A HISTORY OF MINING AND MINERAL EXPLORATION IN CANADA AND OUTLOOK FOR THE FUTURE

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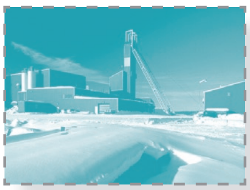

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Foreword

This report traces the emergence of Canada's mineral industry and provides concise information on production, reserves, exploration results and outlook. The report is being published by Natural Resources Canada and also by the German government's Bundesanstalt für Geowissenschaften und rohstoffe (Federal Institute for Geosciences and Natural Resources) for distribution in Germany in that organization's Rohstoffwirtschaftliche Länderreihe series, a series of reports concerning various countries that present summaries of topics such as their geology, mineral industries and production, mineral resources, mineral deposits and mineral production economics.

A brief summary chapter entitled "Canada's Petroleum Industry," included for the benefit of German readers, will also be of interest to Canadians.

Richard T. Haworth, Ph.D.
Assistant Deputy Minister
Minerals and Metals Sector

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1. Early History Of Canada's Mineral Industry[1]

The first Aboriginal inhabitants of the Western Hemisphere arrived about 40 000 years ago, most likely from Asia during a late Pleistocene interglacial period, but possibly by boat across the Pacific or Atlantic oceans. They used various minerals to produce tools, weapons and decorative objects, including pebbles and cobbles for tools and weapons, and flint, chert, pipestone, native copper, gold, silver and turquoise, many of which were traded amongst the Aboriginal peoples.

Vikings from Iceland were the first Europeans known to have reached Canada. About the year 1000, a small group of them sailed from Greenland to L'Anse aux Meadows on the northern peninsula of the island of Newfoundland, where they lived for several years. Almost 500 years later, in 1497, John Cabot sailed from Bristol in England to "discover," in June of that year, what was most probably the island of Newfoundland. Within only a few decades, thousands of fishermen from Portugal, France and England were fishing on the Grand Banks, an area of continental shelf in the Atlantic Ocean to the south of Newfoundland. Some fishermen stayed the winter in Newfoundland during the 1500s, but the first small permanent English settlement was established in 1610 at Conception Bay in eastern Newfoundland. The French had established the first permanent European settlement in what is now Canada at Québec City two years earlier in 1608.

The early settlers in Canada produced a limited number of mineral commodities for local use, chiefly building stone, brick clay, sand, gravel, and lime for mortar and plaster. Coal was discovered on Cape Breton Island, Nova Scotia, by the French in 1672 (Figure 1.1). The British Navy first obtained coal there in 1711. In New Brunswick, coal was first mined by settlers in 1782. Coal was discovered in Alberta in 1800 and, on Vancouver Island, British Columbia, coal deposits were discovered in 1835 and 1850.

Iron ore was found along the St. Lawrence River near the mouth of the Saint-Maurice River and smelted there to produce iron for local use beginning in 1737. During and after the American Revolution, British loyalists (United Empire Loyalists) from the United States moved in the 1780s and 1790s to eastern Canada, including what is now southern Ontario, where iron furnaces utilizing local ore were erected in 1800, 1820 and 1822. The earliest recorded Canadian production of gypsum was in Nova Scotia in 1789 and in Ontario in 1822.

Initial Canadian nonferrous metal production, of copper, began in 1848 at a mine on the north shore of Lake Huron at Bruce Mines, Ontario, mining a deposit that had been discovered there in 1846. Canada's first production of gold was in the late 1850s from the small Early Bird mine on the Queen Charlotte Islands of British Columbia. Placer gold had been found on the Chaudière River in Quebec's Eastern Townships in 1823, but production there did not start until 1862. Placer gold was discovered and initially produced in 1859 in the Cariboo region of British Columbia, which has yielded a total of some 110 tonnes (t) of gold, with minor amounts of gold still being produced from small lode-gold deposits there. Gold was also discovered in Nova Scotia, with the initial gold discovery there made in 1860. Over the years, some 45 t of gold were recovered in Nova Scotia, all of it from small gold deposits. Petroleum, found in 1857 at Oil Springs, Ontario, near Lake Erie, represented North America's earliest commercial petroleum discovery (see Chapter 8, "Canada's Petroleum Industry").

Cariboo gold, Ontario petroleum, and increased output of Cape Breton coal marked a turning point in Canadian mineral production from minor local events to developments of greater significance. During the 1870s, a phosphate industry based on apatite was developed in western Quebec and adjacent eastern Ontario with by-product sheet phlogopite and sheet muscovite production from many small carbonatite deposits located within 100 or 150 km of Ottawa, the

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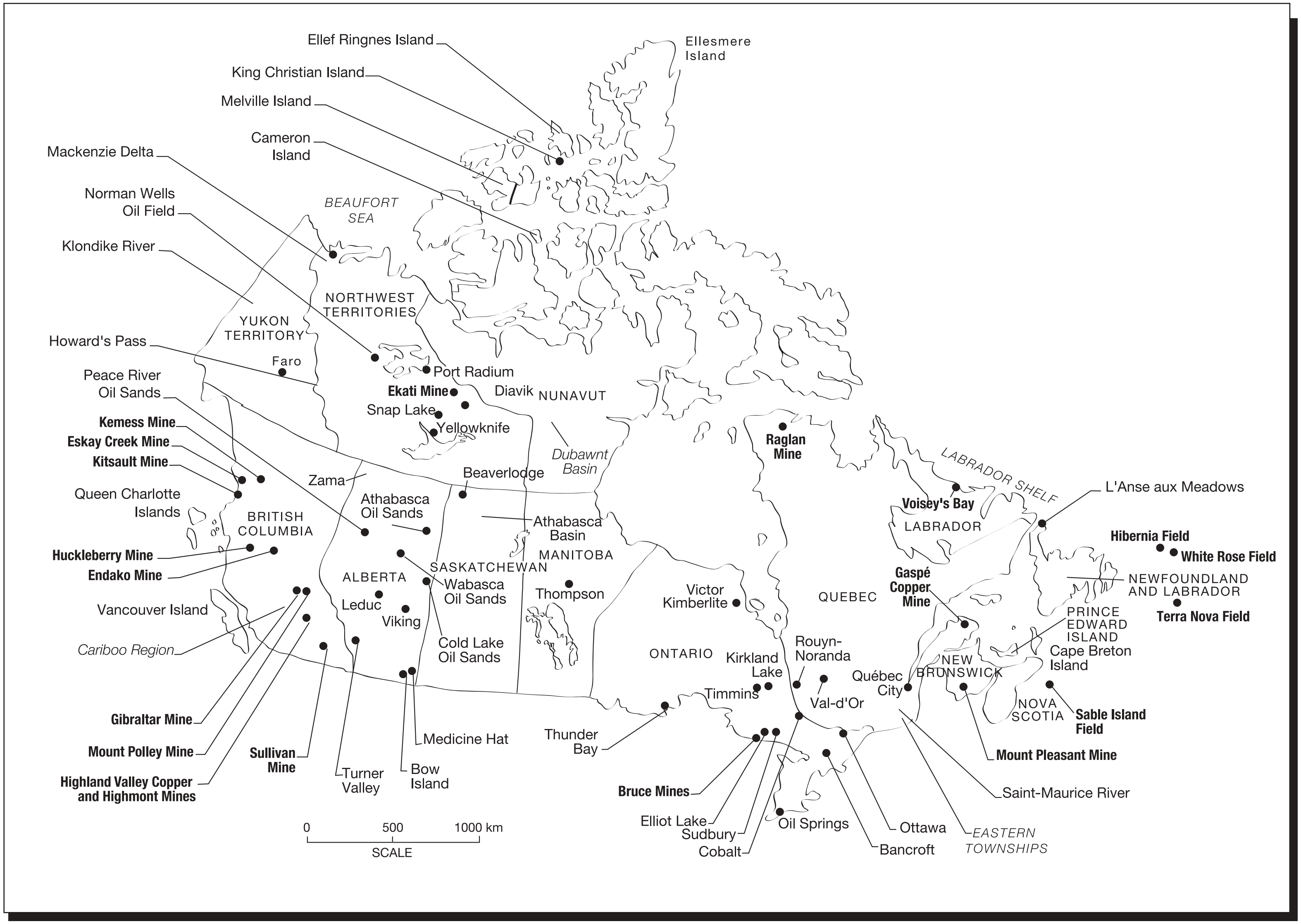
[1] The sources of the historical information presented in this chapter and in Chapter 2, "History of Prospecting and Mineral Exploration in Canada," are: 1) the author's knowledge, gathered from many sources over the past 45 years, and 2) a listing of Canadian mining events over the period 1604-1956 compiled and published in 1957 by the Dominion Bureau of Statistics - now Statistics Canada (see Dominion Bureau of Statistics, 1957, in the list of references).

Figure 1.1
Map of Canada Showing Locations of Places Mentioned in the Text



Source: Natural Resources Canada.

national capital. In the 1880s, asbestos was discovered in the Eastern Townships of Quebec to the south of the St. Lawrence River, and this area is still a world-class asbestos-producing region. Nickel-copper deposits were discovered at Sudbury, Ontario, after mineralization was exposed in 1883 in a rock cut during construction of the Canadian Pacific Railway to western Canada, near what became the Murray mine. The Frood mine, also at Sudbury, where production commenced in 1887, was still in operation in 2000 but with its end in sight after yielding an estimated 5 million tonnes (Mt) of nickel, 5 Mt of copper, 900 t of silver, 55 t of gold, and substantial quantities of platinum group elements, selenium, tellurium, iron ore pellets, and sulphur dioxide gas used to produce sulphuric acid and liquid SO_2.

Prospecting in southern British Columbia led to the discovery of a substantial number of gold, silver and base-metal deposits, including, in 1893, the exceptionally large Sullivan lead-zinc-silver deposit at Kimberley, British Columbia, which closed in 2001 after yielding 10 Mt of lead, 10 Mt of zinc, 9900 t of silver, and much smaller quantities of antimony, tin, bismuth, cadmium, gallium, germanium and indium. In 1896, the discovery of placer gold on the Klondike River in the Yukon Territory resulted in the biggest gold rush in Canadian history. Some 430 t of placer gold have been recovered from the Yukon where the production of placer gold has continued from various rivers and streams over a period of more than 100 years and from recently developed lode-gold mines.

In 1903, silver was discovered at Cobalt, Ontario, during railway construction. Many high-grade but relatively small-sized vein-type silver-cobalt-nickel-arsenide deposits were discovered in the vicinity of Cobalt, which became one of the world's major silver-producing districts. More than 18 000 t of silver, plus quantities of cobalt and nickel, were recovered at mines in the vicinity of Cobalt between 1903 and 1989 when production was suspended at the one remaining mine because of low prices. Additional silver production at Cobalt is likely in the future, if and when the silver price increases.

2. History Of Prospecting and Mineral Exploration In Canada

Prior to the 1870s or 1880s, nearly all of the significant mineral deposits in Canada were discovered accidentally by individuals who were not actively searching for deposits. The discovery of placer gold in the Cariboo district in 1859 resulted in gold and base-metal prospecting in the mountainous regions of British Columbia and also in gold prospecting in the Yukon Territory. Similarly, the discovery of lode-gold deposits in Nova Scotia resulted in widespread prospecting activity there. Prospecting activity slowly spread to other parts of Canada. In 1909, prospectors found high-grade gold quartz veins in the Porcupine District of Ontario (now the City of Timmins). More than 2200 t of gold have been produced from this district and production continues from mines there, both old and new. In 1911, prospectors discovered another major gold deposit, which became known as the "Golden Mile," at what is now the town of Kirkland Lake, Ontario. Some 800 t of gold have been recovered from the six or more mines on this single gold deposit. Production had continued there until 1999 from the one remaining mine, the Macassa mine, which is currently closed awaiting higher gold prices. In the province of Quebec, immediately to the east of Ontario, many important gold deposits, the large Noranda copper-gold deposit, and other base-metal deposits were discovered, beginning in the 1920s, by prospectors working along what became known as the Rouyn–Val-d'Or gold belt. Additional discoveries are still being made along this belt. Prospectors spread through northern Quebec, Ontario, Manitoba and Saskatchewan, making discoveries and arriving at the Yellowknife gold district in the Northwest Territories in the mid-1930s. Many new orebodies were discovered in these previously unknown gold-bearing areas.

In these early days of the industry, many prospectors were "grubstaked" (that is, their prospecting expenses were financed by local business people, in some cases by individual business people and sometimes by "syndicates" of several people in return for an interest in any discoveries made by the prospectors). Small companies, known as "junior companies," were formed to explore for discoveries and hopefully to develop mines on deposits found. They obtained the needed funding by selling company shares to the public.

Until float-equipped aircraft became generally used for transportation into remote areas of Canada, prospectors searching for mineral showings in the Canadian Shield normally traveled by canoe and lived in tents. In the 1920s and 1930s, many mining companies formed their own exploration departments, employing their own geologists and prospectors.

Except for gold and silver, metal prices were low during the Great Depression of the 1930s, and, as a result, exploration for non-precious metals was severely reduced. In 1934, the United States increased the gold price from US$20.67 to US$35.00 per troy ounce (31.103 grams), leading to a major increase in gold exploration, gold mine development and gold production in Canada. In 1939, war soon brought exploration to a halt, except exploration for strategic minerals not normally available from sources in North America, such as chromite, manganese, tin and tungsten. At most mines, work to replace the ore mined by new reserves either ceased or was cut to an absolute minimum.

When the war with Germany began, the United States was a neutral nation and Canada had to pay for needed war material imports with U.S. dollars or with gold. As a result, the manpower, equipment and supplies needed for gold mining in Canada received Canadian government priority. In 1941, a lend-lease agreement was worked out so that war materials could be obtained from the United States on credit. Gold mining lost its priority and it became impossible for many gold mines to obtain the people and supplies that were needed to continue to produce. The result was rapid closure of many of the gold mines in Canada, and employment and production were cut back at those gold mines that did continue to produce.

When the war ended, gold exploration resumed in Canada in 1945 and 1946, but inflation and a fixed gold price soon made it unattractive to explore for gold. New exploration opportunities soon appeared. There were urgent military requirements for uranium. Exploration for that metal was greatly assisted during the 1940s by use in Canada and elsewhere of the Geiger counter, invented in Germany in the 1920s and adapted in Canada in the early 1940s as a field instrument for uranium exploration. Subsequently, the Canadian invention of the much more sensitive scintillometer as a mineral exploration instrument in the early 1950s provided a sensitive radiation detector that could detect uranium from much greater distances than had been possible with the Geiger counter. The subsequent invention of the gamma ray spectrometer made it possible to distinguish radiation from specific radioactive elements, making it possible to determine whether the radiation came from uranium, thorium or other elements – something that the Geiger counter and scintillometer had been unable to do.

Radioactive minerals could now be much more readily detected and important uranium deposits were soon discovered at Beaverlodge Lake, Saskatchewan (the first orebody was discovered there in 1948), in the Bancroft District of Ontario (first ore discovery in 1949), and at the major Elliot Lake, Ontario District (first ore discovery in 1953). Canada's original uranium mine had been discovered in 1930, at what became known as Port Radium, on the east short of Great Bear Lake in the Northwest Territories. Until the early 1940s, radium was the principal product of the mine, used for the treatment of cancer, with the uranium being a by-product used in colouring glass and in ceramic glazes, but the emphasis shifted in 1943 to uranium for the production of nuclear weapons. Reactor-produced nuclear isotopes are now used for medical and engineering inspection purposes and the market for radium has disappeared.

The ability to detect radioactivity was not the only notable development of new geophysical instruments. During the war, the airborne magnetometer was developed to detect submarines. It was recognized that such an apparatus might be used in exploring for metal deposits containing the magnetic minerals magnetite and pyrrhotite, and possibly for petroleum exploration purposes as well.

After the war, Aero Service Corporation, of Philadelphia, Pennsylvania, obtained exclusive rights for use of the airborne magnetometer in mineral exploration, and the Gulf Oil Company of the United States obtained exclusive rights for its use in petroleum exploration. In 1947, the International Nickel Company of Canada Limited (now Inco Limited) acquired a two-year exclusive contract for the use of Aero Service Corporation's one and only airborne magnetometer system and flew it in Manitoba (and in one or two other areas of Canada) over what has subsequently become known as the Thompson Nickel Belt where there is very little outcrop exposed. The magnetic maps produced there showed numerous and extensive elongate magnetic anomalies, too numerous to test by drilling. Inco was not exploring for iron ore deposits, but it was clear from the results that there was now a highly effective method of rapidly exploring large areas for magnetite-bearing oxide-facies and pyrrhotite-bearing sulphide-facies iron formation orebodies. At first, it was not clear to Inco what use could actually be made of these data (H.D.B. Wilson, personal communication).

Massive sulphide and vein-type orebodies are electrically conductive. During the 1930s, Stan Davidson, who was then Chief Geologist for Falconbridge Limited, Canada's other important nickel producer, developed the first ground electromagnetic (EM) system for the detection of electrically conductive orebodies. This apparatus was very cumbersome because, for every reading to be taken, a separate tower had to be built to support the receiving coil. In the early 1940s, a portable EM receiver was developed. This made it possible to use a transmitting coil suspended from a mast together with a small portable receiving coil-detecting unit, a system that was much more efficient to use. Inco was able to obtain one of these systems and successfully tested it over a known nickel-copper orebody at the Murray nickel-copper mine at Sudbury, Ontario. Inco then purchased more of these portable units, which were used to discover several large nickel deposits near Thompson. A single outcrop of ultramafic rock found during the 1930s by an Inco geologist working by canoe had initially led Inco to explore the Thompson district, but it had taken persistence and 10 years of continuous exploration work from 1946 to 1956 before the large and rich Thompson orebody was found and a production decision was made (H.D.B. Wilson, personal communication).

Subsequently, airborne EM equipment developed in Canada during the 1950s was used to survey large areas of Canada and many nickel, copper, zinc and lead sulphide orebodies were discovered. Airborne magnetometer and EM survey equipment used together provided an effective method of exploring for nickel because most nickel-copper orebodies are both magnetic, because of their pyrrhotite content, and electrically conductive.

In overburden-covered regions of Canada, where prospectors or geologists would otherwise have had little chance of discovering deposits, EM exploration technology and its continuous refinement and improvement provided a panacea for Canadian base-metal exploration, especially for base-metal deposits in overburden-covered areas of the Canadian Shield and Appalachian regions, areas that are mostly sufficiently topographically flat for them to be surveyed using fixed-wing aircraft. Prospectors and geologists would otherwise have had little chance of discovering deposits in such outcrop-poor regions. Many new base-metal orebodies were discovered using this new exploration technology.

Extensive areas of Canada are covered by tens of metres of glacial debris. Even in areas of extensive outcrop, considerably less than 50% of the rock surface is generally exposed. There are areas, thousands of square kilometres in extent, with, at most, a fraction of a percent of outcrop exposure and, over about 4 million km^2 of Canada, outcrop exposure probably averages considerably less than 5%. Most base-metal deposits are not as hard as the rocks surrounding them are, so they tend to be hidden because they have been eroded by the action of continental glaciers rather than exposed. Exploration by prospectors is restricted to areas of rock outcrops, but magnetometer and EM-equipped aircraft made it feasible to detect base-metal orebodies with their upper surfaces buried at depths of 100 metres or more.

When an airborne geophysical anomaly of potential interest is detected, follow-up ground geophysical surveys are carried out to more accurately determine its exact nature and location. Drilling with tubular diamond-impregnated bits is used to obtain rock drill core and determine the cause of the anomaly. Many areas contain hundreds of individual conductors; therefore, only the more promising ones can be tested by drilling. EM conductors can be caused by massive sulphide metal ores, by barren sulphide (pyrite or pyrrhotite) zones, or by sulphide zones with low and therefore uneconomic contents of base metals. Low-grade sulphide sections can change along strike or at depth to ore-grade sections, making it impossible to write off an extensive sulphide zone as being barren with only a single drill hole. The great majority of EM conductors are caused by thin graphite-coated shears that are electrically conductive but of no economic interest.

In some areas, so many anomalies are detected that it is not economically feasible to ground-test and drill more than a small fraction of them. Geophysicists and geologists must select the apparently most promising ones for ground follow-up. Undoubtedly, some anomalies caused by mineral deposits that are potential orebodies are not followed up because they do not look sufficiently promising.

More effective and sensitive airborne EM equipment has been developed that is capable of detecting deposits that early equipment could not. Greater depth penetration is now possible, which has made airborne surveys more effective. Areas flown using first-generation airborne geophysical equipment are being reflown and previously undetected orebodies are being discovered in some of those areas.

