Success & Failure in the Canadian Metallurgical Industry

Fathi Habashi

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Success and Failure in the Canadian Metallurgical Industry

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2018
The Book

Canada is a world leader in the metallurgical industry. Many metallurgical processes were invented or developed in Canada. *Success and Failure in the Canadian Metallurgical Industry* describes this industry by a metallurgist who witnessed these events.

The Author

Fathi Habashi, born in Egypt, studied chemical engineering in Cairo University and inorganic chemical technology at the Technische Hochschule in Vienna. He came to Canada in 1960 as a Post-doctoral Fellow in the Mines Branch [now CANMET], spent a few years in USA in teaching and industrial research before joining Laval University in Quebec City in 1970. He authored textbooks on extractive metallurgy and in 1997 edited *Handbook of Extractive Metallurgy* in 4 volumes. His diary was documented in 2014 in *De Re Metallica. A Metallurgist on the Move* in 7 volumes.
SUCCESS AND FAILURE
IN THE CANADIAN
METALLURGICAL INDUSTRY

Fathi Habashi

Québec City, 2018
To Nadia,
Hani and Hatem
with love
Other Books by the Author

Published by Métallurgie Extractive Québec, Québec City and distributed by Laval University Bookstore except otherwise stated.

Technical
F. Habashi, Principles of Extractive Metallurgy,


F. Habashi, Researches on Rare Earths. History and Technology, 2008, 125 pages.


F. Habashi, Industrial Minerals through the Ages, 2016, 442 pages.

Historical


F. Habashi, Story of Metals, 2 volumes, 2015, 1056 pages.


The present book started as a talk addressed to the Canadian Science and Technology Historical Association in its meeting in November 2017 at London, Ontario. It was expanded later to fill the missing data. Although Canada is a leader in the mining and metallurgical industry and has many credits for original processes and successful stories yet there are some failures.

Before my retirement I was in charge of two courses given in our Department: Industrial Visits 1 and Industrial Visits 2 given at the first week of the beginning of each trimester. This allowed our students to visit at least ten metallurgical companies during their studies. We visited most of the companies mentioned in this book and discussed the processes with the engineers in charge.

Also, from time to time the students organized other visits, e.g., to Bathurst Mines in New Brunswick. In addition, the Metallurgical Society of the Canadian Institute of Mining and Metallurgy always organized visits to the nearby industry where the Conference of Metallurgists was being held. In this way I participated in visits to COMINCO in Trail, Sherritt in Fort Saskatechewan, Stelco in Hamilton, and others. Further, I was consultant to Tioxide Canada, QIT Fer et Titane, as well as Société québécoise d’exploitation minière known as SOQUEM for the Niobium Project. We had detailed discussions on some of the processes. My co-worker and I did the basic work for the upgrading of Sorelslag by pressure leaching process. This is briefly documented in De Re Metallica.

Due to acquisitions in recent years, many companies changed names. In the text that follows I used the original names of the companies involved and I included a Table with the new names. The treatment is mainly historical.

The starting point in Canadian research in the metallurgical sector was the formation of the Geological Surveys in 1842. The book then

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opens with the Hunt-Douglas process discovered in 1876 because it was the first metallurgical research in Canada that led to a technical process. Unfortunately, it was a failure. This was followed by the formation of the Mines Branch in Ottawa in 1901 which started a systematic and fruitful research in the metallurgical sector that led to many successful processes. The engineering firms like Kilborn and Hatch also played an important part in building up the mining and metallurgical industries not only in Canada but in other parts of the world.

The major failure of the Canadian industry is in the asbestos industry which unfortunately because of its toxicity issue. The mining and application of the industry had to be closed. Some of the failures were due to exhaustion of mines, economic reasons, incorrect decisions, etc. It is also unfortunate that some research centers were closed. The treatment in this book is as much as possible historical. It is hoped that this sketch will briefly outline the situation of the industry as seen by an observer who witnessed personally most of these cases.

March 2018
Québec City

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Chapter 1

General Outline

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INTRODUCTION

Canada is a world leader in the metallurgical industry. The Canadian mining and metallurgical industries contribute about 40 billion dollars to national economy. The starting point was the formation of the Geological Survey in 1842. Many metallurgical processes were developed or invented in Canada thanks to the new organizations that were created afterwards for these purposes:

• The Canadian Institute of Mining and Metallurgy, founded in 1898, was responsible for promoting the development of the industry by organizing meetings where academic people met industrial engineers and metallurgical processes were discussed.

• The Mines Branch in Ottawa was created in 1907 was also responsible for creating and helping many of the new metallurgical processes.

• The Canadian National Research Council founded in 1916 was behind the magnesium process discovered in Canada.

• The impact of the Second Empire Congress that took place in Canada in 1927 with the participation of 1200 delegates was enormous. Beside diffusion of the technical information about mining and metallurgy in Canada there was also a movement of organisation of the professionals in the industry and association with academic researchers. Five volumes of proceedings were published.
Success and Failure in the Canadian Metallurgical Industry

- Although the Metallurgical Society of the CIM was founded in 1945 its first important achievement was in 1962 when the Mines Branch played an important role in organizing the Conference of Metallurgists where research results from industry and universities were to be presented. It was also in 1962 that the Canadian Metallurgical Quarterly was founded where original Canadian research was to be published.

- The engineering firms created in 1947 and later were responsible for installing many plants in Canada and abroad.

- “Autogenous Smelting of Copper Concentrates with Oxygen-Enriched Air” was published in 1936 by Telfer E. Norman (1908–2001) an undergraduate student at the University of Toronto in Engineering & Mining Journal. This work precedes the flash smelting technology developed in 1947 simultaneously by INCO in Canada and by Outokumpu in Finland.

Metals and fertilizers

Some Canadian metallurgical plants are also producing fertilizers, for example, ammonium sulfate by Sherritt and ammonium phosphate at Trail. The former due to ammonia leaching process of sulfide ores while the latter due to SO\textsubscript{2} and sulfuric acid generated due to roasting sulfide ores. This shows the strong relation between the metallurgical and the chemical industry.

Headquarters

It is said that three quarters of the world’s mining companies are headquartered in Canada mainly in Toronto. This is because there is a concentration of expertise in mining finance and mining law in Canada. Canada also provides favourable conditions. No Canadian directors or Canadian shareholders need to be a Canadian company. Prospectors & Developers Association of Canada holds its annual meeting in March every year in Toronto Convention Centre (Figures 1.1–1.2). It is one of the largest conferences in the world. In 2017 there were 24 161 participants, 867 booths (Figure 1.3), 472 speakers, 19 technical sessions, and 8 short courses. The organization was established in 1932 and currently has 560 corporate members.
Figure 1.1: Toronto Convention Centre.

Figure 1.2: Toronto Convention Centre.
Successes and failure

The industry achieved many successes as well as some failures. The successes are in the fields of hydro-, pyro-, and electrometallurgy as well as in industrial minerals such as the tar sands and the potash industries. The failures are mainly in the asbestos industry, the white pigment manufacture, magnesium recovery, and the recovery of alumina from clay. Canada has also the tallest chimney in the world (Figure 1.4). It is located in Sudbury and is 381 m tall.

BY-PRODUCT METALS

Certain metals are produced in Canada as by-products of main metals (Table 1.1).
Figure 1.4: Chimney at Sudbury is 381 m tall.

Table 1.1: By-product metals in Canada.

<table>
<thead>
<tr>
<th>By-product metal or metalloids</th>
<th>Major metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony</td>
<td>Lead</td>
</tr>
<tr>
<td>Arsenic</td>
<td>Copper, gold</td>
</tr>
<tr>
<td>Bismuth</td>
<td>Lead</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Zinc</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Nickel</td>
</tr>
<tr>
<td>Indium</td>
<td>Zinc</td>
</tr>
<tr>
<td>Molybdenum\textsuperscript{a}</td>
<td>Copper</td>
</tr>
<tr>
<td>Platinum metals</td>
<td>Nickel</td>
</tr>
<tr>
<td>Selenium</td>
<td>Copper, nickel</td>
</tr>
<tr>
<td>Tellurium</td>
<td>Copper, nickel</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Mines in British Columbia produce molybdenite concentrate.
OWNERSHIP AND NAME CHANGE OF MINING COMPANIES

The treatment followed here is as much as possible historic. Over the years, some companies have grown to become multinational. In the 21st century, through mergers and acquisitions, the names have changed. For example (Table 1.2):

- Algoma Steel founded in 1901 in Sault Sainte Marie, Ontario was purchased in 2007 by the Indian’s Essar Group continuing operations as Essar Steel Algoma Incorporated.
- Companhia Vale do Rio Doce is a Brazilian multinational corporation, founded in 1942, engaged in iron ore, nickel, manganese, ferroalloys, copper, bauxite, potash, kaolin, and cobalt. In 2006 it acquired INCO.
- Glencore, an acronym for Global Energy Commodity Resources, founded in 1974 is an Anglo–Swiss multinational commodity trading and mining company with headquarters in Baar, Switzerland, and a registered office in Saint Helier, Jersey [Channel island]. The current company was created through a merger with Xstrata in 2013. It owns also CEZinc Refinery in Valleyfield, Brunswick Lead Smelter, and Kidd operations.
- Magris Resources founded in 2012 is a private equity firm specialising in mining sector based in Toronto, became the new owner of Niobec in 2015.
- Mazarin was founded in 1985 and is headquartered in Thetford Mines. It engages in the management of various mining properties in Canada. It acquired Teck Corporation’s 50% participation in Niobec. In 2002 Les Minéraux Séquoia was created following the restructuring of Mazarin.
- Noranda, founded in 1922, merged with Falconbridge in 2005 and the combined company continued under the name Falconbridge but was later acquired by Xstrata then Glencore. CEZinc which originally belonged to Noranda was also purchased by Glencore but the name CEZinc was maintained.
- Rio Tinto is an Australian-British multinational founded in 1873, when investors purchased a mine complex on the Río Tinto, in Huelva, Spain, from the Spanish government. Since then, the company has grown enormously.
• Teck Resources known as Teck Cominco is a Canadian metals and mining company formed from the amalgamation of Teck and Cominco in 2001.

• Xstrata, founded in 1929, is an Anglo-Swiss multinational mining company headquartered in Zug, Switzerland with its office in London, UK. It purchased Falconbridge and INCO. In 2013 it was fully acquired by Glencore. The name was suggested to mean Extraction & Mining.

Table 1.2: Name change of major mining and metallurgical companies in Canada.

<table>
<thead>
<tr>
<th>Original name</th>
<th>Current name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algoma Steel</td>
<td>Essar Steel Algoma</td>
</tr>
<tr>
<td>Aluminum Company of Canada</td>
<td>Alcoa, Alcan, Rio Tinto Alcan&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Brunswick Mining and Smelting</td>
<td>Glencore</td>
</tr>
<tr>
<td>Cambior</td>
<td>Iamgold</td>
</tr>
<tr>
<td>Canadian Copper Refiners</td>
<td>CCR, Glencore Canada</td>
</tr>
<tr>
<td>Canadian Electrolytic Zinc</td>
<td>CEZinc</td>
</tr>
<tr>
<td>Companhia Vale do Rio Doce</td>
<td>CVRD, Vale</td>
</tr>
<tr>
<td>Consolidated Mining &amp; Smelting Co.</td>
<td>Cominco, Teck&lt;sup&gt;b&lt;/sup&gt; Cominco, Teck</td>
</tr>
<tr>
<td>Eldorado Nuclear</td>
<td>Cameco</td>
</tr>
<tr>
<td>Falconbridge</td>
<td>Xstrata, Glencore Canada</td>
</tr>
<tr>
<td>Global Energy Commodity Resources</td>
<td>Glencore</td>
</tr>
<tr>
<td>International African Mining Gold</td>
<td>Iamgold</td>
</tr>
<tr>
<td>International Nickel Company</td>
<td>INCO, CVRD Inco, Vale Inco, Vale Canada</td>
</tr>
<tr>
<td>Niobec</td>
<td>Iamgold, Magris Resources</td>
</tr>
<tr>
<td>Noranda Mines</td>
<td>Noranda Incorporated, Falconbridge, Xstrata, Glencore</td>
</tr>
<tr>
<td>Quebec Iron and Titanium</td>
<td>QIT Fer et Titane, Rio Tinto QIT</td>
</tr>
<tr>
<td>Sherritt Gordon Mines</td>
<td>Sherritt</td>
</tr>
</tbody>
</table>

<sup>a</sup> Rio Tinto Alcan has 40% interest in Alumenerie Alouette.<br>
<sup>b</sup> Named after the Township of Teck which changed its name to Kirkland Lake, Ontario in 1972.

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Chapter 2

Geological Survey of Canada

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<td>Phosphate rock</td>
<td>11</td>
</tr>
<tr>
<td>Copper</td>
<td>11</td>
</tr>
<tr>
<td>Asbestos</td>
<td>12</td>
</tr>
<tr>
<td>Nickel</td>
<td>12</td>
</tr>
</tbody>
</table>

INTRODUCTION

The province of Canada took the lead in 1842 by creating the Geological Survey of Canada under Montréal-born William E. Logan (1798–1875) (Figure 2.1). It was modelled on the British Survey and American State Surveys. The Survey was at first limited to Upper and Lower Canada, and after 1867, it was faced with the exploration of virtually all the territories now comprising Canada. This marked the beginning of using scientific principles to determine the extent of Canada’s mineral wealth. Within the next few years, important discoveries of mineral deposits were made. For example, in the 1850’s gold was discovered in the Cariboo County, in British Columbia, and in Ontario. Thomas Sterry Hunt (1826–1892), a Yale University graduate, was employed from 1847 to 1852 as chemist-mineralogist.  

