. A table of Canadian nickel production, trade and consumption from 1889 to 1966 is given as Appendix D. More comprehensive export and import data for the period 1965-66 is given as Appendix G.

From 1955 to 1965, nickel exports accounted for 4.4 to 5.9% of the total value of Canadian exports. Nickel thus makes a significant contribution to Canada's export earnings.

From 1955 to 1965, exports of refined metal declined relative to other nickel export forms from 61 to 52% of total nickel exports. Exports of nickel oxide increased from one to 16% over the same period. It would be misleading to interpret these trends as an increase in semiprocessed nickel exports forms* because an important and increasing

*Nickel that requires further processing for industrial usage.

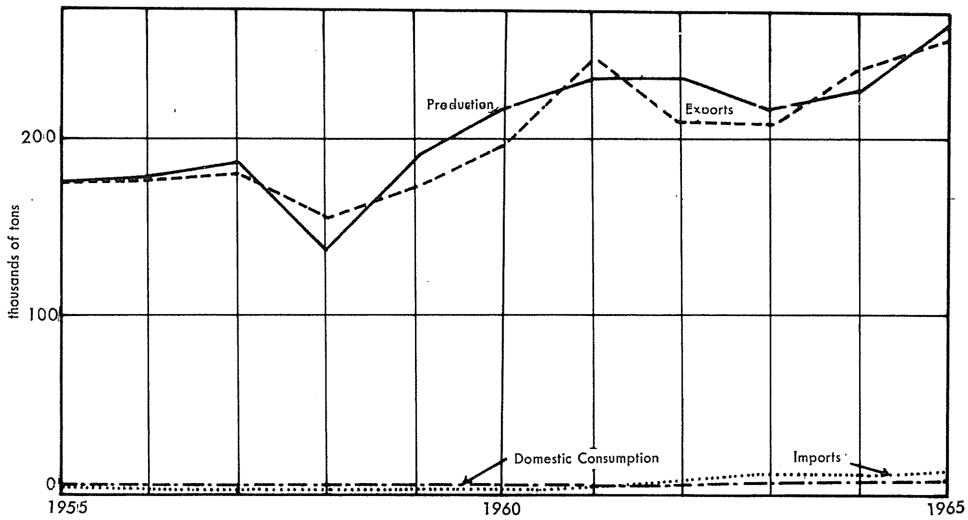


FIGURE 64. Canada — nickel production, trade and consumption.

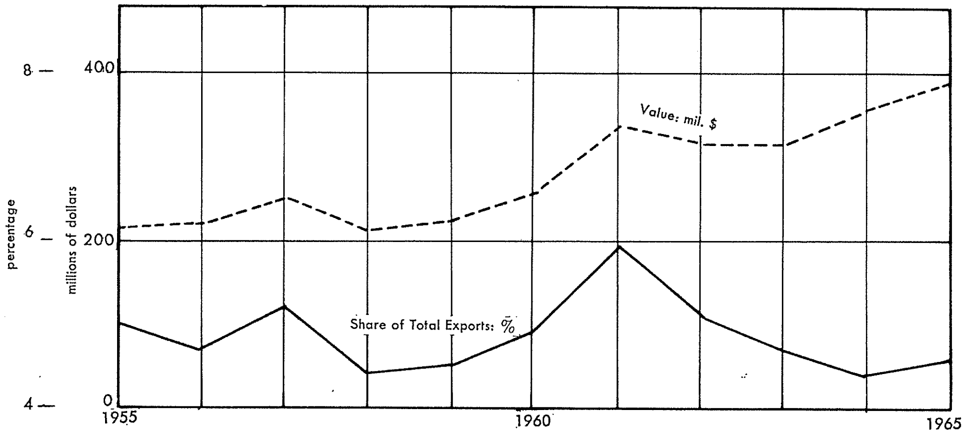


FIGURE 65. Canada — nickel exports.

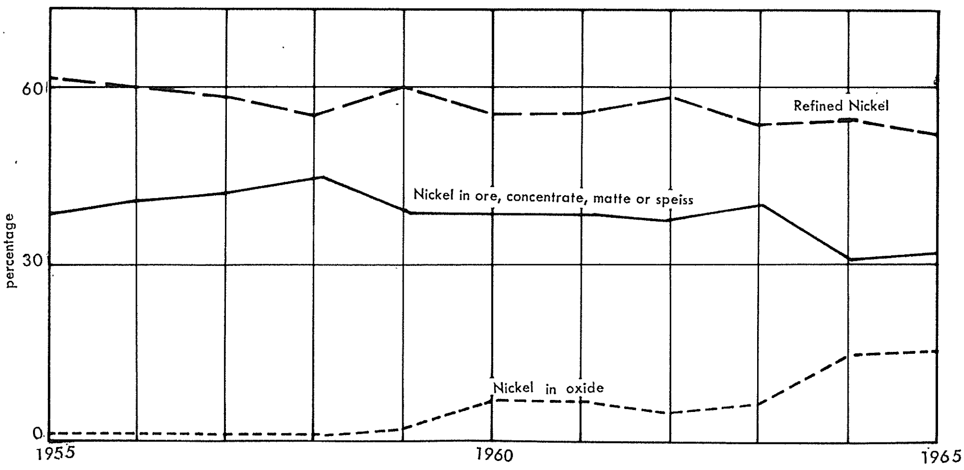


FIGURE 66. Canada — relative shares of nickel export forms.

proportion of the nickel-oxide product is used directly as a substitute for refined metal in the manufacture of nickel alloy steels. The fact that the proportion of nickel exported in ore, concentrate, matte and speiss forms has declined from 40 to 32% over the period indicates that the proportion of nickel exports in processed forms* has increased.

Nevertheless, a substantial quantity of Canadian nickel is exported in semiprocessed form and few fabricated or semifabricated nickel products are exported. For refining abroad, matte is shipped to Norway and oxide to Britain. International Nickel produces semifabricated forms in plants in the United States and Britain. Fabricated nickel products face stiff tariff barriers in the U.S. and proximity to markets is important.

The United States continues to be Canada's most important nickel customer although its share has declined from 67 to 53% from 1955 to 1965. Norway's share has been relatively constant. Other important markets include West Germany, Japan, France, Italy and Australia. A table of Canadian nickel exports by country from 1926 to 1966 is given as Appendix E.

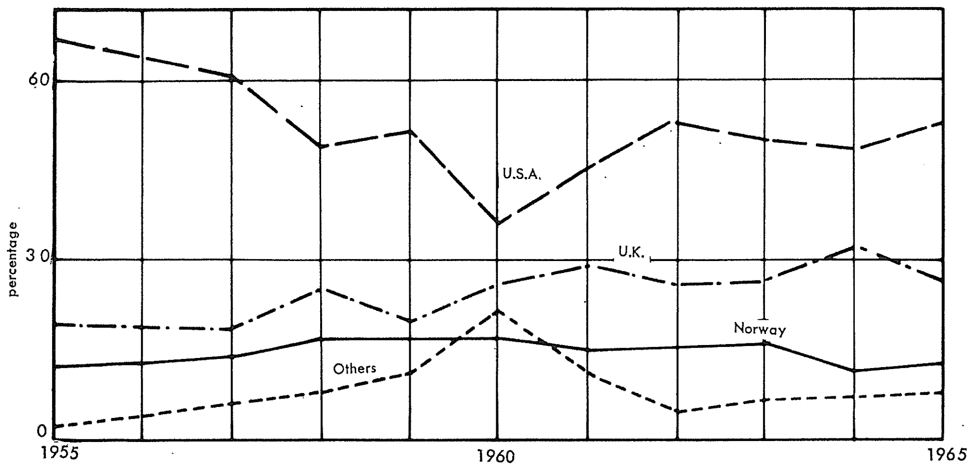


FIGURE 67. Canada — relative shares of nickel exports by country.

Consumption

In 1965 Canadian nickel consumption absorbed 3.5% of production, up from 2.9% in 1955. Annual per capita consumption is presently 0.9 pounds compared to 1.7 pounds in the United States. With continued industrial development, per capita consumption will rise. Aggregate consumption will also increase with population. At present, domestic consumption is not an important factor in stimulating output.

Imports

Since 1960, there has been a seven-fold increase in Canadian nickel imports, with nickel imports totalling 12,000 tons in 1965. The largest part of this is refined metal from Norway, most of which is subsequently re-exported. Quantities of semiprocessed forms, released from the United States stockpile, also have entered Canada for refining. A small but apparently growing factor has been the import of New Caledonian matte for refining at Sherritt Gordon's Fort Saskatchewan plant.

*Includes refined nickel and nickel oxide that is used directly as a ferroalloy.

Employment

From 1955 to 1963, employment in the Canadian nickel industry, including copper and other by-product operations, increased from 21,000 to 25,000 and the average annual wage increased from $4,310 to $5,420. A table of Canadian nickel industry employment and salaries and wages from 1950 to 1963 is given as Appendix F.

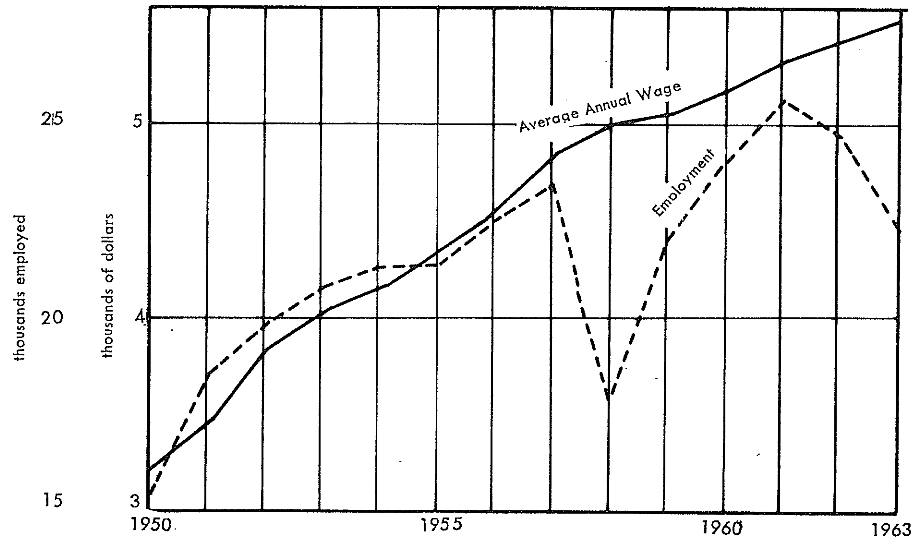


FIGURE 68. Canadian nickel industry — employment and average wage.

Investment

Investment in the Canadian nickel industry, including copper and other by-product operations, almost doubled from 1955 to 1965. Measuring investment as equity plus long term debt capital and considering only the three integrated producers, investment rose from $516 million in 1955 to $1,010 million in 1965.

CHAPTER 8

FOREIGN PRIMARY INDUSTRY

ALBANIA

Albania's most important ferrous nickel mines are the Pishkash and Cervenaka deposits in the vicinity of Kukes(1). Mines are also reported at Bushtrice and Pogradec. Exploration during 1962-63 resulted in the discovery of other ferrous nickel deposits at Puke and Leskovik(2). The ores average about 1% nickel. Hematite is the main iron constitutent but there is also some magnetite in the ore.

Commercial production of ferrous nickel ores started in 1958.

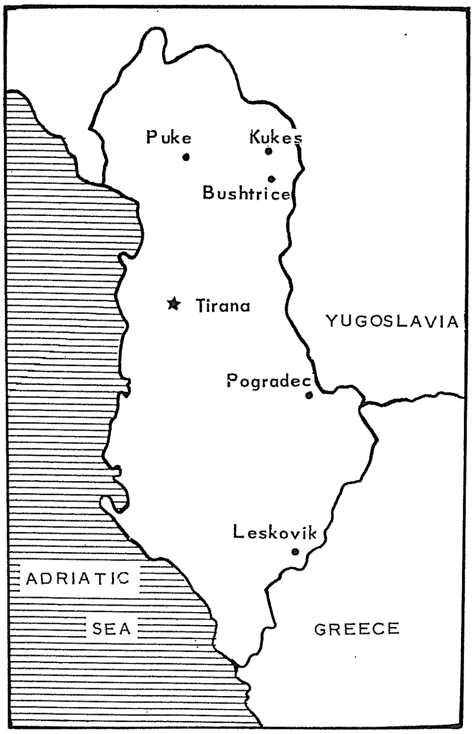


FIGURE 69. Albania.

Nickel Production – Albania
(tons)

	1961	1962	1963	1964	1965
Iron-nickel ore production(1)	395,140	468,534	330,693	385,809	na
Estimated nickel content(3)	3,307	3,307	3,307	3,307	3,307

na Not available

Virtually all production is exported, most of the output being shipped to the nickel refinery at Sered, Czechoslovakia, where 2,000 metric tons of refined nickel is produced annually from Albanian ores(1). Some ores have also been exported to Hungary(4) and China(5).

AUSTRALIA

In 1966, Western Mining Corporation, Limited, discovered a nickel bearing sulphide deposit at Kambalda, Western Australia. The ore occurs in a dome-shaped structure in a contact zone between serpentine and meta-lavas. The ore has been followed by drilling for 3,150 feet down the plunge of the structure and the contact zone has been mapped for 13 miles. By February 1967, ore reserves totalling 2.353 million tons at 4.34% nickel had been established. At the end of 1966 underground development and construction of a treatment plant and surface installations were in progress. The designed mill capacity is 8,000 tons of ore per month and the production of nickel concentrates is expected to start by mid-1967(6). In May 1967, a contract was signed between Western Mining and Sumitomo Metal Mining Company of Japan for the sale of nickel-sulphide concentrates. The contract calls for the shipment of 40,000 tons of nickel metal contained in concentrates over a period of 10 years(7). The first shipment is expected in September 1967.

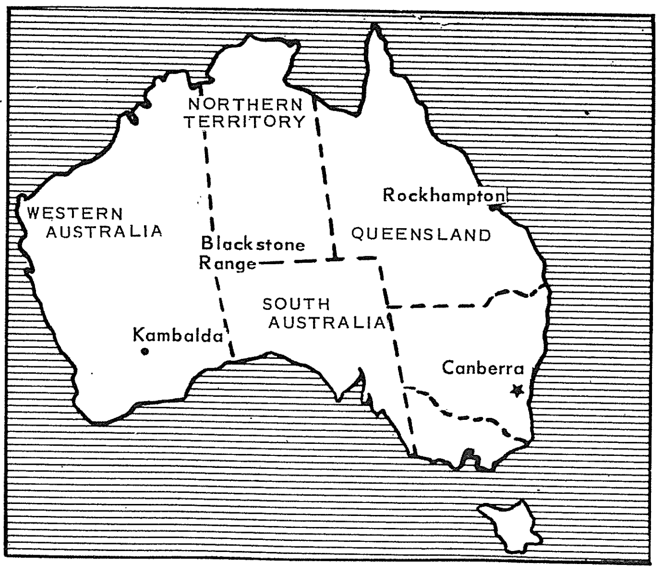


FIGURE 70. Australia.

Southwestern Mining Limited, an Australian company in which The International Nickel Company of Canada, Limited, owns a controlling interest, has, since 1955, carried out extensive exploration in the Blackstone Range area near the common borders of Western Australia, the Northern Territory and South Australia. There are several deposits of nickeliferous laterite in the Mount Davies area of northwestern South Australia and at Wingellina in Western Australia. The nickel is in part at least, associated with goethite, similar to the Cuban deposits, At Claude Hills, South Australia one deposit is estimated to contain 1.4 million tons averaging 1.65% nickel with a further 3.9 million tons at 1.2% nickel(8). Southwestern Mining Limited announced in February 1967, that the Wingellina deposits contain an estimated 60 million tons of laterite averaging 1.32% nickel(9). Drilling, metallurgical tests and a feasibility study were in progress in mid-1966. Natural gas, a possible smelter fuel, is available at Mereenie, 230 miles away(10).

Metals Exploration N.L. holds a nickel-laterite property at Greenvale, northern Queensland. Preliminary exploration indicated a mineralized zone of some 50 million tons with areas assaying from 1.5 to 3.0% nickel(11). Freeport of Australia Inc. will join Metals Exploration in further exploration of the deposit. Freeport will finance a drilling program, being planned on a 1,000-foot grid pattern, in return for a 50% interest in the development(12).

Late in 1966, it was reported that The Broken Hill Proprietary Company Limited, and The International Nickel Company of Canada, Limited, are to jointly investigate nickel-laterite deposits north of Rockhampton, Queensland. The ground is held by BHP. Intensive exploration and metallurgical investigation of the occurrence will proceed. Metallurgical tests are to be carried out by International Nickel at its Ontario research facilities(11).

BOTSWANA

Nickel occurs at Sedibe, 65 miles southeast of Francistown, in an area of ancient copper workings. Mineralization, consisting of nickeliferous pyrrhotite with minor amounts of chalcopyrite and pentlandite, is found in a serpentinite intrusion. Drilling by the Bechuanaland Geological Survey in 1953 indicated grades that varied from 0.42 to 0.71% nickel at depths of about 100 feet(13).

Bamangwato Concessions Limited, a subsidiary of Roan Selection Trust Limited, has been carrying out exploration work in Botswana under a mineral concession agreement with the Bamangwato Tribe. The concession includes the nickel occurrence at Sedibe. Geophysical, geochemical and diamond drilling programs were carried out from 1959 to 1966 in selected areas of the tribal territory(13).

In 1967, Bamangwato Concessions announced the discovery of 33 million tons of copper and nickel ores averaging 2% copper-nickel in two areas; at Sedibe and in the Matsitamma area, 75 miles northwest of Francistown. A pilot plant has been installed at Shashi to determine a mill flowsheet. Production possibilities are being studied(14).

BRAZIL

Brazil has large reserves of nickel silicate ore, but because the country lacked adequate processing facilities before 1963, it was necessary to import about 900 tons of nickel annually for the manufacture of special steels. Installation of a second ferronickel plant in the latter part of 1962 gave Brazil a capacity in excess of domestic ferronickel demand. Several hundred tons of refined nickel per year continues to be imported and some ferronickel is exported.

Nickel Production – Brazil
(tons)

	1961	1962	1963	1964	1965
Nickel ore mined(15)	4,884	17,474	58,419	60,069	na
Nickel content of mine production(3)	150	496	1,025	1,047	1,102
Exports of nickel(15)	–	–	47	na	na
Imports of refined nickel and scrap(15)	836	994	386	na	na

na Not available
– Nil

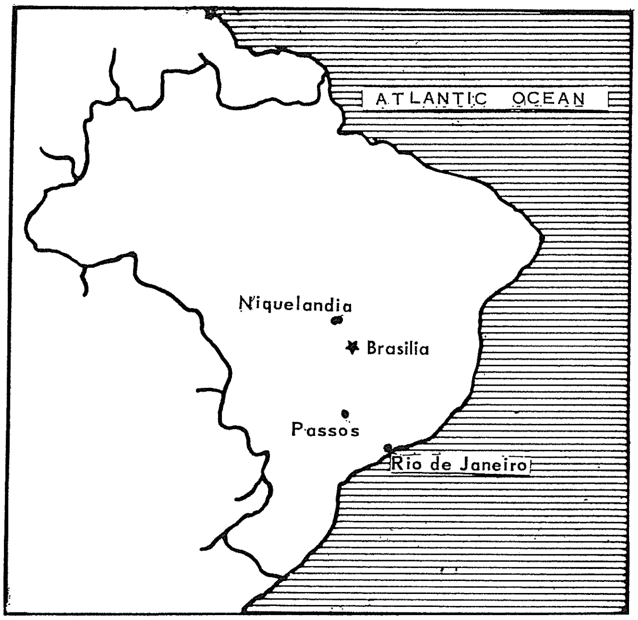


FIGURE 71. Brazil.