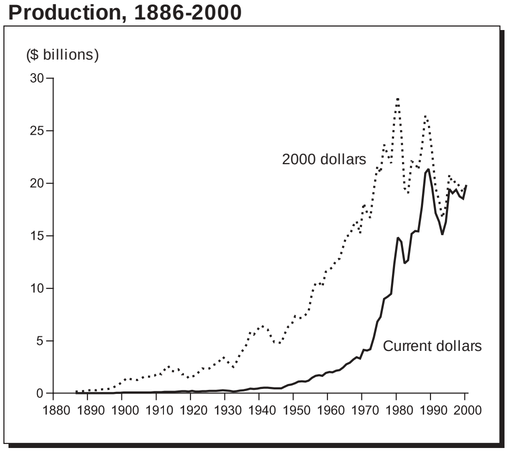
The Canadian mineral industry was essentially immature before the early 1950s. The availability of new geophysical methods, requiring sophisticated equipment, transformed the nature of exploration, while generally attractive metal prices and the substantial number of world-class base-metal and uranium orebody discoveries being made in various parts of Canada soon resulted in a rapid rise in exploration expenditures in Canada during the first half of the 1950s (Figure 4.2). Since 1946, more than 2000 metal deposits, for which sufficient exploration work has been done to measure tonnage and grade, have been discovered in Canada, an average of about 40 deposits annually. Only some of these deposits constitute orebodies.

3. Canada's Mineral Production Through the Years

Exploration expenditures in Canada (Figure 4.1) have risen through the years as Canada's mineral output has risen (Figure 3.1) because increased production has made it clear that Canada is an attractive exploration target and because increased mining profits from Canadian mines have provided more money for exploration.

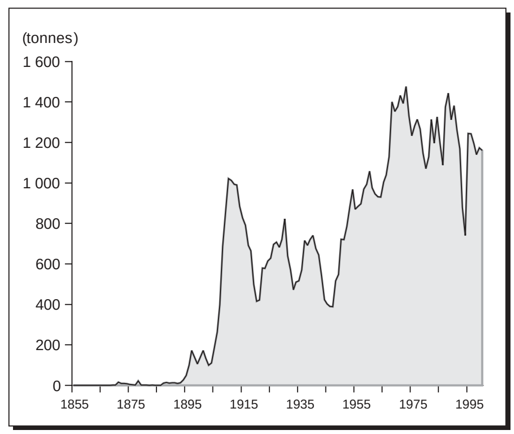
While Canada has produced base and precious metals for almost 150 years, by current standards of large-scale production, Canada did not become a major producer until more recently: of silver since the early 1900s (Figure 3.2); of lead since the 1920s (Figure 3.3); of gold since the 1920s or 1930s (Figure 3.4); of nickel since the 1930s (Figure 3.5); of

Figure 3.1
Value of Canada's Non-Petroleum Mineral Production, 1886-2000



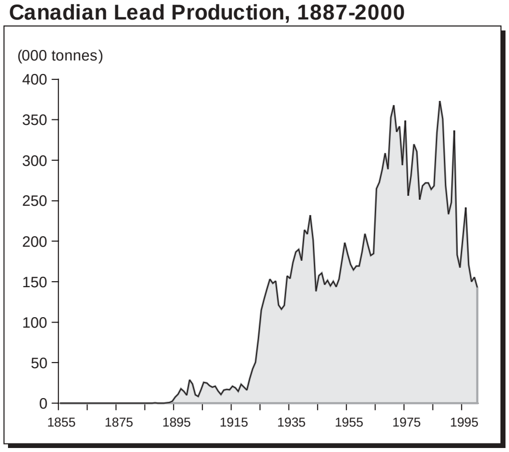
Sources: Statistics Canada; Natural Resources Canada.
Note: Production value statistics prior to 1886 are incomplete.

Figure 3.2
Canadian Silver Production, 1869-2000



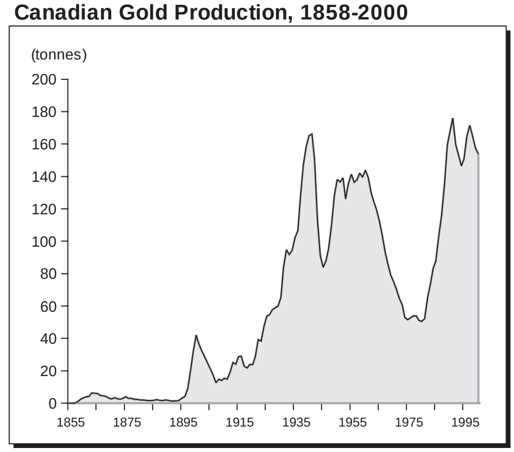
Sources: Natural Resources Canada; Statistics Canada.

Figure 3.3
Canadian Lead Production, 1887-2000



Sources: Natural Resources Canada; Statistics Canada.

Figure 3.4
Canadian Gold Production, 1858-2000



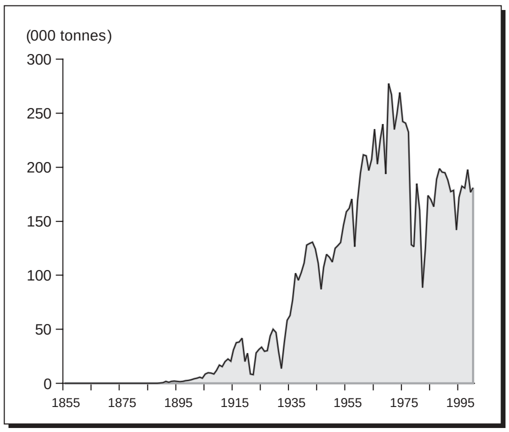
Sources: Natural Resources Canada; Statistics Canada.

platinum group metals since about 1935 (Figure 3.6); of cobalt since about 1955 (Figure 3.7), with a brief production peak after 1905 that resulted from peak production from the cobalt-nickel arsenide-rich native silver deposits at Cobalt, Ontario, where the initial discovery was made in 1903; of copper and zinc since the 1960s (Figures 3.8 and 3.9); of molybdenum since the mid-1960s (Figure 3.10); of uranium since the 1950s (Figure 3.11); and of iron ore since the 1950s or 1960s (Figure 3.12).

For the more important industrial minerals, Canada has been a major producer of asbestos since the 1940s or 1950s (Figure 3.13), of gypsum since the 1950s (Figure 3.14), of potash since the 1960s (Figure 3.15), and of salt since the 1960s or 1970s (Figure 3.l6).

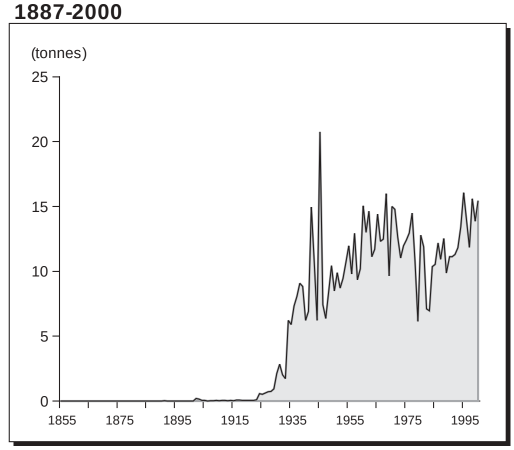
Canada has been a large producer of coal since the 1970s or 1980s (Figure 3.17). Although coal production was a record 75.95 Mt in 1996, Canada is not one of the world's major producers, not because of a lack of coal resources, but because most Canadian coal is located in western Canada where local demand is limited by a relatively low population and by extensive developed and undeveloped resources of cheap hydro-electric power in British Columbia and Manitoba, which means that the use of significant amounts of coal for electric power generation are required only in Alberta and Saskatchewan. Most of Canada's coal and coal mines are located in Alberta and eastern British Columbia where transportation to foreign markets requires long rail haulage (600 km or more) to ocean ports, thus increasing shipping costs and thereby limiting export possibilities.

Figure 3.5
Canadian Nickel Production, 1889-2000



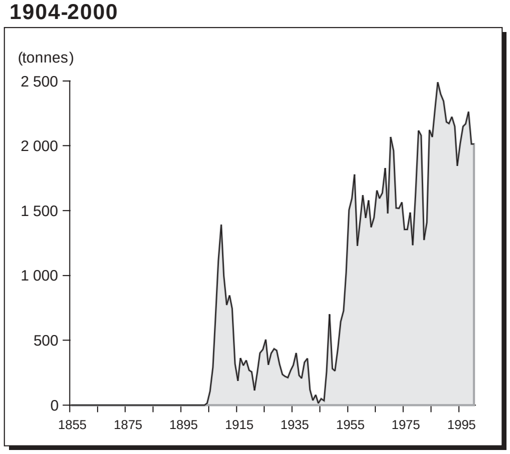
Sources: Natural Resources Canada; Statistics Canada.

Figure 3.6
Canadian Platinum Group Metals Production, 1887-2000



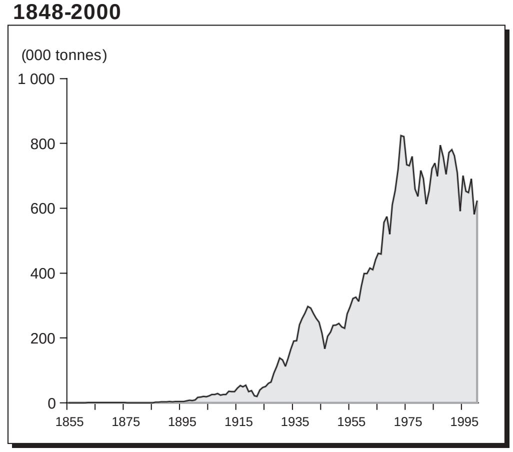
Sources: Natural Resources Canada; Statistics Canada.

Figure 3.7
Canadian Cobalt Production, 1904-2000



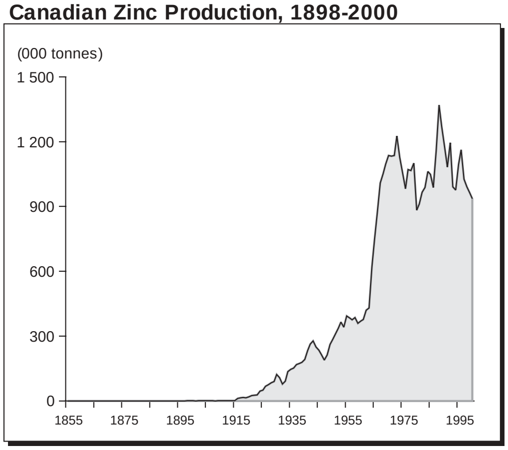
Sources: Natural Resources Canada; Statistics Canada.

Figure 3.8
Canadian Copper Production, 1848-2000



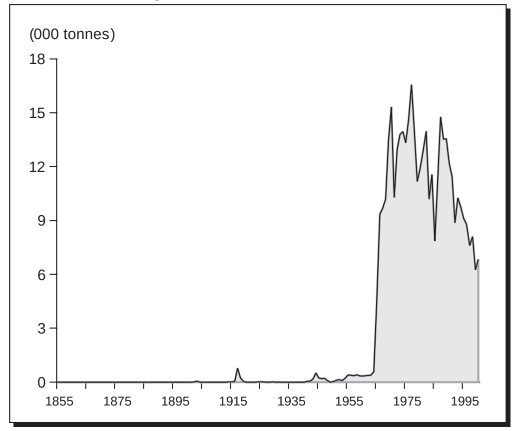
Sources: Natural Resources Canada; Statistics Canada.
Note: Canada produced a cumulative total of 100 000 t of copper from 1848 to 1885 that is not shown in this graph.

Figure 3.9
Canadian Zinc Production, 1898-2000



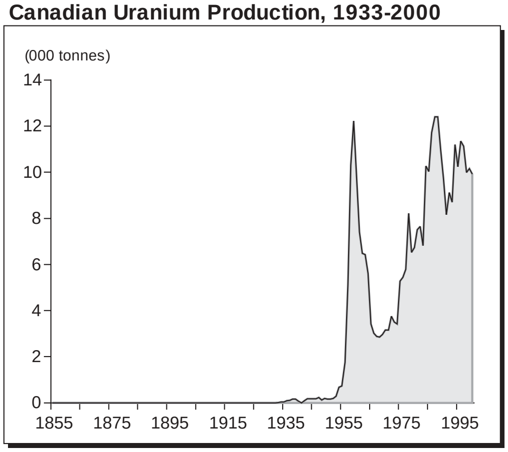
Sources: Natural Resources Canada; Statistics Canada.

Figure 3.10
Canadian Molybdenum Production, 1902-2000



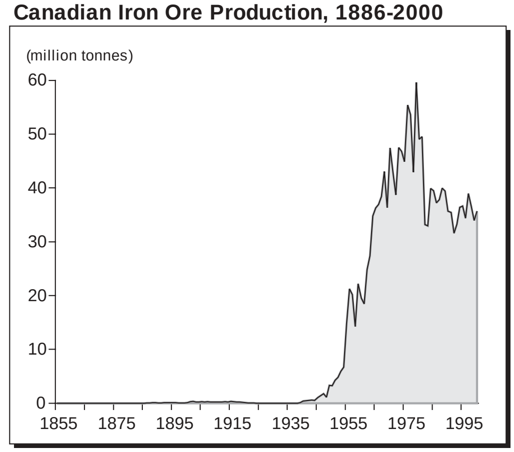
Sources: Natural Resources Canada; Statistics Canada.

Figure 3.11
Canadian Uranium Production, 1933-2000



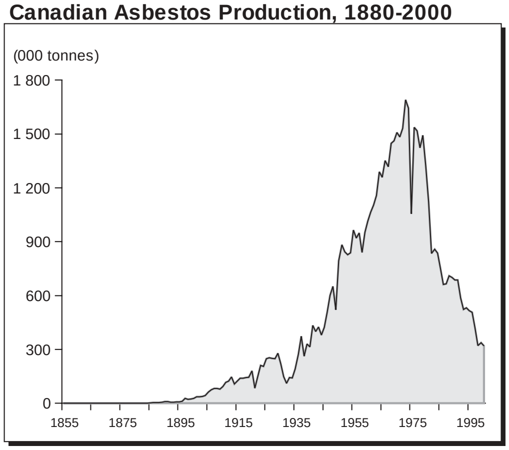
Sources: Natural Resources Canada; Statistics Canada.

Figure 3.12
Canadian Iron Ore Production, 1886-2000



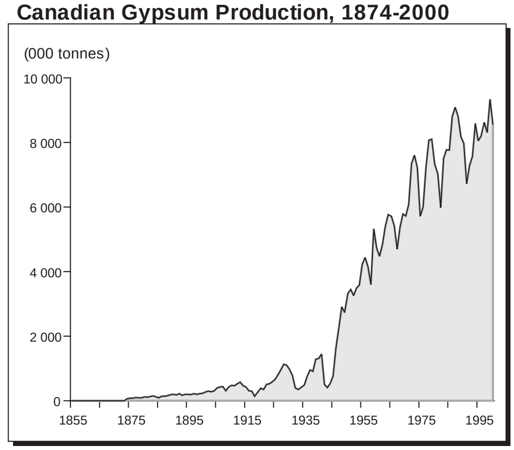
Sources: Natural Resources Canada; Statistics Canada.
Note: Does not include about 50 Mt mined in Newfoundland between 1893 and 1949 before Newfoundland joined Canada.

Figure 3.13
Canadian Asbestos Production, 1880-2000



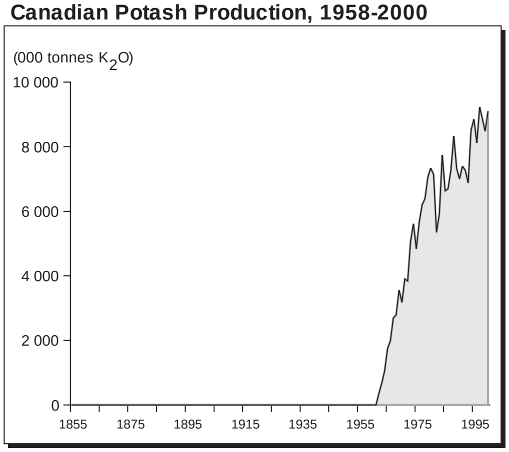
Sources: Natural Resources Canada; Statistics Canada.

Figure 3.14
Canadian Gypsum Production, 1874-2000



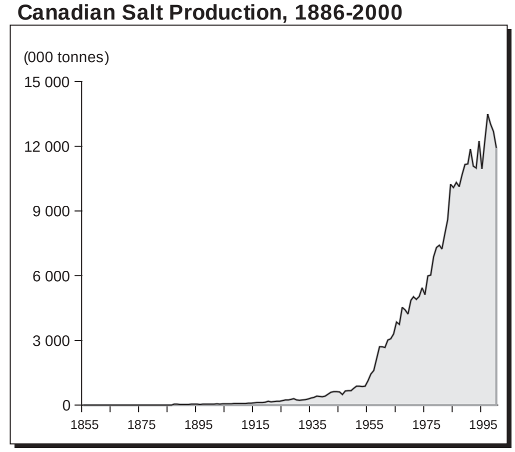
Sources: Natural Resources Canada; Statistics Canada.

Figure 3.15
Canadian Potash Production, 1958-2000



Sources: Natural Resources Canada; Statistics Canada.
Note: The graph does not show the minor production from one mine in 1958 and 1959.

Figure 3.16
Canadian Salt Production, 1886-2000



Sources: Natural Resources Canada; Statistics Canada.

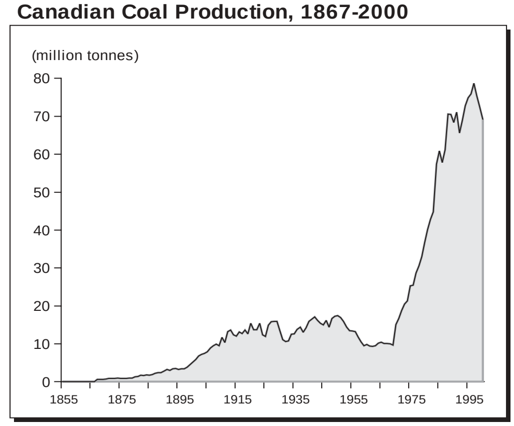
Although Canada produces coal in the provinces of Saskatchewan, Alberta and British Columbia in the west, and in Nova Scotia (where production ceased in the fall of 2001) and New Brunswick in the east, much of the coal used at thermal electric power plants in the province of Ontario is imported from the United States (from Pennsylvania) because the cost of freight from Canadian coal mines is high as a result of the long haulage distance involved.

Thermal power plants in eastern Ontario purchase low-sulphur lignite coal from surface strip mines in southeastern Saskatchewan, but this coal must be hauled by rail unit train a distance of 1000 km to Thunder Bay, Ontario, and then loaded onto ships and transported an additional 1300 km along the Great Lakes-St. Lawrence Seaway system. Not only are transportation costs high, but the St. Lawrence Seaway and some of the Great Lakes are closed to navigation for two or three months each year as a result of winter ice conditions. This means that sufficient coal must be stockpiled at each coal-fired power plant to last until new supplies can be obtained in the next shipping season, which makes coal from Canadian sources even more expensive as a result of the capital that is tied up in coal stockpiles over the fall and winter season.

On the other hand, the relatively low sulphur content of coal from western Canada (about 0.5% sulphur) makes it much more environmentally acceptable than is the high-sulphur coal from Pennsylvania (about 3% sulphur).

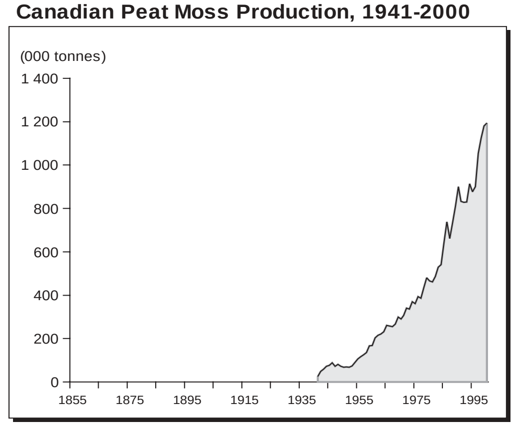
Sphagnum peat moss, used largely for horticultural purposes, began to be produced in Canada in 1941 and production has grown steadily since then (Figure 3.18). In addition to peat moss, a cumulative total of about 40 000 t of peat was produced in Canada for fuel purposes between 1900 and 1955.