The collections of the Survey, first housed in Logan’s home, evolved into the National Museum in Ottawa (now National Museum of Natural Science), by the 1890s. The more economic aspects of geology called forth the creation of different organizations such as the Federal Mines Department (1907). Some provinces had moved earlier, e.g., Nova Scotia had established a Commissioner of Mines before

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1 He later taught chemistry and mineralogy at Laval University (1856–1862) then at McGill (1862–1868) before returning to USA to become professor of geology at the Massachusetts Institute of Technology.
Confederation, and Ontario set up a Bureau of Mines in 1891. After the turn of the century, most provinces maintained government bureaus devoted to mining. In 1898 the Canadian Institute of Mining and Metallurgy was founded in Montreal to group together workers in these fields.

![William E. Logan (1798–1875).](image)

**Figure 2.1:** William E. Logan (1798–1875).

**Canadian Mineral Wealth**

The first oil well in North America was drilled in 1857 by the Canadian James Miller Williams (1818–1890) at Oil Springs near Sarnia, Ontario. During the second half of the 19th century, many other important mineral deposits were discovered in Canada: gold, nickel, copper, asbestos, and phosphate rock.

**Gold**

Canadian gold rush started in the Fraser Canyon in 1858 after gold was discovered on the Thompson River, British Columbia at its
confluence with the Nicoamen River. News of the discovery was spread to California when the Governor of the Colony of Vancouver Island sent a shipment of ore to the mint in San Francisco for study. Within a month, 30,000 men had descended upon Victoria, which until that time had only a population of about 500. By the fall, however, tens of thousands of men who had failed to stake claims, or were unable to because of the summer’s high water on the river, returned to San Francisco. However, tens of thousands of largely American prospectors arrived into the British Columbia and disrupted the established balance between the Hudson’s Bay Company’s fur traders and Aboriginal peoples. The influx of prospectors included large numbers of Chinese as well as Britons, English Canadians and Maritimers, French Canadians, Germans, and others.

**Phosphate rock**

The growing fertilizer industry in Great Britain in the second half of the nineteenth century was dependant on mines in Quebec and Ontario for its phosphate supplies. The first of these mines started in 1850 and was most active between 1878 and 1892. By 1895, output had declined owing to the discovery of easily exploitable deposits in Florida. In spite of this, in 1897 the Electric Reduction Company was founded at Buckingham, Quebec, and an electric furnace was built to produce elemental phosphorus. This was one of the world’s earliest electric phosphorus plants. In 2002, the city of Buckingham became part of the new city of Gatineau.

**Copper**

The Acton mine in Quebec, which operated from 1859–1864, was for a time considered the most important in the world. In 1888 a large copper deposit was discovered at Britannia in British Columbia. From 1925 to 1930, the Britannia mine was the largest copper producer in the British Empire. The mine which is now a National Historic Site, produced 50 million tons of ore during its 70-year history.
Asbestos

The fireproof properties of asbestos were recognized by the Greeks and Romans, but its industrial use began only when large deposits were discovered in the Province of Quebec in 1874. Mining commenced on a small scale in 1877. This proceeded by many years production in other countries: Russia in 1895, and South Africa in 1900.

Nickel

In 1883 a rich copper discovery was made accidentally near what is now Sudbury, Ontario, during the construction of the Canadian Pacific Railroad. The Canadian Copper Company was then formed and in 1886 ore was sent to the Orford Works in New Jersey for smelting at the Orford Copper and Sulfur Company. However, it was found that on smelting, the ore produced a pale yellow metal and not the red metal. On analysis, the product was found to be an alloy of copper with nickel.

Of the numerous attempts to make the separation of nickel from copper the one tried in 1891 using sodium sulfate as a flux was the most promising. Sodium sulfate was a waste product of a nearby nitric acid plant treating the sodium nitrate from Chile by sulfuric acid, to make explosives. This resulted in what became known as the Orford Process. In 1902, the Canadian Copper Company and the Orford Copper Company merged to form the International Nickel Company, now known as INCO. The Orford process continued to be used until 1948 when it was replaced by the controlled cooling process.

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1 See Chapter 8 — The International Nickel Company.
Chapter 3

Hunt–Douglas Process

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A HYDROMETALLURGICAL COPPER PROCESS

The Hunt–Douglas Process is considered as the first metallurgical research conducted in Canada and was further applied in Chile. Unfortunately it was a failure. The story begins in 1862 when the German chemist Max Schaffner found that copper oxide was soluble in ferrous chloride solution. This observation drew the attention of Thomas Sterry Hunt (1826–1892) (Figure 3.1), a US chemist working at the Geological Survey of Canada in Montreal and a part time professor of chemistry at Morrin College the English-Speaking institution in Quebec City.

Figure 3.1: Thomas Sterry Hunt (1826–1892).

Figure 3.2: James Douglas (1837–1918).
Immediately he contacted his friend James Douglas (1837–1918) (Figure 3.2) a theology student who turned medical doctor in Quebec City suggesting to him to apply this knowledge to treat the low grade copper oxide ore from the Harvey Hill mine that belonged to his father who was a medical doctor in Quebec City. The high grade ore was exhausted and the mine was threatened of being closed. The mine was located in Leeds Township, Mégantic County south of Quebec City.

Tests were conducted by James Douglas, Jr. at the mine location and the process looked to be promising. James Douglas, Jr. became interested in mining and metallurgy and abandoned theology and medicine. By 1869 Sterry Hunt and Douglas developed a new hydro-metallurgical process to treat copper ores and filed a Canadian patent
for their process. The leaching agent was prepared by treating commercially available ferrous sulfate solution (copperas) with excess of sodium chloride (salt) and crystallizing as much as possible of sodium sulfate formed according to:

\[
\text{FeSO}_4 + 2\text{NaCl} \rightarrow \text{FeCl}_2 + \text{Na}_2\text{SO}_4
\]

**FAILURE OF THE PROCESS**

The leaching of copper oxide by ferrous chloride solution can be represented by:

\[
\text{CuO} + \text{Fe}^{2+} + \text{H}_2\text{O} \rightarrow \text{Cu}^{2+} + \text{Fe(OH)}_2
\]

The dissolving action is due to the acid generated by the hydrolytic action of the ferrous ion:

\[
\text{Fe}^{2+} + \text{H}_2\text{O} \rightarrow \text{FeOH}^+ + \text{H}^+
\]

\[
\text{FeOH}^+ + \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_2 + \text{H}^+
\]

\[
\text{CuO} + 2\text{H}^+ \rightarrow \text{Cu}^{2+} + \text{H}_2\text{O}
\]

Ferrous hydroxide formed is known to be a gelatinous precipitate difficult to filter. In addition, the leaching action of ferrous chloride could have succeeded for copper oxide ore containing silicate gangue, but not carbonates like limestone. Hence any carbonate present will compete with CuO and immediately reacts with the acid present leading to the precipitation of Fe(OH)$_2$. Thus, the reagent is lost and the process does not function. The Hunt–Douglas process was a failure because it was not based on sound chemistry. However, it was a first attempt to use a hydrometallurgical process to leach ores in Canada.

**REFERENCES**

INTRODUCTION

The foundation of the Geological Survey in Montreal in 1842, the discovery of gold in British Columbia in 1858, and later mineral wealth in different regions created the need for the foundation of the Mining Section of the Ministry of Interior in 1901 to help promote the mining and metallurgical industry through research.

Coal, the backbone of the metallurgical industry, is concentrated at Cape Breton in Nova Scotia and was first found around the 1720s. It was later discovered in many other localities in Canada. Coal was used as fuel for steam locomotives when railways came to Canada. The first oil well in North America was drilled in 1857 by the Canadian James Miller Williams (1818–1890) at Oil Springs near Sarnia, Ontario.

When World War II threatened tropical sources of natural latex for rubber, Sarnia was selected as the site to develop synthetic petroleum-based rubber for war materials. Polymer Corporation was built by Dow Chemical at the request of the Government of Canada. More oil was brought from Alberta to Sarnia in large pipelines, where oil refining and petrochemical production became main industries in the city's economy. Large salt beds found under the city became a source of chlorine, and another significant ingredient in the success of the city. During the 19th century, many important mineral deposits were discovered in Canada.
The Department of Mines and Technical Surveys in Ottawa documented and well disseminated the information on the mineral deposits. The Mines Branch in Ottawa (Figure 4.1), founded in 1907 now called Canadian Centre for Mineral and Energy Technology, and abbreviated Canmet is responsible for the discovery and development of many metallurgical processes.

Figure 4.1: The Mines Branch in Ottawa in 1957.

| 1–3 Physical Metallurgy Division | 10 Industrial minerals |
| 4–5 Fuels | 11 Radioactive ores division |
| 6 Heating plant | 12 Ore dressing and pilot plants |
| 7 Mine safety equipment testing lab | 13–14 New chemical and radioactive materials labs |
| 8 Maintenance section | 15 Site for new Geological Surveys [to be moved from Montreal] |
| 9 Mineral dressing and process metallurgy |

**ENERGY**

The electrification of Niagara Falls was a major item for the industrialisation of the country and the use of electrical energy for metallurgical applications. The Niagara Falls Power Company was founded in 1893. It was at this plant that the great step was taken in the transition from mechanical power for local use to electrical power for universal application. Niagara Falls became the first centre of electrochemical
industries. It was there that the Carborundum Company, the Union Carbide and Carbon Corporation, the Hooker Electrochemical Company, the Mathieson Alkali Company, the Acheson Graphite Company, the Norton Company, the Aluminum Company of America, the American Cyanamid Company, and many others were founded.

**Electric Furnace**

Researchers at the Mines Branch were interested to use the electric furnace in different metallurgical processes like the treatment of ilmenite, the production of steel, etc., to make use of the electric power generated at Niagara Falls. They put the basic fundamentals for this technology. Electric furnace was developed further at McGill University when Alfred Stansfield (1872–1944) came from the Royal School of Mines in London in 1901 as the first professor of metallurgy. He published *The Electric Furnace. Its Evolution, Theory, and Practice* in 1907.

**Hydrometallurgical Research**

Hydrometallurgical research in Canada was started in 1921 at the Department of Mines in the recovery of zinc from the complex sulfide ores at Flin Flon by roasting the ore then acid leaching. In 1927 an agreement of cooperation with Base metals Extraction Company of the United Kingdom and another with Cassel Cyanide Company of Canada were signed, as was another agreement with American Cyanamid Company in 1929. The Base Metals Extraction Company supplied and equipped a laboratory for hydrometallurgical research. As a result, work was initiated in 1929 to recover zinc from a sulfide concentrate by roasting, leaching and electrowinning.

In the same year, uranium ore in Ontario became exploited for the recovery of radium, which was in great demand at the time. In 1930, Gilbert Labine (1890–1977) discovered a rich uranium deposit containing silver in North-Western Territories. Twenty tonnes of this ore were delivered in 1931 to the Bureau of Mines for the hydrometallurgical treatment. A method for the extraction of radium from this ore was developed. This marked the beginning of Canadian involvement
in radioactivity research. At the same time Eldorado Gold Mines in Port Hope, Ontario constructed a plant for the production of radium.

Also in the 1930s extensive research on the cyanidation of gold ores was conducted, and in the 1940s the treatment of nepheline syanite from Ontario for the production of alumina since no bauxite was available in Canada and there was interest to become independent of importing the ore.

**ELEMENTAL SULFUR FROM PYRRHOTITE**

In the 1950s there was a great demand for elemental sulfur. Researchers Downes and Bruce in 1955 discovered that the recovery of elemental sulfur from pyrrhotite was possible if acid were present in the slurry treated with oxygen at high pressure and at 130 °C:

\[
2\text{FeS} + \frac{3}{2}\text{O}_2 \rightarrow \text{Fe}_2\text{O}_3 + 2\text{S}
\]

Any nickel contained in the pyrrhotite can be recovered in the solution. The process was neglected for many years till applied in 2005 in Voisey Bay in the Canadian North when it was not possible to ship the concentrate to Sudbury for treatment in furnaces. This marks nickel recovery from sulfides by hydrometallurgical method. Nickel in the sulfide is found in solution.

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Chapter 5

Engineering Firms

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KILBORN ENGINEERING

Roland Kenneth Kilborn (1902–1959) (Figure 5.1) founded in 1947 Kilborn Engineering, the first major engineering firm in Canada that designed and built some of North America's largest mines and became an industry leader in gold milling, potash refining and uranium processing. Kilborn graduated from Queen's University in 1927 with degree in civil engineering.

Figure 5.1: Roland K. Kilborn (1902–1959).

After two decades of working and gaining experience at a variety of mining projects in northern Ontario, he formed the engineering firm that took part in Canada's uranium industry as well as Canada's coal mines and washing plants, and most of the country's asbestos mines and plants.
Kilborn Engineering also built most of Canada’s potash refinery capacity in Saskatchewan and New Brunswick. In addition, the company designed and built a number of gold mines and plants in North and South America. By 1982, the company had grown to more than 1,500 employees, with offices across Canada and in Denver, Colorado. It is now part of the SNC-Lavalin which built the largest autoclaves in the world [see Nickel in Madagascar].

**HATCH**

Hatch is one of the most successful Canadian metallurgical engineering firms in Canada. It was founded by Gerald G. Hatch (1922–2014) (Figure 5.2). The company has grown from six people in one office in Toronto in 1958 to over 11,000 employees in 65 offices worldwide. The company is owned by the employees. One of the recent achievements is the world’s largest tube autoclaves for processing Saudi Arabian bauxite to prepare alumina for aluminum production (Figure 5.3). Among the many donations offered by Hatch is the Hatch Centre at McMaster University in Hamilton, Ontario (Figure 5.4).