The only nickel deposits presently mined are in the state of Minas Gerais. There are several nickel silicate deposits grading 1 to 2% nickel.

Until 1962, Cia. Niquel do Brasil was Brazil's sole producer of nickel ore and ferronickel. The company operates a mine and processing facilities at Liberdade, Minas Gerais, producing 70 to 80 tons of nickel annually in ferronickel form. Cia. Morro do Niquel, S.A., Brazil's newest ferronickel producer, operates near Passos, Minas Gerais, about 250 miles northwest of Rio de Janeiro. The company is controlled by Société Le Nickel and French banking interests. The reduction plant has a nominal annual capacity of 1,200 tons of nickel in ferronickel form(16).

In the state of Goias, some 50 nickel-silicate deposits occur in a 14 square-mile area near Niquelandia, about 120 miles north of Brasilia. The area is estimated to contain 16 million tons of nickel-silicate ore grading 3 to 6% nickel(16). These deposits are potentially the most important in Brazil but remoteness and attending transportation problems mitigate against development. Pressures by the state of Goias to activate their development resulted in the formation of a new company in 1963(17). Cia. Nibrasa-Niqueis do Brasil, S.A. a group formed with 40% participation by the state of Goias, acquired mining rights for these deposits.

BRITAIN

Nickel processing facilities in Britain are entirely dependent on foreign raw materials.

International Nickel, Limited, the operating arm of The International Nickel Company of Canada, Limited, in Britain, is the major producer of refined nickel. Nickel-oxide sinter from the Copper Cliff smelter, Canada, is refined at Clydach, Wales, to nickel pellets and nickel powder by the Mond process (described in Chapter 5). Since 1958, major plant alterations have been made at the Clydach refinery, significantly increasing both thermal and labour efficiency. Production capacity is 40,000 tons of refined nickel per year. A major modernization scheme was inaugurated in May 1967.

Henry Wiggin and Company, Limited, a subsidiary of International Nickel, operates a rolling mill, extrusion plant, and specialized high-nickel alloy fabrication plant in Hereford.

The Brimsdown works of Johnson, Matthey and Company produce electrolytic nickel from South African nickel-copper-platinum matte.

Nickel Production – Britain(3)
(tons)

	1961	1962	1963	1964	1965
Nickel metal production	41,839	42,254	41,969	41,896	44,629
Nickel metal imports	27,283	15,024	13,620	32,389	29,489
Nickel metal exports	24,582	22,544	26,422	30,113	31,117

Refined nickel is imported primarily from Canada, with lesser quantities from the USSR and Norway. Britain's most important nickel export markets are West Germany, Sweden, France and Italy.

BRITISH SOLOMON ISLANDS

Exploration of the ultrabasic rocks of the Solomons by the Geological Survey from 1953 to 1959, with the help of research funds provided by James Hardie & Company Limited of Sydney, and The International Nickel Company of Canada, Limited, outlined extensive areas of nickel laterite on Santa Isabel, San Jorge and Choiseul Islands(18). Less important nickeliferous laterite occurrences are found on Florida, Guadalcanal and San Cristobal Islands.

Samples obtained by hand auger drilling on Santa Isabel and San Jorge assayed 0.45 to 2.52% nickel(19). Deposits on these islands are of particular interest because of the absence of jungle growth over much of the lateritic country.

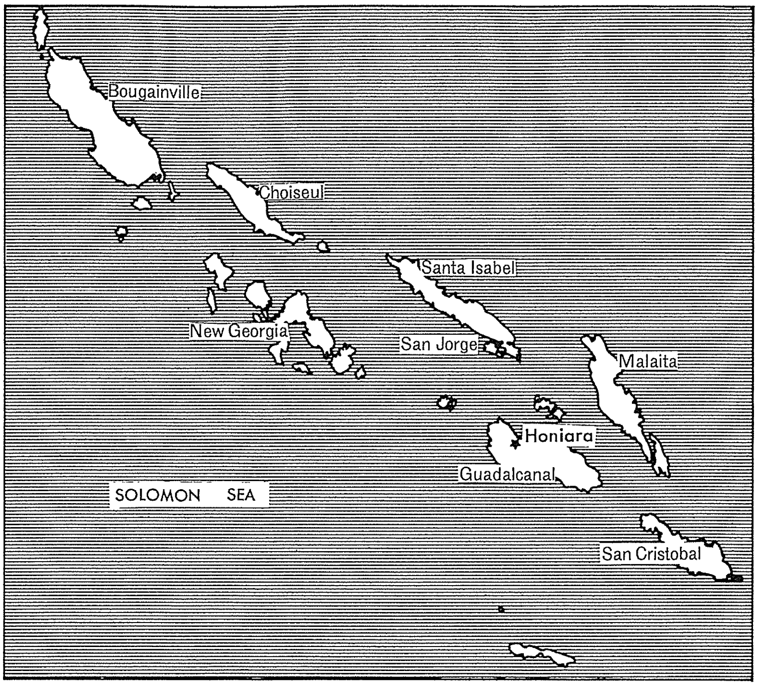


FIGURE 72. British Solomon Islands.

Another nickel exploration research program was initiated by the Geological Survey in 1961 with research funds provided by the Commonwealth Geophysical Company of Canada, a subsidiary of The International Nickel Company of Canada, Limited(4). After three months work had shown the existence of deposits of probable interest, the Commonwealth Geophysical Company, in October 1961, made proposals for simultaneous prospecting in adjoining areas on Santa Isabel, San Jorge and on Choiseul Island. By the end of 1962, 545 holes had been drilled on a 400-metre grid to an average depth of seven metres on the nickel laterites of Santa Isabel and San Jorge. In 1963, the Commonwealth Geophysical Company's prospecting licences were renewed in the name of another subsidiary company, the Southern Mining and Development Company Limited. As a result of the increasing expenditure and proposals to intensify activity still further with power drilling equipment, these prospecting licences were renewed in November 1965 for a final two years(20).

Earth moving equipment and a power drilling plant were in operation on San Jorge by mid-1966. A 550-ton nickel-bearing laterite sample from Santa Isabel was shipped to Canada late in the year for metallurgical test work. Screening equipment had been installed for field tests(21). Engineering feasibility studies were undertaken in the last half of 1966, and a development to production decision was expected by the end of 1967.

BURMA

The Peoples Bawdwin Industry (formerly Burma Corporation 1951 Limited) operates a high-grade lead-zinc sulphide mine at Bawdwin with a mill, smelter and refinery at Namtu, Northern Shan States. The ore contains trace amounts of nickel that is recovered in a speiss containing 17 to 27% nickel. The speiss has been shipped to West

German and Japanese refineries for the recovery of nickel in marketable form. The nickel content of the speiss was: in 1961 – 112 tons; in 1962 – 182; in 1963 – 112; and in 1964 – 70(22).

CUBA

The existence of extensive deposits of low-grade nickel-iron laterites in Oriente province on the northeastern coast of Cuba has been known since the end of the 19th century. Following the early unsuccessful attempts at producing marketable products from these deposits, the United States government during World War II financed the development of a deposit at Levisa Bay (Nicaro). Subsequently a deposit at Moa Bay was brought into production in 1959. These two projects were nationalized by the Cuban government in 1960–after the revolution. After an initial period of operational difficulties, Cuban nickel production is believed to have regained pre-1960 levels. Nickel is the most important mineral commodity produced in Cuba.

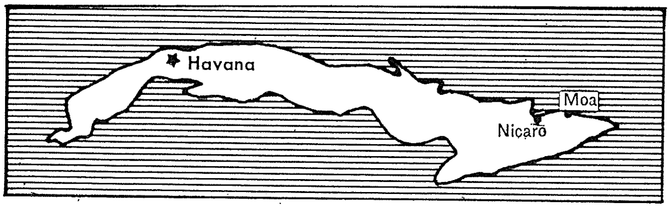


FIGURE 73. Cuba.

Nickel Production – Cuba (22, 23)
(tons)

	1961	1962	1963	1964	1965*
Nickel content – oxide	16,320	16,222	16,121	16,217	20,200
Nickel content – sulphide	–	2,080	5,689	8,491	9,900
Total	16,320	18,302	21,810	24,708	30,148

*Estimate
– Nil

Cuban nickel-laterite ore reserves have been estimated as follows: (24)

	Ore (millions of tons)	Nickel (%)
Levisa Bay	102	1.3
Moa Bay	95	1.3
Other	159	1.3
Total	356	1.3

The above figures represent ore containing 1% or more nickel. Material containing less than 1% is estimated at 1,653 million short tons grading 0.80% nickel.

Levisa Bay

Levisa Bay is on the north coast of Oriente Province, 450 miles east of Havana.

The ores of Levisa Bay are nickeliferous-iron laterites derived from the chemical weathering of serpentinized peridotite that had been intruded into earlier sedimentary rocks(24). The ores are blanket deposits 3 to 16 feet thick, overlain in part by a high-iron low-nickel laterite with an average depth of six feet. The ore is underlain by altered serpentine which grades downward to the unaltered primary rock.

In order to increase the supply of nickel during World War II, the United States government authorized the development of the Levisa Bay laterites. Construction began in March 1942. The primary stage was completed and the first nickel oxide was produced in December 1943. Full production was reached one year later. The plant, operated by the Nicaro Nickel Company, a subsidiary of Freeport Sulphur Company, was 'moth-balled' in March 1947.

The Nicaro plant was reactivated in 1952 on behalf of the United States government, because of the nickel shortages during the Korean War. During this period, the plant was operated by the Nickel Processing Corporation, owned 60% by the National Lead Company and 40% by Fomento de Minerales Cubanos, S.A.(25).

The plant produced nickel-oxide powder by the Caron ammonia pressure leach process (described in Chapter 5). In 1954 sintering machines were installed and nickel-oxide sinter was produced in addition to powder. An expansion program begun in 1954 and completed in 1957 raised the plant's capacity to 25,000 tons of contained nickel per year.

Production was continuous until September 1960 when restrictions and prohibitive taxes imposed by the Cuban government forced closure. On October 24, 1960 the Cuban Government nationalized the plant.

From 1943 until nationalization in 1960, the Nicaro plant treated over 15 million tons of ore, producing 198,000 tons of oxide containing 158,000 tons of nickel and small amounts of cobalt(25).

The Cuban government renamed the Nicaro plant Comandante Rene Ramos Latour. Following nationalization, operational difficulties were encountered and nickel production declined significantly in 1960 and 1961. However, subsequent technical assistance from the USSR and Czechoslovakia was successful in raising nickel production to pre-1960 levels. A process for producing electrolytic nickel from Cuban oxide has been adopted by Czechoslovakia's Sered works(25). It has been reported that plans are being considered for the construction of a $100 million nickel plant at Rene Ramos Latour for the production of refined metal.

Moa Bay

The Moa Bay nickeliferous-iron laterites are on north coast of Oriente Province, 500 miles east of Havana and about 60 miles east of Levisa Bay.

The ore occurs as a mantle of lateritic iron ore that has formed as a residual product of the weathering of underlying serpentine and in which iron, nickel and cobalt have been concentrated. The deposits, cut by a series of northward flowing streams, form a mantle on hills between the stream valleys. The deposits vary from 10 to 100 feet thick(26).

The Moa Bay Mining Company, a subsidiary of the Freeport Sulphur Company began to explore these deposits early in 1952(25). Processing facilities were subsequently installed at Moa Bay to concentrate the ores by the sulphuric acid process (described in Chapter 5), and a refinery was constructed at Port Nickel, Louisiana, to recover nickel and cobalt from the concentrates. Refining was carried out by the ammonia pressure leach process, under an agreement with Sherritt Gordon Mines Limited(27). Production of nickel-cobalt sulphide concentrate began in November 1959 and the initial shipment of concentrate reached the refinery at the end of the year. Because of the excessive taxes that the Cuban government placed on the mining of ores and on the export of mineral products, operations were suspended in April 1960. The Louisiana refinery recovered 1,775 tons of nickel and 152 tons of cobalt during its brief production period.

In August 1960, the Moa Bay plant, in which various bankers had invested $61.5 million, was nationalized by the Cuban government. The leaching plant and Louisiana refinery were designed as interdependent processing units and the Cubans, assisted by foreign engineers, were unable to surmount the technical problems and use the plant until 1962. The plant was renamed Bahia Minera Comandante Pedro Soto Alba. Sulphide slurry has been shipped in barrels to Czechoslovakia, Poland and the USSR for further treatment(16).

CZECHOSLOVAKIA

The Sered plant is the only refined nickel producer in central Europe. Production began in 1962 but operations were subsequently suspended due to technical difficulties and the plant only resumed production in August 1963(16). The plant, using low-grade Albanian ores, has a capacity of 2,000 metric tons of refined nickel per year.

The ores are processed by a hydrometallurgical method, similar in its initial stages to the Caron ammonia pressure leach process(28). The ore is crushed, ground, reduced and leached. After removal of iron from the leach liquor, the dissolved cobalt precipitates. The purified liquor is pumped to extraction columns and the nickel compound is decomposed to nickel carbonate.

At this stage in the ammonia pressure leach process the nickel carbonate is calcined to nickel-oxide powder. In the Czech process, after the removal of undesirable admixtures, the nickel carbonate is dissolved in sulphuric acid to form nickel sulphate. Electrolysis is then performed in vats equipped with insoluble silver-lead anodes. Metallic cathode nickel of a high purity is produced. Construction of a similar electrolytic plant was planned for the Rene Ramos Latour operation in Cuba.

DOMINICAN REPUBLIC

In 1955, Falconbridge Nickel Mines, Limited, began an investigation of lateritic nickel ores in the Dominican Republic. In 1956, a subsidiary Dominican company, Minera y Beneficiadora Falconbridge Dominicana C. Por A., was formed and subsequently acquired a concession of 300 square miles in the Cibao region in which there are several nickel-laterite deposits of economic interest.

Falconbridge continued research and development work on these deposits and in six years incurred expenditures totalling $6 million(29). Ore reserves at the end of 1959 were estimated to be 72.4 million tons(30) averaging 1.55% nickel(31). A pilot plant was installed at Maimon, about 10 miles east of Bonao, with a daily capacity of one ton of ferronickel averaging 50% nickel. Small quantities of ferronickel have been exported for test and demonstration purposes.

It was reported early in 1964 that feasibility studies for the construction of a full scale plant were in progress. However, it was announced by Falconbridge in August 1965 that a decision affecting the construction of a full-scale plant had been postponed because of political instability. Subsequently, a decision was made to enlarge the pilot plant. The enlarged pilot plant, with a capacity four times that of the previous plant, began operating in February 1967(32).

EAST GERMANY

There are three ferronickel smelters in East Germany at Oberschlema, Aue and St. Egidien, Saxony having a combined annual capacity of 1,500 metric tons of nickel in ferronickel form(3).

FINLAND

In 1934, Petsamon Nikkeli Oy, a Finnish subsidiary of the Mond Nickel Company, obtained a concession to mine a nickel-copper deposit in northern Finland. By the end of 1939, the orebody had been developed and a smelter and hydroelectric power plant were under construction. The development of the Petsamo deposit, reported to average 1.61% nickel and 1.32% copper(33), was interrupted when the USSR declared war on Finland late in 1939. From 1934 to 1939 the company expended nearly $7 million on development. The deposit was ceded to the USSR in 1944 under the terms of an armistice between the USSR and Finland. The company received a settlement of $20 million from the Soviet Government(34, p.244).

During World War II, nickel-copper ore was mined at Nivala. This deposit, averaging 0.68% nickel and 0.40% copper, ceased production in 1954. However, exploration of the orebody was reported in 1966(35).

The only presently producing nickel mine in Finland is at Kotalahti. The mine is operated by the state-owned firm, Outokumpu Oy, the sole producer of nonferrous metals in Finland. Concentrates from the Kotalahti mine are shipped to Harjavalta, near Pori, where Outokumpu Oy operates a copper smelter and nickel refinery. The company operates a copper refinery at Pori where small amounts of by-product nickel are recovered.

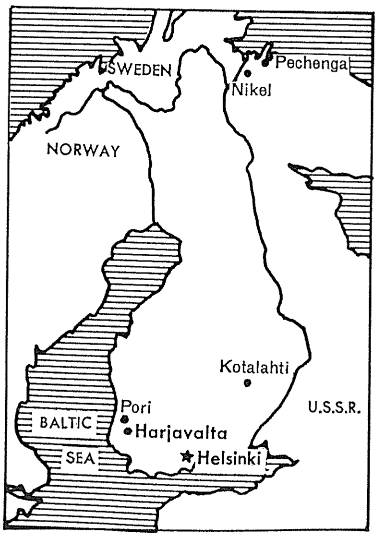


FIGURE 74. Finland.

Nickel Production – Finland
(tons)

	1961	1962	1963	1964	1965
Nickel ore(36-38)	407,501	489,579	504,175	507,256	na
Nickel concentrates (5 to 6% Ni)(39)	38,248	49,507	60,009	64,786	60,978
Nickel content in sulphate(39)	177	178	172	162	178
Refined nickel(3)	1,989	2,567	2,970	3,244	3,060

na Not available

According to reports from the prospecting company, Malminetsija Oy, test drilling during 1964 at Lehtikangos, near Kajaani, indicated a large nickel deposit(38).

It was reported in 1966 that Outokumpu Oy had completed an exploration shaft at the Hitura nickel deposit in the Nivala area and was proceeding with an underground exploration program(40).

Kotalahti Mine

The Kotalahti nickel mine is 37 km from Lehtoniemi station which is the shipping point for the mine concentrate as well as the general supply centre for the mine. The deposit was discovered in 1954 and underground exploration began in 1956. The mine was developed and the plant constructed in the period 1957-59, with production beginning in October 1959.

The deposit is associated with a complex of basic and ultrabasic rocks. The complex is long and narrow, lies within highly metamorphosed schists and conforms to their general trend. The deposit comprises four separate steeply dipping ore shoots, three of which outcrop. The intensity of mineralization is quite variable and there are both disseminated and breccia type ores. As of mid-1965 ore reserves were reportedly sufficient to last 15 years at the current rate of production(39). The ore averages 0.8% nickel and 0.3% copper(40).