Figure 3.17
Canadian Coal Production, 1867-2000



Sources: Natural Resources Canada; Statistics Canada.
Note: Canada produced a cumulative total of 2.6 Mt of coal from 1785 to 1866.

Figure 3.18
Canadian Peat Moss Production, 1941-2000



Sources: Natural Resources Canada; Statistics Canada.
Note: This graph does not include a cumulative total of about 40 000 t of peat fuel produced between 1900 and 1955.

4. Exploration Expenditures in Canada for Non-Petroleum Minerals

4.1 INTRODUCTION

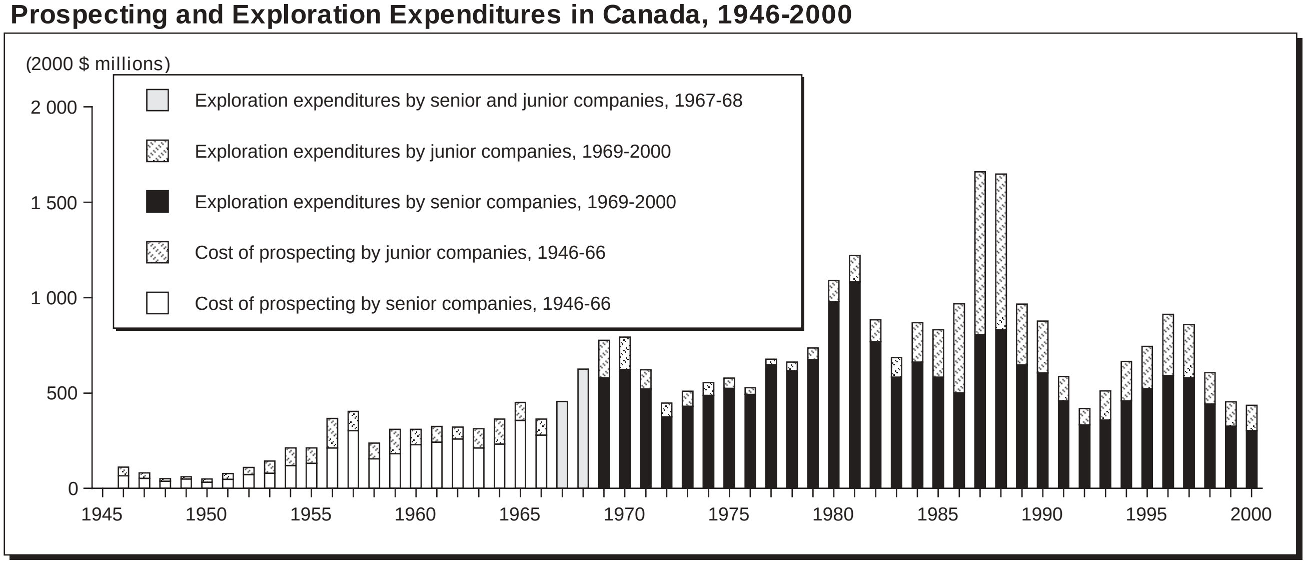
There are no statistics on exploration expenditures in Canada for the years prior to 1946. From 1946 to 1966, Statistics Canada gathered data on "Prospecting Expenditures by Metal Mining Companies," which included prospecting expenditures by all companies carrying out exploration in Canada. There was no definition of the types of exploration activities included in "prospecting," but prospecting appears to have been interpreted by most companies to include essentially the same activities included in "mineral exploration" today. Producers of nonmetallic mineral commodities and coal were not included because such companies were not "metal mining companies." Few, if any, such companies would have been prospecting for metals.

Beginning with the survey year 1967, a question concerning exploration expenditures was included in the "Annual Survey on Exploration, Development, Capital and Repair Expenditures," which gathered exploration expenditures for:

1) "Physical Work and Surveys" - later changed to "Field Work",
2) land costs (costs of staking mineral claims, recording them with government agencies and renewing them),
3) administrative expenses in the field, and
4) exploration-related head office expenses.

In Figure 4.1, expenditures for 1946-66 are "Prospecting Expenditures." Those for 1967-2000 are exploration expenditures (total of item numbers 1 to 4 above). Prior to 1980, Statistics Canada did not include expenditure categories 2, 3 or 4 (above) in published Canadian exploration statistics. The author has added such data, taken from the original questionnaires returned by the companies to Statistics Canada (Natural Resources Canada had access to them because that department's name was also on the questionnaire), for categories 2, 3 and 4 to

Figure 4.1
Prospecting and Exploration Expenditures in Canada, 1946-2000



Sources: Natural Resources Canada; Statistics Canada.
Note: Exploration expenditures from 1975 to 1981 are overstated by an average of about 17% relative to earlier and later years because of changes to the methodology used by Statistics Canada over the years.

Physical Work and Surveys totals for the period 1967-79 inclusive so that the years 1967-79 are comparable to 1980-2000.

Prospecting expenditures for the 1946-66 period are somewhat understated relative to exploration expenditure totals for the 1967-2000 period because prospecting expenditures excluded such expenditures by companies that were producing industrial minerals, construction materials and coal, and because many companies probably did not include prospecting-related head office expenses in their totals. To be comparable to exploration expenditures for years after 1966, prospecting expenditures would have to be increased by roughly 25% or more, as can be seen from the distinct rise in exploration expenditures beginning in 1968. Expenditures for 1967, the initial year of a new survey, are also likely to be incomplete.

4.2 INFLUENCE OF CHANGING METAL PRICES ON EXPLORATION

Although there are no statistical data concerning exploration expenditures in Canada during the 1930s, the increase in the gold price to US$35/troy oz in 1934 led to high levels of gold exploration in Canada. During the Great Depression of the 1930s, base-metal prices were so low that there was little incentive to explore for them. The production of nickel, copper, zinc and lead, the base metals most important to Canada, increased with the outbreak of war in 1939, then declined after 1943 or 1944 because metal stocks on hand, together with then current levels of production, were more than adequate for immediately foreseeable needs. Additional soldiers were needed in Europe, so manpower priorities shifted from mining to the military.

During the war, ore reserves at Canadian mines were allowed to decline. At the end of the war, base-metal prices were low. Demand for most metals did not begin to improve until late 1947 or early 1948 and, when mineral exploration resumed in Canada in 1945, it was chiefly for gold from 1945 until the early 1950s.

There was rapid inflation in Canada. After adjustment for inflation, the new gold price of US$35 and C$35/troy oz, set in 1934, had declined by 1949 (in terms of 1934 Canadian dollars) to only C$19.46/oz (both currencies had equal values in the 1930s), causing gold exploration in Canada to decline rapidly.

In 1940, there were some 140 producing gold mines in Canada. Gold mining was the entire basis of the economy in most of the communities these mines supported. The effective decline in the gold price that resulted from the combined effects of the fixed gold price and rapid inflation soon threatened the continued existence of many of these communities and the continued employment of their residents. To counter these problems, in 1948, the Government introduced the *Emergency Gold Mining Assistance Act* (EGMA). Depending on the per-ounce cost of gold production of each mine, this act provided government assistance of up to C$10.27/oz, with the condition that the gold produced at such mines had to be sold directly to the Government of Canada. Many of the remaining gold mines eventually closed, but over a long period of time with ore reserves mined out rather than having a catastrophic series of closures of many gold mines. The EGMA was finally repealed in 1976 after the U.S. government had set the gold price free when it would no longer sell any quantity of gold at the fixed US$35/oz price and the gold price was high enough that assistance was not required. By 1979, when the gold price began to rise rapidly, only 15 gold mines remained in production in Canada, other than base-metal mines that yielded by-product gold. Only three of those mines had not required EGMA assistance.

Exploration expenditures generally declined until 1950 when the Korean War began, and then demand and prices increased for the metals most needed for that war, including nickel, copper, molybdenum, niobium, tungsten and cobalt.

From 1950 until 1957, prices for many metals, and exploration expenditures, in Canada rose rapidly. There was little interest in exploring for gold because the price was now only C$15.07/oz (1934 dollars). During 1957, premium prices for nickel, offered since the beginning of the Korean War, disappeared and the nickel price dropped. The copper price dropped sharply in 1957-58. Zinc had declined between 1952 and 1954 and its price was still low in 1957-58. Lead and cobalt prices declined after 1956 and the uranium price was sharply down because the United States had, by then, arranged purchase contracts for all of the uranium it required for the long-term future of its nuclear weapons program. Nuclear power generation was still in its infancy and little uranium was required for this purpose. Silver and molybdenum prices were still attractive, but these two metals combined then accounted for only 3% of the value of Canada’s total mineral production. Some Canadian base-metal mines closed and others cut back their production. Prospecting expenditures, which had peaked at $330 million (2000 dollars) in 1957 (Figure 4.1), declined to only $194 million (2000 dollars) in 1958. Despite this, in 1958, prospecting expenditures in Canada were at their third-highest level ever. Exploration increased again in 1959 and a new prospecting expenditure record was attained in 1965. A large number of new base-metal orebodies were discovered in Canada during the 1950s and 1960s.

Exploration expenditures for 1967, the first year of the new exploration survey, appear to have been understated, perhaps because questionnaires were not sent to all companies that actually conducted mineral exploration in Canada that year. The reasons for exploration expenditures being as high as they were from 1968 to 1971 are not known to the author.

Exploration expenditures were down in 1972 and then increased until 1974 and beyond. During the 1970s, several of the world's major oil companies decided to become involved in the metal mining industry and soon began to spend large sums on exploration for non-petroleum minerals. Exploration expenditures in Canada for copper, zinc, uranium and coal increased during the 1970s because of improving prices for those mineral commodities and because of the expenditures by oil companies on Canadian metal exploration.

The prices of gold and silver and, to a lesser extent, the copper price, rose rapidly in 1979. The gold price peaked on January 21, 1980, at US$850/oz (in 2000 dollars, US$1646/oz). The silver price increased more than tenfold from early 1978, and more than thirty-fold from 1971, peaking at US$48/oz (US$93/oz in 2000 dollars) on January 21, 1980, when the Hunt brothers of the United States attempted to corner the silver market but did not succeed in doing so.

Exploration expenditures peaked in 1981 and then declined until 1983 after gold and silver prices dropped rapidly. Prices for nearly all base metals also declined due to a severe world economic slow-down that began in 1982.

From 1983 to 1988, a tax incentive for exploration was introduced to the Canadian income tax system. This incentive, the "Mining Exploration Depletion Allowance" (or MEDA), provided an attractive tax write-off on federal income tax for investment in "flow-through shares" of mineral exploration companies. A company that did not have taxable income could allocate a deduction of 133 1/3% of eligible exploration expenses to individual taxpayers who purchased flow-through shares. This program peaked in 1987 and 1988 when previously unimaginable sums were raised for mineral exploration and new exploration expenditure records were set. Many in the industry are of the opinion that a substantial portion of these flow-through funds were not used effectively and did not yield favourable discovery results.

Exploration declined after 1988, in part because flow-through-share income tax regulations became less attractive, but also because of severe recessionary conditions worldwide that caused metal prices to decline. Exploration reached a low of $385 million in 1992, but increased after that year to $895 million in 1996, then declined to $820 million in 1997, $656 million in 1998, $504 million in 1999, $497 million in 2000, and $491 million (preliminary) in 2001.

4.3 DISCUSSION

Over the 56 years for which Canadian mineral exploration expenditures have been gathered, exploration expenditure levels have tended to ebb and flow, with a generally rising trend, partly in response to changes in the business cycle, but more strongly influenced by other factors. Changing world economic conditions influence demand and prices for metals, but changes in supply, demand and price do not take place in a similar fashion for every metal.

When market prices are depressed for the metals produced by a mining company, that company's profits also tend to be depressed. As orebody discoveries are not immediately essential for their continued existence, many companies tend to spend less on mineral exploration when prices are low. A considerable contribution to exploration expenditures in Canada is made by junior exploration companies (Figure 4.1), small companies engaged in mineral exploration but without, as of yet, a mineral discovery in production. Junior companies are dependent on sales of company shares to finance their mineral exploration activities. When metal prices are low, this is difficult and exploration expenditures by junior companies decline. During the 1970s, by tightening its stock market listing requirements, the Toronto Stock Exchange made it impossible for many junior companies to have their shares traded on that exchange, which made it difficult for them to raise money until the Vancouver Stock Exchange (recently merged with the Alberta Stock Exchange to form the Canadian Venture Exchange) became a major source of junior company financing.

Exploration in Canada was depressed in 1947-49, in 1958, in 1973, in 1983, in 1992, and again at the end of the century. With the possible exception of 1947-49, each of these low-expenditure periods corresponded to a depressed world business cycle.

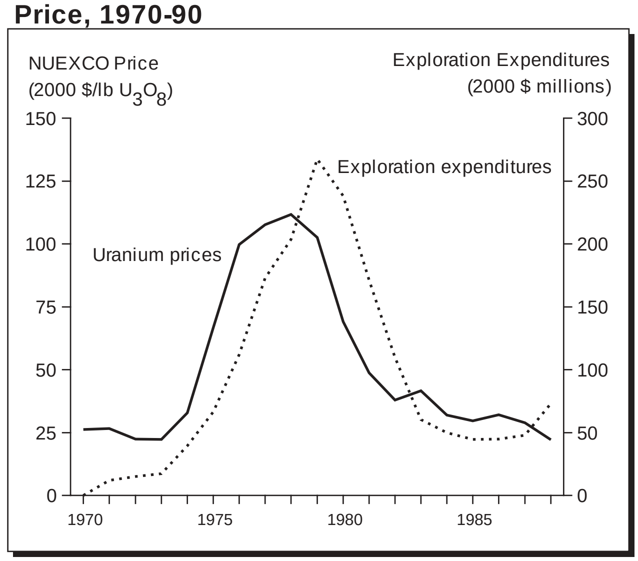
Except for the financial reasons given above, low prices are not a logical reason to cease exploring for a metal because many years are likely to pass between exploration and eventual production from any orebodies discovered. Current-day metal prices will probably have little effect on the profitability of future mines when production eventually begins.

Few companies or investors have expertise when it comes to the forecasting of future market demand and prices. Many companies tend to explore for a commodity only when its price is high and to cease exploring when the price declines. Uranium is an example. A sharp rise in the uranium price in the late 1970s yielded a rapid rise in uranium exploration. When the price declined, interest in uranium exploration waned almost immediately (Figure 4.2). Exploration bursts of this sort are inefficient. Much of Canada's uranium exploration expertise, developed in the late 1940s and the 1950s, was lost as most people had to depart the uranium industry when uranium was in oversupply. In the late 1970s, most Canadian geologists involved in the search for uranium were new to uranium exploration because there had not been much for 20 years, but before they had developed the expert knowledge needed, many of them ceased exploring for uranium. Many uranium exploration projects were shut down prematurely and the data that might have resulted in new discoveries were not properly followed up. As a result, a considerable portion of the large sums spent on uranium exploration between 1975 and 1985 was probably not as effective as it might have been.

While it is not a simple task, the forecasting of mineral commodity supply and demand and prices can be successfully done at least part of the time, as demonstrated by the results achieved by successful forecasters with some of the large multinational mining companies. The availability of high-quality demand/price forecasts might support better decisions concerning which minerals to explore for. However, years normally elapse between the commencement of an exploration program and making a discovery and, once an orebody is discovered in Canada, the attainment of production takes, on average, another six or seven years. It would be an expert forecaster indeed who could predict realistic supply-demand and price conditions as far ahead as 10 or 15 years.

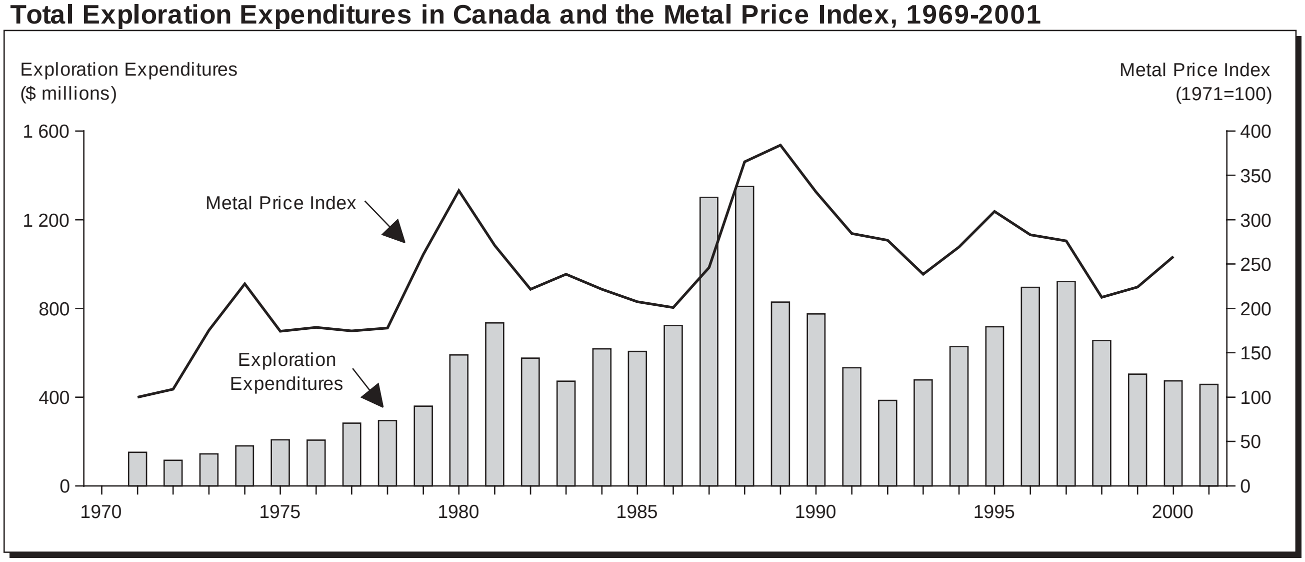
There appears to be some correlation between the prices of the major metals produced in Canada and annual exploration expenditures, but that correlation is not especially close (Figure 4.3).

Figure 4.2
Comparison of Exploration Expenditures for Uranium in Canada and the NUEXCO Uranium Price, 1970-90



Sources: Natural Resources Canada; Nuclear Exchange Corporation.

Figure 4.3
Total Exploration Expenditures in Canada and the Metal Price Index, 1969-2001



Sources: Natural Resources Canada; Statistics Canada.

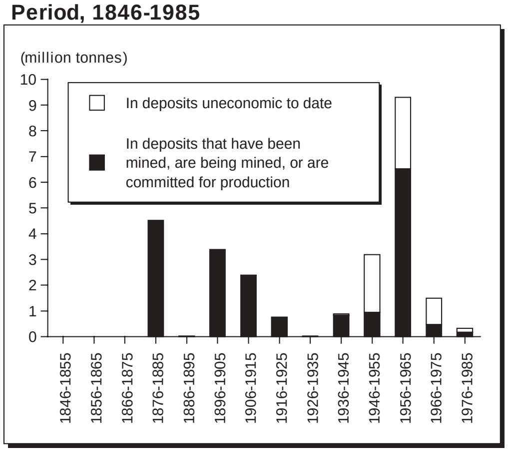
5. Changing Rates and Costs of Ore Discovery in Canada

During the 1970s, 1980s and early 1990s, several analyses of Canadian mineral exploration success were carried out by the federal government's Department of Natural Resources (Cranstone and Martin, 1973; Cranstone, 1980; Cranstone, 1982; Cranstone and Whillans, 1987; Cranstone, 1988; Cranstone, Lemieux and Vallée, 1993). Some of the results of this research are discussed below.

Graphs depicting the tonnages of the six metals (nickel [Figure 5.1], copper [Figure 5.2], zinc [Figure 5.3], lead [Figure 5.4], molybdenum [Figure 5.5], silver [Figure 5.6] and gold [Figure 5.7]) that were discovered in Canada per 10-year period over the 140 years from 1846 (the year of Canada's first nonferrous metal orebody discovery) to 1985 were prepared for an unpublished talk given by the author in 1987. These graphs have not yet been updated to include the subsequent 10-year discovery period 1986-95, nor have they been adjusted to take into account the tonnages of metal in deposits that, in the 1987 graphs, were included in the category "Deposits Uneconomic to Date" but have subsequently been brought into production. In updated discovery graphs, these tonnages should now appear in the mined deposit category because they now constitute ore reserves and past production at currently or formerly producing mines.