![Figure 5.2: Gerald G. Hatch (1922–2014).](image)
Figure 5.3: Tube autoclaves.

Figure 5.4: Hatch Centre at McMaster University in Hamilton, Ontario.
Chapter 6

Iron and Steel Industry

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INTRODUCTION

Steel production in Canada involves the use of blast furnaces, direct reduction processes, and ilmenite partial reduction in an electric furnace (Tables 6.1–6.2). Pelletizing of iron concentrates for direct reduction became an important technology in Quebec (Figure 1). The electric furnace was used for the metallized pellets as well for scrap (Figure 2). Also, bottom blown oxygen process for steel making,
invented in Canada, is used all over the world. The production of ferroalloys was a success story in Canada.

Table 6.1: Steel production in Canada.

<table>
<thead>
<tr>
<th>Source</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blast furnaces</td>
<td>60</td>
</tr>
<tr>
<td>Scrap</td>
<td>30</td>
</tr>
<tr>
<td>Direct reduction</td>
<td>15</td>
</tr>
<tr>
<td>Ilmenite</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

Table 6.2: Iron and ferroalloys plants in Canada.

![Table 6.2: Iron and ferroalloys plants in Canada.](image)

Figure 6.1: Iron and ferroalloys plants in Canada.
Scrap

On the average, the steel industry consumes 50% raw iron and 50% scrap. Steel scrap for steelmaking comes from two main sources (Figure 6.2):

- **Local.** This is scrap produced locally in a steelmaking plant during shaping. In a steel plant, about one third of the steel produced is returned as scrap.

- ** External.** This is old automobiles, farm equipment, railroad rails, ships, etc., that is purchased from outside sources.

![Figure 6.2: Top: steel industry based on ≈ 50% raw iron and ≈ 50% scrap; Bottom: steel industry based on scrap substitutes.](image)

The use of scrap in certain steelmaking processes is necessary because it is used to control the temperature in the converter during steelmaking. As a result of oxidizing the impurities in the pig iron, the temperature rises because of the exothermic nature of the reaction. To prevent the rapid deterioration of refractories, scrap is added to cool down the change.

A certain quantity of iron is produced by direct reduction methods. This iron is not produced in the blast furnace but in less expensive equipment such as a rotary kiln, a static bed, or a fluidized bed. It differs from blast furnace iron in being not subjected to melting, and is suitable as a substitute for scrap. Usually steel produced from such iron is made in electric furnaces.
THE BEGINNINGS

Charcoal iron works

In 1733 François Poulin de Francheville (1692–1733), a French merchant from Montreal, built the first furnace in Canada on the bank of Saint-Maurice River near Trois-Rivières located half way between Québec City and Montreal (Figure 6.3). The furnace was fuelled by charcoal to process local iron ore. Air was blown in the furnace by small bellows operated by a water wheel. The Saint-Maurice River is one of the largest tributaries of Saint-Lawrence River. The temperature of combustion in the furnace was not enough to melt the iron produced. Thus, a product called “bloom,” which was wrought iron mixed with slag, was obtained. This was removed from the furnace, hammered while hot to squeeze away the slag, then obtain a nearly carbon-free iron. This wrought iron was malleable and could be shaped into different forms. At the conquest of New France in 1760, the Forge passed to the British Government and was operated under military authorities until shut down in 1883.

Figure 6.3: Les Forges, half way between Quebec City and Montreal, was the first iron making plant in Canada. It is now a national historic monument

In the mean time other iron works started operation using charcoal, for example, the Marmora Ironworks, near Peterborough, Ontario began production in 1823 (Figure 6.4). It consisted of two charcoal-fired blast furnaces and a forge with two sets of water-powered hammers. In 1860 at Radnor, not far from the St. Maurice Forge, another furnace was also built.
Coke iron works

All charcoal operated furnaces were shut down when more efficient furnaces were erected in Ontario and Nova Scotia employing coke-fired blast furnaces. For example, in 1871 the Canadian Titanic Company built two blast furnaces at Saint-Urban, Charlevoix County in Quebec for the utilization of titaniferous iron ore and using coke (Figure 6.5).

MODERN IRON ORE PRODUCTION

The largest source of iron in Canada is in Labrador discovered in 1892. Two major companies in this region exploit the ore (Figures 6.6–6.11).

Iron Ore of Canada

Iron Ore of Canada was founded in 1949 in Montreal and operated Wabush mine in Schefferville. The hematite ore was first shipped
without treatment in the 1950s then in the 1960s a concentrator and a pelletizing plant were built in Labrador City. The pellets were transported to Sept-Îles and Pointe-Noire, where it was shipped to Contre-cœur for reduction in the Midrex process. In 1970 a concentrator was built in Sept-Îles but closed in 1981. In 1992 Mitsubishi became shareholder and in 2000 Rio Tinto acquires the main shares. A 575-km railway links Schefferville to Sept-Îles.

Figure 6.5: Saint-Urbain iron mines, coke oven beehives [top right of the picture], and two blast furnaces in 1873, about 110 km north of Quebec City.

Quebec Cartier Mining

Québec Cartier Mining Company was founded in 1957 by US Steel. It owned Fire Lake and Jeannine Lake open pit mines for specular hematite or speculrite which is dark silvery metallic colour. It produces more than 26 million tons of concentrates per year containing 66% Fe. The company built the town of Gagnon near Jeannine Lake, in 1963 to accommodate workers and families. Following the depletion of the Jeannine Lake mine in the late 1960s the company began to develop the Mont Wright mine which started in 1973.
The town of Fermont which is 24 km from Labrador City was created. The word is French contraction of Fer Mont, meaning Iron Mountain. The mine product is shipped to Port-Cartier where a pelletizing plant was constructed in 1977 by Sidbec-Normines, a society formed from Sidbec, British Steel Corporation, and Quebec Cartier Mining. The falling market forced the company to shut down its Fire Lake and Jeanine Lake plants in the mid 1980s. In 1989, US Steel sold the company to different investors and in 2005 Dofasco became the sole owner. The town of Gagnon was closed and its population moved to Fermont and Port-Cartier. In 2008 it became ArcelorMittal Mines Canada.

Figure 6.6: Transportation of iron ore from Schefferville to Sept-Îles and from Fermont to Port-Cartier.
Figure 6.7: Mining iron ore in Fermont 24 km from Labrador City.

Figure 6.8: Transporting iron ore from Fermont to Port-Cartier.
STEELMAKING

Dominion Iron and Steel

Dominion Iron and Steel was founded in 1899 by the American businessman Henry M. Whitney (1839–1923) (Figure 6.12) at Sydney, NS. He had already formed the Dominion Coal Company in 1893 in Cape Breton and envisioned a local steel plant as the ideal outlet for coal. Limestone was also available in Newfoundland. Sydney harbour also provided a shipping outlet to the world. Construction was finished in 1901 and it was the most modern steel plant in the world with a battery of 400 coke ovens capable not only of producing coke, but also of recovering saleable by-products such as tar, benzene, and industrial salt. It had four blast furnaces and ten open hearth furnaces. Sydney coal-field supplied more than 44% of Canada’s coal production and iron industry produced more than one-third of the country’s pig iron.
Figure 6.10: Pelletizing plant.
Two Bessemer converters were added in 1907 in an attempt to deal with the low grade iron ore and the high sulphur coal. The company had been a constant money loser but this situation improved when a domestic market developed for its rails. Whitney then sold out the steel and coal companies to a Canadian consortium in 1909.
These two companies merged under the name Dominion Steel Company. The company expanded later by adding more blast furnaces and coke ovens. World War I was a major boom. In 1920, the British Empire Steel Corporation acquired all assets of the company.

By now the steel industry was in a recession. The plant was shut down and the massive layoffs triggered violent strikes. By 1927, the company collapsed into bankruptcy. The plant was operated for two years because of government subsidies which attracted new investors. In 1929, a British consortium took over and was called the Dominion Steel and Coal Company. The start of World War II in 1939 signalled a boom cycle. In 1942 a 10-ton electric arc furnace was introduced for the manufacture of speciality steel. Oxygen lancing was introduced into the open hearths, which reduced the time needed to produce a heat by half. Also, the Wabana Mines were closed in 1966 and a much higher grade of iron ore was imported from Quebec.

During the 1960s there was massive layoffs and closure of operations. By 1967 the plant was losing money. In January of 1968, the plant became the property of the Provincial Government of Nova Scotia and became known as the Sydney Steel Corporation.

A continuous caster was commissioned in 1975 as part of the modernization. By 1982 the plant was in financial difficulty. On May 22, 2000, the lack of a legitimate buyer closed the Sydney Steel Corporation.
Algoma Steel

Founded in 1901 in Sault Sainte Marie, Ontario on the St. Marys River by the American businessman Francis H. Clergue (1856–1939) (Figure 6.13). Bessemer converter was put in operation using pig iron made from the Helen mine but it had to import coal and coke from the United States. Initially the company specialized in manufacture of rails for Canadian railways. Algoma currently is the second largest steel producer in Canada. In 2007, it was purchased by India’s Essar Group continuing operations as Essar Steel Algoma Incorporated.

Iron and Steel Company of Canada

Stelco (Figure 6.14) is a steel company based in Hamilton, Ontario founded in 1910 from the amalgamation of several smaller firms by the Canadian banker William McMaster (1811–1887) (Figure 6.15). Coke was produced in retorts, iron pellets were charged into blast furnace. By 1910 the Bessemer process was no longer in use. Hydrochloric acid was later used as pickle solution replacing sulfuric acid. Iron and steel production grew slowly until World War II and then rapidly as the post-war economic boom created a tremendous demand for steel. It filed for bankruptcy in 2007 and was bought by US Steel. The Hamilton plant has not produced steel since 2011, but its coke ovens and cold rolling finishing works remain in operation. Market conditions caused a shut down permanently on December 31, 2013.

In World War I Stelco produced shell steel and invested in mining operations. In World War II it supplied steel for land transport vehicles as well as thousands of navy ships and cargo vessels. Stelco became Canada’s largest producer of cold drawn steel during the 1960s. In the 1990s, Stelco faced competition from Japanese-owned auto assembly plants in southern Ontario. It continued on for almost 100 years, until it filed for bankruptcy in 2007 and was bought by US Steel and renamed US Steel Canada. Stelco was one of the first to use hydrochloric acid for pickling steel.
Dominion Foundries and Steel

Dominion Foundries and Steel, now known as Dofasco, was founded in 1912 by Clifton Sherman (1872–1955) (Figure 6.16) and his brother Frank Sherman (1887–1967) (Figure 6.17) sons of an American blast furnace and steel mill superintendent. It introduced the Basic Oxygen Process to North America in 1954 and since then the open-hearth process steadily declined, and none are in use today. Dofasco, the major shareholder of Québec Cartier, was bought by
Arcelor Mittal the world’s largest steel producer. This made Québec Cartier one of the leading mining facilities of the world biggest steel producer. Dofasco, in 1999, was the most profitable steel producer in North America.

Atlas Steel

The Welland facility in Ontario was originally constructed in 1918 by Dillon Crucible Steel Alloy to produce high tensile tool steel. In 1920 the Atlas Crucible Steel purchased the company. The facility was acquired by Roy H. Davis and Daniel W. Lanthrop in 1928 and operated under the name Atlas Steel. Subsequently it was expanded to include a rolling mill and other speciality steel production (Figure 6.18).

In 1939 the Canadian government invested heavily in the facility to produce steel for World War II and by 1948 it was regarded as the largest speciality steel company in the British Commonwealth. In 1963 Rio Algom purchased the company until 1985 when the facility was a stand alone company as Atlas Specialty Steels being the largest producer of stainless steel in Canada.
In 1989, it was acquired by SAMMI Corporation, a South Korean steel products manufacturer. In 2000 Atlas Steels including the Welland and Tracy facilities were sold to Slater Steel. In 2006 MMFX, acquired the Welland facility. In 2010 ASW Steel possessed all of the assets previously held by MMFX. Atlas Steel plant in Tracy was closed in 2004.
Atlas Steel in Welland, Ontario was the first in 1954 to adopt continuous casting in North America (Figure 6.19).

![Figure 6.19: Atlas Steel in Welland, Ontario was the first in 1954 to adopt continuous casting.](image)

**QIT Fer et Titane**

For iron and steel production at QIT Fer et Titane see Chapter 15 on ilmenite.

**Quebec Metallic Powders**

Next door to QIT Fer et Titan is Quebec is Metallic Powders established in 1968 to produces iron powder by spraying water on a stream of molten iron obtained from QIT (Figure 6.20).
Midrex process

Sidbec-Dosco in Contrecoeur near Montreal (Figure 6.21) was established in 1968 by the Québec Government. It receives iron ore pellets from Sept-Îles and reduce them in shaft furnaces where fuel was produced by reforming natural gas (Figures 6.22–6.23). Silica content is very critical: if high it sinters and blocks the descending flow of minerals. The electric furnaces convert this metallic charge together with scrap into liquid steel. Two continuous-casting machines solidify the liquid steel into steel slabs and billets. This is the only direct reduction plant in Canada.
Figure 6.21: Midrex plant in Contrecoeur.