Production at the Kotalahti mine is at a rate of 1,500 tons per day. Mining is by the blast-hole method. It was reported in 1966 that the main shaft had been extended to a depth of 680 metres, thus becoming the deepest shaft in Finland(41). A nickel concentrate containing 5 to 6% nickel and a copper concentrate containing 23% copper are produced by selective flotation and shipped to Harjavalta. There are no precious metals in the ore and the cobalt content is very low.

Harjavalta Works

There are no coal resources in Finland and the cost of electricity is prohibitive for smelting purposes. Consequently, Outokumpu introduced a flash smelting process in 1949. Sufficient heat for the smelting is produced by the heat of reaction of the concentrates in the furnace. The Harjavalta works is both a copper smelter and a nickel refinery. The electrolytic nickel refinery was erected in 1960(42).

The nickel concentrate from the Kotalahti mine is dried in a rotary furnace and flash smelted in a second furnace. The matte is then blown in a converter and granulated. The nickel matte is dissolved in acid solution and electrolytic cathodes are produced for market.

Harjavalta copper anodes contain about 0.75% nickel, most of which is recovered in the tankhouse slimes at the Pori electrolytic copper refinery. This by-product nickel is produced in nickel-sulphate form.

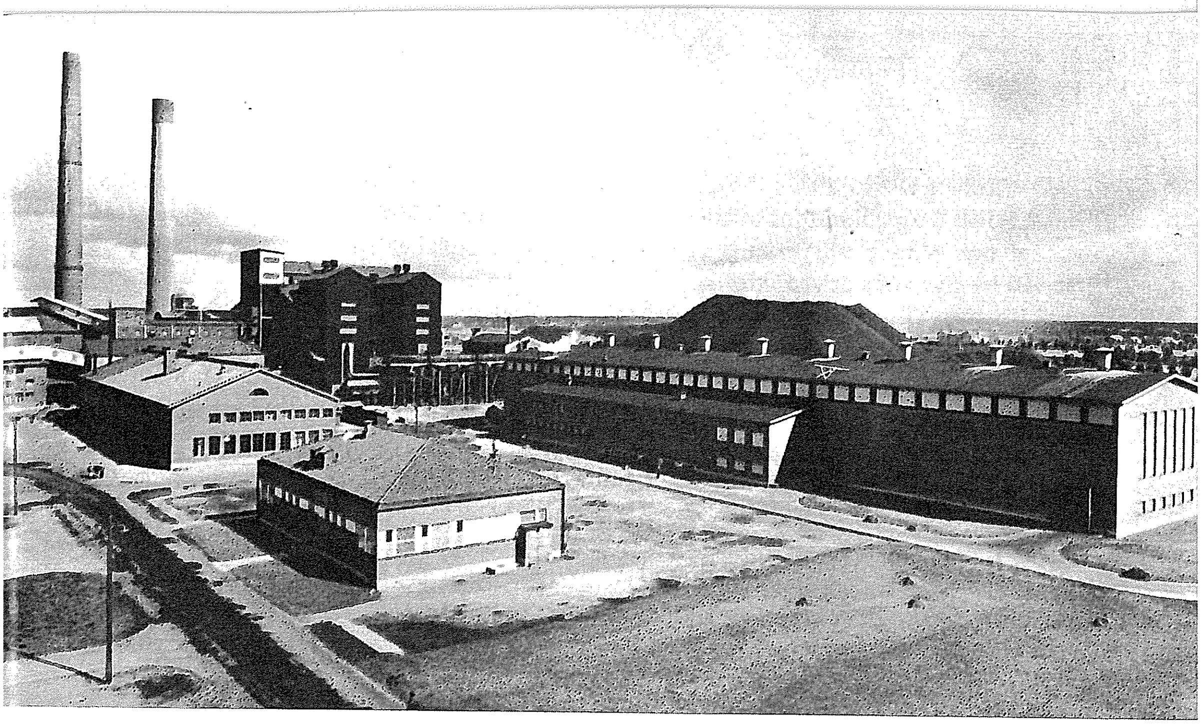


FIGURE 75. Harjavalta smelter, Outokumpu Oy.

FRANCE

Although France has no mine production of nickel, several refineries produce nickel from imported mattes, ores and scrap. In 1961, 12,011 tons were produced; in 1962 – 11,411; in 1963 – 10,595; in 1964 – 8,896; and in 1965 – 8,984(3).

The most important nickel refinery in France is operated by Société Le Nickel at Le Havre. The refinery treats New Caledonian matte by a process described in Chapter 5. Nickel is produced in rondelle form. The plant has an annual capacity of 12,000 metric tons of refined nickel.

Moroccan ores are processed at the nickel-cobalt refinery of Société D'Électro-Chimie D'Électro-Métallurgie et des Aciéries Électriques D'Ugine at Pomblière Saint Marcel, Savoie. Nickel is recovered in powder and salt forms.

At Saint Michel de Maurienne, Savoie, Société Sopamet operates an electrolytic refinery which uses nickel-bearing scrap as a raw material.

GREECE

The most important occurrence of nickel in Greece is near Larymna, on the east coast, adjacent to Euboea Island. The deposit is accessible by road from Athens, situated some 135 km to the south.

The Larymna deposit consists of a succession of sedimentary beds containing iron, chrome, and nickel mineralization. The nickeliferous horizon is about 20 feet thick. The bottom part of this horizon constitutes nickel ore with a nickel-cobalt content which varies from 1 to 3%, averaging 1.9%. The average iron content is 38%. The top part of the nickeliferous horizon averages between 0.3 and 0.5% nickel-cobalt. The deposit is bounded by a dolomite footwall and a limestone hangingwall, all beds dipping at 45 degrees to the west. Recent resource data for the Larymna district are not available. A nickel silicate ore reserve of 500,000 tons averaging 2.5% nickel, was reported in 1943. Reserves of nickeliferous-iron laterite have been estimated at 10 million tons, averaging 0.5 to 1% nickel(24).

From 1929 to 1938, the Larymna deposit was worked for both iron and nickel ores. Some 1.5 million tons of ore were extracted of which 300,000 tons was considered nickel ore. Mining was mainly by underground methods with the underground mine served by five adits driven into the side of a hill. The iron ores mined averaged 46% iron and less than 1% nickel; the nickel ore graded 2.1% nickel.

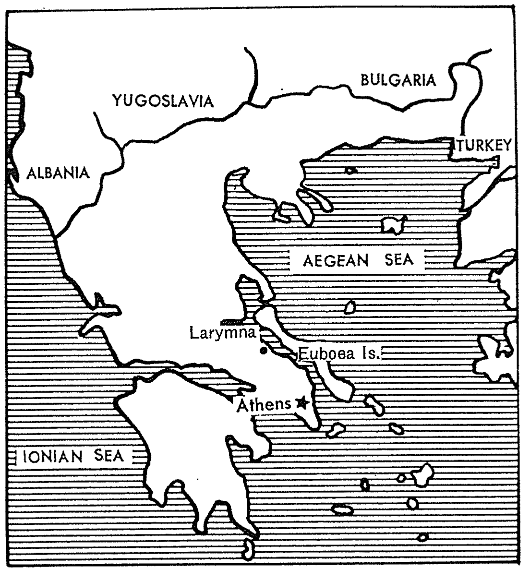


FIGURE 76. Greece.

In 1952, the Greek government authorized Hellenic Chemical Products and Fertilizer Company to reactivate the mine with the proviso that the ore be domestically smelted. The German firm, Krupp, a partner in the project, spent some $15 million erecting ore dressing and smelting facilities. Mine and smelter production began in 1956.

Originally a 6% ferronickel was produced by a German process that had been developed before World War II(43). The process involved the continuous reduction of iron in a sloped rotary kiln. The kiln discharge consisted of metallic nodules of ferronickel dispersed in a slag. Because of market conditions it was subsequently found necessary to upgrade this product to a 25% ferronickel by electric furnace smelting. Economic and technical problems associated with the process forced the termination of operations in 1958.

In 1961, Hellenic Chemical Products and Fertilizer Company signed agreements with Société Le Nickel, forming Société Minière et Métallurgique Larco, to renovate, expand and exploit the Larymna deposit. Le Nickel acquired a 21% interest in the new company(44).

The new Larymna project was planned to combine the extraction of nickel ore with the establishment of an iron and steel plant having a capacity of 4,000 tons of electrolytic nickel and 80,000 tons of steel annually(40). The project was to operate on a low-temperature process, producing alloy one half of which was high-purity nickel(43).

The Larco nickel smelter was scheduled to go into production at the beginning of 1966 but processing problems were experienced. Production of ferronickel to mid-1967 had been intermittent.

It was reported in 1966 that two mines were reopened to produce nickeliferous-iron laterite for export and local blast furnacing. The Tsouka mine was reopened to supply three million tons of ore over a five-year period to the Roumanian government. Halyvourgiki Incorporated was reportedly buying nickeliferous-iron laterite from the reopened Loutsi mine for use in its blast furnaces(20).

GUATEMALA

Nickel-laterite deposits in the Lake Izabal area, near the cities of Quirigua and El Estor, were originally explored by the Hanna Mining Company. Subsequently, controlling interest was sold to The International Nickel Company of Canada, Limited. Hanna retained a 20% interest in the venture. International Nickel has spent over $2 million exploring these deposits and results indicate approximately 30 million tons of lateritic ore, averaging 1.5% nickel(45).

In 1964, plans were announced to bring the deposit into production. A new company, Eximbal (Exploraciones y Explotaciones Mineras Izabal, S.A.), has been formed to develop deposits on both sides of Lake Izabal(46). The enactment of new mining codes during 1965 by the Guatemalan government has encouraged the venture(47).

Plans are to mine and smelt 1.2 million tons of lateritic nickel ore annually, producing 12,500 tons of nickel per year in ferronickel form. Further processing will be done outside Guatemala(47). Mining rights for a period of 40 years were granted by the Guatemalan government in 1965(48).

FIGURE 77. Guatemala.

During 1966, financial arrangements and engineering studies were substantially advanced and important development work was carried out on the properties(49). In 1967, the port facilities at Matias de Galvez were being expanded. Exports of nickel are expected to begin by early 1970.

INDONESIA

The islands of Sulawesi (Celebes), Borneo, and New Guinea contain extensive lateritic-nickel deposits. On Sulawesi, ore deposits have been discovered in the east-central mountainous Lakes region (Bulubalang and Soroako) and in the southeastern part of the island (Pomalaa region, including the islands Lemo and Maiang). Waigeo Island and surroundings and West Irian (New Guinea) contain large deposits of nickelferous iron.

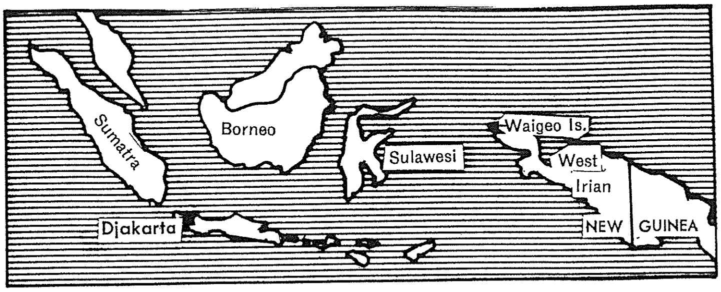


FIGURE 78. Indonesia.

In 1967, Indonesian nickel reserves and potential ore were estimated as follows:(50)

Nickel Reserves and Potential Ore – Indonesia

	Tons ('000)	Nickel (%)
Reserves		
Southeastern Sulawesi	4,960	2.2
East-central Sulawesi*	3,750	2.0
Total	8,710	2.1
Potential Ore		
Waigeo Island and surroundings	69,600	1.4
West Irian	66,100	1.0
Total	135,700	1.2

* Including 1,070,000 tons at 3.5% Ni

Before 1960, Indonesian nickel production was limited to the small-scale production of ore by an Indonesian private mining enterprise on Sulawesi. The ore was exported to Japan.

In 1962, a co-operative agreement was signed between the Japanese Sulawesi Nickel Resources Development Cooperation Company (Sunideco), the Indonesian Government and P.T. Nikel Indonesia, a government owned Indonesian company, for the mining and exporting of the nickel laterites in the Pomalaa area of southeastern Sulawesi. Sunideco, jointly controlled by five Japanese nickel refining companies, agreed to provide a credit of $1.3 million for the purchase of Japanese machinery and technical services. All nickel ore produced was to be exported exclusively to Sunideco until the loan was repaid(51). Mining is administered by the Indonesian government. The first shipment was dispatched to Japan in June 1963.

Nickel Production – Indonesia (tons)

	1961	1962	1963	1964	1965
Nickel ore produced (52)	15,082	11,880	50,186	54,261	112,438
Nickel content (3)	694	491	1,764	1,874	3,307

The ore must be concentrated to 3.2% nickel to meet export contract standards. It was planned that annual production of nickel ores for 1966-68 from southeastern Sulawesi would reach 130,000 tons(52).

Early in 1967, Sunideco reached agreement with the Indonesian government for the construction of a $3 million nickel ore pelletizing plant on Sulawesi. The plant will initially treat 10,000 metric tons of ore per month for shipment to Japanese smelters(53).

In 1966-67 the Indonesian government was reportedly studying the feasibility of installing a smelter to treat Sulawesi nickel ores(54).

New mining legislation was being planned in 1967 to encourage foreign investment in the development of Indonesia's mineral industry(54).

ITALY

In 1966, Société Le Nickel formed an Italian company, Nickel Sarde, to construct and operate an electrolytic nickel refinery at Cagliari, Sardinia. It is anticipated that the plant will have a capacity of 5,000 metric tons of refined nickel per year. Nickel matte will be supplied from New Caledonia(55). Power will be obtained from the new thermal plant at Porto Vesme(56). In 1967, the company was completing negotiations for the purchase of the required land from the Consortium for the Cagliari Industrial Development Area.

JAPAN

A considerable quantity of domestic nickel ore was mined during World War II, averaging 0.4 to 1% nickel(57). Known laterite and sulphide occurrences average 0.1 to 0.5% nickel.

Japanese ferronickel smelters and nickel refineries are wholly dependent upon foreign raw materials. In 1965 and 1966 more than 85% of Japan's nickel ore requirements were imported from New Caledonia. Ore and concentrate is also imported from Canada and Indonesia. Matte is imported from New Caledonia. Nickel metal and alloy products are imported, primarily from Canada, the United States and Norway. The import of nickel ingots from the USSR was expected to reach 4,000 metric tons for the period April–September 1967(58). The import of nickel was liberalized in October 1961(59). Japan is the only country that places the importation of unwrought nickel, unalloyed on a tariff quota basis.* This protects Japan's primary industry but at the same time allows the import of nickel if demand warrants.

In 1967, Japanese nickel production capacity was estimated at 8,000 metric tons of nickel metal per year, 28,540 metric tons of nickel per year in ferronickel form, and 4,500 metric tons of nickel per year in oxide form (see following table).

Sumitomo Metal Mining Company, Limited, operates a nickel smelter at Shisakajima where silicate and sulphide ores are reduced to matte in a blast furnace and roasted to nickel-oxide sinter(64). An electrolytic nickel refinery is operated at Niihama, producing cathodes assaying 99.98% nickel. Electrolytic nickel capacity is 4,500 metric

*Effective June 1, 1967, the Tariff Quota System was scheduled to be extended to unwrought nickel alloy, waste and scrap (unalloyed and alloyed), powders and nickel flakes, alloyed powders and electroplating anodes of nickel.

tons per year. The company also operates two ferronickel smelters; the annual capacities of the Toyama and Hyuga plants are 5,000 and 2,000 metric tons, respectively, of contained nickel.

Nickel Production – Japan
(tons)

	1961	1962	1963	1964	1965	1966
Imports						
Ore and concentrate	na	743,918	749,016	1,260,193	1,065,650	1,399,872
Matte	na	757	4,340	5,984	4,788	5,564
Metal and alloy products	na	1,918	1,062	4,244	2,965	3,584
Production						
Ferronickel	69,056	39,652	51,680	86,336	81,335	78,859
Nickel metal	6,686	6,245	6,823	7,356	6,946	7,917

Ref: 1961-64 (60)
1965-66 (61-63)

na Not available

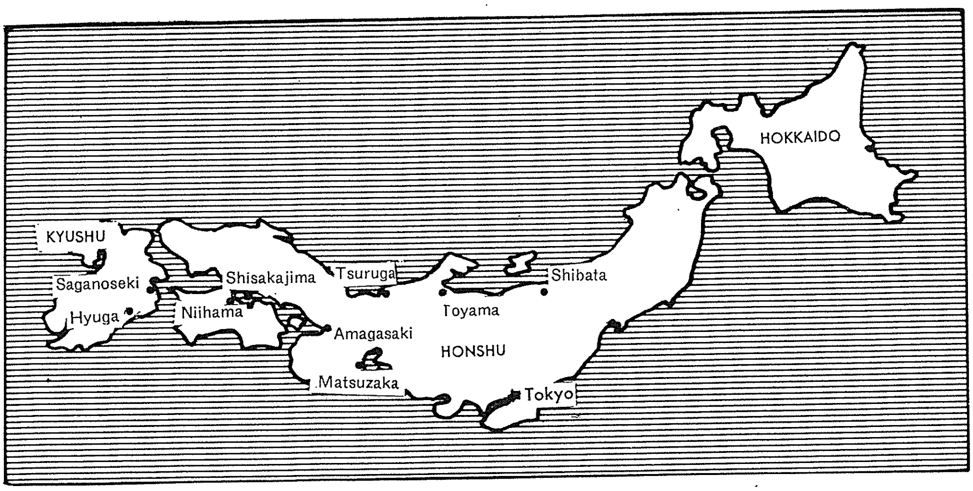


FIGURE 79. Japan.

Shimura Kako Company, Limited, operates a smelter and refinery near Tokyo with an annual capacity of 3,500 metric tons of electrolytic nickel. The company also operates two ferronickel plants, at Tokyo and Amagasaki, with a combined annual capacity of 3,000 metric tons of contained nickel.

Nippon Yakin Kogyo Company, Limited, treats silicate ore from New Caledonia in rotary kilns at its Oeyama plant. The product is smelted into a 20 to 33% ferronickel. Annual plant capacity is 7,800 metric tons of contained nickel per year(65).

Nippon Mining Company Limited, operates nickel processing facilities at Saganoseki, producing a 30% ferronickel. Annual plant capacity is 6,240 metric tons of contained nickel. Capacity is to be expanded to 12,000 metric tons per year by 1970(65).

Tokyo Nickel Company, a joint enterprise, 50% owned by Shimura Kako, 40% by The International Nickel Company of Canada, Limited, and 10% by Mitsui, was formed in 1965. The company manufactures and markets nickel-oxide sinter in Japan. Their Matsuzaka plant has a capacity of 4,500 metric tons of contained nickel per year.

Taiheiyo Nickel Company is a manufacturer of ferronickel. The plant, at Shibata, has an annual capacity of 4,500 metric tons.

Early in 1967, it was reported that three Japanese companies—Nippon Mining, Taiheiyo Nickel and Nippon Yakin Kogyo—are to build a nickel-oxide sinter plant with processes and raw materials supplied by Société Le Nickel. The joint enterprise is to be called Nihon Nickel Company Limited. The plant, to be constructed at Tsuruga, will have a capacity of 5,000 metric tons of contained nickel per year. Société Le Nickel will later join the venture, participating to a maximum of 50% ownership(66).