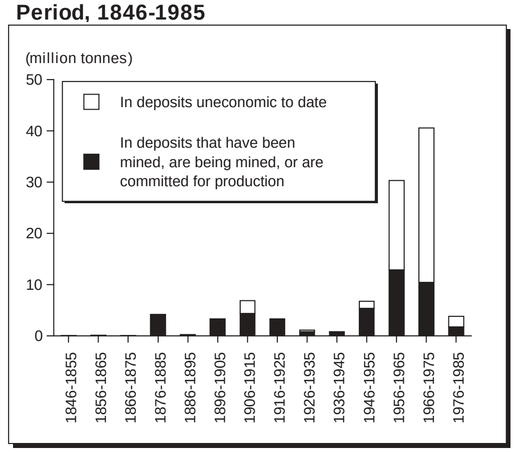
The most recent analysis of rates and costs of ore discovery in Canada, by Donald Cranstone, André Lemieux and Marcel Vallée of Natural Resources Canada (Cranstone, Lemieux and Vallée, 1993), covered the 45-year interval 1946-90 inclusive. The year 1946 was chosen as the initial year of the discovery analysis because 1946 is the first year for which Canadian exploration expenditure statistics were gathered. In this analysis, the interval 1946-90 was subdivided into 15 three-year periods. Iron ore was excluded from this discovery analysis because the development of new iron mines is not generally related to new discoveries but, rather, to marketing opportunities. In addition, the inclusion of the vast tonnages of iron in known Canadian iron deposits, some 45 000 Mt of iron contained in crude ore (Energy, Mines and Resources Canada, 1977), if valued at nominal prices for iron ore, would have seriously distorted the results of this study.

Figure 5.1
Nickel Discovered in Canada by 10-Year Period, 1846-1985



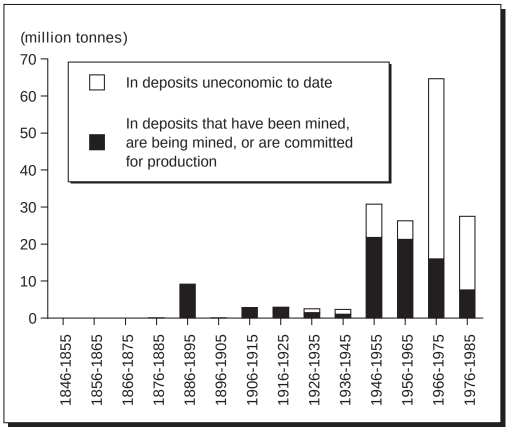
Source: Natural Resources Canada.

Figure 5.2
Copper Discovered in Canada by 10-Year Period, 1846-1985



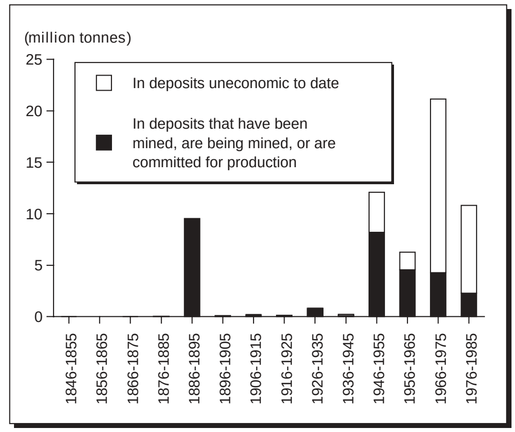
Source: Natural Resources Canada.

Figure 5.3
Zinc Discovered in Canada by 10-Year Period, 1846-1985



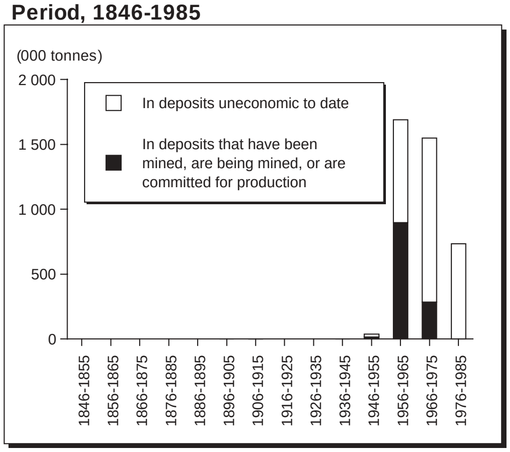
Source: Natural Resources Canada.

Figure 5.4
Lead Discovered in Canada by 10-Year Period, 1846-1985



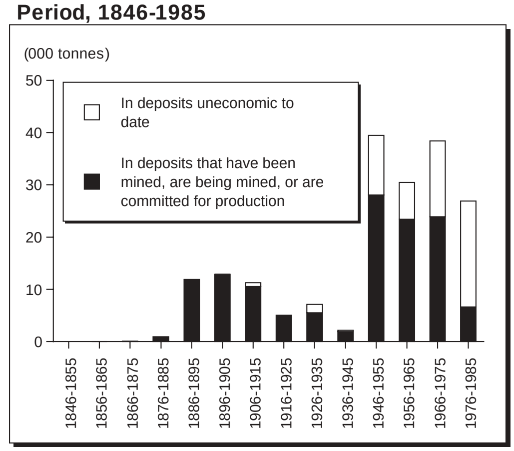
Source: Natural Resources Canada.

Figure 5.5
Molybdenum Discovered in Canada by 10-Year Period, 1846-1985



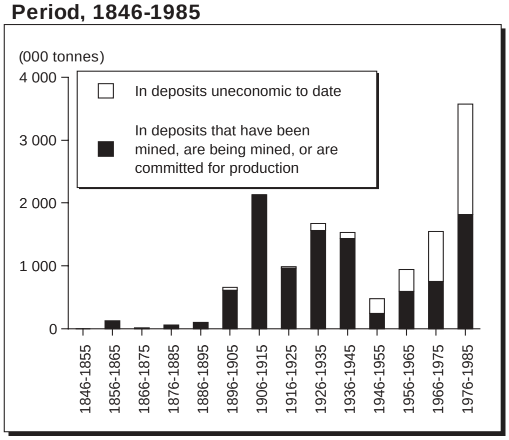
Source: Natural Resources Canada.

Figure 5.6
Silver Discovered in Canada by 10-Year Period, 1846-1985



Source: Natural Resources Canada.

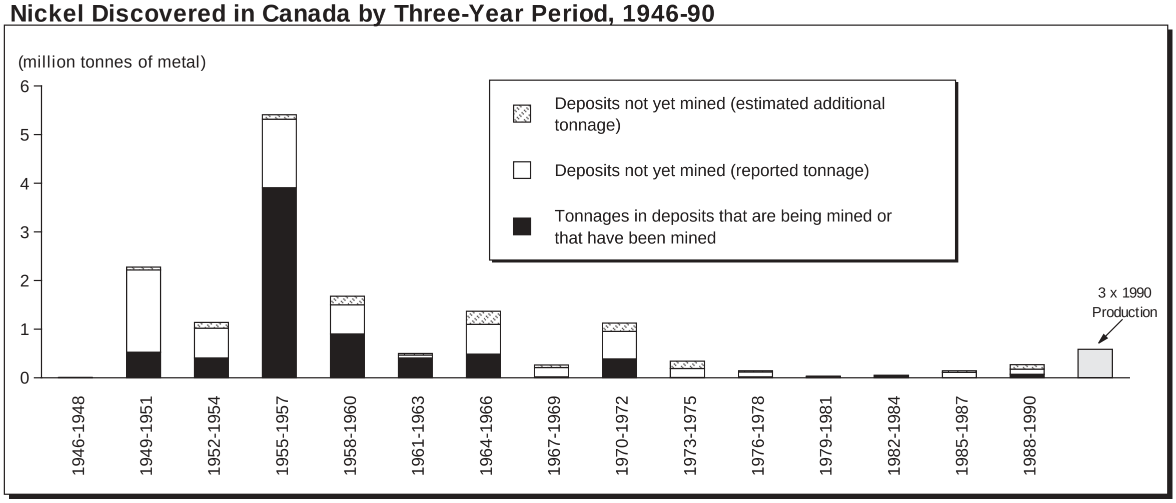
Figure 5.7
Gold Discovered in Canada by 10-Year Period, 1846-1985



Source: Natural Resources Canada.

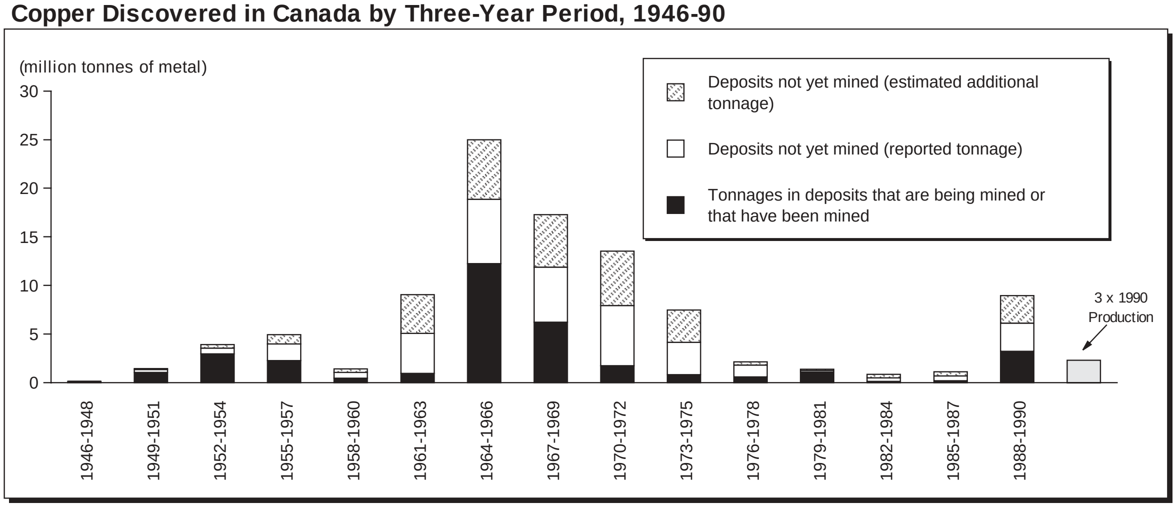
Figures 5.8 to 5.15 depict the tonnages of each of the major metals (other than iron ore) discovered in Canada per three-year period over the 45 years 1946-90. Figure 5.16 depicts the value of metals discovered in Canada over the same three-year periods. To compile this figure, metal prices were used to add together the various tonnages of the various metals discovered in each three-year discovery period of the 45 years. The black portion of each bar indicates values of the total quantities of metal discovered in deposits that have subsequently been mined and closed, in deposits that are currently being mined, and in deposits that are currently committed for production (positive feasibility study, financing arranged and mine construction under way). The quantities of metals contained in anticipated recoverable extensions to those deposits are also included in the black bars. The white portion of each bar depicts quantities of metal contained in reported tonnages at discovered deposits that are not yet being developed for production (most of these deposits are uneconomic under current conditions, but it is not unusual for some deposits to remain undeveloped for many years after they are discovered). The cross-hatched portion of each bar shows quantities of metal contained in estimated additional tonnages in those deposits. The relatively smaller proportions of black in more recent three-year discovery bars are not a matter to be concerned about because it takes time for most deposits to become producing mines. As time goes on, the proportion of a bar that is black should increase, and the white and cross-hatched portions should decrease, as more of the discovered deposits are developed for production. In fact, over the nine years since Figure 5.16 was prepared, a considerable number of the mineral deposit discoveries have already been developed for production.

Figure 5.8
Nickel Discovered in Canada by Three-Year Period, 1946-90



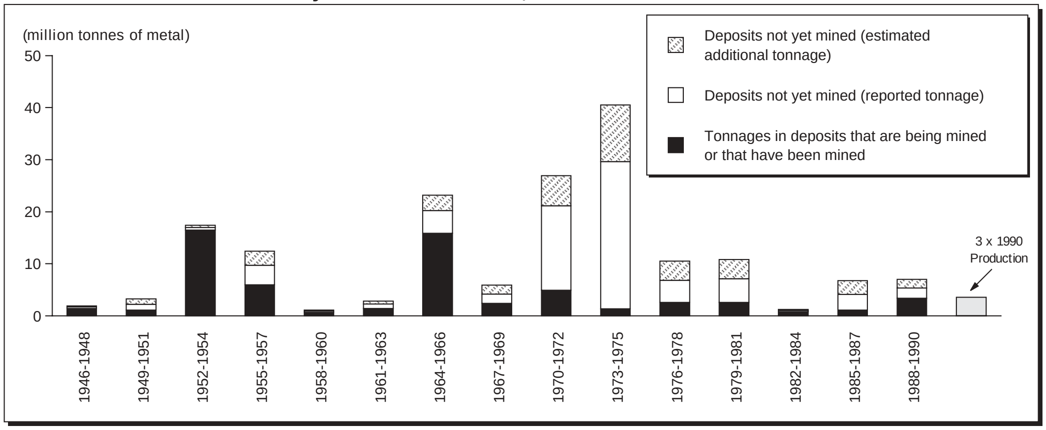
Source: Natural Resources Canada.

Figure 5.9
Copper Discovered in Canada by Three-Year Period, 1946-90



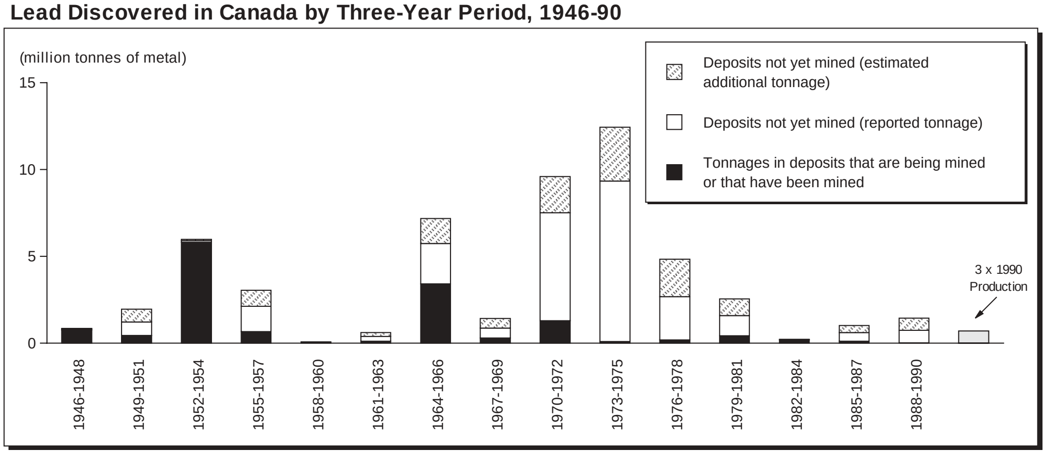
Source: Natural Resources Canada.

Figure 5.10
Zinc Discovered in Canada by Three-Year Period, 1946-90



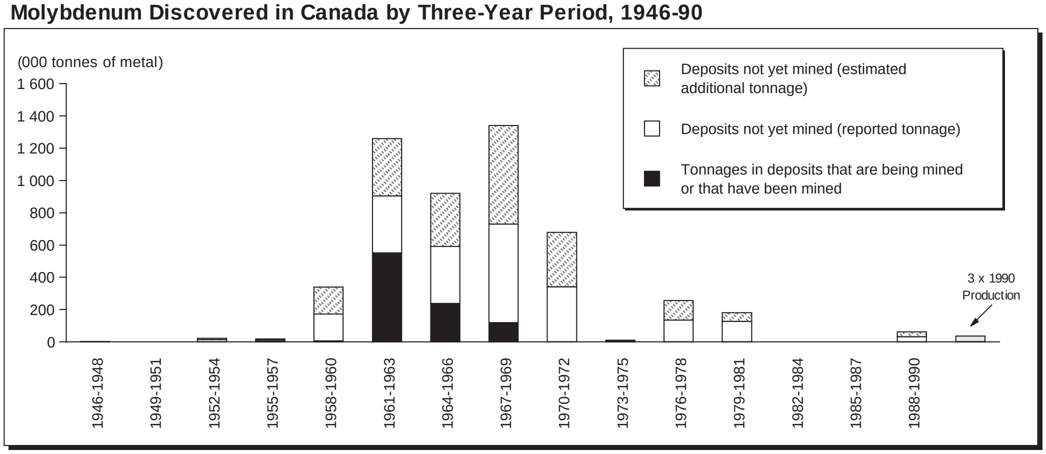
Source: Natural Resources Canada.

Figure 5.11
Lead Discovered in Canada by Three-Year Period, 1946-90



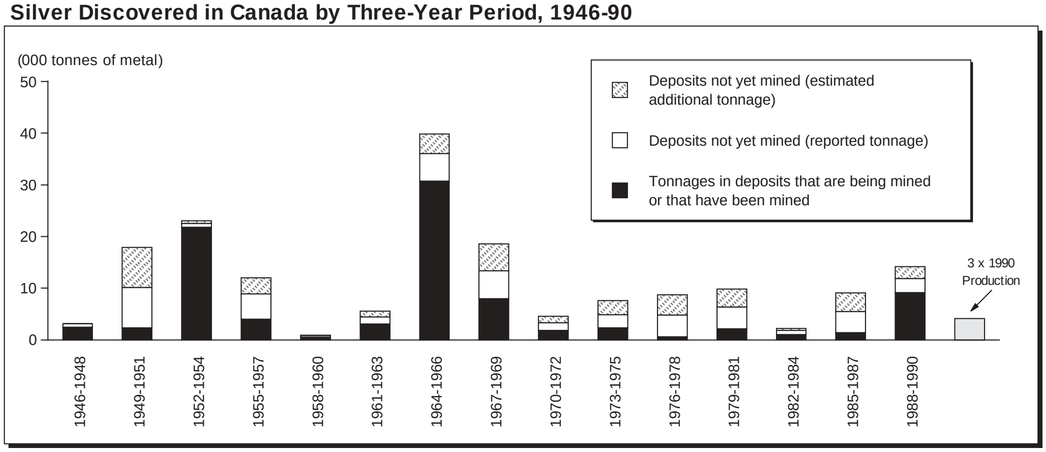
Source: Natural Resources Canada.

Figure 5.12
Molybdenum Discovered in Canada by Three-Year Period, 1946-90



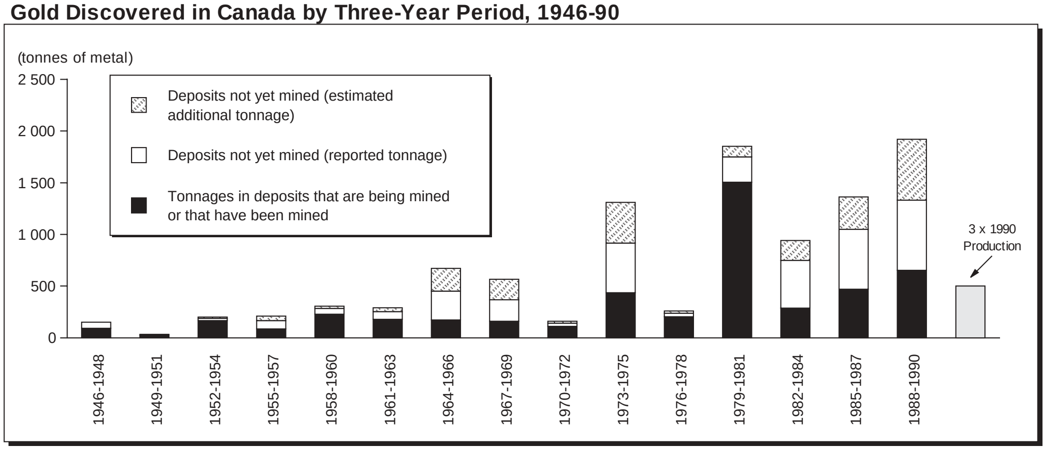
Source: Natural Resources Canada.