Figure 6.22: Midrex plant in Contrecoeur, Quebec.
OXYGEN FOR THE STEEL INDUSTRY

LD process

After World War II intensive research was underway to intensify melting of steel scrap generated during the war. Researchers at the Vereinigte Österreichische Eisen- und Stahlwerke abbreviated (VÖEST) in Linz in Austria came up in 1955 with the oxygen lance top blowing technology the so-called Linzer Düsenverfahren (Linz Lance Technology) or LD process, which had enormous advantages. The plant was built by the Germans before the war and originally named the Hermann Göring Works. After the war, it was considered a German property and was confiscated by the Occupying Forces, later became an Austrian nationalized industry. The process developed there was adopted worldwide. As a result, the demand for oxygen increased and oxygen production plants were installed at the steelworks. The process, however, had the disadvantage of being noisy and generating much extremely fine dust.

In spite of all the advantages of top blowing technology, it was felt that the bottom oxygen-blowing was superior for the following reasons:
The reaction time is shorter because of the increased volume of oxygen that can be introduced into a batch.

The slag formed does not hinder the flow of oxygen as in the case of top blowing.

Less iron evaporates and consequently the amount of brown smoke is minimal, and the iron losses are reduced.

Reduced iron losses by splashing from the converter because of the reduced volume of gases passing through it. This, together with the previous point are responsible for 1–2% increased production.

All attempts to use pure oxygen in bottom-blowing were unsuccessful because of the high temperature involved, which resulted in the destruction of refractories.

Research in Canada

In 1939, Air Liquide Canada member of the Air Liquide Group, headquartered in Paris hired Guy Savard (Figure 6.24), a young graduate from the Royal Military College in Kingston, Ontario as a welding engineer in its Montreal branch. When the Nazi troops invaded France, directors of the Air Liquide left Paris and settled in Montreal. They expanded the Montreal Branch and gave it special attention after the war.

Figure 6.24: Guy Savard.  
Figure 6.25: Robert Lee.
In 1947 the company hired a young graduate from McGill University, Robert Lee (Figure 6.25), as a research assistant in metallurgy. His assignment was to keep Air Liquide in contact with the Canadian iron and steel industry. In 1950, Savard became director of a new department at Air Liquide called Industrial Gas Applications to which Robert Lee was also attached. The knowledge that nitrogen not only plays no role in oxidation processes, but also it decreases the efficiency of combustion, Lee persuaded steel companies to use oxygen instead of air. For example, oxygen was introduced at the burners in the open hearth furnaces and into lances to accelerate the refining. This technology was adopted by steel companies and also extended to other Canadian industries such as pulp and paper industry, in rotary kilns in cement manufacture, and in glass-making furnaces.

In 1963, Savard and Lee built experimental vessel using bottom oxygen blowing (Figure 6.26) where 150 kg of molten iron was used. Figure 6.27 shows the oxygen trailer used to handle oxygen. After months of reflection Lee decided to use a shrouded injector with natural gas as the protecting gas (Figure 6.28). It was argued that hydrocarbons crack readily at a temperature of about 800 °C and therefore the heat absorbed for cracking should result in cooling the tip of the nozzle. Contacts were made with many steel companies but nobody was interested.

Maximilianhütte

In the fall of 1967, Karl Brotzmann, Director of Research for Eisenwerk-Maximilianhütte in Sulzbach-Rosenberg near Nürnberg in Germany having learned of these activities in bottom blowing, requested a meeting. This company was facing difficulty in smelting its ores. A metal of high phosphorus and silicon contents refined by Thomas process had the disadvantages of high nitrogen content and a low scrap rate. It was impossible to process this iron by the LD process because lime injection was not possible through the oxygen lance. The meeting took place in Montreal in October, 1967. This led to a license agreement which enabled the company to develop the process to the full industrial scale. This process became the major steelmaking process and became known as Q-BOP, i.e., the Quiet Basic Oxygen Pro-
cess because the consumption of oxygen takes place quietly during blowing.

Figure 6.26: Experimental vessel.

Figure 6.27: The primitive oxygen trailer used to handle oxygen.
FERROALLOYS

Due to the cheap electric power, Quebec became the centre of ferroalloys by electric furnaces (Figure 6.29). Ferrosilicon, ferromanganese, and ferrochromium are produced by reducing the corresponding oxide with coke. In the case of the reduction of silica sand at SKW in Bécancour, Quebec it was found that silicon monoxide, SiO, volatilized then oxidized to very fine SiO$_2$ in the recovery system. Such fine silicon dioxide found application in the concrete industry. Ferroalloys produced in electric furnace are expanding greatly while production in blast furnaces is decreasing. For Ferroniobium see Chapter 17 on Niobium and Ferroniobium

SUGGESTED READINGS

Figure 6.29: An electric furnace under construction in 1973 at the Union Carbide plant at Beauharnois in Quebec showing the 3-metre diameter openings at the top for the carbon electrodes.
Chapter 7

Alumina and Aluminum Industry

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ALUMINA

Although Canada is the third largest producer of aluminum in the world, all its alumina is imported except one plant in Saguenay which is producing alumina from bauxite imported from Jamaica. Any attempt to recover alumina from silicates by hydrochloric acid cannot compete with bauxite using alkaline solution because of the low tenor of aluminum in the raw material as compared to bauxite and the ease with which aluminum hydroxide is recovered from the basic solution (Figure 7.1). Orbite in Cap Chat in Quebec tried to obtain alumina from clay but after 5 years operation and spending $127 million has announced bankruptcy and suspended operation in 2017.

Figure 7.1: Alumina production from clay. Orbite process.

ALUMINUM INDUSTRY

The aluminum industry was first established in Canada in Shawinigan, Québec in 1901 by the Northern Aluminum Company (now Alcan Aluminum). Over the next 5 decades, Alcan established a network of smelters and an alumina refinery in Québec and one smelter in British Columbia (Figure 7.2). The availability of abundant
hydroelectric power led to the establishment of the aluminum industry in Canada. Canada is the world’s fourth largest producer of aluminum, after the US, Russia and China.

Figure 7.2: Aluminum plants in Canada. All plants are in Quebec except Kitimat in British Columbia.

Søderberg electrodes which caused pollution were replaced by prebaked electrodes (Figure 7.3), fluorine capturing systems were added (Figure 7.5), and pollution problems were solved by installing gas scrubbing systems (Figure 7.6).

**Alcan Research Laboratory**

Alcan Research Department (Figures 7.7–7.9) in Kingston was directed by Dr. Peter McGeer was in operation in the 1980s but it was closed few years later.
Figure 7.3: Prebaked electrodes.

Figure 7.4: Söderberg electrode.
Figure 7.5: Fluorine capturing systems.

Figure 7.6: Gas scrubbing system.
Figure 7.7: Alcan Research Department.

Figure 7.8: Alcan Research Department.
Figure 7.9: Alcan Research Department.

REFERENCES


INTRODUCTION

The International Nickel has its origin in 1902 when Orford Copper Company in Orford, Province of Quebec was merged with Canadian Copper in Sudbury and the new company acquired in 1928 the Mond Nickel Company — a British firm also active in nickel production in Sudbury. Processing revealed that the ore was also rich in nickel. Orford Copper Company had devised a process for the refining of nickel using sodium sulfate waste product from a nitric acid plant treating sodium nitrate with sulfuric acid. The International Nickel was first based in New York then moved to Toronto. It created a Research Department in Toronto that many of the innovations in nickel metallurgy over the next 50 years can be traced to this effort.
INCO NICKEL YARD

Destruction of vegetation

The destruction of vegetation in Sudbury was due to cutting of trees and emission of sulfur dioxide in the environment by operating the nickel sulfide roasting yards for 40 years from 1889 to 1929 (Figures 8.1–8.2). Trees were cut, wood was laid on the yard on which the ore was stacked. When the wood was ignited pyrrhotite burned emitting \( \text{SO}_2 \) for about six months. The residue was then collected and smelted to a nickel–copper matte from which nickel and copper were obtained.

Figure 8.1: Trees were cut, wood was laid on the yard on which the ore was stacked.

Figure 8.2: Sulfur dioxide emitted for about six months.
ORFORD PROCESS

The separation of CuS$_2$ from Ni$_3$S$_2$ obtained from the Sudbury ore by matte formation was a problem since its discovery. The Orford process also known as tops and bottoms process, based on fusion with sodium sulfide was used for 60 years from 1890. It was based on the fact that Cu$_2$S is soluble in molten Na$_2$S while Ni$_3$S$_2$ is practically insoluble (Figures 8.3–8.6).

Figure 8.3: The system Cu$_2$S–Na$_2$S.

Figure 8.4: The system Ni$_3$S$_2$–Na$_2$S.
Figure 8.5: The Orford Process.

Figure 8.6: Orford process or tops and bottoms process.
COOLING OF BINARY SULFIDES PROCESS

In 1950 it was replaced by slow cooling of the binary sulfides followed by grinding then a more economical flotation process (Figure 8.7). It was also possible to separate an alloy containing the platinum metals.

Figure 8.7: Separation of CuS₂ from Ni₃S₂ by slow cooling, grinding, and flotation.
FLASH SMELTING

The invention of flash smelting for copper concentrates by Outokumpu in Finland and INCO took place simultaneously in 1940s. It was based on the use of the heat generated by the oxidation of sulfides to melt the charge instead of using an extra fuel in a reverberatory furnace (Figure 8.8). The difference between the two was in some details but the principle was the same. The same furnace was adopted to treat copper–nickel sulfides using oxygen instead of air.

![INCO flash smelting furnace](image)

**Figure 8.8:** INCO flash smelting furnace.

TOP-BLOWN ROTARY CONVERTER

The company introduced in 1960s the Top-Blown Rotary Converter (Figure 8.9) to convert directly nickel sulfide to metallic nickel instead of oxidation of nickel sulfide to oxide then reduction to metal thus shortening the treatment which is a great advantage:

\[ \text{Ni}_3\text{S}_2 + 2\text{O}_2 \rightarrow 3\text{Ni} + 2\text{SO}_2 \]

As a background to this technology in the case of nickel sulfide, the following difficulties are encountered:

1. Nickel oxide is insoluble in the metal sulfide phase and has a high melting point. Thus, it separates as a finely dispersed phase that
increases the viscosity of the bath and reduces the rate of mixing, causing the converting reaction to stop.

2. Metallic nickel is completely soluble in the metal sulfide phase; thus, it cannot be removed easily from the system, causing a shift in the reaction equilibrium toward product.

3. Metallic nickel has a relatively high melting point (1,455 °C); thus, a temperature of more than 1,600 °C is needed to keep the bath molten and easily agitated.

To solve these problems the nickel oxide must be mixed intimately in the sulfide phase and the bath must have as high a temperature as possible to keep metallic nickel in the molten state. This has been successfully achieved in 1960s by using a rotating reactor to enhance mixing of both phases and by using oxygen instead of air to maintain the necessary high temperature. Eliminating nitrogen reduces the heat lost from the system.

Figure 8.9: Top-blown rotary converter,
**CARBONYL PROCESS**

The pressure carbonyl process developed by INCO permitted the production of nickel carbonyl very fast at a higher temperature (Figures 8.10–8.11). The carbonyl process is used for refining nickel. Nickel carbonyl is very poisonous. Carbon monoxide gas reacts with nickel for form gaseous nickel carbonyl. By this method pure nickel powder is obtained.

\[ Ni + 4CO \rightarrow Ni(CO)_4 \]

**Figure 8.10:** Carbon monoxide gas reacts with nickel for form gaseous nickel carbonyl.

**ELECTROLYSIS OF NICKEL SULFIDE**

Sulfides are semiconductors and conduct the electric current. At Thompson Refinery in Manitoba INCO cast nickel sulfide white...
metal into anodes and by electrolysis it was possible to get pure nickel at the cathode and elemental sulfur at the anode:

Anodic reaction: \( \text{Ni}_3S_2 \rightarrow 3\text{Ni}^{2+} + 2S + 6e^- \)

Cathodic reaction: \( \text{Ni}^{2+} + 2e^- \rightarrow \text{Ni} \)

Thus, it would be possible to recover the metal and the sulfur directly in one step, instead of roasting the sulfide to oxide, reduction of the oxide to metal, and then casting the metal in form of anodes for electrolytic refining. In this direct electrolysis it is possible to recover the sulfur in the elemental form instead of emitting it in the form of \( \text{SO}_2 \).

**PURE NICKEL BY ELECTROLYSIS**

INCO developed a purification step to prepare pure nickel by electrolysis in a diaphragm cell. To keep impurities at a tolerable level a calculated volume of the electrolyte is continuously bled to a purification circuit. The purified solution is returned to the cathode compartment, which is separated from the anode by a porous diaphragm in the form of a box enclosing the cathode, at such a rate that a hydrostatic head of solution builds up relative to the rest of the electrolyte (Figure 8.12). This prevents impurity ions from diffusing into the cathode compartment.

Figure 8.12: Introducing the purified solution in the cathode compartment of diaphragm cell.
PRESSURE LEACHING OF NICKEL SULFIDE

With the discovery of the Voisey Bay sulfide deposits in the Canadian North it was decided in 2005 to use a pressure leaching process to produce elemental sulfur instead of $\text{SO}_2$ (Figures 8.13–8.14). The decision was made because the Government of Newfoundland refused that the concentrate be shipped outside the Province. This is the first acid pressure leaching process for nickel sulfides and was originally developed at the Mines Branch in Ottawa by Downes and Bruce in the 1950s. The sulfide concentrate is mainly pendlandite–pyrrhotite containing 1.6% nickel.

AMMONIA LEACHING IN NICKEL METALLURGY

In 1960s INCO built an ammonia leaching pilot plant. In this plant, nickel sulfide concentrate containing about 0.8% Ni was roasted to oxide, the oxide reduced to metal, and the metal was leached with ammonia to get a solution from which nickel oxide containing 80% Ni was precipitated (Figure 8.15). The plant was operated for nearly a year when it was shut down because it proved to be uneconomical.