MOROCCO

Morocco's only nickel production is derived from the deposits of Bou Azzer and El Graara, 100 miles southeast of Marrakech, on the eastern edge of the Anti Atlas mountains. The mines, operated by Société Minière de Bou Azzer et du Graara, have been in continuous production since 1932. The ores are primarily worked for cobalt but nickel, silver and gold are also recovered. The ores have a high arsenic content and require special treatment.

Nickel Production – Morocco (67)
(tons)

	1961	1962	1963	1964	1965*
Nickel content of ore	284	316	302	336	331

* Estimate

The ore occurs in areas of Precambrian rock, exposed by the erosion of an anticline of younger rocks. The deposits are veined, having a maximum width of five feet. The ore consists of skutterudite with small amounts of cobaltite, niccolite and gold in a gangue of carbonate and quartz.

Gravity concentrates, averaging 12% cobalt and 2% nickel, are exported. Concentrates were smelted in Canada from 1948 by Deloro Smelting and Refining Company, Limited, nickel being recovered in oxide form. Since the end of this marketing arrangement increasing amounts have been shipped to the nickel-cobalt refinery of Société D'Électrochimie D'Électrométallurgie et des Aciéries Électriques D'Ugine at Pomblière Saint Marcel, Savoie, France. Lesser amounts are shipped to Belgium, Luxembourg, West Germany and in 1960, 4,000 tons of concentrate was exported to China.

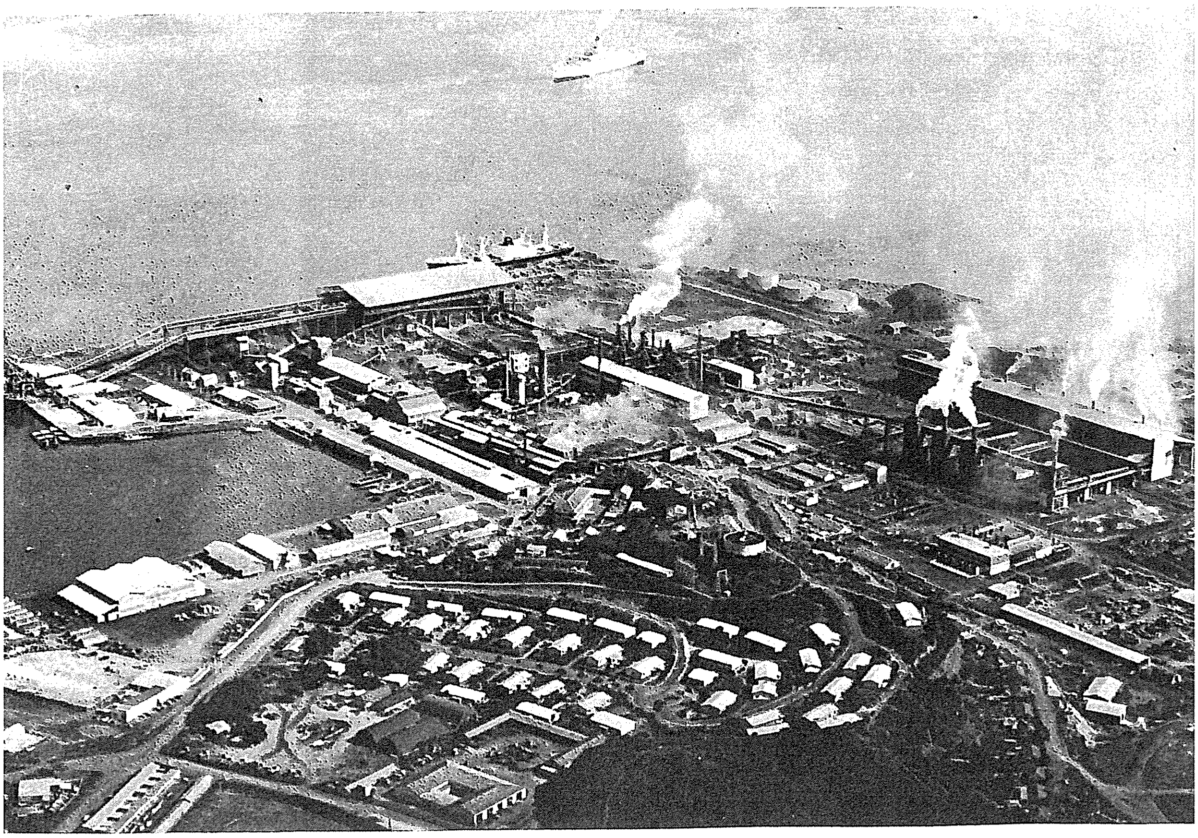
NEW CALEDONIA

Nickel was discovered on New Caledonia in 1865 by Garnier, but the economic development of the deposits did not begin until 1875. In 1876-77 some 8,000 tons of ore grading 8 to 10% nickel was shipped to France. New Caledonia was the world's leading producer of nickel from 1884 until surpassed by Canada in 1905(68, p.234). Annual nickel output varied between 3,000 and 12,000 tons until the 1950s when capacity was greatly expanded. In 1965, ores mined contained 63,500 tons of nickel(3).

The New Caledonian ore is a hydrated silicate of iron and magnesia formed by the tropical weathering of serpentinized peridotite of tertiary age. Nickel has replaced a portion of the iron and magnesia. The 6- to 40-foot blankets of nickel laterite are scattered beneath the higher plateaus of the island and are overlain by 10 to 30 feet of overburden that must be stripped before the ore can be mined by open-pit methods. Attempts to beneficiate the ore have been unsuccessful and it must be treated metallurgically. The ore is highly refractory and requires high temperatures to smelt.

FIGURE 80 Thio mine, Société Le Nickel.

FIGURE 81. Doniambo smelter, Société Le Nickel.



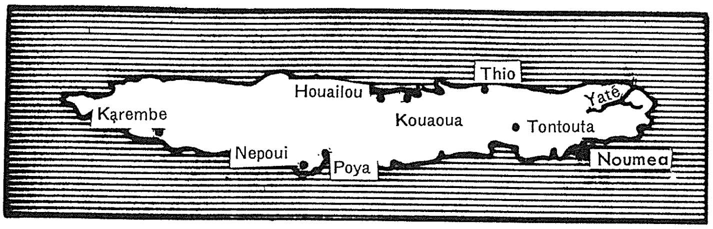


FIGURE 82. New Caledonia.

Published information concerning New Caledonian nickel resources is out of date. A 1955 estimate placed reserves at 12.6 million tons averaging 3.9% nickel and potential reserves at 1,400 million tons averaging 1.1% nickel(24). However, since that time more efficient processing and increased prices have lowered the economic cut-off grade and deposits with average grades as low as 2.6% were being exploited in 1965. Present reserves are, therefore, in all probability, very large.

Nickel ore averaging 3.0% nickel is mined on the island by some 15 companies. About two-thirds of the mine production is accounted for by the French firm, Société Le Nickel. Le Nickel's most important mines are Plateau Supérieur, Toumourou-Plateau Inférieur and Bornets in the Thio district, and at Kouaoua and Poro. Other important deposits are in Karembe, Poya, Tontouta and Houailou districts(69). The bulk of the small operators' mine production is exported to Japan and these shipments are supplemented by Le Nickel when the small operators cannot meet Japanese requirements.

At Le Nickel's Doniambo metallurgical plant at Noumea, ore is either smelted into matte for subsequent refining or smelted to ferronickel in electric furnaces. In 1963, two new electric furnaces were installed. Power is generated from a thermal plant and from hydroelectric facilities on the Yaté River. The smelter produces ferronickel in grades ranging from 24 to 28% nickel and matte containing 77% nickel and 23% sulphur. The smelting and refining processes are described in Chapter 5.

Nickel Production – New Caledonia
(tons)

	1961	1962	1963	1964	1965
Ore mined (70)	2,546,000	1,607,000	2,129,000	2,840,000	2,869,000
Nickel content ore (3)	58,753	37,257	49,053	64,155	63,494
Nickel content: ferronickel (3)	14,731	6,070	9,154	14,649	17,157
Nickel content: matte (3)	13,209	10,859	15,590	14,657	17,431
Ore exported (70)	na	657,000	705,000	1,211,000	960,000

na Not available

Le Nickel mined 1.830 million metric tons of ore in 1965. The company was implementing the first phase of an expansion program that was designed to raise production capacity to 38,000 metric/tons of contained nickel by the end of 1966. Le Nickel's nickel deliveries for 1966 were reportedly 43,643 metric tons(71). The new mining centre at Poro started production in December 1965. The deposit averages 2.6% nickel. The ore is pelletized before shipment to the Doniambo works. A 30,000 kw addition to the thermal power plant facilitated the installation of a sixth electric furnace at Doniambo that started production in February 1966(72).

By 1969, Le Nickel plans to raise annual production capacity to 50,000 metric tons of nickel. This will entail opening a new mine and pellet plant at Nepoui on the west coast, and expanding furnace and handling facilities at Doniambo(73).

Le Nickel and Sherritt Gordon have established a joint pilot project at Sherritt Gordon's Fort Saskatchewan, Canada, works for the processing of nickel laterite on a commercial scale. Such a process would be applied to New Caledonian ores(74). Sherritt Gordon has a contract with Le Nickel for the purchase of an annual supply of 3,000 tons of nickel in matte form.

In 1965, it was announced that Kaiser Aluminum and Chemical Corporation, USA and Société Le Nickel had formed two new companies. One of the companies will construct and operate production facilities in New Caledonia. Production is scheduled for 1969. These facilities, to be managed by Le Nickel, will process nickel ores into ferronickel and other products. The second company plans to further refine some of the nickel products for sale in North America as well as to market ferronickel. Ownership in the two companies will be divided equally between the two participants(75).

The French government has decided to allow a second integrated nickel company, with minority foreign participation, to operate in New Caledonia. The announcement of December 1966 stated that in addition to the company's minority foreign interest, it would be capitalized by interests in France and in New Caledonia. The International Nickel Company of Canada, Limited, has been prominent among the foreign companies that have sought entry into New Caledonia(76).

Nickel products are New Caledonia's most important export and the island's economy is almost completely dependent on the nickel industry. France is the principal destination of nickel matte and ferronickel but Japan is becoming an increasingly important importer. Japan imported over 5,000 tons of nickel in matte form in 1964. Ferronickel sales to Japan increased from 62 tons in 1962 to more than 7,000 tons in 1964(77). Japan purchases virtually all of the nickel ore exported. The French government offers subventions on the import of New Caledonian ore into France but payments have only occurred in 1957, 1958 and 1963(69). In 1965, Le Nickel signed a four-year contract with mainland China for the delivery of 9,300 tons of New Caledonian nickel(77).

NORWAY

The demand for nickel that attended the development of the nickel-silver and electroplating industries in the early decades of the 19th century, stimulated the development of nickel mines in Norway. From 1848 to 1883 Norway was the world's leading nickel producer. In the mid-1870s, 15 mines and seven smelters were operating. The depressed prices that followed New Caledonian and later Canadian developments, forced the closure of most of these operations(78).

The Flaat mine was the most important Norwegian producer, located 65 kilometers up the Otra river from Kristiansand. Evje Nikkelverk operated the mine and a smelter that produced 40,000 tons of nickel from 1872 to 1945. A refinery at Kristiansand, completed in 1910 to process matte from the Evje smelter, was taken over by Falconbridge Nikkelverk A/S, a wholly owned subsidiary of the Canadian company in 1929, and has evolved into the present refinery(78).

Norway possesses a large hydroelectric potential that has enabled the country to become an important producer of refined metals from imported raw materials. The Kristiansand works refines Falconbridge's entire smelter output. The process is described in Chapter 5. The plant has an annual production capacity of 35,000 short tons of electrolytic nickel. An expansion program, in progress during 1967, was aimed at increasing capacity by about 30% by late 1968. Virtually all production is exported. Most of the output has traditionally been marketed in Europe but an endeavour is being made to market more nickel in the United States and Canada. In 1965, the United States received about one third of the shipments with Britain, West Germany and Sweden absorbing most of the balance.

Nickel Production – Norway(3)
(tons)

	1961	1962	1963	1964	1965
Nickel metal produced	35,505	32,190	29,123	33,191	35,092

PHILIPPINES

A very small amount of nickel-platinum concentrates containing 21 to 23% nickel were produced as a chromite processing by-product in the 1961-62 operation of Acoje Mining Company. The production was shipped to Japan. However, because of metallurgical difficulties encountered in the final separation of the metals the shipments were stopped(79).

Nickel in enormous quantities may still be tapped from the extensive nickel-iron laterite deposits in Surigao province, Mindanao. The high nickel concentrations are found near the base of the lateritic mantles in contact with the underlying partially weathered serpentine. Similar occurrences are noted in the Pujada peninsula, Davao, Samar, and Zambales region.

The substantially explored Surigao Mineral Reservation has for practical purposes been divided into four parcels. Estimated reserves for the four parcels are as follows:(80)

	Tons ('000)	Nickel (%)
Indicated Ore		
Laterite – Parcel I	375,000	0.88
Parcel II	143,000	0.93
Total	518,000	0.89
Decomposed		
Serpentine – Parcel I	149,000	1.23
Parcel II	14,400	1.70
Total	163,400	1.27
Inferred Ore		
Laterite – Parcel I	153,000	0.77
Parcels II and III	1,591,000	0.71
Parcel IV	314,000	0.50
Total	2,058,000	0.68

The production of ferronickel and iron from these deposits was pronounced technically feasible by the United States Bureau of Mines in a report issued in 1963. This conclusion was reached after a six-year series of laboratory and pilot-plant test on samples from Nonoc Island (part of Parcel II)(16).

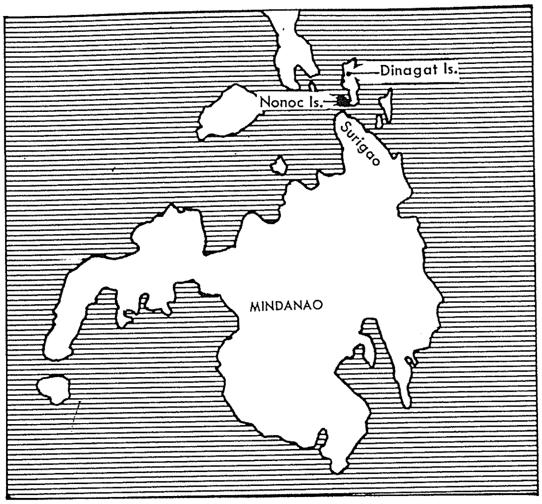


FIGURE 83. Philippines.

Although the development of these deposits has been contemplated by several firms over the last few years, the necessary capital outlay has not as yet been forthcoming. Passage of the amended nickel law in 1964 renewed interest in the development of the nickel deposits by encouraging the participation of foreign mining companies in a joint venture. It was reported in mid-1965 that Japan had been invited to invest in a joint Philippine-Japanese venture to exploit the Surigao deposits. The project called for a capital investment of $50 million of which the Japanese share was to have been 40% and the Philippines share 60%(81). Apparently this offer was rejected by the Japanese interests.

Since 1959, Sherritt Gordon Mines Limited and Marinduque Mining and Industrial Corporation, a Philippine company, have been jointly studying the application of Sherritt Gordon's processes and experience in nickel extraction to the recovery of nickel and cobalt from the lateritic ores in Parcel II of the Surigao Mineral Reservation.

The ore reserves, on Nonoc Island only, for a hydrometallurgical operation are as follows:(82,83)

	Tons ('000)	Nickel (%)
Iron ore (overburden)	35,300	0.72
Laterite	43,000	1.28
Weathered serpentine	19,800	1.48

In order to develop the nickel and other metallic resources of the Surigao Mineral Reservation, the Government called for tenders in February 1967 in Manila. Nine proposals from foreign and domestic firms were received. Two of the proposals, namely those from Marinduque using Sherritt Gordon's processes and a consortium of six Philippine investment groups (Phinma) with Société Le Nickel, were selected for detailed comparison(84,85). The Surigao Mineral Reservation Board, the government agency taking charge of the project, was evaluating these offers in mid-1967.

Marinduque's proposal is based on the ammonia pressure leach process, used at Sherritt Gordon's Fort Saskatchewan refinery and described in Chapter 5. The Phinma-Le Nickel proposal is based on the process being installed at Larymna, Greece.

POLAND

The Legnica metals combine produces small amounts of electrolytic nickel, presumably as a by-product from the copper ores mined in the district(30).

Nickel Content of Mine Production – Poland(3)
(tons)

		1961	1962	1963	1964*	1965*
Nickel content (mine production)	....	1,455	1,400	1,458	1,433	1,433

*Estimate

The known reserves of low-grade nickel silicate in Poland are unsuitable for smelting, but there are secondary reserves of nickel and cobalt in slag waste dumps in Silesia. Nickel content is about 0.25%. A large pilot-plant to test the slags was under construction in 1967.

RHODESIA

Nickel occurs in a number of localities in Rhodesia, the most important deposits being located in the lower Gwanda gold belt, in the northeast near Bindura and Shamva, and west of Gatooma in central Rhodesia. Production has been small and sporadic but there has been an increasing amount of development activity in recent years.

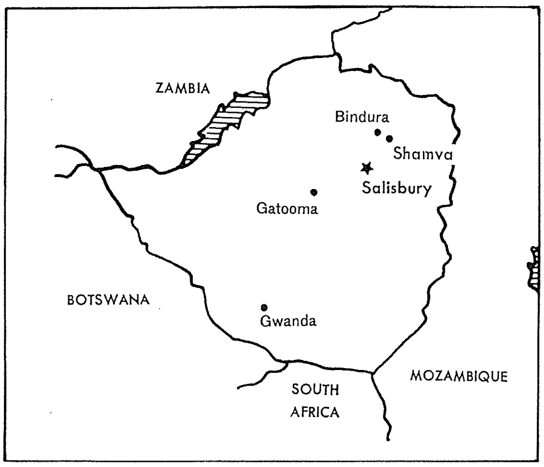


FIGURE 84. Rhodesia.

Nickel Content of Mine Production – Rhodesia(3)
(tons)

		1961	1962	1963	1964	1965*
Nickel content (mine production)	....	64	86	131	187	187

*Estimate

The Noel mine, in the Lower Gwanda gold belt, 85 miles south of Bulawayo, was discovered in 1928(86). The deposit occurs in a fault fissure in a serpentine belt. Nickel is present in the minerals niccolite and chloanthite which fill lenticular patches in the fissure. These patches seldom exceed 20 feet in length and 18 inches in width. Small amounts of high-grade hand-cobbed ore were produced from 1935 to 1939. The mine was reopened in the mid-1950s but closed at the end of 1957(87).

In 1961, there was a limited production of cobbed nickel-sulphide ore from a mine in the Shamva district, northeast of Salisbury, owned by Holdryhill Nickel Mining and Exploration Company (Pvt.)(35). In mid-1967 Anglo American Corporation of South Africa, Limited, had an option to examine the deposit owned by Shamva Nickel (Pvt.) Limited.