Figure 5.13
Silver Discovered in Canada by Three-Year Period, 1946-90



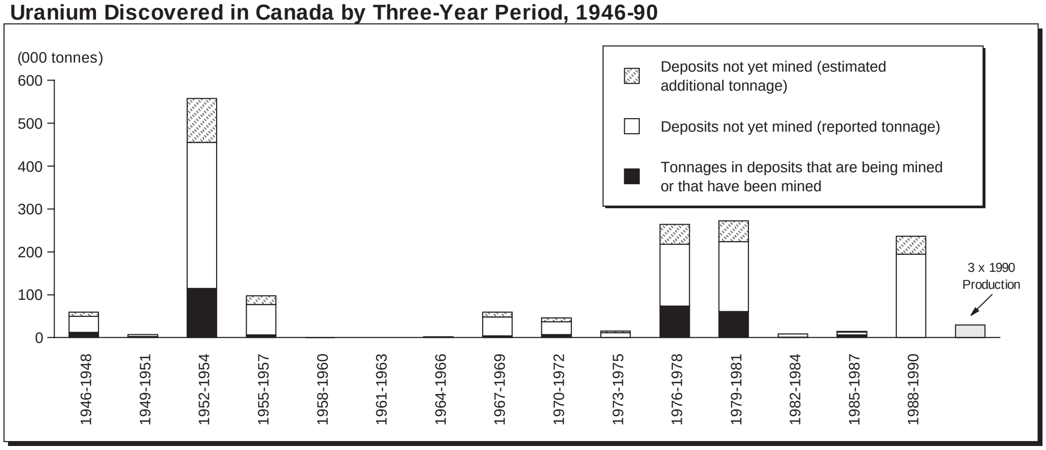
Source: Natural Resources Canada.

Figure 5.14
Gold Discovered in Canada by Three-Year Period, 1946-90



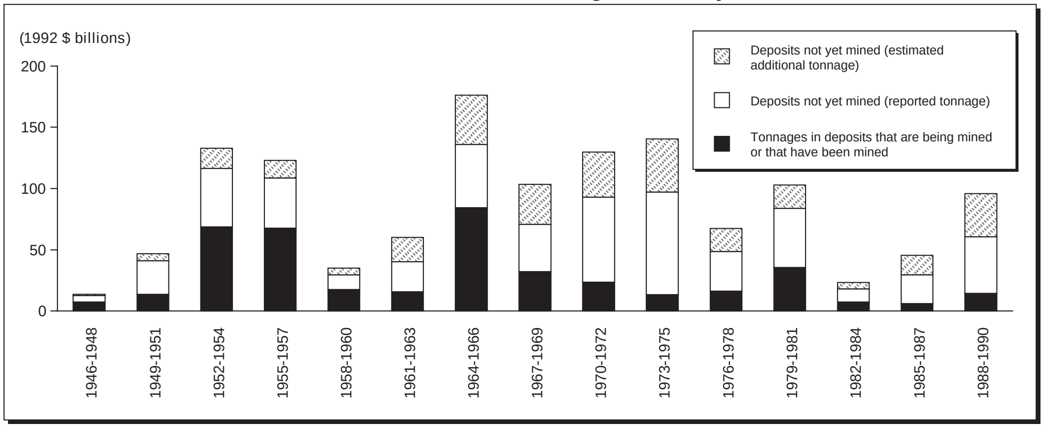
Source: Natural Resources Canada.

Figure 5.15
Uranium Discovered in Canada by Three-Year Period, 1946-90



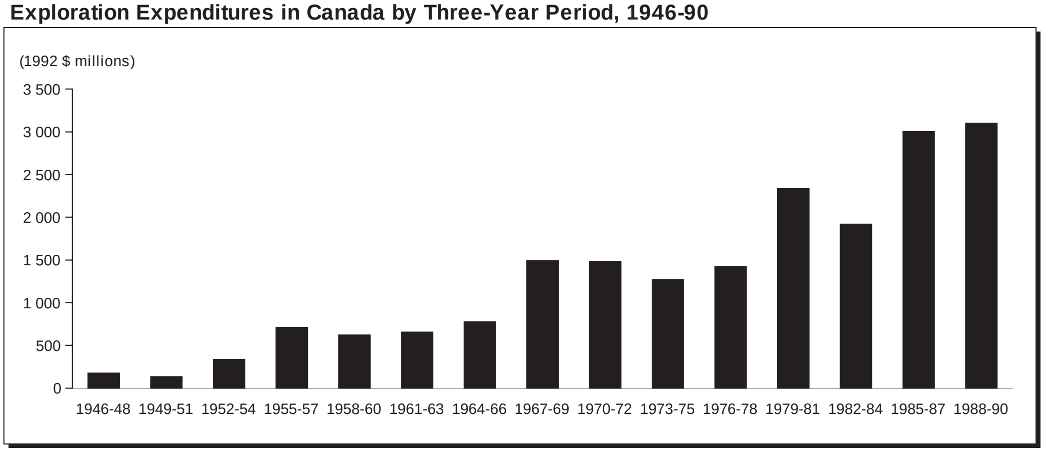
Source: Natural Resources Canada.

Figure 5.16
Value of Metals Discovered in Canada at 1987-91 Average Prices, by Three-Year Period, 1946-90



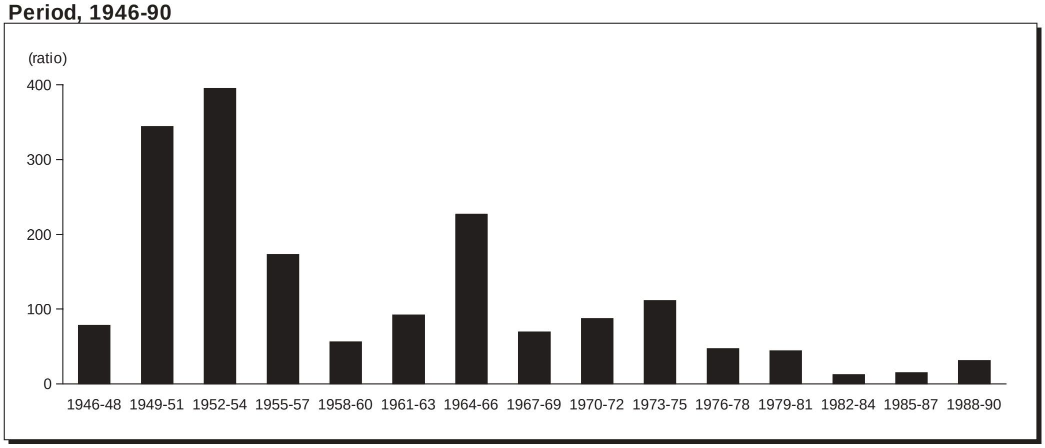
Source: Natural Resources Canada.

Figure 5.17
Exploration Expenditures in Canada by Three-Year Period, 1946-90



Source: Natural Resources Canada.

Figure 5.18
Value of Metals Discovered in Canada Per Dollar Spent on Mineral Exploration, by Three-Year Period, 1946-90



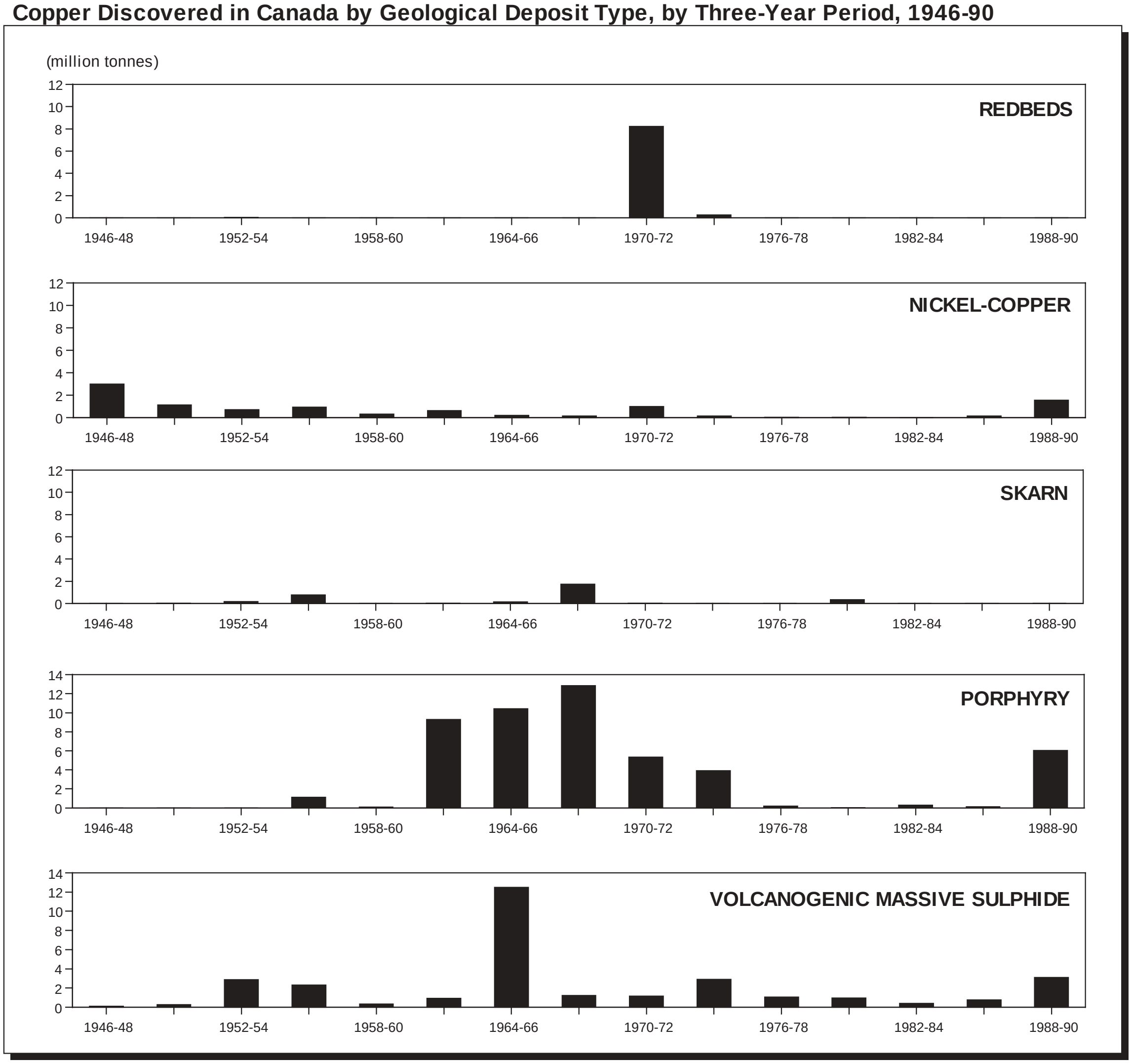
Source: Natural Resources Canada.

The quantities of metal discovered in Canada in each of the three-year periods 1946-48, 1949-51, 1958-60, 1982-84 and 1985-87 were all relatively small. The value of metal discovered in the most recent three-year discovery period shown, 1988-90, exceeds the combined average values of the 14 other three-year discovery periods, and therefore represents a considerable improvement over the immediately preceding periods 1982-84 and 1985-87.

However, over the years, there has been a major increase in the amounts spent annually on mineral exploration in Canada (Figure 5.17). These exploration expenditures must be taken into account in analyzing Canadian discovery success. This has been done by dividing the gross values of metal in all deposits discovered in Canada during each three-year discovery period by total inflation-adjusted exploration expenditures for all metals (excluding exploration expenditures for iron ore) for the same three-year discovery periods (Figure 5.18). Using this measure, discovery costs (metal value discovered per dollar of exploration expenditures) were exceptionally high in 1982-84 and in 1985-87. In 1988-90, the final discovery period analyzed, there was a notable improvement but, despite this improvement, it was concluded that considerable additional improvement would be needed if exploration results were to continue to sustain the Canadian metal mining industry over the long term.

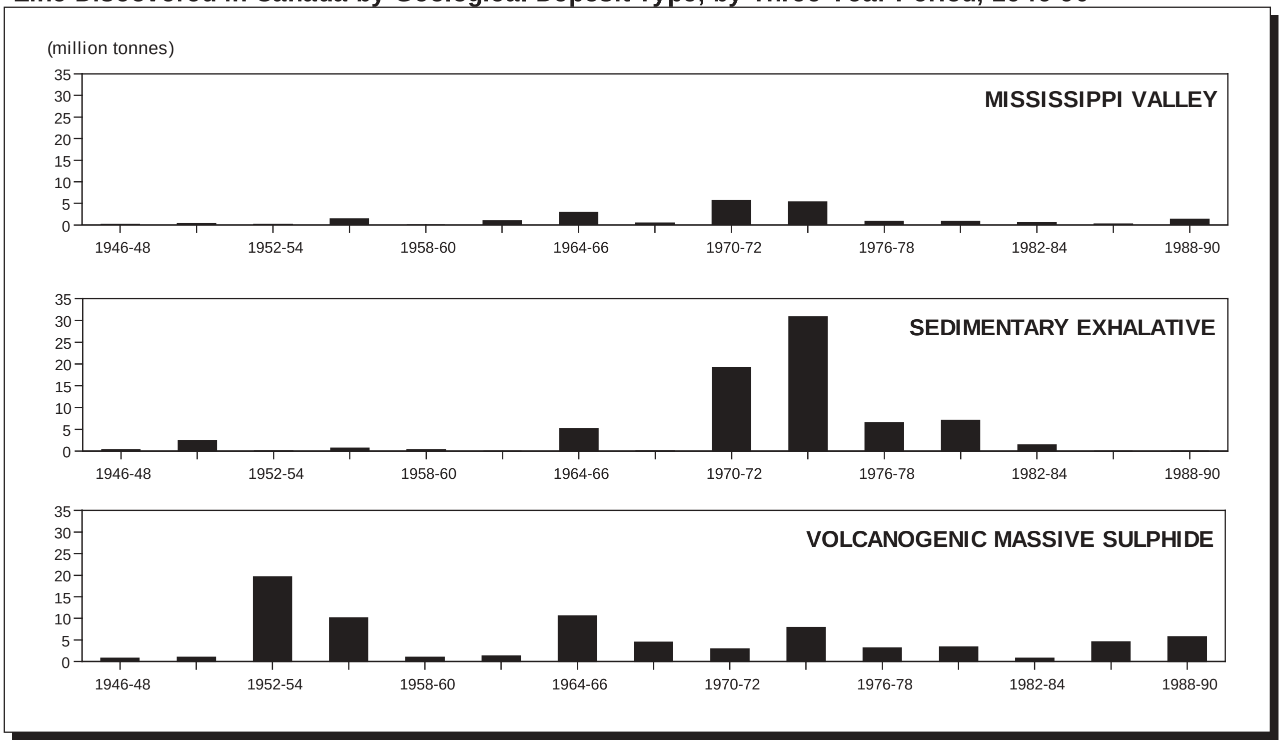
Tonnages of copper, zinc, gold and uranium discovered in Canada in each three-year discovery period of the interval 1946-90 are portrayed by geological deposit type in Figures 5.19 to 5.22, respectively.

Figure 5.19
Copper Discovered in Canada by Geological Deposit Type, by Three-Year Period, 1946-90



Source: Natural Resources Canada.

Figure 5.20
Zinc Discovered in Canada by Geological Deposit Type, by Three-Year Period, 1946-90



Source: Natural Resources Canada.

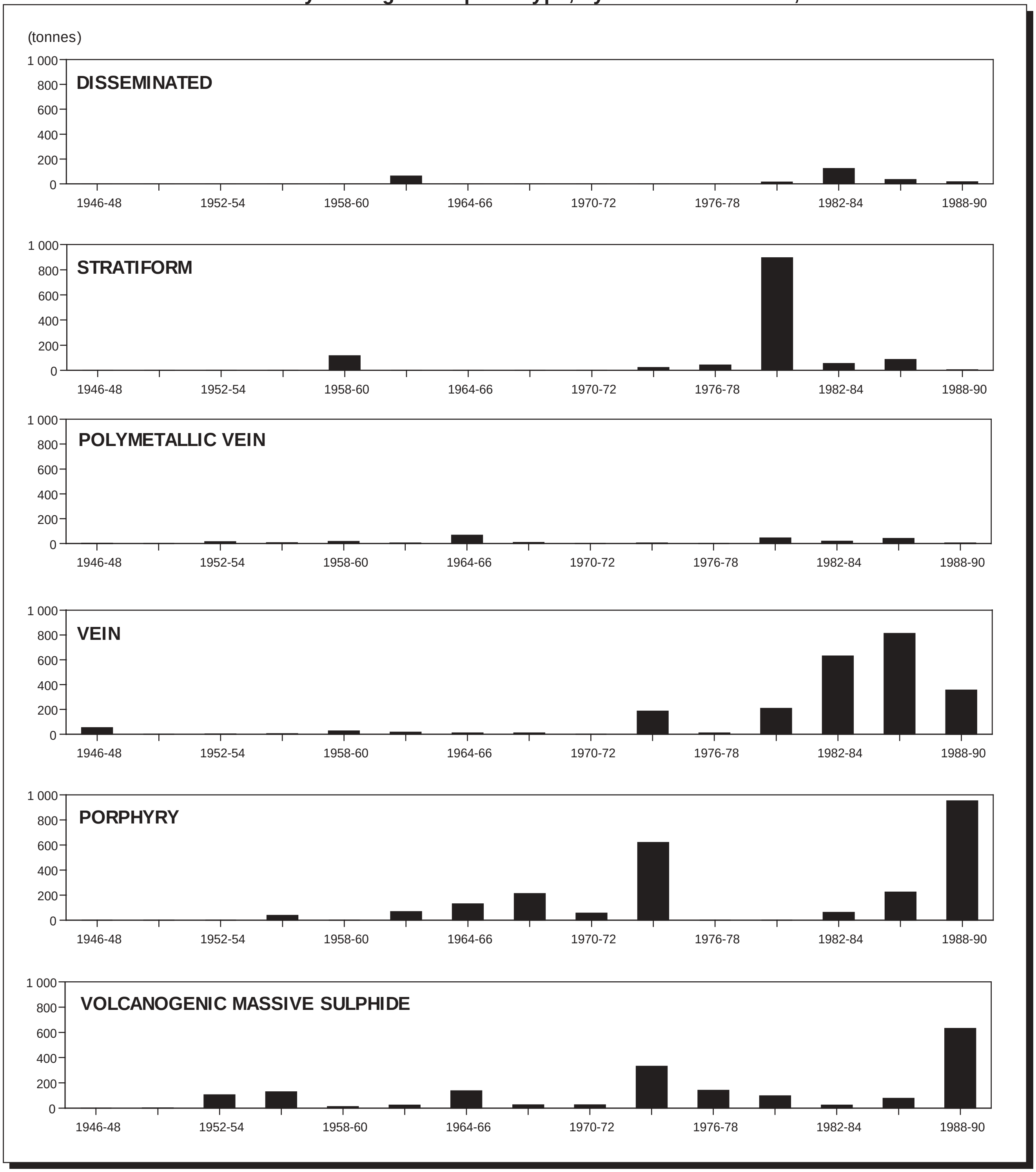
The discovery analysis covering the years 1946-90 has not, as yet, been updated. Indications are that the number of deposits and contained metal tonnages discovered in the next successive three-year period, 1991-93, were relatively low, but this can be explained in part by the fact that exploration expenditures in Canada in those three years were the lowest (in inflation-adjusted terms) in any three-year period over the 21 years that ended in December 1993.

There appears to have been considerable improvement in mineral deposit discoveries during the 1994-96 period. This period included the discovery of the large Voisey's Bay nickel-copper-cobalt deposit, discovered in 1994 near the Atlantic coast of Labrador, and 15 or more attractive diamond deposits at various locations in the Northwest Territories. Eight of these diamond deposits are on the property of the Ekati diamond mining operation where production from the first deposit to be mined began in October 1998. The Diavik property contains at least four high-grade diamond deposits with initial production expected in 2003.

Subsequent diamond discoveries include the Snap Lake kimberlite dyke, now owned by De Beers Canada Corporation, reported to contain some 86 million carats (ct) of recoverable diamonds valued at about US$100/ct. The deposit is expected to be in production in about 2006. Early in 2000, De Beers took a 7000-t bulk sample from the Victor kimberlite in Ontario, 100 km west of James Bay. De Beers has stated that the Victor deposit contains 37 Mt with a diamond content valued at C$100/t. There is also potential for production from two additional diamond deposits discovered in 1994-96 at other locations, one in the Northwest Territories and the other in Nunavut, but it is too early to be certain of this because additional diamond discoveries may be needed in their vicinity to increase the tonnages of mineable ore. Diamonds are not metals; therefore, diamond deposit discoveries should not be considered as belonging in a metal deposit discovery analysis. However, they do constitute important discoveries and because diamond values per tonne of ore are available for such deposits, they can be added to the discovery analysis provided that exploration expenditures for diamonds are also taken into account.