Figure 8.13: Pressure leaching process for treating the Voisey Bay concentrate.
Figure 8.14: Nickel sulfide pressure leaching plant under construction at Argentia in Newfoundland.

Figure 8.15: INCO ammonia leaching pilot plant for pyrrhotite.
SUDBURY

The International Nickel became known as INCO then Vale is a pioneer in many extractive metallurgy processes that is became the world capital of nickel (Figure 8.16). It produced coins made of nickel (Figure 8.17).

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Figure 8.16: 200 years nickel in Sudbury [1751–1951].
Figure 8.17: Five cents made of nickel.
Chapter 9

COMINCO

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INTRODUCTION

In 1906 the Consolidated Mining and Smelting Company of Canada was formed by the amalgamation of several units controlled by the Canadian Pacific Railway to exploit Sullivan mine in Kimberley, Trail, British Columbia. It produced lead, zinc, silver, and tin in 1909. It changed its name to Cominco in 1966. It was purchased by Teck in 2001 (Figure 9.1).

LEAD REFINING

In 1902 Cominco was the first to use the Bett’s process for lead refining. The electrolyte for this process is a mixture of lead fluorosilicate (PbSiF$_6$) and hexafluorosilicic acid (H$_2$SiF$_6$) operating at 45 °C. Cathodes are thin sheets of pure lead and anodes are cast from the impure lead to be purified. A potential of 0.5 volts is applied. At the anode, lead dissolves into solution, as do metal impurities that are less noble than lead. Impurities that are more noble than lead, such as silver, gold, and bismuth, dissolve and settle to the bottom of the vessel as anode mud. Pure metallic lead plates onto the cathode, with the less noble metals remaining in solution. Because of the high cost of electrolysis, this process is used only when very pure lead is needed.
WORLD WAR I

Consolidated Mining & Smelting Company in Trail, British Columbia together with Anaconda in USA introduced during World War I the leaching–electrowinning process for zinc to replace the retort process which was uneconomical (Figure 9.2). Incidentally, the process was replaced in the 1980s by the pressure leaching process referred to earlier.

WORLD WAR II

In World War II 6 tonnes/year electrolytic heavy water plant started operation in 1943 (Figure 9.3). Heavy water constitutes only one part in 4 500 in ordinary water. The production of heavy water by electrolysis is based on the fact that $\text{H}_2\text{O}$ breaks apart more readily than $\text{D}_2\text{O}$, and the residual water left after electrolysis is relatively rich in $\text{D}_2\text{O}$. By reprocessing the residual water over and over again, it was possible to eventually isolate heavy water. This was Canada’s contribution to Manhattan project for the fabrication of an atomic bomb in USA. Heavy water is used in nuclear reactors as a moderator to slow down neutrons.
Figure 9.2: The retort process [left] was replaced by the hydro-metallurgical process [right] during World War 1.

Figure 9.3: Plan for heavy water production at Trail.

**Elimination of the Multiple Hearth Furnace**

Cominco engineers made the discovery that in the multiple hearth furnace invented in the 1880s that if the intermediate hearths were
removed, the productivity of the furnace increased (Figure 9.4). This paradox is due to the fact that the rate of a solid–gas reaction on the hearth is low and most of the reaction takes place when the sulfide particles descend from one hearth to the next as it becomes completely surrounded by air. As a result, the flash oxidation reactor was introduced in the 1940s in which the sulfide concentrate was simply sprayed in a co-current flow with preheated air in an empty chamber (Figure 9.5). This was the basis of the fluidized bed concept invented in Germany in which the finely divided sulfide particles were introduced counter-current to the air flow in such a way that they were kept in a suspended state in a certain region in the reactor like a boiling liquid.

Figure 9.4: When the middle hearths were removed from a hearth furnace, the productivity of the furnace increased.
Figure 9.5: Flash oxidation reactor: co-current flow of sulfide concentrate and preheated air (products are not melted).

**QSL versus Kivset**

The company in 1966 became known as Cominco. It used QSL reactor for few years to produce lead (Figure 9.6). QSL is named after Paul Queneau, Reinhardt Schumann, and Lurgi Company in Germany who developed the process. The reactor is a 40-metre long horizontally laid brick-lined cylinder with slightly inclined bottom part that can be tilted 90° in case of interruption of operation. At one end of the reactor, oxygen is introduced at the bottom through nozzles protected by natural gas (the oxidation zone) and at the other end a reducing atmosphere is maintained through pulverized coal–air injection. The pelletized concentrate and flux mixture is introduced at the
top of the oxidation zone where the conversion reaction takes place. Lead bullion separates at the bottom while a PbO-rich slag forms as a top layer. Before tapping, the slag is depleted of its PbO content by the reducing atmosphere in the reduction zone. The lead that separates in this zone migrates by gravity to join the bullion initially formed in the oxidation zone. Industrial operation of this process is at present in South Korea and China. However, the engineers were unable to operate the American plant and as a result they scrapped it and used the Russian technology known as Kivset (Figure 9.7).

Figure 9.6: QSL-lead plant. This process incorporates a flash smelting furnace to which an electrically heated section is attached where the metal content in the slag can be reduced by adding coke. Lead bullion is produced directly from a variety of lead-zinc raw materials such as: lead sulfide concentrate, lead-zinc sulfide concentrate, residues from zinc leaching plant containing zinc and lead. Part of the zinc in the raw material volatilizes and is recovered in the dust collecting system. The remainder is recovered from the slag by fuming. Kivset is a Russian acronym for oxygen flash smelting.
COPPER PROCESS

CESL chalcopyrite process was developed by Cominco Engineering Services Limited in Trail. It is used in Brazil by Companhia Vale do Rio Doce known as CVRD. The process is in two leaching steps: the first step in dilute sulfuric acid containing NaCl and oxygen at 150 °C. The conditions are so chosen to be less corrosive; thus at pH 3 chalcopyrite is decomposed forming copper sulfate hydroxide, ferric oxide, and elemental sulfur. After solid–liquid separation, the solids are subjected to a second stage leaching at atmospheric pressure and pH 1.8 to selectively dissolve the copper sulfate hydroxide. Copper sulfate solution obtained is then extracted by organic solvents and the strip solution electrolysed to produce copper cathodes (Figure 9.8).
Figure 9.8: CESL process.

REFERENCES


INTRODUCTION

The name “Noranda” is a combination of the words “North” and “Canada.” Noranda Mines was founded in 1922 by James Y. Murdoch (1880–1962) (Figure 10.1) to exploit the Horne copper deposit, discovered by Edmond Henry Horne (1856–1953) (Figure 10.2) on mineral claims he staked in 1920.
COPPER

Extraction of copper began in 1927. In 1955 it opened the Gaspé Copper Mines. In 1995 Noranda gained control of Brunswick Mining and Smelting in New Brunswick and entered in Latin America, In 2002 it opened a large aluminum foil plant in Tennessee. In 2005 Noranda completed a merger with Falconbridge and the combined company continued under the name Falconbridge. In less than a year, the new company was acquired by Xstrata In 2013 ownership of Xstrata was fully acquired by Glencore.

Copper Smelter in Murdochville

Noranda closed in 2002 its copper smelter in Murdochville, Quebec (Figure 10.3) because the ore deposit exploited since 1950s was depleted.

![Copper smelter in Murdochville.](image)

Figure 10.3: Copper smelter in Murdochville.

TECHNOLOGY CENTRE

Noranda Technology Centre in Pointe-Claire near Montreal was opened in 1970. It closed in 2002 (Figure 10.4).
Noranda developed a process for recovery of copper in one reactor (Figure 10.5). However, the process was abandoned because of rapid deterioration of refractories. In this process the reactor is similar to a conventional Peirce–Smith converter with the exception of the raised hearth in the slag reduction and settling zone. The vessel can be tilted to expose the nozzles in case the air flow is interrupted. Feed is introduced continuously while copper and slag can be tapped continuously or intermittently. As the concentrate melts, slag and matte layers are formed. The matte is continuously injected with an air stream through nozzles. At this stage, FeS in the matte is oxidized to FeO and combines with silica in the slag which exists above the matte at all times. About half way along the reactor, the matte is converted to white metal. Under a strong oxidizing atmosphere, a copper-rich (98 to 99% Cu) phase is formed in the copper-settling section of the vessel. Slag layer flows past the copper settling zone into the slag-treating area where reducing gases are introduced through another series of nozzles, and pyrite and pyrrhotite are added to the surface of the bath to decrease its copper content. As conceived the process suffered from two drawbacks:

- Raw copper produced contains 1–2% S, which is removed in a Peirce–Smith converter by blowing with air. Gases leaving this reactor contain low concentrations of SO$_2$, which cannot be economically recovered thus emitted to the atmosphere.
The amount of copper in the slag is appreciable. Although it is separated by flotation and recycled, it represents a heavy load: for the recovery of 1 ton of raw copper, about 1/2 ton of copper must be recovered and recycled.

- Arsenic elimination was not possible and this caused troubles in the electrolytic refining.

The process was later modified to produce a high-grade matte and in this respect it has an advantage over a flash smelting furnace in its compactness and in accepting a more coarse feed.

![Figure 10.5: Noranda reactor.](image)

**Copper Refinery**

In 1931, the company opened the CCR refinery in Montreal East, which processes all the copper produced by the Horne smelter (Figure 10.6) the largest in the world. It also produces copper sulfate for agricultural purposes (Figure 10.7).
Anodic slimes

Anodic slimes remaining in the cells after copper electrorefining are treated to recover gold, silver, selenium, and tellurium beside pure copper. Baking with sulfuric acid was used for a long time, e.g.,:
The problem with this process is the formation of SO$_2$. Pressure leaching at 125 °C was then used in which selenium was volatilized and recovered while tellurium was recovered from solution:

\[
\text{Cu}_2\text{Se} + 4\text{H}_2\text{SO}_4 \rightarrow 2\text{CuSO}_4 + \text{Se} + 4\text{H}_2\text{O} + 2\text{SO}_2
\]

\[
\text{Cu}_2\text{Te} + 4\text{H}_2\text{SO}_4 \rightarrow 2\text{CuSO}_4 + \text{Te} + 4\text{H}_2\text{O} + 2\text{SO}_2
\]

Further development led to the use of oxidation of anodic slimes in top-blown rotary converter to get directly doré metal. Gases evolved during this treatment are collected for selenium and tellurium recovery.

**ZINC**

In 1963 Noranda founded the Canadian Electrolytic Zinc in Val-leyfield, Quebec which later became known as CÉZinc then pur-\[\text{Cu}_2\text{Se} + 4\text{H}^+ + \text{O}_2 \rightarrow 2\text{Cu}^{2+} + \text{Se} + 2\text{H}_2\text{O} \]
\[\text{Cu}_2\text{Te} + 2\text{H}^+ + \frac{5}{2}\text{O}_2 \rightarrow 2\text{Cu}^{2+} + \text{TeO}_4^{2-} + \text{H}_2\text{O} \]

For the production of magnesium from asbestos tailings, see “Asbestos.”

**REFERENCES**


INTRODUCTION

Falconbridge started in 1928 as a subsidiary of Ventures Limited and a local mining and smelting company in the Sudbury district (Figure 11.1). It was named after the town Falconbridge in Ontario which in turn was named after Sir William G. Falconbridge, High Court Judge whose father had migrated to Ontario from Lisburn in Ireland.

In Sudbury nickel–copper concentrate is smelted to a matte in an electric furnace. The matte is granulated and sent by rail to Quebec City, then shipped to Falconbridge in Norway for refining into pure metals. In 1929, the new company acquired the Kristiansand Nikkelraffineringssverk refinery in Kristiansand, Norway.

CHLORIDE PROCESS

Falconbridge Company developed a commercial process for the treatment of a mixture of Cu$_2$S–Ni$_3$S$_2$ obtained by smelting a copper–nickel sulfide concentrate: Ni$_3$S$_2$ is solubilized in concentrated HCl while Cu$_2$S is not. The leaching reaction is:

$$\text{Ni}_3\text{S}_2 + 6\text{HCl} \rightarrow 3\text{NiCl}_2 + 2\text{H}_2\text{S} + \text{H}_2$$

Cu$_2$S is separated by filtration for copper recovery, while NiCl$_2$ solution is first purified from dissolved H$_2$S by air oxidation and removal of the sulfur formed, then crystallized as NiCl$_2$·2H$_2$O. Since it is technically difficult to reduce NiCl$_2$ by hydrogen to nickel, the chloride is first calcined to NiO then reduced:
NiCl₂·2H₂O → NiO + 2HCl

NiO + H₂ → Ni + H₂O

Kidd Mine is an underground copper–zinc–silver mine in the city of Timmins, Ontario discovered in 1964 by the Texas Gulf Sulphur Corporation. It is owned by Glencore and operated by its subsidiary Kidd Operations. The mine was formerly owned by Xstrata Copper, Falconbridge, and Texas Gulf Sulphur. Ore from the Kidd Mine is processed into concentrate at the Kidd Metallurgical Site, located 27 km southeast of the mine, which until 2010 also smelted the ore and refined the metal produced. Following the closure of the majority of the Met Site, concentrate is now shipped to Quebec for processing.
The mine began operation in 1966, as an open pit mine and eventually evolved into an underground mine. The smelter started in 1981 and produced copper, zinc, cadmium, and indium. There are sulfuric acid plant and liquid sulfur dioxide for pulp and paper. It was the only Canadian company that used the Japanese process Mitsubishi (Figure 11.2). It was closed in 2010.