Rio Tinto (Rhodesia) has, during the last several years, spent £1 million exploring and developing its Empress nickel-copper deposit at Ngondamo, 45 miles west of Gatooma in central Rhodesia. Mineralization occurs as a segregation in gabbro. Indicated ore reserves are 16 million tons grading 0.83% nickel and 0.65% copper(35). In 1965, it was announced that the company planned to spend an additional £4 million to bring the mine to production by 1967(88).

The Trojan nickel property, discovered in 1957, is located south of the town of Bindura in northeastern Rhodesia. The Anglovaal Rhodesian Exploration Company carried out an extensive drilling program from 1960 to 1963. Following the expiration of their option, the government carried out a series of metallurgical tests on the ore. In April 1964, Trojan Nickel (Pvt.) Limited, was formed to bring the mine into production(89).

The mine was brought into production in 1965 at a rate of 130 tons of ore per day. The mill, capable of treating 4,500 tons of ore per month, obtained a 75% recovery, producing concentrate containing 15 to 18% nickel. The initial production rate was 300 tons of concentrate per month, all of which was sold under contract to an overseas consumer(90).

In 1966, Anglo American Corporation of South Africa purchased an 85% interest in Trojan Nickel and assumed management of the mine.

A major mine development program has been initiated. The orebodies are tabular ultrabasics occurring in a serpentine body. There are three known orebodies referred to as the hanging wall, main and footwall bodies. The first two contain most of the reserves; it is proposed to mine them by the blast-hole method. The footwall deposit does not exceed 20 feet in width and may be mined by an open underhand stoping method(91). Mineralization consists of an intimate intergrowth of magnetite and pyrrhotite, pentlandite forming a fine intergrowth with the latter. Drilling has indicated reserves of 7 million tons averaging 1.0% nickel(91).

An 1,800 ton per day flotation mill was being constructed in 1966. Large scale production of concentrates was scheduled to begin by mid-1968. In the meantime, the existing mine and treatment plant were to be operated at capacity to fulfil outstanding contracts. The new mill will treat 350,000 tons of ore for each of the first two years of operation and 600,000 tons per year thereafter. Flotation is expected to produce a 10 to 15% nickel concentrate. There are tentative plans for smelting the concentrate to a 65% nickel matte followed by electrolytic refining or the production of ferronickel(91).

SOUTH AFRICA

Although nickel bearing deposits are widespread in the Republic of South Africa, the only current production of nickel is as a by-product from platinum mining at Rustenburg in the western Transvaal. Other areas of economic interest are the Pilandsberg deposits northwest of Rustenburg, and the Insizwa copper-nickel deposits in the eastern Cape.

Nickel Content of Mine Production – South Africa(92)
(tons)

	1961	1962	1963	1964	1965
Nickel content (mine production)	3,140	2,760	3,310	4,410	5,730

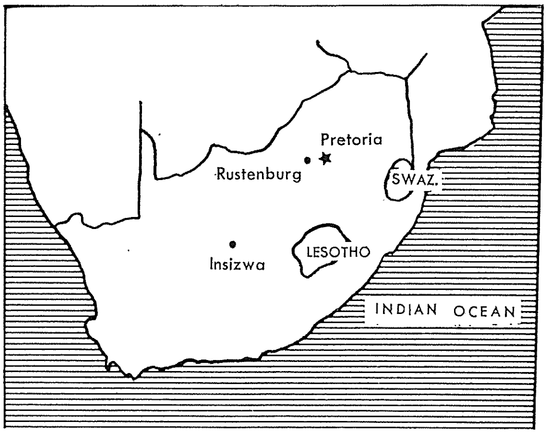


FIGURE 85. South Africa.

Rustenburg

In 1925, the platinum reefs, known as the Merensky Reef Horizon of the Bushveld Igneous Complex, were discovered. Within a short time several mines were brought into production but during a period of depressed prices all but two were forced to close. These two companies merged in 1932 to form Rustenburg Platinum Mines, Limited. In 1947, the Union Platinum Mining Company was formed to mine the Merensky Reef Horizon some 60 miles north of Rustenburg. This company was absorbed in 1949 and now forms the Union Section of Rustenburg Platinum Mines.

Platinum, nickel and copper values occur in chromite segregations, known as the Merensky Reef, in the lower part of the differentiated norite zone of the Bushveld Complex. The zone has been traced for scores of miles but in only a few places is the mineralization sufficiently concentrated to constitute ore. The ore band is about 12 inches thick and averages 0.25 ounces of platinum per ton over a 30-inch mining width. Nickel occurs as pentlandite, millerite and nickeliferous pyrite, averaging 0.27%. Reserves are large.

Both nickel and copper are recovered as by-products. In the mill, a high-platinum gravity concentrate is recovered from corduroy tables and sent directly to the refinery. The tailings from the tables are thickened and dispatched to the flotation plant. Concentrates are dried and pelletized in Lurgi pelletizing pans. The pellets are smelted in blast furnaces and the resulting matte is blown in converters. The white metal is poured into moulds, solidified, crushed, bagged and shipped to the refinery. The matte contains about 75% combined nickel-copper. Part of the matte is locally treated by Matte Smelters (Pty.) Limited, jointly owned by Rustenburg and Johnson, Matthey and Company, resulting in an enriched platinum-bearing product and a nickel matte. These products, together with gravity concentrate and crushed matte, are shipped to Johnson, Matthey and Company Limited, London, for refining and selling. At the refinery, matte is treated by the classical Orford "tops and bottoms" process. The nickel-sulphide bottoms are roasted to nickel oxide, reduced to metallic nickel in a reverberatory furnace and electrolytically refined. The tankhouse slimes, the gravity concentrate and the enriched platinum-bearing product are treated for the separation of platinum metals.

Increased by-product production of nickel can be expected as Rustenburg Platinum Mines has been implementing a large expansion program scheduled for completion by the end of 1969. Brakspruit Platinum Mine, owner of an adjacent property at Rustenburg, began production in 1965 under a tribute agreement with Rustenburg(93). It is estimated that by-product nickel production from the Rustenburg mines will reach 11,000 tons per year by 1969. The domestic nickel market in South Africa is expected to increase to 9,400 tons per year by 1969.

Pilandsberg

The Pilandsberg (Vlakfontein) deposits, 40 miles northwest of Rustenburg, occur in hortenolite dunite pipes that are differentiates of the Bushveld Complex. The pipes are vertical, up to 60 feet in diameter and as much as 1,000 feet deep and are distributed over a wide area. The pipes grade from disseminated ore at the margin to massive sulphides in the centre, the principal minerals being pyrrhotite, pentlandite and chalcopyrite(94).

The South African Minerals Corporation, a subsidiary of the Johannesburg Consolidated Investment Company, developed a nickel-copper mine in the Pilandsberg area at a cost of $200,000 and small scale production of concentrate began in March 1963(95). The mine operated at a loss due to insufficient and erratic mineralization and high exploration and mining costs(96). It was therefore announced in May 1965 that the company was suspending operations. Concentrate was shipped to Sherritt Gordon's refinery at Fort Saskatchewan, Canada.

In 1962, Kashane Exploration Company was formed by South African Minerals, Anglo American Corporation, and The International Nickel Company of Canada. The company acquired four-year rights to prospect an area of 140 square miles in the Pilandsberg area(95). It was announced in 1965 that exploration work would be terminated.

Insizwa

The Insizwa nickel-copper deposits are in Griqualand, eastern Cape province. The deposits are associated with a massive sheet of dolerite with the mineralized zone occurring along the lower contact of the sheet. The deposit is an example of immiscible liquid segregation(97).

In the past, geophysical surveys and diamond drilling indicated fairly wide zones of disseminated sulphides but the values were too low to warrant economic mining. Border Exploration and Development Company (Pty.), a joint venture of Anglo American Corporation and The International Nickel Company of Canada, formed to explore the Insizwa deposits, completed most of its surface investigations during 1962. Subsequently, the company sank several boreholes to 400 feet but found nothing of economic interest(95).

USSR

Production of nickel in the USSR dates back to August 1933 when the first nickel smelter at Ufaley began treating local nickel silicates. In 1936, the Rezhskiy plant at Ufaley was completed. Soviet output increased from 863 metric tons in 1934 to 2,000 metric tons in 1937. In October 1938, the Severonikel plant at Monchegorsk in the Kola Peninsula, began production with an annual capacity of 2,500 metric tons. The ore was obtained from the nickel-copper-cobalt mines at Nittis-Kumuzh'ye.

FIGURE 86. USSR.

At the beginning of World War II, the Orsk (Yuzhuralnikel) and Noril'sk plants were in operation. The Orsk plant processed nickel silicate ores from Orsk, Kimpersayskiy and Khalilovo. The Noril'sk operation was based upon a low-grade copper-nickel-cobalt ore containing platinum metals. The Monchegorsk plant was severely damaged and put out of operation during the war and the Orsk and Noril'sk plants were expanded to absorb this loss in production. The Monchegorsk plant was rebuilt after the war(98).

The Petsamo deposit, reported to average 1.61% nickel and 1.32% copper, was ceded to the USSR in 1944 under the terms of an armistice between the USSR and Finland. The Mond Nickel Company, which had developed the deposit, received a settlement of $20 million from the Soviet government(34, p. 244). The USSR has renamed the minesite Nikel and the site of the smelter, Pechenga.

The development of the nickel-cobalt industry has always attracted particular attention on the part of the Government of the USSR. It is estimated that the objectives of the 1959-65 seven-year plan have been met, because of the increase in production of nickel from 58,000 tons in 1958 to about 99,000 tons in 1965. The past seven years was a period of reconstruction for the Soviet nickel industry. Recoveries of metal were greatly improved in all plants. At present the Soviet Union is the only country that produces nickel from both sulphide and silicate deposits. The current five-year plan from 1966 to 1970, provides for a "substantial" increase in production.

Nickel Production – USSR(99)
(tons)

	1961	1962	1963	1964	1965
Nickel production	82,700	88,200	88,200	93,700	99,200

Monchegorsk

The Sevronikel combine at Monchegorsk is 100 miles south of Murmansk in the Kola peninsula of northwest Russia.

The metallurgical plant was initially designed to treat the low-grade disseminated copper-nickel sulphide deposits of "Sopcha". Subsequently, high-grade nickel-copper sulphide ores at Nittis-Kumuzh'ye were developed and mined by underground methods. More recently, the Monchegorsk plant began treating concentrates from a large open-pit mine and mill at Zhdanov(100). The plant also processes matte from the Pechenga smelter(101).

Nickel concentrates are smelted in electric furnaces. The matte flotation process has been adopted; matte concentrate is cast into anodes and electrolytically refined(100). In 1958, plant capacity was reported to be 6,000 metric tons of nickel per year(102) but since that time capacity has been considerably increased(103, 104).

Pechenga

Pechenga is on the Barents Sea, in the Kola peninsula of northwest Russia.

The "Petsamo" deposit at Nikel is associated with a basic magmatic intrusive, apparently of Precambrian age. The dominant mineral is pentlandite with a lesser concentration of chalcopyrite and minor amounts of cobaltite and platinum metals(98). Both open-pit and underground methods are used(100).

Nickel concentrates are smelted in electric furnaces. The converter matte so produced is sent to the Monchegorsk plant for further processing(105). In 1958, smelter capacity was reported to be 13,000 metric tons of nickel per year(102) but since that time capacity has been increased. An additional electric smelter was installed in the early part of the 1959-65 seven-year plan and a new ore-dressing plant has been placed in operation(81).

Noril'sk

Noril'sk is in the arctic region of north central Russia, beyond the 69th parallel.

The Noril'sk deposits are associated with an intrusion into limestone, sandstone and shale. The characteristic ores are massive or disseminated sulphides in contact zones. Mineralization consists of pyrrhotite, chalcopyrite, pentlandite and pyrite. Ores have been reported to average 0.47% copper, 0.31% nickel, and two grams of platinum metals, mostly palladium, per metric ton(98). There are several deposits the most important of which are Noril'sk I, which is reported to contain reserves sufficient for 90 years production, and Talnakhskoe, in the same general area, discovered in 1962.

Nickel concentrates are smelted in electric furnaces. Matte flotation is followed by electrolytic refining(103). The Noril'sk combine started production of high-purity nickel in 1962. Before that time, high-purity nickel was only produced at Orsk.

In 1958, capacity of the Noril'sk combine was 5,000 metric tons of nickel per year. It was planned to increase ore extraction more than 300 per cent during the 1959-65 seven-year plan(106). This target was apparently achieved in 1962(81). Noril'sk is probably the largest nickel combine in the Soviet Union.

Following the development of large new nickel-copper sulphide deposits at Talnakh, near the Kharaelakh Mountains, Taimyr Peninsula, in 1964-65, the Noril'sk combine was being further expanded. A new mine, to be known as Mayak, was to begin production in 1965(107).

Verkhnii Ufaley

Verkhnii Ufaley is in the central Urals, west of the railway between Sverdlousk and Chelyabinsk.

Low-grade nickel silicate laterites, containing 0.7 to 2% nickel, are mined in open pits. Deposits occur at Ufaley, Murzinsk, Revda, Uktus, Rezh and elsewhere. Processing comprises the following stages: briquetting, shaft smelting, conversion, multi-hearth roasting, and smelting to ferronickel in electric furnaces(100, 108). The plant was reconstructed and expanded during the 1959-65 seven-year plan. The briquetting process was modernized and new horizontal converters were installed. Electric furnaces were installed to recover cobalt from converter slags(101). In 1958, plant capacity was 2,000 metric tons of nickel per year, in ferronickel form.

Orsk

The Yuzhuralnikel combine at Orsk is in the southern Urals, north of the Kazakh border.

The nickel silicate laterites, formed by the weathering of serpentine, average 1.5% nickel. There are both residual and fissure type deposits; the latter are usually higher grade. Important mines are at Khalilovo, Aktyubinsk, Novo Akkerman, Buranovo-Shelekta, Aidyrla, Kimperaysk, Batamshinsk and Tavtenkentsk(98, p. 79).

Processing comprises agglomeration, shaft smelting under high draft pressure, conversion, multi-hearth roasting and smelting to ferronickel in electric furnaces. Cathode nickel is also produced(100). During the 1959-65 seven-year plan, shaft furnaces were reconstructed and electric furnaces for the recovery of cobalt from converter slags were installed(101). In 1958, plant capacity was 12,000 metric tons of nickel per year(102).

New Developments

A large, new nickel-cobalt combine was under construction in February 1967 at Buruktal in Orenburg Oblast in southeast Russia.

In the northern Urals production was anticipated from reportedly large nickel deposits discovered between Serov and Severo-Uralsk(110).

In the Ukraine, a nickel concentrator was being constructed for low-grade ores. It was to be commissioned in 1965(81).

Trade

Soviet trade statistics in nickel are mainly included in a "non-ferrous metals and alloys" category and are thus obscured. Those directly published are summarized below:(111)

Nickel Trade – USSR
(tons)

	Nickel Metal and Alloys			
	Imports		Exports	
	1963	1964	1963	1964
France	3,307	–	–	–
Czechoslovakia	–	–	3,086	1,874
East Germany	–	–	2,315	2,646
Mainland China	–	–	1,258	1,205

– Nil

In addition, the statistics show that the USSR imported from Cuba, in 1964, 26,438 metric tons of "metallic ores and concentrates". The corresponding figure for 1963 was 20,004 metric tons. It may be surmised that these figures largely comprise imports of nickel-sulphide concentrates and nickel-oxide powder.

Before 1962, Canada exported substantial quantities of nickel products to the Soviet Union and communist bloc countries. Since then, Cuba has displaced Canadian trade in this commodity. This is evident from the following table of Canadian export statistics (112).

In 1958, the Soviet Union had, or had anticipated, a shortage of nickel. The need was stressed for economy in the consumption of nickel and cobalt through substitution by chromium, molybdenum and boron, and the elimination of nickel and cobalt from non-essential alloys. Currently, however, there are indications that the shortage of nickel is over, mainly as a result of very favourable developments in the USSR, where a large expansion in capacity has been achieved and substantial new reserves developed.

Canadian Exports
(tons)

	1959	1960	1961	1962	1963	1964	1965
Nickel Oxide							
Czechoslovakia	–	138	–	–	–	–	–
Nickel and Alloys							
USSR	952	4,198	1,117	–	–	–	–
Czechoslovakia	2,546	3,151	572	–	–	–	–
Roumania	–	49	123	–	–	125	–
Hungary	439	420	–	–	–	–	–
Mainland China	112	582	–	–	–	–	–
Total	4,049	8,538	1,812	–	–	125	–

Furthermore, with large nickel supplies now available to communist bloc countries from Cuba, there appears to be an actual surplus of nickel. Soviet stockpiling needs must have been, at least temporarily, met since considerable quantities of nickel were released in 1965 and 1966 to non-communist markets mainly in Europe.

UNITED STATES

Nineteenth century activity in the mining and smelting of nickel was centred in Connecticut, Missouri and Pennsylvania(113). The most important early United States nickel mine, located at Lancaster Gap, Pennsylvania, was worked initially for copper but from 1853 to 1893 nickel was also recovered, the mine being for a time the principal nickel producer in North America(114). Joseph Wharton's nickel refinery at Camden, New Jersey, that treated ores from the Gap mine and elsewhere by a chemical process, was sold to the Orford Copper Company in 1902 and, subsequently, closed.

The Orford Copper Company began experimenting with Sudbury nickel matte in 1887 and on developing the "tops and bottoms" process in 1891, began nickel refining on a large scale at Bayonne, New Jersey. The Bayonne works refined matte produced by the Canadian Copper Company and its successor The International Nickel Company. In 1921, the Bayonne refinery was closed.

United States mine production of nickel in the present century has been sporadic. From 1953 to 1958, Calera Mining Company recovered a small amount of nickel as a by-product from cobalt mining operations in Idaho(115). From 1955 to 1961, the National Lead Company recovered a pyrite concentrate containing cobalt and nickel from lead ores in southern Missouri. Nickel was recovered from the concentrate at the company's refinery at Frederickstown, Missouri(116).

In 1956, the United States re-entered the field of refining metallic nickel for the first time since the closing of the Bayonne Works. The refinery, operated by a subsidiary of the National Lead Company at Crum Lynne, Pennsylvania, converted nickel-oxide sinter from Nicaro, Cuba, to metallic nickel pig(117). The refinery had a capacity of 7,000 tons of nickel per annum and operated under government contract until terminating operations in 1958.

In the 1950s, the Freeport Sulphur Company built a refinery at Port Nickel, Louisiana, to treat nickel-sulphide concentrate from Moa Bay, Cuba. The refinery operated for a short period in 1960 but closed when Cuba nationalized its raw material supply.

The Hanna Mining Company operates a nickel silicate mine at Riddle, Oregon, and since it began production in 1954, it has accounted for the major share of domestic mine output. Hanna Nickel Smelting Company processes the ore to ferronickel by the Ugine Process described in Chapter 5.