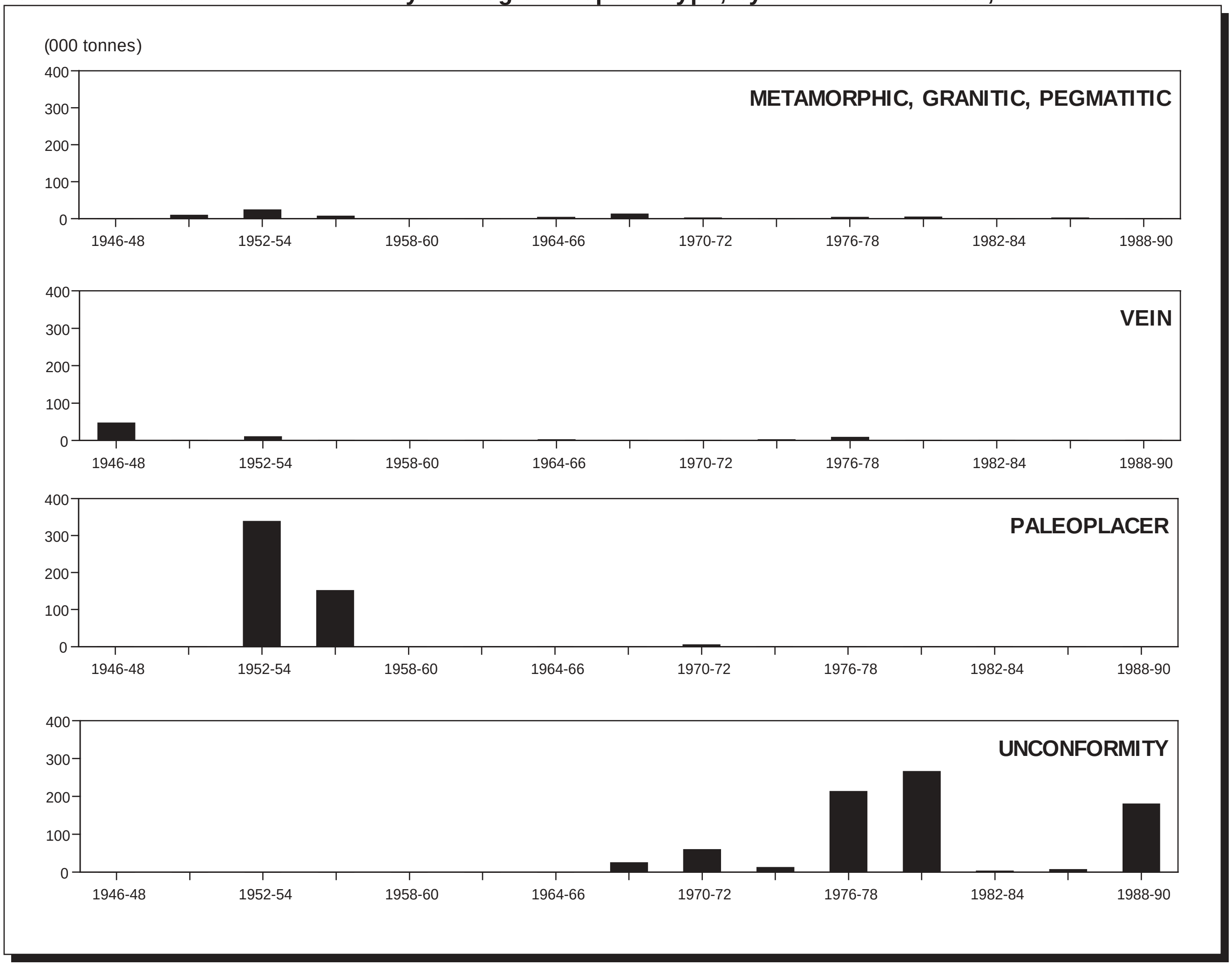
In summary, there would appear to have been some improvement in mineral exploration and discovery success in Canada in the mid-1990s. When this paper was written, it was too early to adequately evaluate the success of exploration in Canada in 1997, 1998, 1999 and 2000, but a significant number of discoveries of base metals, gold and other mineral commodities have been made.

Figure 5.21
Gold Discovered in Canada by Geological Deposit Type, by Three-Year Period, 1946-90



Source: Natural Resources Canada.

Figure 5.22
Uranium Discovered in Canada by Geological Deposit Type, by Three-Year Period, 1946-90



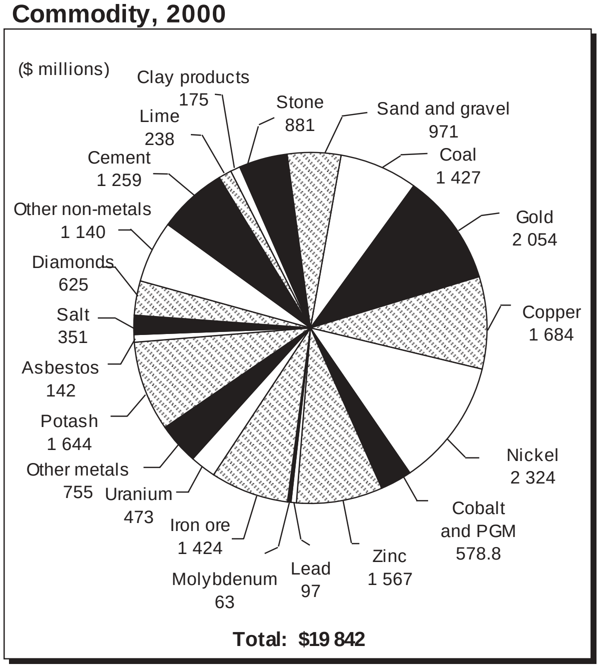
Source: Natural Resources Canada.

6. Ore Reserves and the Long-Term Future of Canadian Mineral Production

6.1 INTRODUCTION

Mining yields many different mineral commodities. Over the years, the balance of the various minerals produced in Canada has changed and will undoubtedly continue to change in the future. Figure 6.1 shows 2000 production values for all mineral commodities being produced in Canada. The base metals are actually all metals that are not considered to be precious metals, but common usage in Canada seems to include nickel, copper, zinc, lead and perhaps molybdenum in the base-metal category. By this usage, base metals, together with the various by-products recovered in their production, currently constitute 40% of the value of total Canadian mine output of all mineral commodities (excluding the petroleum recovered by mining and processing of the Alberta oil sands).

Figure 6.1
Value of Mine Production in Canada by Commodity, 2000



Source: Natural Resources Canada.

On a national basis, Canada's reserves of any particular metal (or of any other mineral commodity) in ore are not normally what matters, provided that any decline in the production of some metals or minerals is compensated for by increased production of other metals or minerals. However, there may be regional problems in terms of employment, concentrate feed for smelters, and the like.

6.2 CANADA'S RESERVES OF METALS IN ORE

Natural Resources Canada first compiled reserves for the major metals as at January 1, 1974, and has continued to do so for each year since then. The most recent ore reserves compilation is as at January 1, 2000 (Reed, 2001). Reserves are compiled for the total of proven and probable mineable ore only. Inferred mineral resources are not included because the existence and metal grades of such "resources" are based on little information and are therefore too uncertain to be relied upon. The reserves include all ore in producing mines and in all deposits that were, at that date, committed to production. "Committed to production" means that there was a positive feasibility study, all needed permits had been received, equipment had been ordered, and construction was in progress. For each major metal, one figure illustrates annual ore reserves of that metal from January 1, 1974 to January 1, 2000. For the years 1973 to 1999, the other figure illustrates for each metal the ratio of reserves at the end of each year to overall mine production during that year.

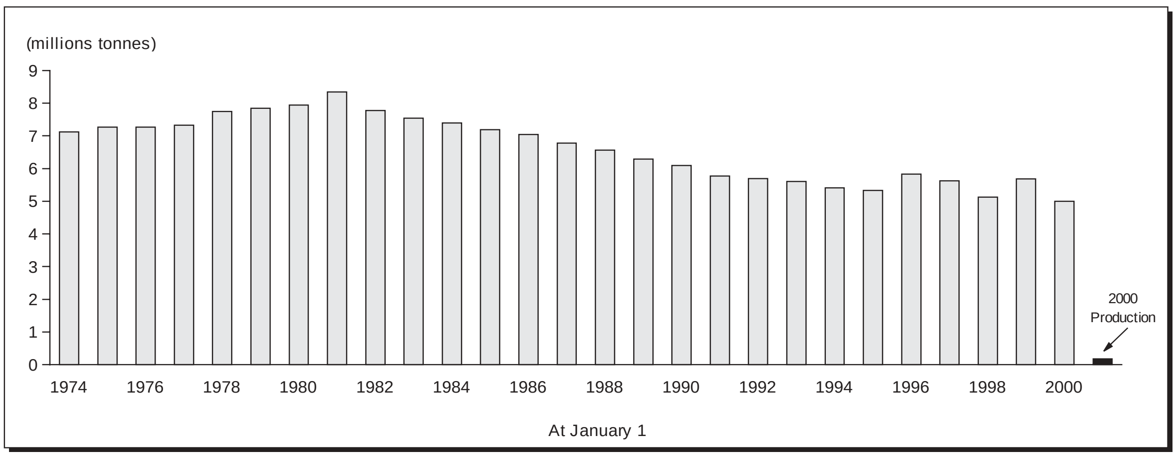
Nickel

From 1981 to 1994, Canada's reserves of nickel in ore (Figure 6.2) declined by more than one-third. For many years Canadian nickel production had been increasing; therefore, nickel reserves had also been increasing. Production subsequently declined as Canada lost nickel market share. About the year 1980, the Canadian reserves-to-production ratio for nickel (Figure 6.3) was in excess of 45 to 1, a ratio that was considerably higher than were the reserves-to-production ratios for the other metals and that was too expensive for the nickel industry to continue to maintain. Nickel reserves appear to have been deliberately allowed to decline to a more realistic reserves-to-production ratio of about 28 to 1. Nickel reserves increased by some 500 000 t on January 1, 1996, mostly because of the addition of the nickel at the Raglan nickel-copper mining operation in the Cape Smith-Wakeham Bay Nickel Belt, in the Ungava Region of northern Quebec. The various nickel showings and deposits currently known in this region were originally discovered in the 1950s and 1960s, but it was not until 1995 that a decision was made to bring a nickel deposit into production. When there is eventually a production go-ahead for the Voisey's Bay nickel deposit in Labrador, discovered in 1994, Canada's nickel reserves could increase by as much as 50%, depending on how much of the known nickel there Inco Limited (the owner of the deposit) chooses to add to its proven and probable reserves of nickel in ore. Recently, Inco Limited and Falconbridge Limited, Canada's two major nickel producers, have each discovered several new, deep nickel-copper deposits at Sudbury, Ontario, and have other attractive, known, but as yet undeveloped, nickel deposits at Sudbury. Therefore, Canada's reserves of nickel in ore are likely to continue to be maintained for at least a decade or two.

If annual nickel production from the Voisey's Bay deposit is as high as some predict when production begins, the reserves-to-production ratio is most likely to fall below the levels of the late 1980s and early 1990s, but only the future will tell.

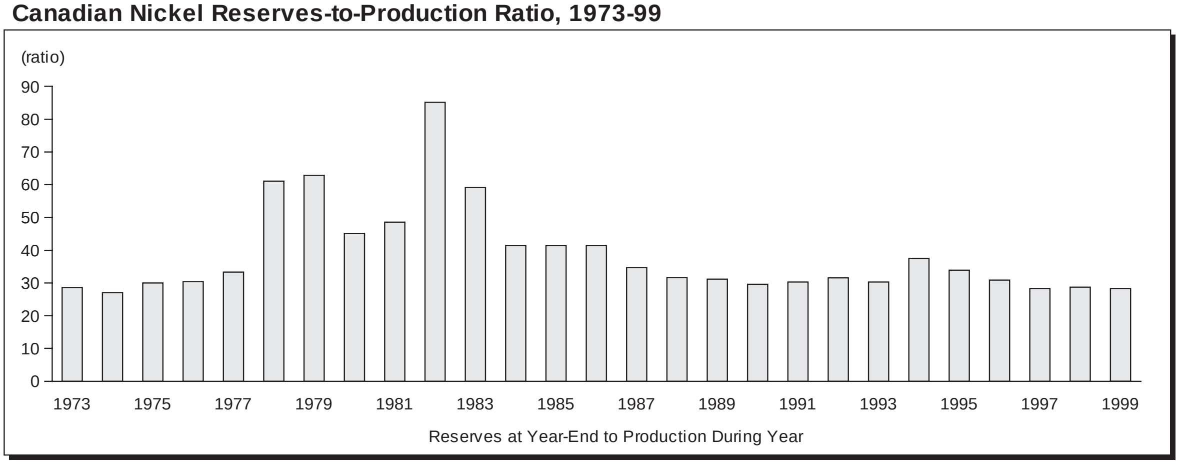
It should be noted that in the reserves-to-production ratio graph for nickel, and for all the other metals, sudden changes in the ratio, either up or down, normally reflect temporary lows or highs in annual production rather than annual changes in ore reserves.

Figure 6.2
Canadian Proven and Probable Reserves of Nickel Metal in Ore, 1974-2000



Source: Natural Resources Canada.

Figure 6.3
Canadian Nickel Reserves-to-Production Ratio, 1973-99

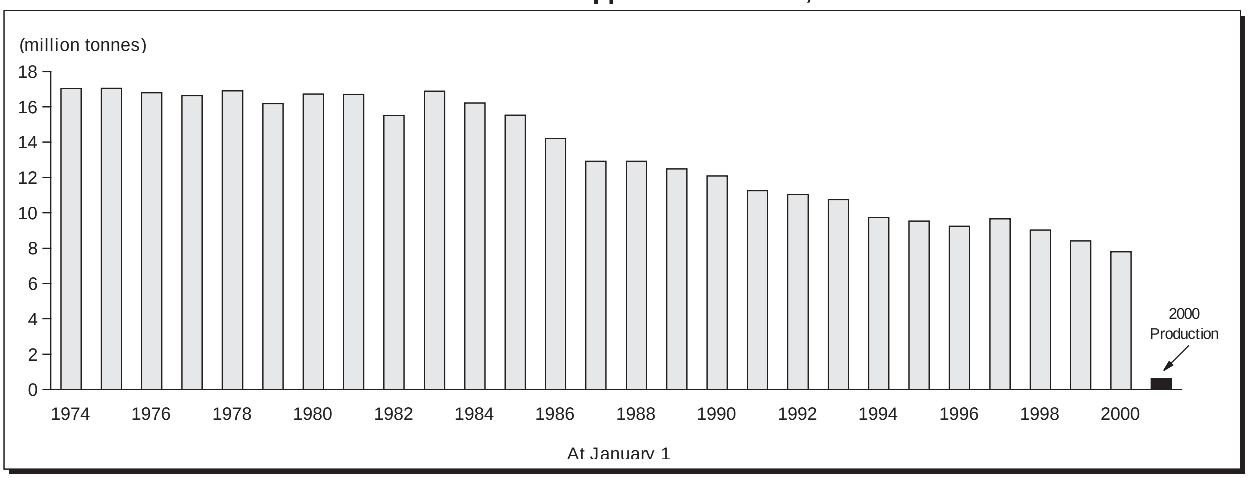


Source: Natural Resources Canada.

Copper

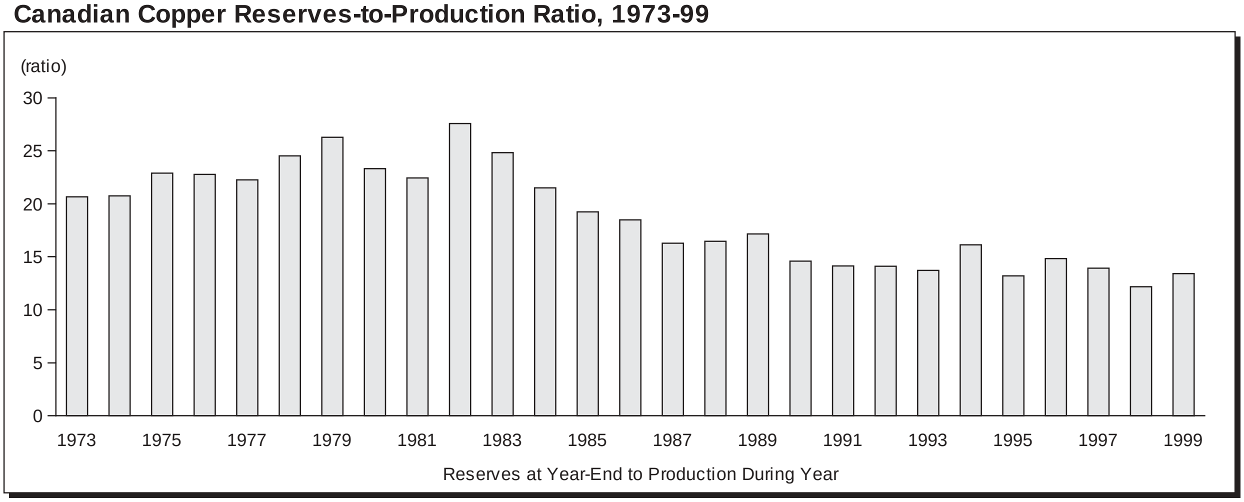
Copper reserves in Canada were fairly steady from 1974 to 1982, but subsequently declined by about 45% (Figure 6.4). The reserves-to-production ratio for copper has also declined (Figure 6.5). Production decisions for the Huckleberry, Kemess South and Mount Polley porphyry-copper deposits in British Columbia added some 1.1 Mt to Canadian reserves of copper as at January 1, 1997. The Voisey's Bay nickel-copper-cobalt deposits could add as much as 2 Mt more when a production decision is eventually made. Significant further replacement of the copper produced from reserves at Sudbury, Ontario, is likely when production decisions are eventually made for some 10 as yet undeveloped but attractive nickel-copper deposits that are known there. There is also potential for development of a few already known, but as yet undeveloped, porphyry copper deposits in British Columbia.

Figure 6.4
Canadian Proven and Probable Reserves of Copper Metal in Ore, 1974-2000



Source: Natural Resources Canada.

Figure 6.5
Canadian Copper Reserves-to-Production Ratio, 1973-99



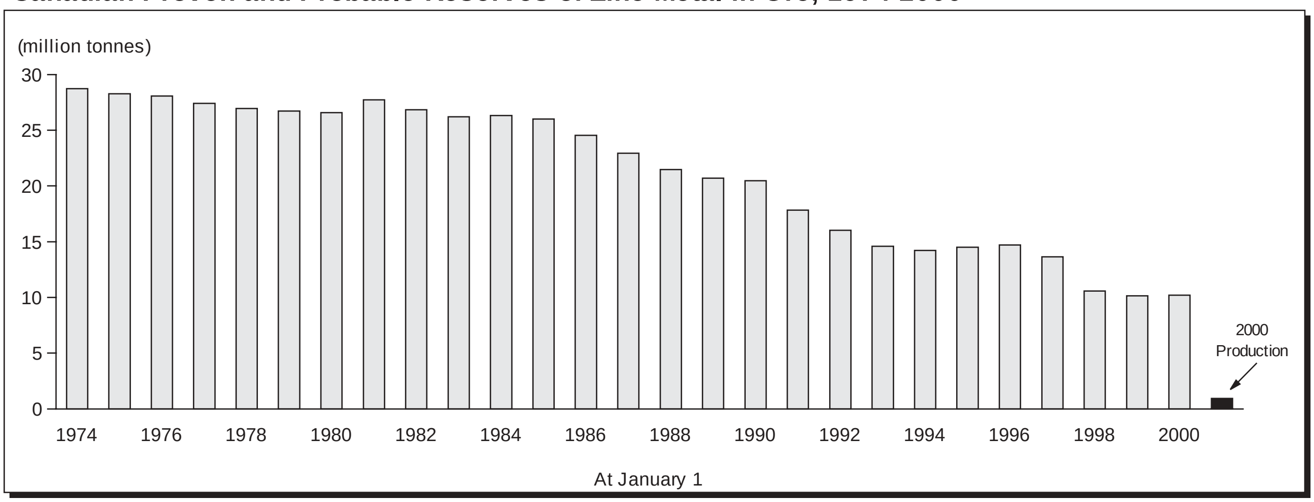
Source: Natural Resources Canada.

Zinc

Aggregate zinc reserves in Canada (Figure 6.6) were relatively constant until 1985, but have declined since then by some 58%. Canada has several known but as yet undeveloped zinc deposits, some of which may be developed if favourable market conditions return. The major undeveloped Howard's Pass zinc-lead deposit, discovered in the mid-1970s in the vicinity of Howard's Pass on the Yukon Territory-Northwest Territories boundary and the world's largest undeveloped zinc-lead deposit, contains 27 Mt of zinc, an amount that is more than 2.5 times Canada's January 1, 2000, zinc reserves of 10.2 Mt. Production from this deposit will require zinc prices to be somewhat higher than those that have prevailed since the mid-1970s.