In the first furnace, the smelting furnace, melting of the charge is achieved. The matte and slag formed overflow to the second furnace by means of launders. Sulfur dioxide content in the gas leaving this furnace is 12–15%. In the second furnace, the slag furnace, which is an electric arc furnace, the matte is allowed to separate from the slag, to decrease its Cu content to 0.4%. Slag from this furnace is discarded, while the matte containing 65% Cu overflows to the third furnace. In the third furnace, the converting furnace, oxygen-enriched air is injected through lances and fluxes added to slag the iron, then convert the white metal to blister copper. Slag from this operation contains 13–18% Cu; it is usually granulated and then returned to the first furnace. Sulfur dioxide content in the gas leaving this furnace is 14–16%.

Figure 11.2: Mitsubishi process for copper production.
FALCONBRIDGE RESEARCH LABORATORY

Falconbridge opened two research laboratories: one in Toronto and one in Sudbury in 1954. The Norwegian refinery also has a research laboratory. Ventures also ran Lakefield Research [now SGS] as a commercial mineral processing laboratory near Toronto supporting their operations. The Toronto research facility was closed in the early 1980s but the Sudbury laboratory is still functioning but in a new building.

REFERENCES

Chapter 12

Sherritt Gordon Mines

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INTRODUCTION

Sherritt Gordon Mines (Figure 12.1) in Fort Saskatchewan, Alberta, is a pride of the Canadian metallurgical industry. It was founded in 1927 by Carl Sherritt, an American prospector, and J. Peter Gordon, a civil engineer who worked on railroad construction. The formation of the company was largely due to the efforts of Eldon Brown, a young mining engineer.

It built a refinery in 1954 to produce nickel and cobalt as well as ammonium sulfate, ammonium phosphate, and urea fertilizers. It is a progressive company had its success in the collaboration in the 1950s with the University of British Columbia and the Mines Branch in Ottawa. In 1957 Sherritt purchased Chemical Construction Corporation, in 1994 acquired fertilizer assets from Imperial Oil, in 1995 acquired nickel and cobalt from Cuba, in 2007 acquired Dynatec Mining Company, and in 2008 created Sherritt Technologies to licenses technology. There are more than 35 commercial plants worldwide that currently use Sherritt technology. It is also a consulting firm that built plants all over the world to produce nickel and cobalt from laterites as well as to liberate gold from refractory ores to be followed by cyanidation.
Figure 12.1: Sherritt Gordon Mines in Fort Saskatchewan, Alberta.

PRESSURE HYDROMETALLURGY

The company introduced modern hydrometallurgy in the world and specially pressure reactors (Figure 12.2).

Figure 12.2: Typical pressure reactor used by Sherritt.
Ammonia leaching process

The process (Figure 12.3) is used for treating concentrates of copper, nickel, and cobalt since they form soluble ammine complexes. The process has minimum corrosion problems and any pyrite present will not be attacked. The overall reaction is:

\[ MS + n\text{NH}_3 + 2\text{O}_2 \rightarrow [\text{M(NH}_3)_n]^2^+ + \text{SO}_4^{2-} \]

where M stands for Ni, Cu, and Co. Ammonium sulfate is a by-product; it is marketed as a fertilizer.

Precipitation under pressure

It precipitated nickel and cobalt directly from ammoniacal solution by hydrogen under pressure the first in the world by the reaction:

\[ M^{2+} + \text{H}_2 \rightarrow M + 2\text{H}^+ \]
Crystals of cobalt produced by this process are shown in Figure 12.4.

![Cobalt crystals precipitated from aqueous solution by hydrogen under pressure.](image)

**Figure 12.4:** Cobalt crystals precipitated from aqueous solution by hydrogen under pressure.

**Zinc industry**

Sherritt also introduced in the 1980s a zinc process that made the industry independent of the fertilizer industry (Figure 12.5). In one step the zinc concentrate was treated with sulfuric acid and oxygen in an autoclave to produce a solution of zinc sulfate which can be electrolysed to pure metallic zinc while elemental sulfur is produced during the leaching step thus no SO$_2$ and the necessity to make sulfuric acid:

$$\text{ZnS} + 2\text{H}^+ + \frac{1}{2}\text{O}_2 \rightarrow \text{Zn}^{2+} + \text{S} + \text{H}_2\text{O}$$

In the old method the sulfide ore was roasted, the calcine leached with sulfuric acid, and the zinc sulfate solution was electrolysed to get pure metallic zinc. Sulfur dioxide formed during the roasting step is transformed to acid which was always used to treat phosphate rock to produce fertilizer. The new process freed the zinc industry from the need to produce fertilizers.
Figure 12.5: Leaching of zinc sulfide concentrate in an autoclave.

**Laterites**

Sherritt designed the plant for nickel recovery by pressure leaching plant for laterites in Madagascar. The autoclaves (Figure 12.6) built by SNC-Lavalin were the largest in the world.

Figure 12.6: Autoclaves at Ambatovy in Madagascar.
**SHERRITT MINT**

Sherritt also was a pioneer in powder metallurgical applications. It produced by hydrometallurgical methods 5-cent nickel coins for Canada for 40 years (Figure 12.7) as well as the Canadian dollar from nickel covered by a thin layer of brass (Figure 12.8).

![Figure 12.7: Five-cent coin produced by Sherritt.](image1)

![Figure 12.8: One dollar produced by Sherritt.](image2)

**SHERRITT–COMINCO PROCESS**

In 1971 Sherritt Gordon and Cominco obtained financial support from the Canadian Government to develop a process for treating copper sulfide concentrates without polluting the environment. The process was developed and tested in a pilot plant during the period 1971–
1976 but never applied on commercial scale. It involves partial roasting of chalcopyrite concentrate then leaching the so-called activated product with dilute sulfuric acid. Hydrogen sulfide generated during this step is allowed to react with SO$_2$ formed during the partial roasting to form elemental sulfur. After a series of solution purification, CuSO$_4$ solution is electrolysed to get metallic copper. Evidently, the process is so complicated and there are more obvious and direct routes to get elemental sulfur and copper from chalcopyrite. As a result the process was abandoned.

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Chapter 13

Magnesium

THERMAL PROCESS

Lloyd Pidgeon (1903–1999) (Figure 13.1) is best known for the development of the process for the production of high-purity magnesium. He was born in Markham, Ontario, graduated in 1925 in chemistry from the University of Manitoba, and a Ph.D from McGill University in 1929. After several years at Oxford University, Pidgeon joined the National Research Council of Canada where he developed the process for the production of magnesium metal using the reaction between calcined dolomite and ferrosilicon:

$$4\text{MgO} \cdot \text{CaO} + 2\text{Si} \rightarrow 2\text{Ca}_2\text{SiO}_4 + 4\text{Mg}$$

Figure 13.1: Lloyd Pidgeon (1903–1999).
A group of prominent mining men from Toronto became interested in the project and raised capital that enabled Pidgeon to establish a pilot plant. Pidgeon’s discovery led to the formation of Dominion Magnesium, which he joined in 1941 as a director of research. The plant is now owned and operated by Timminco. Because of the demand for magnesium during the Second World War, six magnesium plants were built throughout North America. Magnesium was used for a variety of military efforts and was considered to be the metal of choice where strength with lightness was required, as for example, in aircraft. In 1943, Pidgeon was appointed professor and head of the department of metallurgical engineering at the University of Toronto, a post he held until his retirement in 1969.

NORSK HYDRO PROCESS

In Bécancour, just opposite to Trois-Rivières in the Province of Quebec on the western side of Saint Lawrence River, Norsk Hydro constructed a 40 000-t/y magnesium production plant in 1986 (Figure 13.2). It was the largest primary magnesium producer in the world based on the dissolution of imported magnesite, MgCO₃, in hydrochloric acid, evaporating the magnesium chloride obtained, and its electrolysis. It was shut down in 2006 because it was not able to compete with the Chinese companies at this time.

MAGCAN

The MagCan plant (Figure 13.3) north of High River in Alberta opened in 1991 at 30% of its capacity, with support from the Alberta government in an attempt to diversify the economy away from oil and gas when the price of natural resources declined sharply. It was based on chlorination of imported magnesite with chlorine and CO to produce MgCl₂ for electrolysis. It closed down after less than a year in operation. The company started its activity at a moment when the magnesium price was low. The Province provided a $103 million loan guarantee and 145 people lost their jobs.
Figure 13.2: Norsk Hydro magnesium plant in Bécancour, Quebec.

Figure 13.3: MagCan plant in Alberta.

MAGNOLA

See Chapter 25 on Asbestos.
Chapter 14

Equity Silver

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INTRODUCTION

Equity Silver mine is 64 km south of Houston in British Columbia was owned by Goldcorp headquartered in Vancouver operated from 1980 to 1994 when the mine exhausted. Equity Silver is now part of the greater Silver Hope Project (Figure 14.1) totally owned by Finlay Minerals founded 1999 in Vancouver.

Figure 14.1: Silver Hope in British Columbia.
REMOVAL OF ARSENIC AND ANTIMONY

The presence of arsenic and antimony in copper sulfide concentrates is undesirable because these metals complicate the smelting and refining of copper. As a result, there is interest in removing them before smelting. A copper sulfide concentrate containing 4% As and 7% Sb is treated by sodium sulfide. The finely divided concentrate is leached for 16 hours at 110 °C to solubilize arsenic and antimony sulfides:

$$\text{As}_2\text{S}_3 + 3\text{S}^{2-} \rightarrow 2\text{AsS}_3^{3-}$$
$$\text{Sb}_2\text{S}_3 + 3\text{S}^{2-} \rightarrow 2\text{SbS}_3^{3-}$$

After filtration, the copper concentrate is shipped to smelters. The plant was shut down in the 1990s.

REFERENCES

QIT Fer et Titane was founded in 1948 by Kennco Explorations, the Canadian subsidiary of the American Kennecott Copper to exploit the largest deposit of ilmenite in the world located at Lac Tio in the north of the Province of Quebec near Havre-Saint-Pierre. The deposit was massive ilmenite containing small amounts of pyrite contrary to the black sands usually found at the mouths of great rivers. Pilot tests were done by the New Jersey Zinc company of Palmerton, Pennsylvania. In 1950 the first electric furnace in Sorel was in operation and the scale of operations were increased later to nine furnaces to partially reduce ilmenite containing 36% TiO$_2$ to iron and titanium slag known as Sorelslag containing 72% TiO$_2$ (Figures 15.1–15.4). The slag was used to make TiO$_2$ white pigment.

Further development took place as follows:

- In 1976 the company constructed electric furnaces to exploit the rich black sands deposits at Richards Bay in Natal, South Africa to produce slag containing 85% TiO$_2$.
- In 1986 a steel plant was constructed to transform the iron produced into steel.
- In 1990 autoclaves were installed to upgrade the slag quality to 94.5% TiO$_2$ by pressure leaching with hydrochloric acid to remove calcium and magnesium. The technology of manufacturing Sorelslag was adopted before the hydrometallurgical route for making “synthetic rutile.”
• In 2005 QIT Madagascar Minerals owns and operates a mineral sands mining project near Fort Dauphin on the southeastern tip of Madagascar.

• In 2014 SO$_2$ removal plant was constructed by scrubbing the exit gases from the rotary kiln by hydrated lime.

Figure 15.1: QIT Fer et Titane electric furnace plant on the top left in Sorel, Quebec.

**Tioxide Canada**

Tioxide Canada was founded in 1962 in Tracy, next door to QIT Fer et Titane in Sorel, Quebec, where ilmenite was treated in electric furnaces to produce iron and Sorelslag. The company treated Sorelslag by concentrated sulfuric acid to produce pure titanium dioxide white pigment (Figures 15.5–15.6). The process produced ferrous sulfate and dilute sulfuric acid which was uneconomical to concentrate and recycle in the process. As a result the acid and ferrous sulfate were thrown in the Saint Lawrence River for many years. When the Prov-
ince of Quebec formed the Ministry of Environment in the 1960s it warned the industry from throwing the acid in the river. As a result the industry was shut down in the 1980s.

Figure 15.2: QIT Fer et Titane Sorelslag. SO₂ formed was later removed by scrubbing and the iron was transformed to steel.

Figure 15.3: Massive ilmenite, FeTiO₃ (59.4% TiO₂).

Figure 15.4: Ground titanium slag, FeTi₄O₁₈ (70–80% TiO₂).
It should be noted, however, that the largest producer of white pigment which is in Salvador, Brazil uses this process because the waste product is thrown away in the ocean. A solution to the sulfuric acid process was found later in Canada by treating the Sorel slag with concentrated hydrochloric acid at 80 °C to get synthetic rutile so that...
dilute HCl can be economically concentrated and recycled thus bypassing the electric furnace (Figure 15.7). Synthetic rutile can be treated by known methods to produce the white pigment as well as titanium metal.

REFERENCES

Chapter 16

Brunswick Mining and Smelting

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INTRODUCTION

The province’s name comes from the Braunschweig in German in Lower Saxony, the ancestral home of the Hanoverian George III of the United Kingdom. Belledune is one of the leading ports in Canada. Bathurst mines are located in the Heath Steele area. The mine is located 20 km southwest of Bathurst produces lead–zinc–copper ore. It belongs to Glencore.

Ore is ground in the semi-autogenous grinding mill followed by differential flotation, filtering, and drying. The products are lead and bulk concentrates, copper concentrates and zinc concentrates.

Zinc concentrate is shipped by rail to CEZinc, in Valleyfield, Quebec or shipped to smelters in Europe. Copper concentrate is shipped by rail to the Xstrata Horne copper smelter, in Rouyn-Noranda, Quebec. Lead concentrate is treated in Belledune, a deep-water port on the Atlantic Ocean. Flotation tailings are sent to the paste backfill plant for recovery to produce paste backfill for the mine. Residual tailings are sent to the tailings impoundment facility.