Several refineries recover small amounts of nickel in the form of sulphate as a by-product of copper refining. Refined nickel salts are also produced in the United States.

In September 1965, it was announced that Kaiser Aluminum and Chemical Corporation and Société Le Nickel of France had formed two companies for the production of nickel products and their sale in North America. One company will process nickel-bearing ores into ferronickel and matte products in New Caledonia. The United States company, Kaiser Nickel Company, will further refine matte to refined nickel for sale in North America as well as market New Caledonian ferronickel. Initial capital requirements are estimated at $40 million, with ownership equally divided(118).

The International Nickel Company of Canada, Limited, through its wholly owned United States subsidiary, The International Nickel Company, Incorporated, operates a large nickel alloy rolling mill at Huntington, West Virginia. Installation of a new rolling mill unit and forging press was completed in 1964. Further installations for the production of sheet and strip were completed in 1965 and 1966.

In 1966, International Nickel was granted mining leases in the Duluth gabbro complex, near Ely, Minnesota. Chalcopyrite, cubanite, pyrite, pentlandite and bornite are disseminated in layers and lenses for five miles along the base of the gabbro lopolith where it is thickest. Deposits containing several hundred million tons of material averaging 0.25% nickel and 0.75% copper are reported(114). Preliminary exploration was carried out by International Nickel in the 1950s. Further investigation and evaluation is in progress to determine the overall feasibility of the project. It was announced in 1967 that International Nickel had let a contract for the sinking of a 1,095-foot exploration shaft, 10 miles southeast of Ely. It is expected to take about a year to complete. If preliminary findings are confirmed the company intends to put the properties into production. An annual output of 62,500 tons of copper and nickel is anticipated(119, 120).

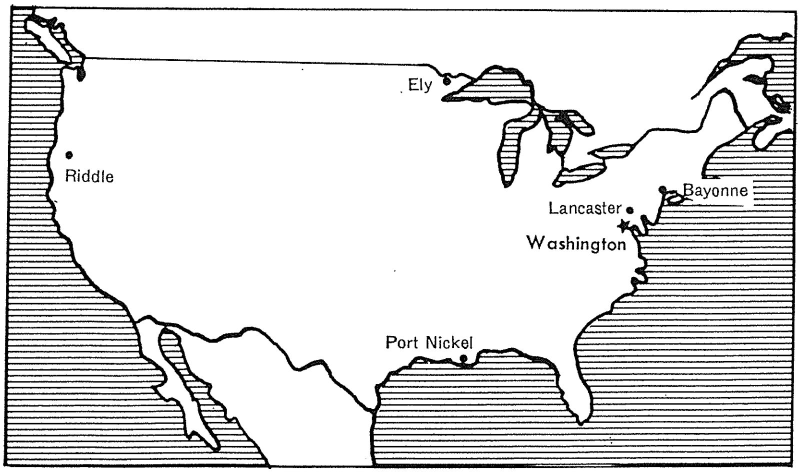


FIGURE 87. United States.

Nickel Production – United States (121)
(tons)

	1961	1962	1963	1964	1965
Mine production	13,133	13,110	13,394	15,420	16,188
Plant production:					
primary	11,176	11,217	11,432	12,185	13,510
secondary	10,688	11,108	18,996	23,114	19,407

Riddle, Oregon

A garnierite deposit near Riddle, Oregon, was discovered in 1864. The Freeport Sulphur Company leased the deposit and carried out extensive exploration work in 1942 and 1943. The company subsequently relinquished the lease which was taken up by the Hanna Mining Company in 1948. Production began in 1954(122).

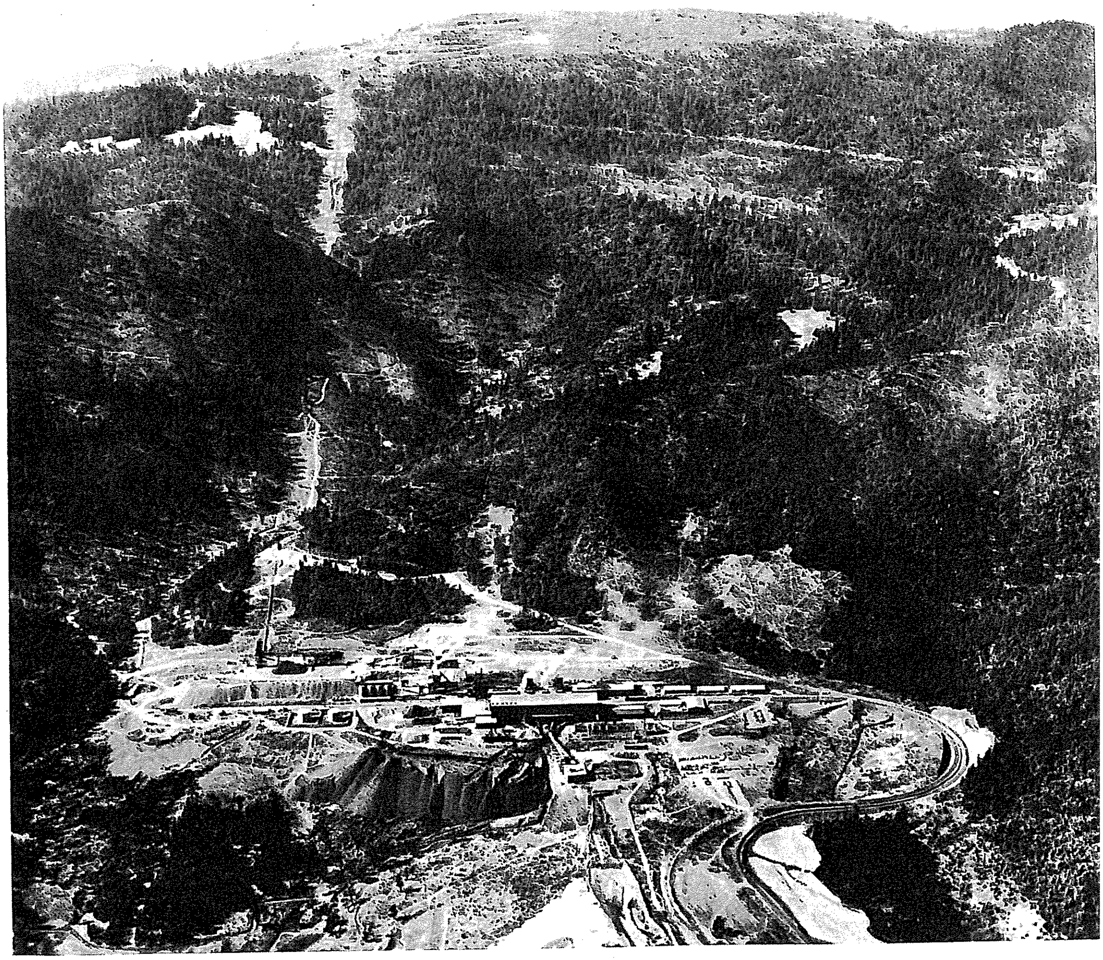


FIGURE 88. Mine site and smelter, Hanna Mining Company, Riddle, Oregon.

The deposit is four miles northwest of the town of Riddle at elevations of 3,000 to 3,500 feet above sea level, in the Coast Range, some 60 miles inland from the Pacific Ocean. The nickel silicate is contained in a layered blanket which rests upon unserpentinized peridotite. The blanket consists of three layers: a top brick-red soil layer, an intermediate thick yellow limonitic layer containing some quartz-garnierite box work, and fresh peridotite. Nickel occurs in all three layers of the blanket but is most abundant in the box-work veins carrying garnierite. The nickel is believed to have been derived from olivine in the peridotite by decomposition during lateritic weathering. The orebody is roughly 3,000 by 6,000 feet with an average depth of about 60 feet. In 1965, reserves were estimated to total 16.2 million tons averaging 1.5% nickel(114).

The ore is mined at the rate of 5,000 tons per day by an open-pit method. Broken ore is screened, crushed, and transported to the smelter by an aerial tramway. The critical problem of the mining operation is to maintain a 1.5% nickel smelter feed(122).

Ferronickel is produced at the smelter by the Ugine Process (described in Chapter 5). Production capacity was increased in 1964 from 11,000 to 13,000 tons of nickel per year. Alloy containing more than 50% nickel is made for export, but the average is held to 48% to minimize the loss of metal in the slag. The entire ferronickel production was under contract to the United States government until 1960. In 1961, sales were made to industry as well as to the United States government. Since 1962, all sales have been made commercially.

Government Stockpile

United States government stockpile inventories have been accumulated under Public Law 117 (1939) and its successor Public Law 520 (1946) as amended. The objective was to accumulate strategic materials to prevent dependence on foreign supply in times of national emergency. Materials were at first accumulated on the basis of a five-year mobilization period but in 1958 this was reduced to a three-year period(123).

The nickel stockpile currently consists primarily of cathode nickel, with significant amounts of nickel in briquette and nickel-oxide powder forms. At June 30, 1964, stockpile inventories totalled 219,278 tons of nickel. Of the total 50,000 tons was considered essential, the remaining 169,278 tons being declared surplus(124). Subsequently, during a period of tight supply, large quantities of government surplus nickel were marketed, particularly between November 1965 and June 1966. By October 1966, the stockpile had been reduced to 101,491 tons of nickel(125) of which 39,241 tons had been allocated(126). At that time government authorization was obtained for allocating of the remaining 12,250 tons of surplus nickel. It was stipulated that the surplus was to be allocated primarily to those holding government defense contracts with a lesser quantity allotted primarily to "hardship" non-defense consumers. The hardship allocation had been distributed by the end of January 1967 and the remaining surplus nickel was distributed during March 1967.

On January 13, 1967, the Office of Emergency Planning reduced the nickel stockpile objective to 20,000 tons leaving a surplus of 30,000 tons. If sale is authorized by Congress, this surplus nickel would be made available to industry.

VENEZUELA

Extensive deposits of nickel laterite occur in Venezuela in the Cordillera de la Costa. Three deposits are known: the Tocugito, Tinaguillo, and the Loma de Hierro. Only the latter has been extensively studied.

The International Nickel Company of Canada, Limited, through its subsidiary Compania Meridional de Minas S.A., explored over a period of several years the Loma de Hierro deposits, 20 km south of Tejerias on the state border between Aragua and Miranda. In 1964, the Venezuelan Supreme Court upheld a decision to revoke the mining concessions held by that company on the grounds that the deposits were not being exploited in accordance with the law(127). In 1965, the Venezuelan government announced that deposits of 58.4 million tons, grading 1.1% nickel had been discovered in the Loma de Hierro region(128). In February 1967, it was reported that the French nickel producer, Société Le Nickel, was continuing negotiations with the government on the possibility of developing these deposits(129).

WEST GERMANY

There are no nickel mines in the Federal Republic of Germany. However until 1964, there were four nickel refineries with a total capacity of 8,500 metric tons per year. The two biggest plants, however, i.e., the refinery of the Badische Anilin und Sodafabrik (BASF) in Ludwigshafen and the refinery of H.C. Starck in Goslar were closed. In 1966, only two firms produced nickel: Norddeutsche Affinerie, Hamburg, 86 tons; and Werner Meis, Solingen, 265 tons(130).

The Norddeutsche Affinerie's raw material is residue from the melting and electrolytic processing of copper and lead. These residues are, if necessary, treated chemically several times to produce electrolytic nickel.

Nickel Production – West Germany (3)
(tons)

	1961	1962	1963	1964	1965	1966
Refined nickel production	3,308	3,553	2,133	839	336	351

The production of metallurgical nickel within the Federal Republic of Germany, amounting to about 8,500 metric tons in 1938 and to about 3,000 metric tons per year from 1960 to 1962, has been drastically reduced. On the other hand, nickel consumption has increased continuously. The importation of refined nickel which was somewhat reduced in the years from 1960 to 1963 because of higher imports of ferronickel has continuously increased since that time. The scarcity of nickel in the Federal Republic of Germany during 1967 was particularly acute(130).

YUGOSLAVIA

Nickeliferous-iron-laterite deposits of economic importance have been discovered in the Kosmet region of southern Serbia, near Pristina. A preliminary estimate of ore reserves is 7.5 million tons averaging 1.36% nickel. Work was expected to begin late in 1967 to develop a mine and processing plant – the project estimated for completion by the end of 1970 at which time 3,500 metric tons of nickel would be produced annually. Currently, Yugoslavia imports all of its nickel requirements of approximately 600 tons per year and the opportunity to exploit this natural resource gives base to an estimate of domestic consumption of up to 1,500 tons early in the 1970s. This could still free more than 2,000 tons per year for export to European markets. Cost of the project is estimated to be $15 million(131).

CHAPTER 9

WORLD SUPPLY AND DEMAND

SUPPLY

In 1965, Canada accounted for 56% of the world's mine production of nickel. The other major producing countries are the USSR (19%) and New Caledonia (14%). World mine production of nickel from 1961 to 1965 is shown as Appendix H.

Canada is also the world's leading supplier of processed nickel; nickel in refined, ferronickel or oxide forms that is not processed further for industrial use.* In 1965, Canada produced 39% of the world's output of processed nickel. The other major producing countries are the USSR (20%), Britain (10%), Norway (8%) and Japan (7%). World production of processed nickel from 1961 to 1965 is shown as Appendix I.

The primary problem of the nickel industry in the period 1964-66 has been to increase productive capacity quickly enough to keep abreast of the growth in demand in all major nickel markets. Production in 1966 did not keep pace with consumption due to labour problems in Canada and New Caledonia, and more importantly, to heavy and fast-rising defense and civilian demands. The shortfall was met by drawing down inventories and by releases from the United States government stockpile. International Nickel, Falconbridge and Le Nickel have implemented large-scale development programs in their producing areas. However, the increased production capacity from these projects will probably not make a significant impact on supply conditions before 1968. Expectations are for another shortfall in production during 1967(1). Some relief may be obtained in the United States by authorization of further sales from the government stockpile but industry inventories are at low levels. There is also the probability of increased nickel sales by the USSR in Europe and Japan.

DEMAND

With the exception of the USSR, the major nickel consuming nations are almost entirely dependent on imports of nickel in semiprocessed** or processed forms. In 1965, the United States accounted for 37% of world nickel consumption. The other major consuming nations were the USSR (24%), Britain (10%), West Germany (7%), Japan (6%) and France (5%). World nickel consumption from 1961 to 1965 is shown as Appendix J.

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*Processed nickel includes nickel oxide that is used directly as a ferroalloy but excludes nickel oxide that is subsequently refined.

**Nickel that requires further processing for industrial usage; that is, ore, concentrate, matte or oxide forms, excluding that portion of nickel oxide production that is used directly as a ferroalloy. For any country, assuming no imports of semiprocessed forms: semiprocessed production = (mine production-processed production).

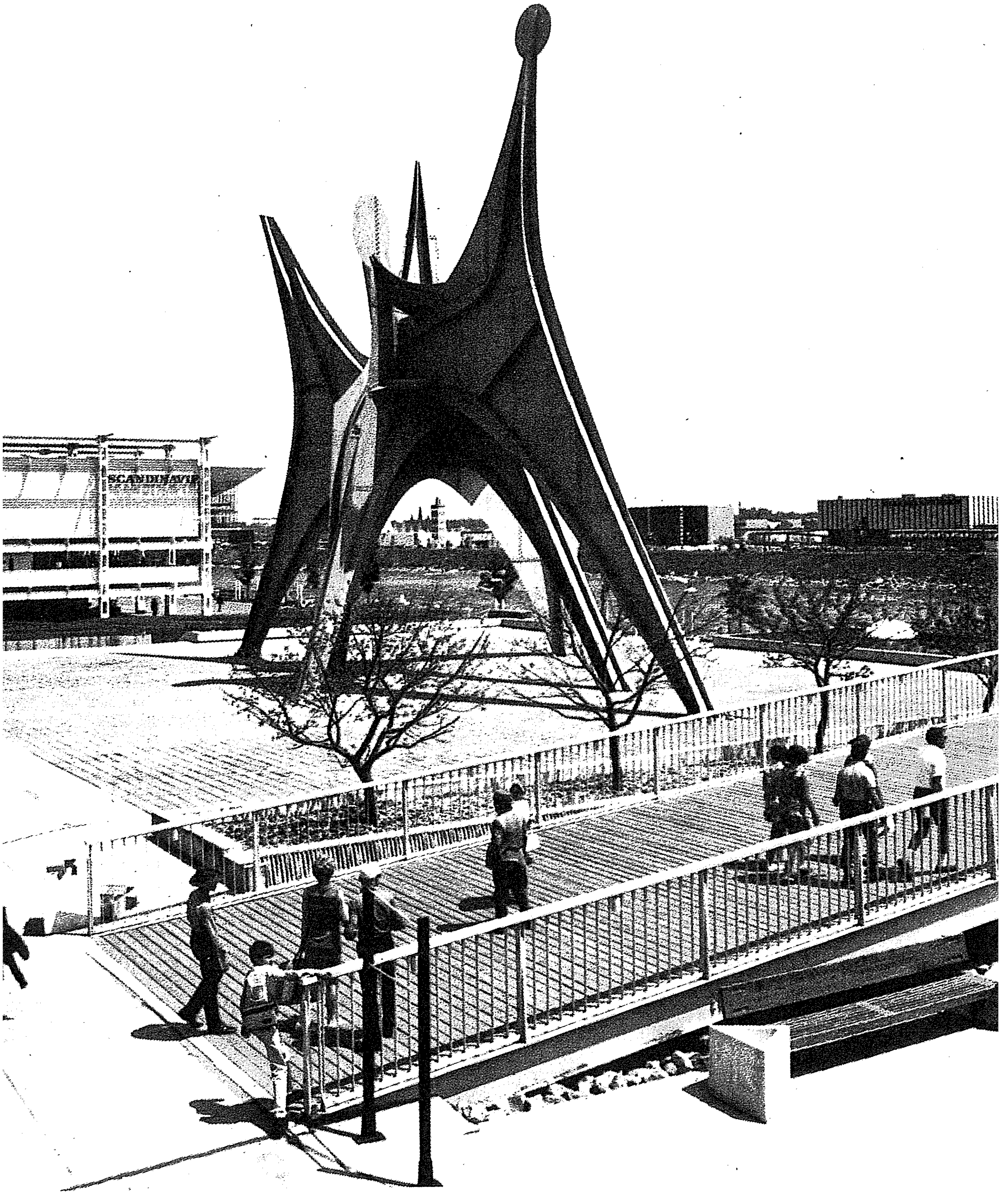

FIGURE 89. "Man" at Expo/67, a stainless steel stabile by Alexander Calder.

Heavier-than-expected demand for nickel in 1966 and the first half of 1967 was the result of fast-rising civilian demand, particularly for high nickel alloys, and United States defense needs created by the war in Vietnam. The extremely tight supply conditions have necessitated temporary rationing of supply by both the United States government and the integrated producers. Free market sales at very high prices have been reported. The United States government stockpile was reduced to its objective of 50,000 tons in March 1967. In January 1967, the stockpile objective was reduced to 20,000 tons leaving a surplus of 30,000 tons. If sale is authorized, this surplus nickel would be made available to industry.