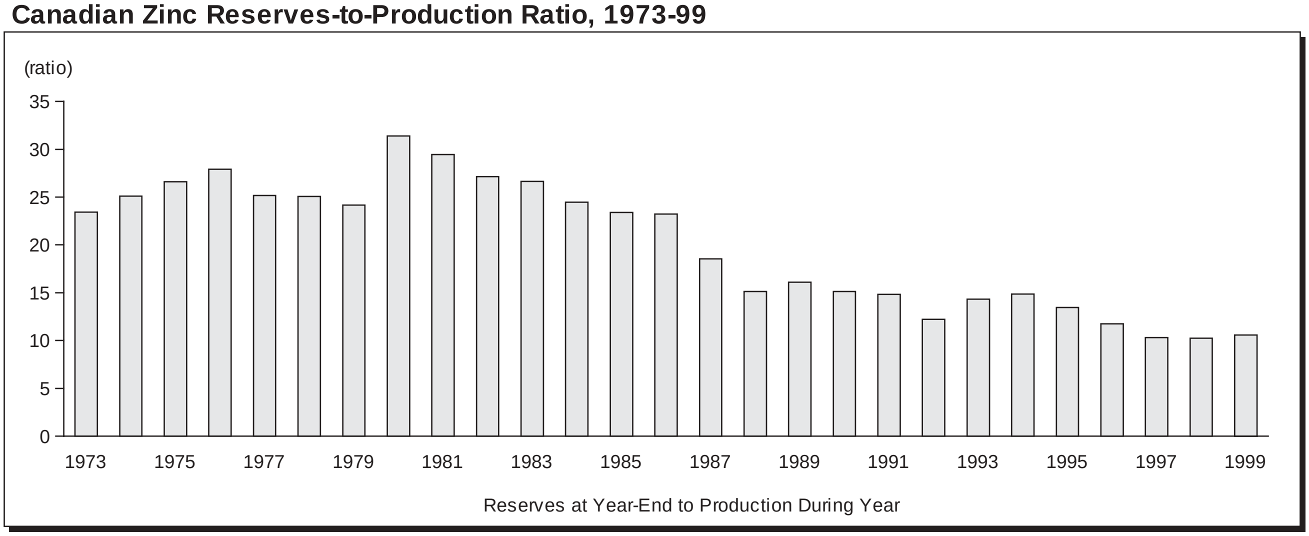
The Canadian reserves-to-production ratio for zinc (Figure 6.7) has also been declining.

Figure 6.6
Canadian Proven and Probable Reserves of Zinc Metal in Ore, 1974-2000



Source: Natural Resources Canada.

Figure 6.7
Canadian Zinc Reserves-to-Production Ratio, 1973-99



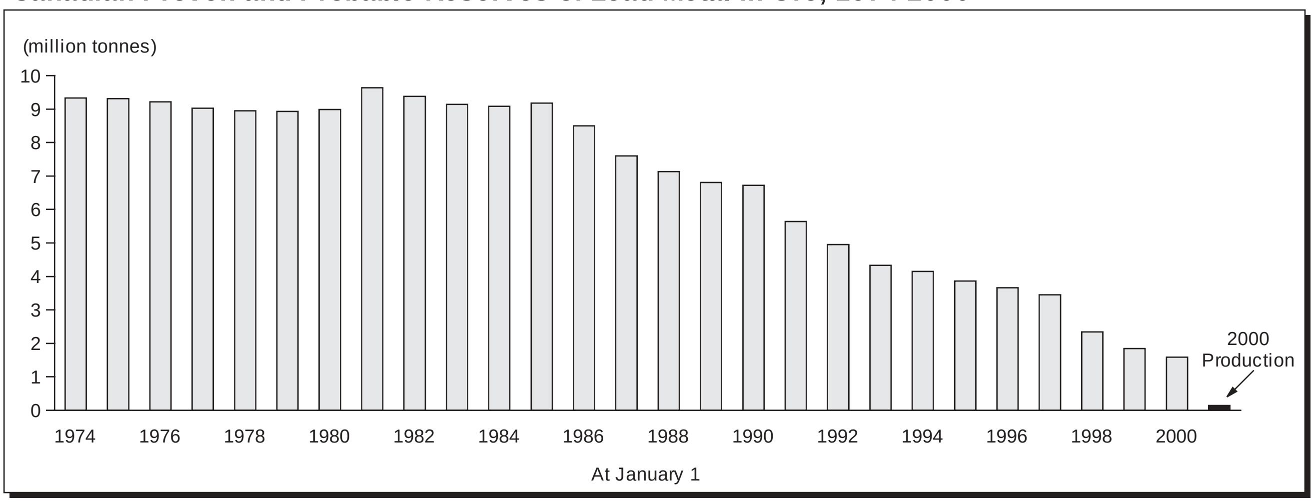
Source: Natural Resources Canada.

Lead

Lead reserves (Figure 6.8) have been declining and, without new orebody discoveries or development of known deposits, will continue to decline. As with zinc, substantial tonnages of lead are contained in a number of undeveloped zinc-lead deposits located in northern British Columbia and the Yukon. At least some of these deposits are likely to be developed when market conditions for zinc and lead improve. The lead content of the immense Howard's Pass zinc-lead deposit, not included in Canadian reserves, is some 10.5 Mt, which is more than six times the 1.59 Mt of Canadian reserves of lead in ore as at January 1, 2000.

The reserves-to-production ratio for lead (Figure 6.9) has been decreasing. The Brunswick No. 12 zinc-lead-copper-silver mine in New Brunswick is the only remaining Canadian lead producer of any significance. When that mine closes in about 2010, Canada may no longer produce lead. However, the value of Canada's lead production is not large.

Figure 6.8
Canadian Proven and Probable Reserves of Lead Metal in Ore, 1974-2000



Source: Natural Resources Canada.

Figure 6.9
Canadian Lead Reserves-to-Production Ratio, 1973-99

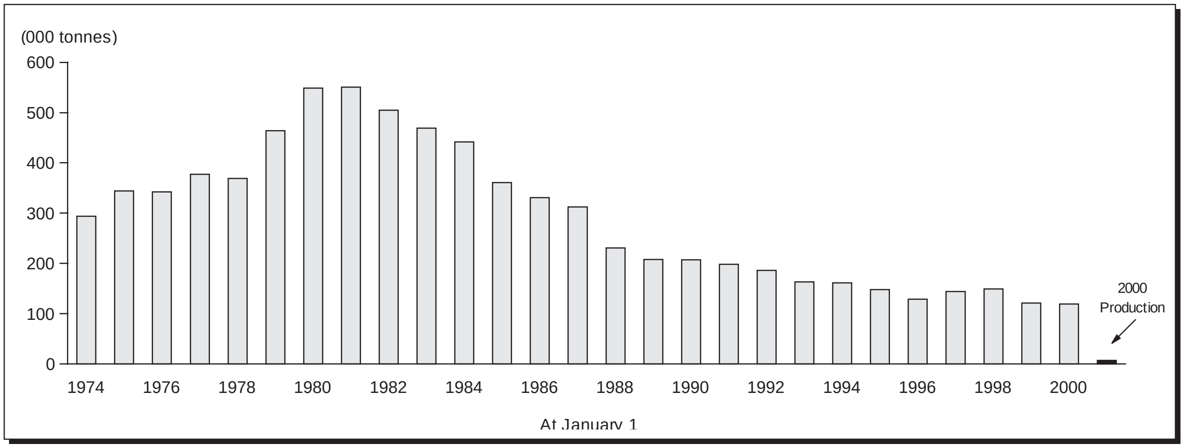
Source: Natural Resources Canada.

Molybdenum

Canadian molybdenum reserves (Figure 6.10) rose from the 1960s until 1981 and then declined rapidly. By January 1, 2000, they were down to 22% of the peak reserves of 549 000 t as at January 1, 1981. Some explanation is needed for this exceptional decline. The relatively sharp climb and decline of molybdenum reserves evident in Figure 6.10 resulted from the exceptionally high molybdenum prices that were in effect at the end of the 1970s. These high prices resulted in production decisions for the large but low-grade Kitsault porphyry molybdenum deposit and the low-grade Highmont porphyry copper-molybdenum deposit, both in British Columbia, and for the low-grade Mount Pleasant molybdenum-tungsten-tin-bismuth deposit in New Brunswick. Ore reserves were also increased at the Endako (porphyry molybdenum) mine in British Columbia, and the molybdenum that was contained in the ore, but was neither recovered nor included in published ore reserves until the molybdenum price increased, was added to ore reserves at the Gibraltar (porphyry copper-molybdenum) mine, also in British Columbia, and at the Gaspé Copper mine in Quebec.

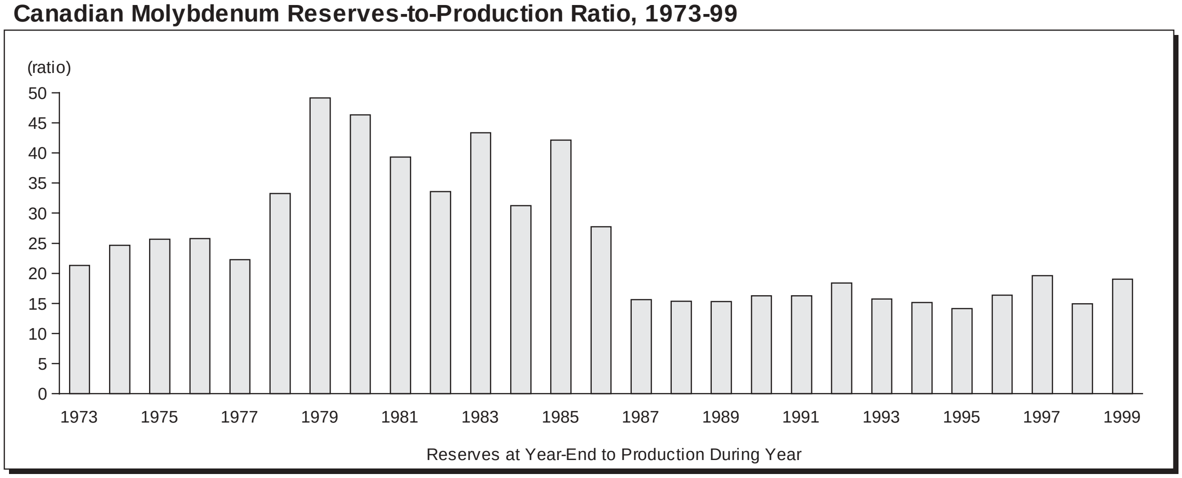
The molybdenum price soon declined to much lower levels, the new mines were closed, molybdenum recovery ceased at both Gibraltar and Gaspé Copper, and the molybdenum in ore reserves at Endako was cut by 30%. All of this molybdenum was ultimately removed from Canadian reserves totals.

Figure 6.10
Canadian Proven and Probable Reserves of Molybdenum Metal in Ore, 1974-2000



Source: Natural Resources Canada.

Figure 6.11
Canadian Molybdenum Reserves-to-Production Ratio, 1973-99



Source: Natural Resources Canada.

Only three molybdenum producers remain: the Endako, Highland Valley Copper and Huckleberry mines. There has not been a molybdenum deposit discovered in Canada in many years. During 1997, the new Huckleberry porphyry copper-molybdenum mine (developed on a deposit originally discovered in 1963) added 13 000 t of molybdenum in ore to Canadian molybdenum reserves. Without additional new molybdenum mines, Canadian molybdenum reserves will continue to decline. The annual value of Canada's molybdenum production is low relative to many of the other metals produced and this will not be a serious problem with respect to its effect on the value of Canada's mineral production. The reserves-to-production ratio for molybdenum (Figure 6.11) has remained relatively constant over the past decade.

Silver

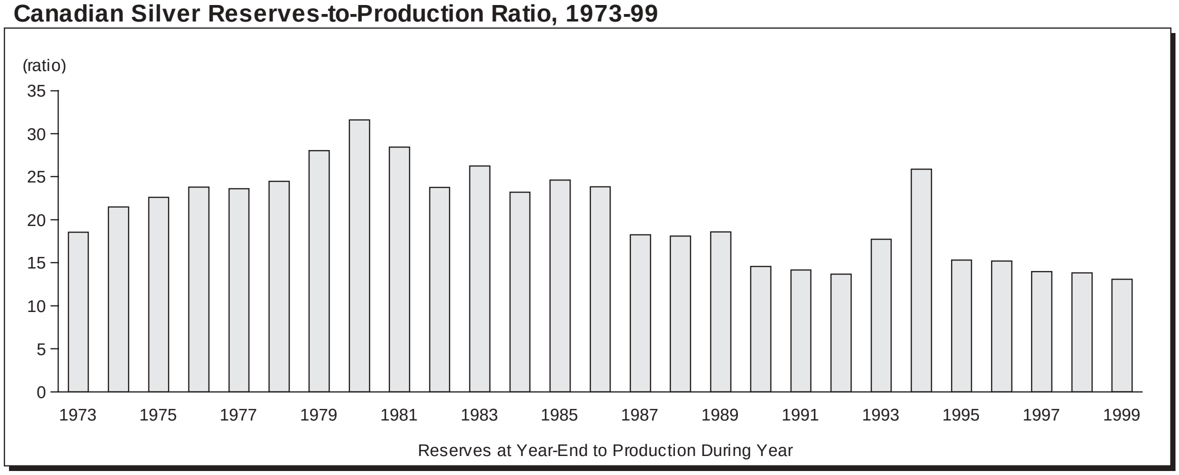
Most of Canada's silver production is a by-product of base-metal mining. Silver reserves (Figure 6.12) peaked in 1981 and then declined. By the end of 1993, reserves were down by 44%. Most of the increase that occurred in 1995 was silver contained in ore at the rich Eskay Creek gold-silver mine in British Columbia.

The future of Canadian silver reserves is closely tied to the future of reserves of the base metals. The reserves-to-production ratio for silver (Figure 6.13) has generally been declining along with the reserves-to-production ratios for the base metals.

Figure 6.12
Canadian Proven and Probable Reserves of Silver Metal in Ore, 1974-2000

Source: Natural Resources Canada.

Figure 6.13
Canadian Silver Reserves-to-Production Ratio, 1973-99

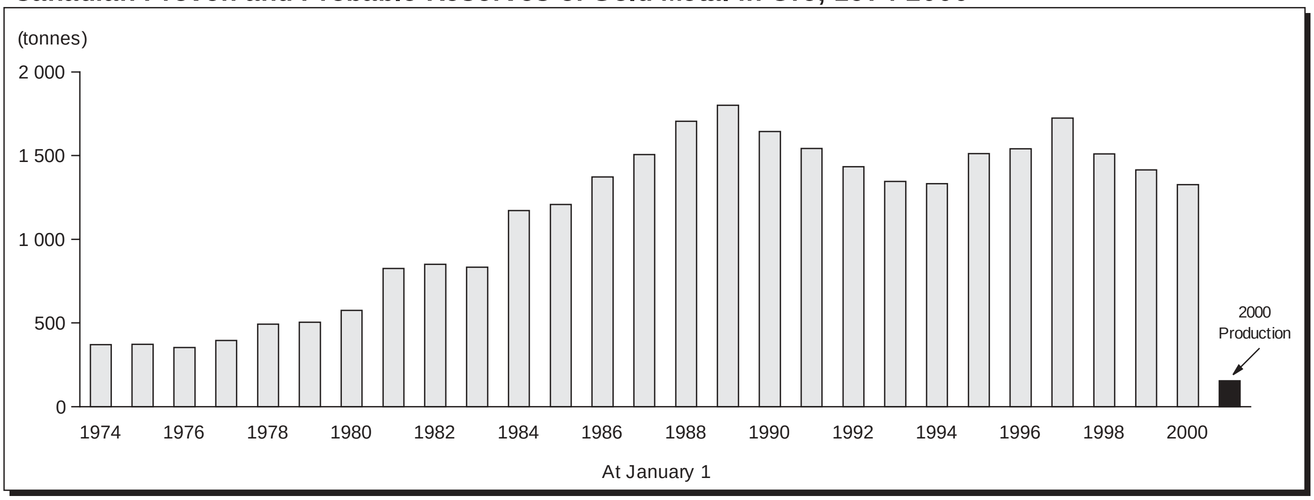


Source: Natural Resources Canada.

Gold

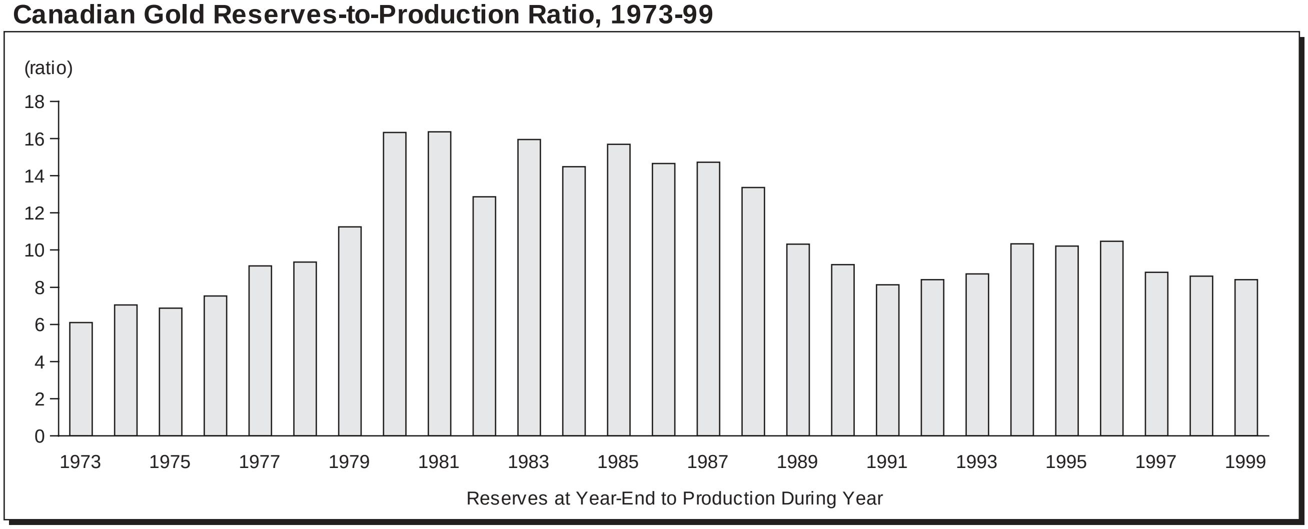
In the early 1970s, the United States allowed the gold price to rise from the fixed US$35/troy oz (31.10 grams) that had been in effect beginning in 1934. As a result, Canadian reserves of gold in ore (Figure 6.14) increased steadily over the period 1977-89. Gold reserves subsequently declined from 1989 to 1994, and in 1994 they stood at 74% of their 1988 peak. With new gold mines in production, reserves of gold in ore in Canada had increased to 1724 t as at January 1, 1998, not much below the all-time record of 1801 t attained as at January 1, 1988. The gold price declined again and, as a result, Canadian reserves of gold in ore are declining again. The Canadian reserves-to-production ratio for gold (Figure 6.15) rose in the mid-1990s but has declined again somewhat.

Figure 6.14
Canadian Proven and Probable Reserves of Gold Metal in Ore, 1974-2000



Source: Natural Resources Canada.