LEAD SMELTER

Brunswick Lead Smelter (Figure 16.1) is a primary lead/silver smelter in Belledune. The smelter is a sinter–blast furnace and refinery. The smelter separates out copper matte, antimony–lead alloys, silver–gold doré, and bismuth alloys in successive steps.
Sulfur dioxide produced during sintering is used to make sulfuric acid which is used to make phosphoric acid and ammonium phosphate. The phosphate rock is imported from Florida.

Since the mine has now closed, the smelter is transitioning to a custom smelter. It processes lead/silver concentrate, by-product from the zinc smelter and a variety of recycled materials including batteries.
Chapter 17

Pyrochlore and Ferroniobium

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PYROCHLOR

Carbonatites are igneous limestones — rare igneous rocks composed of calcite and dolomite (Figure 17.1). It contains the niobium mineral pyrochlore, (Ca, Na)$_{2-m}$Nb$_2$O$_6$(O, OH, F)$_{1-n}$·$x$H$_2$O. The lattice positions of sodium and calcium can also be occupied by barium, strontium, rare earths, thorium, and uranium. The ore contains 0.5–0.7% Nb$_2$O$_5$.

![Figure 17.1: Carbonatite containing pyrochlore, mica, and magnetite [black].](image)
SAINT LAWRENCE COLUMBIUM

The Saint Lawrence Columbium mine in Oka, Province of Quebec was one of the most important niobium mines in the world when it opened in 1961. A concentrate was prepared by Harvey L. Noblitt in Ottawa. Opposition from both the Mohawk community of Kane-satake and local farmers forced the mine to close in 1976. The Oka carbonatite complex contain some rare elements, including economic concentrations of niobium.

NIOBEC

The Société québécoise d’exploitation minière known as SOQUEM discovered niobium deposit in 1967 in the carbonatite of Saint-Honoré in the Saguenay region in Quebec Province. Teck mining group joined forces with SOQUEM, now called Niobec, to mine the deposit and production started in 1976. It is processed by physical methods involving magnetic separation, flotation, leaching of phosphates, filtration, and concentrate drying to produce a concentrate. Each ton of ore produces about 2.4 kg of Nb₂O₅ in form of concentrate containing about 60% Nb₂O₅. Niobium concentrate was sold world wide.

Since 1977 Niobec was owned by Cambior a Canadian gold producer. Ferroniobium contains 63–68% niobium was produced in 1994 by the aluminothermic process. The concentrate was mixed with aluminum powder, metallic iron, and sodium nitrate and in less than 10 minutes the exothermic reaction was complete when initiated. A typical load of 6 400 kg generates 2 400 kg of ferroniobium. Following a cooling period, the ferroniobium is crushed to sizes specified by various steel plants (Table ).

Table 17.1: Analysis of ferroniobium produced by Niobec.

<table>
<thead>
<tr>
<th>%</th>
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<tbody>
<tr>
<td>Nb</td>
<td>63–68</td>
</tr>
<tr>
<td>Al</td>
<td>2.0</td>
</tr>
<tr>
<td>Si</td>
<td>3.0</td>
</tr>
<tr>
<td>C</td>
<td>0.2</td>
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<tr>
<td>P</td>
<td>0.15</td>
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<tr>
<td>Ta</td>
<td>0.5</td>
</tr>
<tr>
<td>Ti</td>
<td>1.0</td>
</tr>
<tr>
<td>S</td>
<td>0.10</td>
</tr>
<tr>
<td>Mn</td>
<td>1.0</td>
</tr>
<tr>
<td>Sn</td>
<td>0.10</td>
</tr>
<tr>
<td>Pb</td>
<td>0.01</td>
</tr>
</tbody>
</table>
After a series of acquisitions by Marazin, Les Minéraux Séquoia, Iamgold, Magris Resources became the new owner in 2015.

NIOCAN

Established in 1995, Niocan is focused on financing, developing, and obtaining permits for its Oka Niobium Project and the Great Whale Iron property. Both projects are located in the Province of Quebec.

REFERENCES


INTRODUCTION

Canada produces about 200 tons of gold every year of which about 80% comes from 70 mines and the rest is by-product of copper and nickel production.

CYANIDATION PROCESS

Explanation of the cyanidation process was done in Canada when the effect of cyanide concentration and oxygen concentration were studied (Figure 18.1). This led to the establishment of the theoretical equation based on the formation of anodic and cathodic areas:

\[
\text{Rate} = \frac{2A \, \delta_{\text{CN}^-} \, \delta_{\text{O}_2} [\text{CN}^-] [\text{O}_2]}{\delta \{ \delta_{\text{CN}^-} [\text{CN}^-] + 4 \delta_{\text{O}_2} [\text{O}_2] \}}
\]

where \( \delta_{\text{CN}^-} \) and \( \delta_{\text{O}_2} \) = the diffusion coefficients of cyanide and dissolved oxygen, \( \cdot \text{cm}^2 \text{sec}^{-1} \), [\( \text{CN}^- \)] and [\( \text{O}_2 \)] = the concentrations of \( \text{CN}^- \) and \( \text{O}_2 \) in the bulk of the solution in mole/mL, \( \delta \) = the thickness of the boundary layer, in cm, and \( A \) = the total surface area of metal in contact with the aqueous phase.

At low cyanide concentration the term [\( \text{CN}^- \)] can be neglected in the above equation and the rate becomes: Rate = \( \delta_{\text{CN}^-} [\text{CN}^-] \) which agrees with the experimental data. If on the other hand at high cyanide concentration the term [\( \text{O}_2 \)] can be neglected in the above equa-
tion and the rate becomes: Rate = $\mathcal{D}_{O_2} [O_2]$ which again agrees with the experimental data.

**Figure 18.1:** Effect of cyanide and oxygen on the rate of dissolution of silver [Deitz and Halpern, 1953].

**BARRICK GOLD**

Barrick Gold Corporation is the largest gold mining company in the world, with its headquarters in Toronto. The Company has mining operations and projects all over the world. Peter Munk (born 1927) (Figure 18.2) founded the company in 1983, building it into one of Canada’s leading global corporations. He is a Hungarian Jew who came to Canada in 1948 and studied electrical engineering at the University of Toronto. Barrick used autoclaves to liberate gold from sulfide ores before cyanidation.

**Figure 18.2:** Peter Munk.
REFERENCES


Chapter 19

Uranium

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INTRODUCTION

The existence of uranium in outcrops along the shores of Great Bear Lake in northwestern Canada had been discovered in 1900 by a pioneering geological survey of the area. In 1931 Edgar A. LaBine (1890–1977) (Figure 19.1) announced that the extensive of pitchblende deposits included ores containing 30 to 60% uranium oxide. He developed the deposit under the name of Eldorado Gold Mines. The ore was rich in silver and cobalt. Radium at that time was selling at $120,000/gram and therefore the discovery was of great significance. A shaft was sunk and a gravity plant constructed; the site was named appropriately “Port Radium” (Figures 19.2–19.3).

Figure 19.1: Edgar A. LaBine (1890–1977).
A sample was sent to the Mines Branch in Ottawa and a process for separating radium was developed by R. J. Traill (Figure 19.4).
RADIUM PROCESSING

In 1933 LaBine found a place and a person to handle the complicated radium processing. The place was a converted seed plant on the waterfront of Port Hope, Ontario (Figure 19.5), and the person was Marcel Pochon (1883–1958), a former co-worker of Madame Curie who was the first manager of the plant. The reactions took place in glazed earthenware vessels manually agitated with wooden paddles. Buckets were used to add the seven tons of corrosive chemicals needed for every ton of 40% uranium concentrate to get 0.1 grams of radium. The production capacity of about two grams of radium/month was completed by the end of 1933 which more than doubled by 1938.
Important pitchblende deposits were discovered in what became known as Shinkolobwe in the Haut Katanga district of the Belgian Congo between 1913 and 1915. The Société Générale Métallurgique de Hoboken was formed to manage the plant at Olen near Antwerp. The high output from the factories at Olen and Port Hope rapidly forced down the price of radium, and in 1938 an agreement that divided up the world market and attempted to stabilize the price at $40,000/gram was negotiated by Belgium and Canada. After World War II radionuclides such as cobalt 60 and cesium 137 became available for radiation therapy sources. Today radium is classified as a waste and methods are devoted to fix it in a form suitable for long-term burial.

NEW BEGINNING FOR THE URANIUM INDUSTRY

During World War II many pioneers of the radium industry turned their attention to nuclear fission and its military applications. In 1940 Eldorado Gold Mines was quietly taken over by the government as a war industry. The Port Hope refinery began to produce uranium from old plant tailings and from concentrate brought in from
the Belgian Congo. By 1944, plans were completed for the establishment of the National Research Council facility at Chalk River, Ontario, the first step in the series of events that led to the formation of Atomic Energy of Canada and the development of CANDU reactor. In anticipation of an increased demand for uranium when World War II ended, the ban on private prospecting for it was lifted in 1947 and the boom was on.

In the meantime researchers from the Radioactivity Division of the Mines Branch, Department of Mines and Technical Surveys in Ottawa, from the Port Radium operations, and from the Uranium Extraction Section at Port Hope, tackled the problem of uranium recovery from the gravity plant tailing. A pilot plant to prove out the process started up at Port Radium in 1950 and the commercial plant began operations in 1952. In 1959, twenty three mines were supplying 12 000 tonnes of uranium annually.

A major development, however, was the finding of large uraninite deposits near Beaverlodge on the north shore of Lake Athabasca in Northern Saskatchewan. These discoveries, made by Eldorado, now a Crown Corporation, posed a problem because of the high calcite content of the ore, and the consequent excessive acid consumption. Researchers from Sherritt Gordon Mines, the University of British Columbia, from Port Hope, and from the Radioactivity Division of the Mines Branch developed the pressure carbonate leach with caustic precipitation of yellow cake. A mill was constructed, and the town of Uranium City was built to house the workers. The plant ran for nearly thirty years, closing down in 1982.

In 1953, geologists of Gunnar Gold Mines discovered another uranium ore body near Lake Athabasca and a mill went on-stream. In 1954, the Lorado discovery was made near Uranium City.

**PRESENT URANIUM INDUSTRY**

Rich uranium deposits were found in Saskatchewan (Figure 19.6) and as a result the uranium industry is well developed in Canada. Uranium refinery is still in Port Hope, Ontario. Leaching uranium ore with sodium carbonate was introduced in Canada when the ore con-
tained acid-consuming gangue. Uranium also occurs in phosphate rock but no attempt was carried out to recover it from this source.

Figure 19.6: Uranium processing plants in Canada.

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Other Metals

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INTRODUCTION

Usually a mine produces more than one metal. This is the case of Tanco mine on the northwest shore of Lac du Bonnet in Manitoba (Figure 20.1). It is an underground mine producing pollusite, spodumene, and tantalum minerals formerly owned by Tantalum Mining Corporation of Canada now owned and operated by Cabot Corporation. Cabot Corporation, founded in 1922 by Godfrey Lowell Cabot (1861–1962), an American company with headquarters in Boston, Massachusetts.

LITHIUM

Sociedad Química y Minera de Chile is the world's largest lithium carbonate producer from natural brines but lithium carbonate is also produced in Canada to meet the growing demand for electric and hybrid electric vehicles.
Canada Lithium Corporation

In La Corne Township, 60 km north of Val-d’Or (Figure 20.2), was located the Quebec Lithium Project, operated under Quebec Lithium Incorporated and owned 100% by Canada Lithium Corporation. Between 1955 and 1965, the underground mine of spodumene, Li₂O·Al₂O₃·4SiO₂, produced lithium carbonate for sale. RB Energy, formerly Canada Lithium Corporation, is building an open pit mine and processing plant near Val-d’Or for producing lithium carbonate.

Cabot Corporation

A spodumene concentrate about 7% Li₂O was produced by Tantalum Mining Corporation of Canada from Tanco mine in Manitoba now owned by Cabot Corporation since 1996.

Cesium

Tanco Mine owned and operated by Cabot Corporation on the northwest shore of Lac du Bonnet in Manitoba is producing pollucite. The mine has the largest known deposit of pollucite, (Cs,
Na\textsubscript{2}Al\textsubscript{2}Si\textsubscript{4}O\textsubscript{12}·2H\textsubscript{2}O, and is also the world’s largest producer of cesium. The ore contains 24\% Cs\textsubscript{2}O.

Figure 20.2: Val-d’Or, Quebec.

**TANTALUM**

Tantalum concentrates, 28\% Ta\textsubscript{2}O\textsubscript{5} was produced at Tanco mine since 1969 by Tantalum Mining Corporation of Canada established in 1967 in Lac du Bonnet, Manitoba. Pyrochlore concentrate from Niobec in Saint Honoré, Quebec contains about 0.3\% Ta\textsubscript{2}O\textsubscript{5}. It is not separated and remains in the ferroniobium produced; the alloy contains 0.5\% Ta or 2.44\% Ta\textsubscript{2}O\textsubscript{5}.

**MOLYBDENUM**

There are two sources of molybdenite, MoS\textsubscript{2}, in Canada:

1. A by-product of porphyry copper industry obtained by selective flotation.

2. Molybdenite occurring in quartz. The Endako mine (Figure 20.3) is the only mine in Canada of this type and one of the largest molybdenum mines in North America. It is located at Endako, British Columbia and opened in 1965.
Some of the molybdenum sulfide is further refined into a lubricant-grade and the rest is processed into molybdic oxide, MoO₃.