Nickel's suitability as an alloying agent and its resistance to corrosion are the properties of primary advantage in almost all its uses. Stainless steel remains the largest single outlet for nickel followed by nickel plating and high nickel alloys (see Chapter 6).

TRADE

Canada is by far the most important factor in world trade in nickel, accounting for approximately two thirds of the non-communist world's exports of semiprocessed and processed nickel forms. Most of the rest of the export trade is carried on by Norway and Britain which rely almost entirely on Canadian semiprocessed forms. Nearly 80% of Canada's exports of processed nickel are to the United States. Most of the remaining United States processed nickel requirements are imported from Norway. In European and other markets outside North America, processed nickel from Britain and Norway often equal and sometimes exceed Canadian sales. New Caledonia is an important supplier of nickel, in matte and ferronickel forms, to both France and Japan. France is a smaller exporter of refined nickel. Appendices K and L show trading patterns in semiprocessed and processed nickel forms in 1965.

Although fabricated and semifabricated nickel and nickel alloys have not been explicitly considered in the above outlines of world supply and demand, it should be mentioned in passing that the non-communist countries with the most advanced metallurgical industries – the United States, Britain and West Germany – account for approximately three quarters of the trade in such forms as bar, sections, wire, plate, sheet and tube. The main destinations are other industrial countries. Canada and France, exporters of processed nickel, are net importers of fabricated and semifabricated nickel and nickel alloy forms.

PRICE

During the early 1950s, nickel was in short supply due primarily to United States government demands for the Korean War and for stockpiling. From 1951 to 1956, the producers price for refined nickel increased by approximately 30%. By 1957, the non-communist world's nickel output was 50% higher than in 1951 and United States government demand for nickel had eased. The producers price of nickel remained virtually constant for a period of four years beginning at the end of 1956. In 1961, there was a 10% price increase in refined nickel and in 1961-62 the Canadian price increased by an additional 10% due to devaluation of the Canadian dollar. The United States price was reduced by approximately 3% in 1962 but even at this price production had to be cut back in the latter part of the year(2, p.43). Demand strengthened in 1963 and even more markedly from 1964 to 1966 but no further price changes were made until the price was raised by about 7% toward the end of 1966.

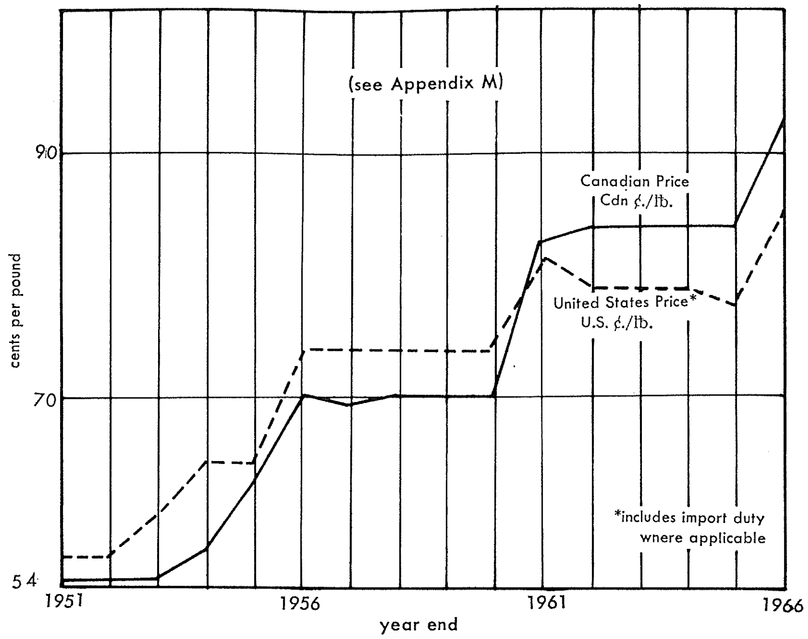

FIGURE 90. Refined nickel prices.

Appendix M lists Canadian and United States price trends for refined nickel from 1951 to 1967. Appendix N lists Canadian and United States price trends for nickel content in oxide sinter from 1962 to 1967. Price differences between countries for processed nickel forms appear small and seem to have moved along parallel lines(2, p.44).

TARIFFS

The following schedule of nickel tariffs on semiprocessed and processed nickel forms was in effect at the end of 1966(1,3). Expectations in mid-1967 were that these duties would be significantly reduced as a result of Kennedy Round G.A.T.T. negotiations. On June 30, 1967, it was announced that the United States' 1.25¢/lb tariff on unwrought nickel and nickel powders was to be removed.

	British Preferential (%)	Most Favoured Nation (%)	General (%)
Canada			
Nickel anodes	5	7 1/2	10
Nickel matte, scrap and concentrates	free	free	free
Nickel powder	free	free	free
Ferronickel	free	5	5
United States			
Ore, Matte, and oxide			free
Ferronickel			1.25¢/lb
Unwrought nickel			1.25¢/lb
Nickel powders			1.25¢/lb

	General (%)
European Economic Community	
Ferronickel	7% ad valorem
Other semiprocessed and processed nickel forms	free
Britain	
Ferronickel	10% ad valorem(4)
Other semiprocessed and processed nickel forms	not available
Japan	
Nickel ingots, blocks, anodes and shot	duty free quota (2,810 tons in 1966/67) (5). 25.2¢/lb on imports in excess of quota
Nickel ore, matte and speiss	free
Ferronickel	not available

FUTURE

Expectations are for a steady long-run growth in nickel demand. Traditionally, a major problem in the nickel industry has been depressed short-run demand resulting from the shifting between military and civilian needs. This problem has eased as a strong civilian demand for nickel has been developed. The sharp upsurge in non-communist world demand from 1963 to 1966, has resulted from the combination of a rapidly growing civilian demand to meet a number of modern technological requirements and a substantial military demand. During this period, non-communist world nickel demand increased by about 18% per year. It would seem improbable that this growth rate could be sustained in the long-run. Nevertheless, expectations are for a strong long-run growth rate for the nickel industry; a growth rate dependent on general economic conditions but levered by the aggressive product research and market development activities that have characterized the non-communist world's integrated nickel producers.

The United States accounts for approximately one-half of the non-communist world's nickel demand. An indication of long-run nickel growth expectations may be obtained from the following estimate of United States net domestic consumption of nickel for 1960 with projections for the years 1980 and 2000, made by Resources for the Future in the early 1960s(6, p. 306).

United States Net Domestic Nickel Consumption
(thousand tons)

1960	1965		1980	2000
118		Low projection	169	253
(108)*	(172)*	Medium projection	263	563
		High projection	394	1,142

* U.S.B.M. consumption figures; the 1960 RFF figure is higher largely due to the inclusion of nickel recovery from old scrap (6, p.893).

Interpolating between the 1960 figure and the 1980 projections, low, medium and high projections for 1965 were 130, 155 and 187 thousand tons respectively. The actual 1965 figure—172,000 tons—lies between the medium and high projections, indicating a higher than expected growth in demand from 1960 to 1965.

Fast-rising demand through the mid-1960s has spurred nickel research and development activities, and exploration efforts in many parts of the world to find new deposits. Early in 1967, it was estimated that new nickel mine capacity representing 130,000 tons of nickel per year was under construction in the non-communist world: 70,000 tons in Canada and 60,000 tons in New Caledonia, Australia, the United States, Rhodesia and Greece(7). The non-communist world's nickel production capacity is expected to double from 1966 to 1975.

As far as resources are concerned, it appears probable that the nickel industry will be able to cope with demand expectations for many years. While Canadian nickel resources are large and growing, appraisal of the laterite deposits is also critical to long-run judgment of nickel resource adequacy, for they constitute most of presently identified potential ore (see Chapter 2)*. These would include deposits in New Caledonia, Cuba, Guatemala, the Dominican Republic, the Philippines and Indonesia. New nickel-laterite developments depend in part, on further advances in processing technology particularly with respect to ore concentration and the recovery of by-products. The development decision for a given deposit is essentially economic, based on profit expectations and uncertainties. The problems of economic development for nickel-laterite deposits are frequently associated with price, grade of resource, transportation cost, and political and processing uncertainties. There are strong indications that in certain cases these problems are being surmounted; for example in the Philippines.

Future long-run developments will probably lessen the market dependence on Canada for nickel supply, but expectations are for a healthy growth rate in Canadian nickel output. Furthermore, the intergrated Canadian producers have been in the forefront with respect to the application of skilled and financial resources to the exploration for and development of nickel deposits around the world. Consequently, Canada's prominent position in the world nickel industry will continue for many years into the future.

*Manganese nodules from the sea floor can at this stage only be regarded as a potential nickel resource. Some nodules recovered have averaged more than 1.5% nickel(8, p.223).

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STATISTICAL APPENDICES

APPENDIX A

Canada–Nickel Reserves*

Company	Ore Reserves tons	Nickel Grade %	Nickel Content tons	Notes
International Nickel. . . .	324,870,000	1.6**	5,197,900	proven.
Falconbridge Mines	74,860,000	1.3**	973,200	proven + probable.
Sherritt Gordon Mines . .	11,400,000	0.84	95,800	
Metal Mines	1,088,000	1.38	15,000	proven, probable + indicated; Dec. 31, 1965.
Giant Mascot Mines. . . .	831,000	0.92	7,600	proven + probable; Sept. 30, 1966.
Marbridge Mines.	145,000	1.86	2,700	developed + indicated.
Lorraine Mining	210,000	0.57	1,200	
Kidd Copper Mines	772,000	0.62	4,800	at start of production, late 1966.
TOTAL	414,176,000	1.52	6,298,200	

* At December 31, 1966 except where noted.

** Estimate.

Note: see Chapter 7 for details.

APPENDIX B

Canada – Potential Nickel Ore*

Location	Company	Potential Ore tons	Grade % Nickel	Nickel Content tons
Belleterre, Quebec	Consolidated Regcourt Mines	2,200,000	0.67	14,700
Bird River, Manitoba	Maskwa Nickel Chrome Mines	1,210,000	1.23	14,900
Kluane Lake, Yukon	Hudson-Yukon Mining	740,000	2.04	15,100
	Canalask property	550,000	1.68	9,200
Limerick Township, Ontario	Macassa Gold Mines	2,000,000	1.0	20,000
Pardee Township, Ontario	Great Lakes Nickel	40,000,000	0.20	80,000
Populus Lake, Ontario	Kenbridge Nickel Mines	3,500,000	1.06	37,100
St. Stephen, New Brunswick	Atlantic Nickel Mines	3,500,000	0.70	24,500
Shebandowan Lake, Ontario	International Nickel	na	na	na
Sudbury, Ontario	Nickel Rim Mine	750,000	0.90	6,700
	Other	na	na	na
Thompson Nickel Belt, Manitoba	Estimated minimum nickel content for International Nickel's Birchtree, Soab, Pipe, Moak Lake, Mystery Lake and Hambone deposits and Falconbridge's Bowden Lake and Bucko deposits	na	na	4,400,000
	Other	na	na	na
Timmins, Ontario	McWatters Gold Mines	640,000	1.07	6,800
	Texmont Mines	5,300,000	1.0	53,000
Ungava, Quebec	New Quebec Raglan Mines	15,590,000	1.79**	278,300
Werner Lake, Ontario	Norpax Nickel Mines	1,010,000	1.2	12,100
TOTAL		76,990,000	0.74	572,400
		na	na	4,400,000
		na	na	4,972,400

*Estimated in early-1967.

**Katiniq reserves assumed to be of similar grade to Cross Lake reserves.

na Not available.

NOTES: (i) to the extent that resources data lies outside the public domain, individual estimates and totals are undervalued.

(ii) see Chapter 7 for details and references.

APPENDIX C

Canadian Production[1] of Nickel by Provinces
1889–1966

	Ontario	Manitoba	Quebec	B.C.	Other	Total (tons)
1889[2]	415	–	–	–	–	415
1890	718	–	–	–	–	718
1891	2,018	–	–	–	–	2,018
1892	1,207	–	–	–	–	1,207
1893	1,991	–	–	–	–	1,991
1894	2,454	–	–	–	–	2,454
1895	1,944	–	–	–	–	1,944
1896	1,699	–	–	–	–	1,699
1897	1,999	–	–	–	–	1,999
1898	2,759	–	–	–	–	2,759
1899	2,872	–	–	–	–	2,872
1900	3,540	–	–	–	–	3,540
1901	4,595	–	–	–	–	4,595
1902	5,347	–	–	–	–	5,347
1903	6,253	–	–	–	–	6,253
1904	5,274	–	–	–	–	5,274
1905	9,438	–	–	–	–	9,438
1906	10,745	–	–	–	–	10,745
1907	10,595	–	–	–	–	10,595
1908	9,572	–	–	–	–	9,572
1909	13,141	–	–	–	–	13,141
1910	18,636	–	–	–	–	18,636
1911	17,049	–	–	–	–	17,049
1912	22,421	–	–	–	–	22,421
1913	24,838	–	–	–	–	24,838
1914	22,759	–	–	–	–	22,759
1915	34,154	–	–	–	–	34,154
1916	41,479	–	–	–	–	41,479
1917	42,165	–	–	–	–	42,165
1918	46,254	–	–	–	–	46,254
1919	22,272	–	–	–	–	22,272
1920	30,668	–	–	–	–	30,668
1921	9,647	–	–	–	–	9,647
1922	8,799	–	–	–	–	8,799
1923	31,227	–	–	–	–	31,227
1924	34,768	–	–	–	–	34,768
1925	36,929	–	–	–	–	36,929
1926	32,857	–	–	–	–	32,857
1927	33,399	–	–	–	–	33,399
1928	48,378	–	–	–	–	48,378
1929	55,138	–	–	–	–	55,138
1930	51,884	–	–	–	–	51,884
1931	32,833	–	–	–	–	32,833
1932	15,164	–	–	–	–	15,164
1933	41,632	–	–	–	–	41,632
1934	64,344	–	–	–	–	64,344
1935	69,258	–	–	–	–	69,258
1936	84,870	–	–	–	–	84,870
1937	112,395	57	–	–	–	112,452
1938	105,286	–	–	–	–	105,286
1939	113,053	–	–	–	–	113,053

	Ontario	Manitoba	Quebec	B.C.	Other	Total (tons)
1940	122,779	–	–	–	–	122,779
1941	141,129	–	–	–	–	141,129
1942	142,606	–	–	–	–	142,606
1943	144,009	–	–	–	–	144,009
1944	137,299	–	–	–	–	137,299
1945	122,565	–	–	–	–	122,565
1946	96,062	–	–	–	–	96,062
1947	118,626	–	–	–	–	118,626
1948	131,740	–	–	–	–	131,740
1949	128,690	–	–	–	–	128,690
1950	123,659	–	–	–	–	123,659
1951	137,903	–	–	–	–	137,903
1952	140,559	–	–	–	–	140,559
1953	143,693	–	–	–	–	143,693
1954	158,010	3,269	–	–	–	161,279
1955	161,161	13,767	–	–	–	174,928
1956	167,576	10,939	–	–	–	178,515
1957	177,396	10,034	–	–	528	187,958
1958	127,144	9,778	–	704	1,933	139,559
1959	173,964	10,139	–	531	1,921	186,555
1960	201,650	9,059	–	1,890	1,907	214,506
1961	196,218	32,978	–	2,090	1,705	232,991
1962	166,582	61,482	1,540	1,738	900	232,242
1963	149,089	63,585	2,506	1,850	–	217,030
1964	162,094	62,365	2,338	1,699	–	228,496
1965	191,238	63,212	3,026	1,661	–	259,182
1966P	169,878	58,171	4,297	1,715	–	234,061

Source: Dominion Bureau of Statistics.

[1]Refined metal and nickel in oxide and salts produced plus recoverable nickel in matte or speiss and in ores and concentrates exported.

[2]First year of recorded production.

– Nil; P Preliminary.

APPENDIX D
Canada
Nickel Production, Trade and Consumption
1889–1966

	Production[2]	Exports[3] In matte, speiss or oxide	Exports[3] Refined Metal	Exports[3] Total	Imports	Consumption[5]
	(tons)	($)	(tons)	($)	($)	(tons)
1889[1]	415	..	–	..	..	..
1890	718	89,568	–	89,568	3,154	..
1891	2,018	667,280	–	667,280	3,889	..
1892	1,207	293,149	–	293,149	3,208	..
1893	1,991	629,692	–	629,692	2,905	..
1894	2,454	559,356	–	559,356	3,528	..
1895	1,944	521,783	–	521,783	4,267	..
1896	1,699	658,213	–	658,213	4,787	..
1897	1,999	723,130	–	723,130	4,737	..
1898	2,759	1,019,363	–	1,019,363	5,882	..
1899	2,872	939,915	–	939,915	9,449	..
1900	3,540	1,031,030	–	1,031,030	6,988	..
1901	4,595	751,080	–	751,080	12,029	..
1902	5,347	1,007,211	–	1,007,211	15,448	..
		(tons)		(tons)		
1903	6,350	6,350	–	6,350	26,177	..
1904	5,274	5,617	–	5,617	14,682	..
1905	9,438	8,659	–	8,659	19,076	..
1906	10,745	10,327	–	10,327	15,976	..
1907	10,595	9,688	–	9,688	19,511	..
1908	9,572	9,710	–	9,710	36,870	..
1909	13,141	12,808	–	12,808	14,930	..
1910	18.636	18,007	–	18,007	23,266	..
					(tons)	
1911	17,049	16,310	–	16,310	308	..
1912	22,421	22,111	–	22,111	334	..
1913	24,838	24,730	–	24,730	296	..
1914	22,759	23,264	–	23,264	310	..
1915	34,154	33,205	–	33,205	355	..
1916	41,479	40,221	–	40,221	446	..
1917	42,165	40,636	–	40,636	427	..
1918	46,254	42,884	855	43,739	319	..
1919	22,272	15,198	5,310	20,508	200	..
1920	30,668	25,851	4,249	30,100	368	..
1921	9,647	4,032	2,397	6,429	166	..
1922	8,799	8,384	7,225	15,609	683	..
1923	31,227	14,485	11,449	25,934	413	..
1924	34,768	18,356	12,993	31,349	438	..
1925	36,929	20,104	15,058	35,162	530	..
1926	32,857	19,589	12,349	31,938	559	..