VANADIUM

In 1963, Petrofina Canada was interested in the recovery of vanadium from residues of a refinery treating Venezuelan petroleum. The residue was first transformed to coke which was burned in boilers; gases emitted in this process contained about 10% vanadium and some nickel. A hydrometallurgical process was developed and a plant was constructed two years later. There is currently no vanadium production or industry in Canada.

There is also substantial vanadium potential in the Athabasca tar sands, Alberta.

TUNGSTEN

Cantung is one of the largest operating tungsten mines outside of China. It is located in the Nahanni area of western Northwest Territories, about 300 km northeast of Watson Lake, Yukon (Figure 20.4). Prospectors discovered the mine in 1954. The ore contained 1.5% WO₃ in form of scheelite. In 1959, the Canada Tungsten Mining was
formed to acquire and develop the property. Production started in 1962 from an open pit.

Processing is carried out by gravity and flotation circuits producing a concentrate containing 65% WO₃ and a copper concentrate averaging 28% Cu. In 1965 the concentrate was leached by hydrochloric acid and the solution purified by ion exchange from which pure tungsten oxide was obtained. In 1997, North American Tungsten Corporation purchased the mine.

Figure 20.4: Cantung tungsten mine in Yukon.

ZIRCONIUM

Zirconium research was conducted at Eldorado Nuclear in a plant at Port Hope for producing zirconium tubes for the nuclear reactor. Zircon sand remains after recovery of tar sands.

RARE EARTHS

The pyrochlore deposit in the carbonatite of Saint-Honoré in the Saguenay region in Quebec Province contains rare earths. A concentrate contains about 0.8% rare earths. Currently, there is no rare earths production or refining in Canada.
THORIUM

The pyrochlore deposit in the carbonatite of Saint-Honoré in the Saguenay region in Quebec Province contains thorium. A concentrate contains about 1% ThO$_2$. Currently, there is no thorium production or refining in Canada.

TIN

For many years by-product cassiterite, SnO$_2$, has been produced from the Sullivan mine in Trail, British Columbia, where it is a minor constituent of lead–zinc ores. Yearly production amounts to a few hundred tons of tin. The Rio Algom tin mine in East Kemptville in Nova Scotia formerly owned by BHP Billiton and now owned by Avalon Rare Metals operated from the mid-1980s to 1992. At the time, it was North America’s only open pit tin mine, but it had to close after prices for the metal dropped.

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F. Habashi, *The Story of Metals*, two volumes, Métallurgie Extractive Québec, Quebec City, Canada 2015. Distributed by Laval University Bookstore.
INTRODUCTION

Royal Canadian Mint (Figure 21.1) founded in 1901 operates a technically advanced refinery in which it refines precious metals from a variety of sources including primary producers, industry, recyclers and financial institutions. The Mint refines raw gold to 995 fine through the Miller chlorination process. The gold is then cast into anodes for electrolytic purification to 9999 fine using the Wohlwill process.

Figure 21.1: Royal Canadian Mint in Ottawa.
Success and Failure in the Canadian Metallurgical Industry

The mint issued a commemorative coin on the occasion of 250 years of the first Canadian iron making plant at Saint-Maurice in Quebec — half way between Quebec City and Montreal (Figure 21.2).

Figure 21.2: Commemorative dollar on the occasion of 250 years of Forge Saint Maurice the first Canadian iron making plant.

REFERENCES

INTRODUCTION

Canada is the world's largest potash producer and exporter. In 1943, it was discovered in Saskatchewan in the process of drilling for oil. Active exploration began in 1951. Underground and solution mining is practised (Figure 22.1).

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Tar Sands

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INTRODUCTION

Oil is now produced in Canada from tar sands in Alberta (Figures 23.1–23.2). Tar is a mixture of many organic substances, which are separated by distillation at different temperatures. The distillation residue is pitch. The tar sands of northeastern Alberta constitute one of the largest deposits of liquid hydrocarbons in the world. The tar sands extend over an area of over $900 \times 10^6 \text{ km}^2$ and are estimated to contain $126 \times 10^9$ tons from which at least $35 \times 10^9$ tons of crude oil are expected to be produced. A part of the deposit located at Athabasca is amenable to surface mining, while the major part is expected to be available by in-situ techniques.

PROCESSING OF TAR SANDS

The mining method generally used is mixing the oil sand with warm water to create a slurry which can be transported by pipeline to a separating vessel where the sand settles to the bottom and air bubbles form a froth on the top (Figure 23.3–23.4). The bitumen froth is skimmed off, mixed with solvent, and spun in a centrifuge to remove the water and solids. The bitumen can then be processed into crude oil.
Figure 23.1: Tar sands in Alberta.

Figure 23.2: Tar sands.
Figure 23.3: Exploiting the tar sands.

Figure 23.4: Processing of tar sands.

REFERENCES

Chapter 24

Diamonds

In 1991 two geologists, Chuck Fipke and Stewart Blusson, found evidence of diamond-bearing kimberlite pipes about 320 km north of Yellowknife, Northwest Territories. One of these pipes was developed by BHP Billiton into the EKATI Diamond Mine, which produced Canada's first commercial diamonds in 1998.

The Diavik mine opened in 2003 in the Northwest Territories. Two additional mines were discovered at Snap Lake, NWT (opened in 2008), and Victor, in Ontario (in 2010) to be joined by two more mines at Gahcho Kué, NWT, and Renard, Quebec both to be commissioned to start production in the second half of 2016 (Figure 24.1). Canada as the third largest producer of diamonds in the world after Russia and South Africa. About 1750 tons of earth has to be extracted to find one carat.

Figure 24.1: Diamonds in Canada.
The Diavik mine is located in the North Slave Region of Northwest Territories. The pipes being mined were originally exposed on the bottom of Lac de Gras. Dikes were built around the pipes and the area to be mined was dewatered by pumping. This created an island which now allows mining below the level of the surrounding lake.

The mines are in remote location and receive overland freight during six and ten weeks. Any supplies must be delivered by air. The mines are all located away from towns or settlements. Wages are high as compared to African mines and Indian cutting facilities. The open pit mines are being depleted and continued work in the ore body requires underground mining. Some of the mines also incur a high water pumping cost as they excavate below the water table.

Figure 24.2: Aerial photograph of the Voctor mine.
Chapter 25

Asbestos

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EXPLOITATION IN QUEBEC

History

Although known in ancient times it has been first discovered in economic mines in 1876 in Thetford Township in Quebec Province. The exploitation was simple and the workers often inexperienced (Figures 25.1–25.2) but by 1895 mining started to be mechanized. This marks the beginning of a stage of unprecedented growth. The number of workers grew with the demand for asbestos.

Asbestos is recovered from the crushed and ground rock by aspiration (Figure 25.3). The air-tight building housing the equipment is under slight pressure to make sure that no fibres are released in the work place. This is done by re-circulating the clean air sucked by the fans at the top of the building through air-pressurized rooms.
Figure 25.1: Early mining of asbestos in Quebec.

Figure 25.2: Crushing room at Johnson Mine in Quebec, 1900. Note the girls were using hammers to crush the ore.
Asbestos is an industrial mineral of great economic importance. About 70% of the asbestos is used in the fabrication of asbestos cement whereby the fibres are slurried in water with Portland cement for making pipes and other construction materials (Figures 25.4–25.5). Such material contains 12–15% of asbestos which increases greatly its resistance. Asbestos in admixture with plastics and asphalt enters in the manufacture of a variety of tiles and sheets used as a covering material.

Figure 25.4: Asbestos cement pipes.
The growing railroad industry was among the first to make extensive use of asbestos in refrigeration units, as insulation for pipes, boilers, and fireboxes (Figure 25.6). Ship builders also made extensive use of asbestos material. It was also used in the building industry as wall insulation, for floor and ceiling tiles, in exterior siding, and in roofing.
Because of its heat resistance, asbestos mixed with metallic fibres and resins to the extent of 40% is used in the manufacture of what is called friction materials, e.g., brakes for motorcars and aeroplanes (Figure 25.7). Asbestos also enters in the manufacture of certain industrial paper and gaskets. Asbestos was also used for the brakes in the elevators in skyscrapers.

Nationalization

As Minister of Natural Resources in 1976, Yves Bérubé (1940–1993) (Figure 25.8) presided over the creation of State Corporation for Research, Prospection, and Promotion of Asbestos. In 1978 the National Society of Asbestos was created as a Quebec Government organization located in Sherbrooke, Quebec. The Society had a Research Department directed by Jean-Marc Lalancette, Chemistry Professor at the University of Sherbrooke. In 1980 the Quebec Government decided to nationalize the industry.

Carcinogenic mineral

The nationalization of the industry was followed by a campaign against asbestos as a carcinogenic mineral resulting in a drastic decreased production. It was at the turn of the twentieth century that
researchers began to notice a large number of deaths and lung problems in asbestos mining towns. In 1917 and 1918, it was observed by several studies that asbestos workers were dying young. In 1924 a woman had been working with asbestos since she was thirteen. She died when she was thirty-three years old, and an English doctor determined that the cause of death was what he called “asbestosis.”

Because of this, a study was done on asbestos workers in England. Twenty five percent of them showed evidence of asbestos-related lung disease. Laws were passed in 1931 to increase ventilation. In the 1930s major medical journals began to publish articles that linked asbestos to cancer. The use of asbestos was at its highest in the 1940s to 1970s. The warnings and regulations of the 1970s and beyond put an end to much of the production although the industry greatly improved its operation with respect to ventilation and dust control. Its use was banned in many countries.

**RESEARCH TOWARDS PREVENTION OF ASBESTOSIS**

**Chrysophosphate**

The Research Centre of Société nationale de l’amiante in Sherbrooke, Quebec developed in 1980s a process for decreasing the toxicity of asbestos by treatment with vapours of POCl$_3$ (Figure 25.9). The product was known as Chrysophosphate. The process was uneconomical and technically unsound. Treatment of asbestos with phosphate ion in aqueous solutions was found to have the same effect:
\[ 3\text{Mg(OH)₂ in Asbestos} + 2\text{HPO}_4^{2-}_{\text{aq}} \rightarrow 6\text{Mg}_5\text{(PO}_4\text{)}_2 + 4\text{OH}^- + 2\text{H}_2\text{O} \]

Colouring with organic dyes

Chrysotile asbestos has the advantage of a large surface area and can be coloured by organic dyes. The appearance of new peaks in its X-ray diffraction patterns and in infrared spectra of the dyed product together with the absence of precipitates supports that chelates are formed with its Mg(OH)₂ component. Some organic compounds, e.g., bromocresol purple and phenolphthalein, although they are not dyestuffs, they colour asbestos. It was found that some dyes, e.g., Thiazol Yellow G and Trypan Blue decreased the toxicity of the fibres. Unfortunately, the project was abandoned due to lack of financing, retiring of the inventor, and departure of the chemist doing the job. At that time all financial efforts were directed to the attorneys defending the case with the US Environment Agency.
Asbestos tailings

Asbestos tailings became also a problem because to produce one tonne of asbestos about 30 tonnes of tailings have to be discarded. In Quebec about 600 million tons of tailings were piled up in the form of a mountain (Figure 25.10) which contain about 40% MgO.

![Asbestos tailings in Quebec.](image)

Magnola project

In 1996, a magnesium pilot plant was running at CEZinc in Valleyfield, Quebec, to recover magnesium from asbestos tailings containing 24% Mg. In 1997, Noranda Company approved construction of the Magnola magnesium plant at a cost of approximately $730 million to be located in Danville, Quebec next to the tailings disposal heap (Figure 25.11).
Magnola production capacity would be 63 000 tonnes of magnesium per year, or close to 20% of world supply. Plant construction began in 1998 and metal production began in late 2001. The process involved hydrochloric acid leaching, brine purification, drying to produce granular magnesium chloride which are melted and electrolysed to produce metallic magnesium. The metallic magnesium is tapped and then cast in ingots.

Chlorine produced during electrolysis is converted into acid to be used in the leaching stage. It is washed with water and compressed. Then HCl gas is synthesized by burning chlorine with hydrogen. The gas is stripped and distilled so that 99%-HCl gas can be fed into the chlorinator. The hydrochloric acid coming off the chlorinator undergoes a thermal quench and oxidization. It then passes through activated carbon to absorb any chlorinated hydrocarbons that are present. The clean, 35% HCl acid is used in the leach and neutralization circuit.

In January 2003 the plant was shut down for economic reasons. The cost of filtration of the brine was a major cost item because the large volume of residue to be filtered while other processes using magnesite the residue to be filtered is insignificant. If the process were developed to solve an environmental problem then the amount of tail-
ings consumed annually would be insignificant as compared to the hundreds of millions of tonnes already accumulated.

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Chapter 26

Conclusions

The mining and metallurgical industries are important contributors to the Canadian economy. Canada is a top producer of minerals and metals (Figure 26.1). Many new technologies and new processes in extractive metallurgy were invented in Canada together with theories of metal extraction were formulated.

![Mining Map of Canada](image)

**Figure 26.1:** Mining map of Canada (Mining Association of Canada 2016).

There were successes and failures in these industries in the past few years. Examples of the success stories are those of Sherritt Gordon Mines in Alberta for hydrometallurgy, the International Nickel Company in Sudbury for pyrometallurgy, the aluminum industry in the Province of Quebec for electrometallurgy, and the Bottom Blown Oxygen Converter for the steel industry by Liquid Air engineers in Montreal. The failure took place in the asbestos industry, some magnesium production, the titanium pigment plant of Tioxide Canada, Noranda, and Orbite.
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