	Production[2]	Exports[3]				Imports[4]	Consumption[5]
		In matte, speiss or oxide		Refined Metal	Total		
	(tons)	(tons)		(tons)	(tons)	(tons)	(tons)
		In matte or speiss	In oxide				
1927	33,399	18,229	2,598	14,508	35,335	1,227	..
1928	48,378	18,185	4,804	25,594	48,583	583	..
1929	55,138	14,815	5,801	34,204	54,820	803	..
1930	51,884	22,445	1,867	21,561	45,873	691	..
1931	32,833	16,644	1,554	13,566	31,764	391	..
1932	15,164	7,585	868	7,583	16,036	269	..
1933	41,632	19,163	3,832	21,046	44,041	496	..
1934	64,344	29,172	2,542	27,362	59,076	345	..
1935	69,258	29,232	1,317	40,814	71,363	286	500
1936	84,870	30,812	2,661	53,346	86,819	467	500
1937	112,452	40,404	2,554	68,427	111,385	491	900
1938	105,286	44,324	1,842	52,686	98,852	491	657
1939	113,053	47,051	2,426	67,914	117,391	697	635
1940	122,779	38,484	3,864	82,168	124,516	594	1,509
1941	141,129	42,616	7,240	87,739	137,595	1,011	3,464
1942	142,606	41,263	9,224	88,308	138,795	499	4,509
1943	144,009	36,415	3,892	95,240	135,547	545	3,440
1944	137,299	33,848	1,242	97,509	132,599	424	2,350
1945	122,565	28,295	1,759	78,168	108,222	762	2,410
1946	96,062	30,625	517	80,797	111,939	1,602	1,820
1947	118,626	39,767	6,534	70,756	117,057	1,376	1,670
1948	131,740	50,801	9,792	71,247	131,840	1,364	1,887
1949	128,690	56,902	1,152	69,088	127,142	1,448	1,749
1950	123,659	53,090	1,667	66,894	121,651	1,337	2,226
1951	137,903	57,882	944	72,357	131,183	1,306	2,744
1952	140,599	63,753	1,211	77,058	142,022	1,650	2,223
1953	143,693	63,910	1,299	79,909	145,118	3,083	2,275
1954	161,279	65,823	1,486	91,410	158,719	1,584	2,595
1955	174,928	65,954	1,452	106,473	173,879	2,103	5,020
1956	178,515	70,715	1,767	104,356	176,838	2,554	5,545
1957	187,958	73,694	1,706	103,258	178,658	2,092	4,532
1958	139,559	67,659	1,393	85,168	154,220	2,155	4,099
1959	186,555	65,657	4,157	102,111	171,925	1,857	4,059
1960	214,506	73,910	13,257	108,350	195,517	1,762	4,861
1961	232,991	92,938	18,021	133,504	244,463	4,304	4,935
1962	232,242	77,410	11,120	121,712	210,242	7,494	5,322
1963	217,030	83,392	15,208	109,156	207,756	10,973	5,869
1964	228,496	74,766	35,800	128,330	238,896	10,444	6,899
1965	259,182	82,327	40,956	135,197	258,480	12,172	8,924
1966P	234,061	83,586	33,631	132,712	249,929	28,916	..

Source: Dominion Bureau of Statistics.

[1] First year of recorded production.

[2] Refined metal and nickel in oxide and salts produced plus recoverable nickel in matte or speiss and in ores and concentrates exported.

[3] Exports are for calendar years 1890 to 1966.

[4] Imports for fiscal years 1890 to 1910 incl. and calendar years 1911 to 1966 incl. Imports consist of nickel in bars, rods, strips, sheets and wire; nickel and nickel-silver in ingots; nickel-chromium in bars.

[5] To 1959, producers' domestic shipments of refined metal; subsequent to 1959, consumption of nickel, all forms, (refined metal, oxide and salts) as reported by consumers.

– Nil; .. Not available; P Preliminary.

APPENDIX E
Canada
Nickel Exports*
1926–1966

Year	United States	Britain	Norway	Germany	Italy	Other Countries	Total (tons)
1926	16,344	12,554	–	112	–	2,928	31,938
1927	14,107	15,920	–	246	–	5,062	35,335
1928	26,508	14,665	–	742	225	6,543	48,683
1929	38,909	8,046	–	244	527	7,094	54,820
1930	25,443	15,935	1,448	273	269	2,505	45,873
1931	14,843	11,830	2,243	579	364	1,905	31,764
1932	8,267	3,427	2,919	107	163	1,153	16,036
1933	20,951	13,149	4,598	277	123	4,943	44,041
1934	25,008	22,977	5,336	270	348	5,137	59,076
1935	33,402	24,592	5,194	19	1,577	6,579	71,363
1936	47,116	25,137	5,674	507	1,233	7,152	86,819
1937	47,512	42,907	6,987	1,158	896	11,925	111,385
1938	25,902	49,974	7,662	1,012	–	14,302	98,852
1939	57,491	37,309	9,473	–	–	13,118	117,391
1940	82,845	32,349	2,671	–	–	6,651	124,516
1941	100,180	31,036	–	–	–	6,379	137,595
1942	108,249	25,741	–	–	–	4,805	138,795
1943	113,490	17,196	–	–	–	4,861	135,547
1944	103,868	19,171	–	–	–	9,560	132,599
1945	86,488	16,683	1,263	–	–	3,788	108,222
1946	82,203	13,888	9,248	–	1,173	5,427	111,939
1947	74,063	26,845	10,402	–	30	5,717	117,057
1948	96,433	25,555	8,968	–	1	883	131,840
1949	86,525	28,265	11,848	–	22	482	127,142
1950	88,543	21,644	10,888	–	143	433	121,651
1951	88,394	31,342	11,255	–	17	175	131,183
1952	95,292	30,952	15,193	–	24	561	142,022
1953	95,752	32,592	16,365	43	35	331	145,118
1954	105,906	32,016	19,563	212	67	955	158,719
1955	116,162	33,910	20,721	636	557	1,893	173,879
1956	112,993	34,003	23,382	2,864	909	2,687	176,838
1957	109,773	34,299	24,524	3,846	2,192	4,024	178,658
1958	76,139	39,271	26,085	5,590	2,216	4,919	154,220
1959	88,680	34,856	29,409	2,853	1,272	14,855	171,925
1960	69,904	51,626	33,242	6,755	3,642	30,348	195,517
1961	110,120	70,332	36,483	4,808	2,350	20,370	244,463
1962	111,558	54,526	33,396	2,000	1,136	7,626	210,242
1963	103,954	56,603	33,548	2,767	1,784	9,100	207,756
1964	116,131	77,021	27,937	4,773	1,104	11,930	238,896
1965	137,532	69,590	32,810	4,551	895	13,102	258,480
1966P	121,081	69,541	37,167	5,895	1,694	14,551	249,929

Source: Dominion Bureau of Statistics.

*Nickel in ores, concentrates, matte or speiss, nickel in oxide and refined nickel metal.

–Nil, P Preliminary

APPENDIX F
Canadian Nickel-Copper Industry – Employment, Salaries and Wages* 1950–1963

	Number Employed	Salaries and Wages $
1950	15,348	49,174,618
1951	18,546	64,543,280
1952	19,976	76,445,452
1953	20,887	84,074,041
1954	21,172	87,776,066
1955	21,356	92,113,487
1956	22,684	103,619,044
1957	23,464	113,459,592
1958	17,784	88,929,124
1959	21,913	110,373,734
1960	24,052	124,723,533
1961	25,637	136,801,446
1962	24,787	134,441,487
1963	22,160	122,975,367

Source: Dominion Bureau of Statistics.

* includes smelting and refining operations.

APPENDIX G
Canada–Nickel Trade
1965–1966

	1965		1966P	
	Tons	$	Tons	$
Exports				
Nickel in ores, concentrates, matte or speiss				
Britain	47,067	77,025,888	44,364	74,094,000
Norway[1]	32,810	49,887,419	37,167	59,467,000
Japan	2,124	2,072,463	1,605	1,765,000
United States	326	449,145	450	629,000
Total	82,327	129,434,915	83,586	135,955,000
Nickel in oxide sinter				
United States	27,069	38,593,770	18,931	27,420,000
Britain	7,388	10,564,385	4,929	7,081,000
West Germany	2,333	3,661,098	2,690	4,230,000
Sweden	469	732,001	2,000	3,136,000
Belgium and Luxembourg	1,001	1,572,092	1,532	2,382,000
France	976	1,532,399	1,473	2,313,000
Italy	473	743,010	1,087	1,713,000
Australia	741	1,052,022	562	807,000
Austria	300	471,739	164	259,000
Netherlands	6	9,245	154	245,000
Mexico	95	150,130	69	113,000
Other countries	105	164,969	40	62,000
Total	40,956	59,246,860	33,631	49,761,000
Nickel and nickel alloy scrap				
United States	861	539,226	919	604,000
Britain	22	19,643	95	127,000
Netherlands	11	9,752	56	116,000
France	20	12,847	53	81,000
Norway	30	27,258	29	26,000
Japan	25	2,200	14	19,000
Other countries	77	43,373	17	37,000
Total	1,046	654,299	1,183	1,010,000
Nickel anodes, cathodes, ingots, rods				
United States	110,137	162,749,253	101,700	156,962,000
Britain	15,135	22,244,989	20,248	29,978,000
West Germany	2,218	3,601,545	3,205	5,219,000
Japan	1,902	3,158,612	1,624	2,752,000
France	1,309	2,170,941	1,392	2,254,000
Sweden	499	809,278	924	1,511,000
Italy	422	686,418	607	995,000
Australia	1,129	1,718,095	571	915,000
Belgium and Luxembourg	151	253,932	494	779,000
Brazil	244	400,643	354	583,000
Argentina	345	614,955	293	505,000
India	909	1,510,332	257	432,000
Mexico	244	404,167	244	404,000
Other countries	553	949,997	799	1,392,000
Total	135,197	201,273,157	132,712	204,681,000

	1965		1966P	
	Tons	$	Tons	$
Nickel and nickel-alloy fabricated materials, n.e.s.				
United States	2,296	4,437,245	3,446	6,770,000
West Germany	22	38,990	89	143,000
India	52	91,344	68	114,000
Republic of South Africa	350	931,615	67	209,000
Japan	24	40,518	59	101,000
New Zealand	50	214,712	38	151,000
Britain	43	145,514	36	75,000
Mexico	32	54,572	20	36,000
Other countries	311	636,180	53	153,000
Total	3,180	6,590,690	3,876	7,752,000
Imports				
Nickel in ores, concentrates and scrap[2]				
United States	. .	. .	12,247	14,989,000
Britain	. .	. .	8,704	1,464,000
French Oceania	. .	. .	5,646	6,608,000
Other countries	. .	. .	80	81,000
Total	. .	. .	26,677	23,142,000
Nickel anodes, cathodes, ingots, rod and shot				
United States	90	228,079	18,097	29,110,000
Norway	12,082	20,790,906	10,789	18,470,000
West Germany	–	–	30	73,000
Total	12,172	21,018,985	28,916	47,653,000
Nickel alloy ingots, blocks, rods and wire bars				
United States	610	1,800,080	718	2,246,000
West Germany	4	16,583	20	62,000
Other countries	. . .	949	. . .	1,000
Total	614	1,817,612	738	2,309,000
Nickel and nickel alloy fabricated materials, n.e.s.				
United States	2,154	6,660,215	1,731	5,922,000
West Germany	34	84,419	156	746,000
Britain	53	204,176	95	327,000
Other countries	23	90,227	10	41,000
Total	2,264	7,039,037	1,992	7,036,000

Source: Dominion Bureau of Statistics

[1] For refining and re-export.

[2] Not available as a separate class prior to 1966.

Ppreliminary; –nil; . . .less than one ton; n.e.s. not elsewhere specified; . .not available.

APPENDIX H
World Mine Production of Nickel by Country
1961-65
(tons of nickel content)

	1961	1962	1963	1964	1965
Canada	232,991	232,241	219,029	228,509	261,137
USSR*	77,162	88,185	88,185	88,185	88,185
New Caledonia	58,753	37,258	49,053	64,155	63,493
Cuba*	16,314	19,952	22,046	22,046	22,046
United States	11,606	11,217	11,432	12,185	13,510
South Africa	2,899	3,858	3,858	3,858*	3,858*
Albania*	3,307	3,307	3,307	3,307	3,307
Indonesia	694	491	1,764*	1,874*	3,307
Finland	2,204	2,680	3,231	3,490	3,256
Poland	1,455	1,400	1,458	1,433*	1,433*
Brazil	150	496	1,025	1,047	1,102
Rhodesia	64	86	131	187	187*
TOTAL (tons)	407,599	401,171	404,519	430,276	464,821

*Estimate.

Source: *Statistiques – 1965.* Minerais et Métaux Société Anonyme, July 1966.

APPENDIX I
World Production of Processed Nickel** by Country
1961–1965
(tons of nickel content)

	1961	1962	1963	1964	1965
Canada	128,970	126,865	107,087	123,459	170,858*
USSR*	77,162	88,185	88,185	88,185	88,185
Britain	41,839	42,254	41,969	41,896	44,629
Norway	35,512	32,190	29,123	33,191	35,092
Japan	22,203	14,968	18,193	30,309	29,141
Cuba	16,314	18,298	18,409	19,842	19,842
New Caledonia	14,731	6,070	9,154	14,649	17,157
United States	12,386	12,469	13,051	13,751	14,551*
France	12,011	11,411	10.595	8,896	8,984
Finland	1,989	2,567	2,970	3,244	3,060
South Africa*	1,323	2,646	2,756	2,756	2,756
Brazil	–	150	1,025	1,047	1,102
West Germany	3,308	3,553	2,133	839	336
Others	3,252	3,803	4,740	4,795	4,409
TOTAL (tons)	371,000	365,429	349,390	386,859	440,102

*Estimate

**Includes refined nickel, ferronickel, and nickel oxide that is used directly in the production of ferro-alloys.

Source: *Statistiques – 1965.* Minerais et Métaux Société Anonyme, July 1966.

–Nil

APPENDIX J
World Nickel Consumption by Country
1961–1965
(tons of nickel content)

	1961	1962	1963	1964	1965
United States	118,498	118,677	124,478	146,962	172,435
Soviet Bloc*	104,720	104,720	110,231	110,231	110,231
Britain	29,177	27,650	30,380	42,004	44,092
West Germany	24,251	21,164	22,377	27,558	33,841
Japan	18,530	15,103	20,589	33,859	26,455
France	16,958	14,551	17,417	22,597	23,149
Sweden	9,776	8,929	9,257	12,778	13,779*
Italy	7,385	7,716	8,267	8,818	9,480
Canada	4,935	5,321	5,897	8,003	9,003
Other	12,728	14,539	16,262	18,012	19,891*
TOTAL (tons)	346,958	338,370	365,155	430,822	462,356

*Estimate

Source: *Statistiques – 1965.* Minerais et Métaux Société Anonyme, July 1966.

APPENDIX K
Nickel Trade – Semiprocessed Forms**
1965
(tons of nickel content)

		Exporter					
		Canada	New Caledonia	Cuba	South Africa	Albania	Indonesia
Importer	Norway	32,810(m)					
	Britain	47,067(ox)			1,102*(m)		
	Japan	2,124(c)	22,000*(o) 3,365 (m)				3,307*(o)
	France		8,238 (m)				
	Czechoslovakia			9,900*(c)		3,307*(o)	
	Other Soviet Bloc			na (ox)			
	Canada		5,797 (m)				

*Estimate

**Nickel that requires further processing for industrial use; that is, ore, concentrate, matte or oxide forms, excluding that portion of nickel oxide production that is used directly as a ferroalloy.

(o) ore
(c) concentrate
(m) matte
(ox) oxide

na Not available

Sources (1) *Statistiques – 1965.* Minerais et Métaux Société Anonyme, July 1966.
(2) Killin, A.F. 'Nickel', preprint, *Canadian Minerals Yearbook – 1966.* Mineral Resources Division, Ottawa, 1967.
(3) Bureau of Mines *Minerals Yearbook: 1965.* United States Department of the Interior, Washington, 1967.

Note: Table indicates general trade patterns. Only trade from major producers to major consumers is shown.

APPENDIX L
Nickel Trade – Processed Forms*
1965
(tons of nickel content)

Importer	Exporter: Canada	Norway	Britain	New Caledonia	Cuba	France
United States	110,137(r) 27,069(ox)	12,490(r)				
West Germany	2,333(ox) 2,218(r)	5,211(r)	10,593(r)			
Britain	7,388(ox) 15,135(r)	5,787(r)				
France	1,309(r)		4,187(r)	15,762(f)		
Soviet Bloc					22,000**(ox)	na (r)
Sweden		5,655(r)	4,939(r)			
Italy		1,747(r)	3,249(r)			
Japan	1,902(r)			1,100(f)		
Belgium & Luxembourg	1,001(ox)		1,257(r)			
Austria			1,951(r)			
Australia	1,129(r)					
Spain			1,033(r)			

*Nickel in refined, ferronickel, or oxide form that is not processed further for industrial use.

**Total nickel oxide production

(ox) oxide

(f) ferronickel

(r) refined

na Not available; 3,309 tons in 1963

Sources (1) *Statistiques – 1965.* Minerais et Métaux Société Anonyme, July 1966.

(2) Killin, A.F. 'Nickel', preprint, *Canadian Minerals Yearbook – 1966.* Mineral Resources Division, Ottawa, 1967.

(3) *Bureau of Mines Minerals Yearbook: 1965.* United States Department of the Interior, Washington, 1967.

Note: Table indicates general trade patterns. Only trade from major producers to major consumers is shown.

APPENDIX M
Price of Electrolytic Cathode Nickel
1951–1967

(f.o.b. Canadian producers' plant)

	CANADA		UNITED STATES**	
	Date of Change in Price	New Price Can. ¢/lb.	Date of Change in Price	New Price U.S. ¢/lb.
1951	na	55.12*	June	56.50
1952	na	55.45*	unchanged	56.50
1953	na	55.50*	January	60.00
1954	na	57.45*	November	64.50
1955	unchanged	63.00	unchanged	64.50
1956	December	70.00	December	74.00
1957	August	69.00	unchanged	74.00
1958	January	71.50	unchanged	74.00
	July	70.50		
	August	70.00		
1959	unchanged	70.00	unchanged	74.00
1960	unchanged	70.00	unchanged	74.00
1961	January	72.75	June	81.25
	June	82.50		
1962	May	84.00	May	79.00
1963	unchanged	84.00	unchanged	79.00
1964	unchanged	84.00	unchanged	79.00
1965	unchanged	84.00	September***	77.75
1966	November	92.15	November	85.25
1967	September	101.50	September	94.00

*average annual price.
**includes import duty where applicable.
***1.25¢/lb. import duty suspended Sept. 1965.
na Not available

Sources: (1) *Canadian Minerals Yearbook.* Mineral Resources Division, Ottawa, various years.
(2) Ware, Glen C. 'Nickel', *Mineral Facts and Problems.* 1965 edition, Bulletin 630, United States Department of the Interior, Washington, 1965.

APPENDIX N
Price of Nickel Oxide Sinter
1962 – 1967

f.o.b. Copper Cliff
(nickel content)

	Date of Change in Price	Canada New Price Can. ¢/lb	United States New Price U.S. ¢/lb
1962	May	81.50	75.25
1963	unchanged	81.50	75.25
1964	unchanged	81.50	75.25
1965	unchanged	81.50	75.25
1966	November	87.80	81.00
1967	September	95.50	88.50

Sources: (1) *Canadian Minerals Yearbook.* Mineral Resources Division, Ottawa, various years.
(2) Ware, Glen C. 'Nickel', *Mineral Facts and Problems.* 1965 edition, Bulletin 630, United States Department of the Interior, Washington, 1965.

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