Figure 6.15
Canadian Gold Reserves-to-Production Ratio, 1973-99

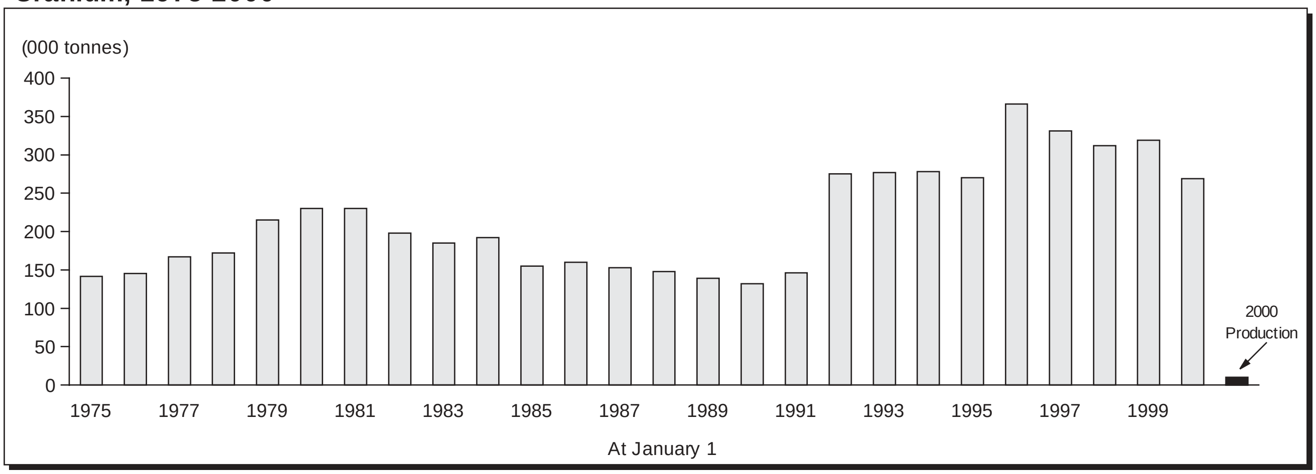


Source: Natural Resources Canada.

Uranium

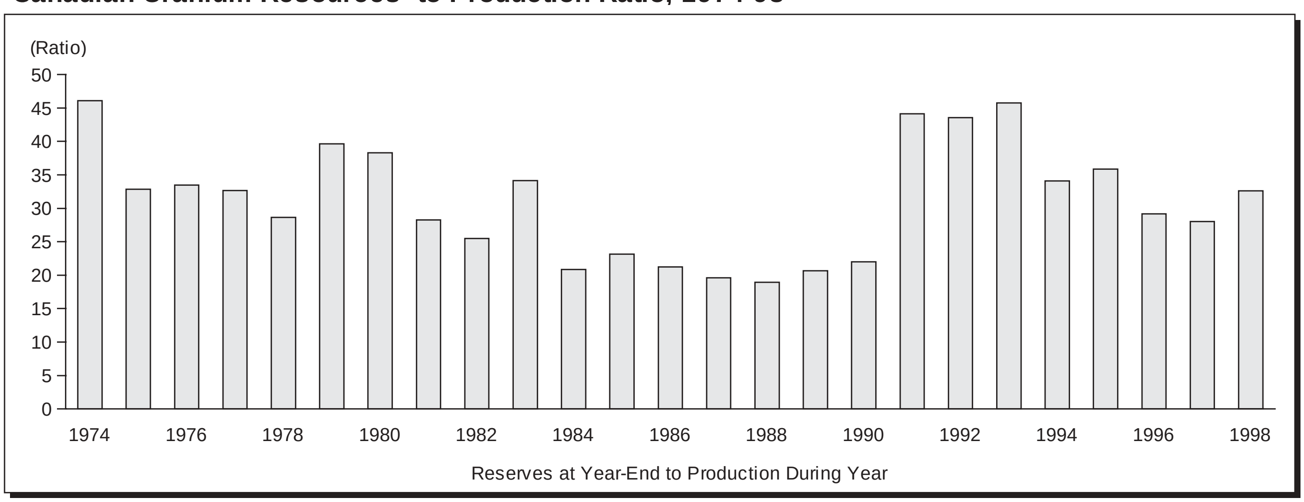
Uranium resources (Figure 6.16) are calculated on a different basis from the reserves of other metals. This is because the world's nuclear power reactor operators want to know how much uranium will be available at a price they could afford to pay if they had to (a price that is well above current market prices), rather than how much uranium is available at current prices (reserves). These uranium resources represent recoverable uranium after mining and milling losses, whereas reserves of the other major metals take mining losses into account but do not allow for milling losses. Figure 6.17 portrays the Canadian uranium resources-to-production ratio over the period 1974-99.

Figure 6.16
Canadian Measured and Indicated Uranium Resources Recoverable at Prices[1] Up to $100/kg of Uranium, 1975-2000



Source: Natural Resources Canada.
[1]These prices are not adjusted for inflation. Prices used for 1975-83 varied from year to year.

Figure 6.17
Canadian Uranium Resources[1]-to-Production Ratio, 1974-98



Source: Natural Resources Canada.
[1]Resources recoverable at prices up to $100/kgU.

Iron Ore

Current ore reserves at producing iron ore mines in Canada amount to some 4 000 000 000 t of ore, sufficient to yield 1 400 000 000 t of iron ore product, an amount that is equivalent to 39 years of Canada's current iron ore production. In addition to these reserves, there are vast tonnages of comparable iron-bearing material that are close to current iron mines. Therefore, if Canadian iron mines remain profitable, which seems likely, iron ore production should continue in Canada for centuries to come.

Total Canadian resources of iron in "ore" amount to some 45 000 000 000 t of contained iron (calculated from data presented in *A Summary View of Canadian Reserves and Additional Resources of Iron Ore*, Energy, Mines and Resources Canada, 1977, Figure 1, p. 4). While much of this material is not economic at current prices, it constitutes an enormous and relatively low-cost resource for the future.

Potash

Canada has vast reserves/resources of high-quality potash ore that contain more than 60 000 000 000 t of KCl (Zwartendyk, 1988). This material is sufficient to support the current or a much higher level of output for many centuries.

Salt

Canadian reserves/resources of rock salt amount to more than 100 000 000 000 000 t of NaCl, sufficient to support current or higher levels of production far into the future. But the great majority of this salt underlies areas of Alberta, Saskatchewan and Manitoba where the local market for salt is not large, both because the population of the region is not large and because salt is not normally used to melt ice from highway and road surfaces there because the winter climate is cold, with temperatures commonly below the minus 20.6ºC eutectic temperature for the system sodium chloride-water. Transportation charges make the shipment of salt over long distances prohibitively expensive; the available markets for the salt are therefore limited.

Coal

Canada's reserves of coal are adequate to support current or much higher levels of production for many centuries. Canadian coal production is limited by the relatively small population of the western half of Canada where most of that coal is located and local demand is therefore limited, and by the fact that abundant hydro-electric power and additional undeveloped hydro-electric sites are available in Manitoba and British Columbia so that thermal electrical power in these two provinces is used only for meeting peak demand. The only thermal power generation in British Columbia uses natural gas, not coal, and the Manitoba thermal plants have now been converted from coal to natural gas. Potential coal production is also limited by market conditions and rail transportation costs from the interior plains and eastern Cordillera to ocean ports and by ship to offshore markets.

Despite these limitations, Canada's coal output grew rapidly from 1969 until 1997, after which production began to decline as a result of low prices (Figure 3.15).

6.3 SUMMARY OF CANADA'S ORE RESERVES IN THE FUTURE

In summary, Canada's future ore reserves status is likely to be as follows:

- Provided market prices remain comparable to the averages of the past 10 or 15 years, reserves of nickel and associated cobalt and platinum group elements can be expected to be maintained for many years to come. Reserves of all of these metals can be expected to increase when a production decision is made for the large Voisey's Bay deposit and the metals in Voisey's Bay ore are added to reserves.

- Copper reserves are continuing to decrease, for the present at least. A production decision for the Voisey's Bay deposit will reverse this trend for a few years.

- Reserves of zinc and lead will continue to decline unless prices are adequate to permit development of a sufficient number of new mines from as yet undeveloped deposits that have already been discovered and from future zinc-lead ore discoveries. Lead reserves may reach zero in about 2010.

- Molybdenum reserves will likely continue to decline.

- Silver reserves may decline, but slowly, and only if reserves of the base metals decline.

- Reserves of iron ore can be maintained or even increased for many decades, or for even longer than that.

- Uranium reserves can be maintained at close to recent levels for the foreseeable future.

- Reserves of potash and salt can be readily increased if market demand requires it.

- Asbestos reserves are expected to continue to decline because asbestos markets are disappearing and because Canada's existing large orebodies are being depleted. Known undeveloped asbestos deposits in Canada will be developed only if more stable asbestos markets exist in the future.

- In western Canada, coal reserves can be increased to any level that is required to meet market demand. The potential for increasing the reserves of coal in eastern Canada (in Nova Scotia and New Brunswick) is low.

- The discovery of gold deposits in Canada continues. There are substantial additional gold resources in the "inferred resources" category at many producing Canadian gold mines, much of which will ultimately become proven and probable ore reserves. Relatively large and quite promising gold deposits are known in various parts of Canada, especially in Nunavut, and many more may be discovered. Therefore, provided the gold price is adequate, Canada's reserves of gold in proven and probable ore are unlikely to decline significantly in the foreseeable future.

Reserves of zinc, lead, molybdenum and asbestos, and possibly copper and silver, are the potential problems in the foreseeable future, but Canada has substantial tonnages of zinc and lead in deposits that can be developed if and when market prices permit. Canada produces more than 60 non-petroleum mineral commodities. With regard to the future of Canada's mining industry, a decline in reserves of only a few minerals is not an immediate concern because increased production of other minerals, such as diamonds, coal, iron ore, potash, salt and gypsum, will help maintain overall mineral production.

Diamonds

Diamonds had not been produced in Canada until October 1998. It was only in 1991 or 1992 that the first promising Canadian deposit was discovered. The Ekati diamond mining operation at Lac de Gras, Northwest Territories, which commenced production in October 1998 and which has more than five known diamond orebodies, is currently yielding more than $600 million of diamonds annually. A comparable value of diamond production is expected, beginning in the first half of 2003, from the Diavik diamond mining operation of Rio Tinto plc of London, England (60%) and Aber Resources Ltd. of Vancouver (40%). The Diavik operation, also at Lac de Gras, will be some 35 km to the southeast of the Ekati mine. In addition, a third mining operation at Snap Lake, also in the Northwest Territories, is likely to produce beginning in about 2005 or 2006, and there would appear to be potential for production from one other project in the Northwest Territories, another in Nunavut, and perhaps also from the Victor kimberlite pipe of De Beers in Ontario. Additional diamond discoveries are highly likely, so the value of Canada's diamond production can be expected to increase for some time to come.

7. The Future of Mineral Exploration in Canada

Prior to 1950, both the Canadian mining industry and available exploration technology were essentially immature. Since then, exploration expenditures have been on a generally rising trend because of growing production and because, even after adjustment for inflation, discoveries have become increasingly more costly.

The large Voisey's Bay nickel-copper-cobalt deposit, discovered in 1994, and some 20 potentially mineable diamond deposits in the Northwest Territories, Nunavut and Ontario, provide examples of previously insufficient exploration in the Voisey's Bay area and of previously insufficient exploration for diamonds in Canada. Voisey's Bay was found by geologists searching for diamonds who were sufficiently curious to check an iron-stained gossan they observed from a helicopter – Voisey's Bay is therefore essentially a prospecting discovery. The first diamond discovery of significance was by two persistent geologists who followed diamond indicator minerals for 10 years until they made a discovery. Their discovery soon led to the discovery of additional diamond deposits and orebodies. Many more diamond deposits seem likely to be found in Canada where extensive areas of Archean-aged crust provide a promising exploration target.

Vast areas of Canada remain only superficially explored, mostly because nothing much has ever been found there. But until they are adequately explored, they should not be written off as having no potential for ore discovery. Such areas, and also areas that have been explored for many years, might benefit from more innovative exploration. More attention should probably be given to ore types that are at present unknown, or essentially unknown, in Canada. The discovery of more than 50 porphyry-type copper, molybdenum and gold deposits in the western Canadian Cordillera in the late 1950s and the 1960s provides one such example, as does the discovery, in the 1960s, 1970s and 1980s, of unconformity-type uranium deposits in the Proterozoic Athabasca and Dubawnt Basins in Saskatchewan and in Nunavut, respectively. The discovery of diamond deposits and orebodies in the 1990s provides a third example.

Mineral exploration in Canada can be expected to continue to yield attractive mineral discoveries and Canada can therefore be expected to continue to have a bright future as a major mineral-producing nation.

8. Canada's Petroleum Industry

Although this report is chiefly about the Canadian mining industry, this chapter provides a brief overview of Canada's growing petroleum industry, which surpassed the Canadian mining industry in terms of annual value of production about 25 years ago and which, in 1999, when crude oil and natural gas prices were considerably lower than at present (2001), had a total production value about double that of non-petroleum minerals. In 2000, because of higher crude oil and natural gas prices, the value of oil and gas production had risen to 3.2 times that of the non-petroleum minerals.

The first recorded observations of Canada's largest petroleum resource, the Athabasca oil sands, were by Peter Pond in 1778, a fur trader from Connecticut, and in 1789 by Alexander Mackenzie, a fur trader and explorer from Montréal who was employed by the Northwest Company, a fur trading company. Both of these men reported deposits of bitumen on the banks of the Athabasca River in what is now the province of Alberta. The local Aboriginal inhabitants of the area ("Indians") had used liquid bitumen from this source for waterproofing their canoes, probably for thousands of years.

In addition to the Athabasca oil sands, there are three other oil sands deposits in Alberta: the Peace River, Wabasca and Cold Lake oil sands. Together these four oil sands deposits have an in-place bitumen content of some 270 000 000 000 m^3 (1.7 trillion barrels) with about 75% of this total contained in the Athabasca oil sands. Canada's other large oil sands deposit, on Melville Island, one of the Arctic islands in Nunavut, contains about 80 000 000 000 m^3 (500 billion barrels) of in-place bitumen. The 350 000 000 000 m^3 (2.2 trillion barrels) of in-place bitumen in these five oil sands deposits amount to somewhat more than double the world's total current reserves of conventional crude oil. The quantities of bitumen economically recoverable from these oil sands deposits are much smaller than the total resource and will depend on relative production costs and crude oil prices.

The discovery, in 1857, of petroleum at Oil Springs, Ontario, north of Lake Erie, represents North America's earliest commercial oil discovery, a discovery that was made the same year that the European oil industry began in Romania and two years prior to the first commercial discovery in the United States at Oil Creek, near Titusville, Pennsylvania. Petroleum has been produced in the Lake Erie region of Ontario ever since. By present-day standards, this region has never been an important source but, after 140 years of production, new wells continue to be drilled and the region yielded some $155 million of crude oil and natural gas in 2000.

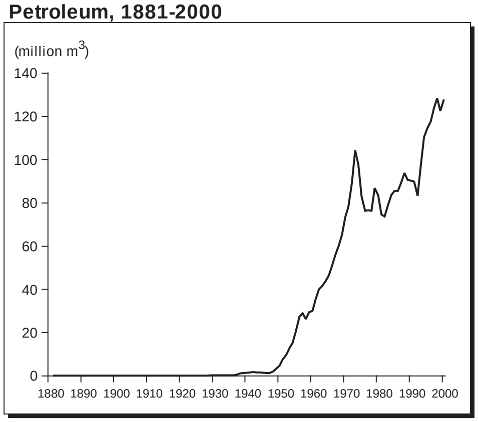
In the early 1900s, small quantities of oil and gas began to be discovered and produced in the provinces of New Brunswick and Alberta. Petroleum production has ceased in New Brunswick, but some exploration continues there. Alberta has become Canada's dominant producer.

In 1919, crude oil was discovered at Norman Wells in the Northwest Territories, located on the Mackenzie River, 190 km south of the Arctic Circle. In the 1920s, a small 475-m^3/day (3000 barrels/day) refinery was constructed at Norman Wells, with production limited by local demand from communities along the Mackenzie River; the petroleum products were distributed to northern communities by river barges. In the 1980s, an 869-km-long pipeline, to transport 4770 m^3 (30 000 barrels) of crude oil daily, was constructed from Norman Wells to Zama, Alberta, where it connects with the Canadian crude oil pipeline system to Ontario, the Pacific Ocean and the United States.

Gas was discovered in Alberta, at Medicine Hat, where it was first obtained from a shallow well during the 1880s and where commercial production began in 1904. Additional natural gas discoveries were made at Bow Island and at Viking, followed by the discovery of gas in the Turner Valley (near Calgary) in 1914. Crude oil was discovered at Turner Valley in 1936 and annual crude production from there peaked at 1 600 000 m^3 (10 million barrels) in 1942 and then slowly declined.

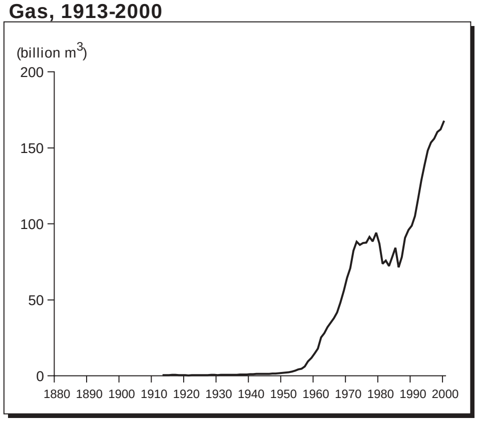
The discovery of crude oil near Leduc, Alberta, in 1947 resulted in a greatly increased petroleum exploration effort in western Canada and ultimately in the discovery of the many oil and gas fields that have turned Canada into the world's eleventh largest producer of crude oil (in 2000).

Figure 8.1
Volume of Canadian Production of Crude Petroleum, 1881-2000



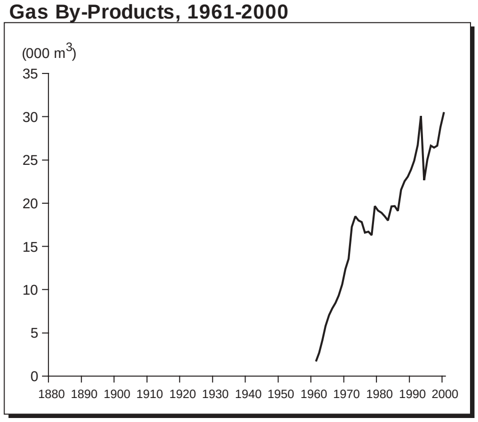
Source: Statistics Canada.
Note: Crude petroleum production began in 1858, but production statistics are unavailable prior to 1881.

Figure 8.2
Volume of Canadian Production of Natural Gas, 1913-2000



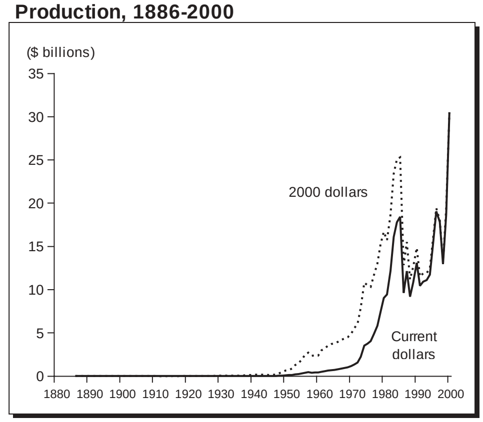
Sources: Statistics Canada.

Figure 8.3
Volume of Canadian Production of Natural Gas By-Products, 1961-2000



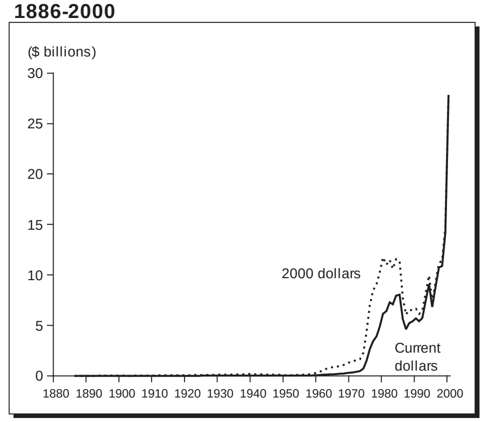
Source: Statistics Canada.

Figure 8.4
Value of Canadian Crude Petroleum Production, 1886-2000



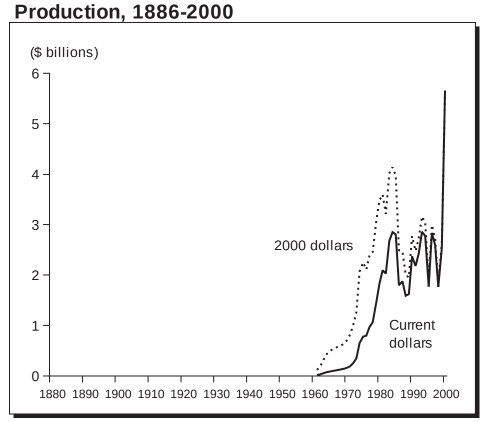
Source: Statistics Canada.

Figure 8.5
Value of Canadian Natural Gas Production, 1886-2000



Source: Statistics Canada.

Figure 8.6
Value of Canadian Natural Gas By-Products Production, 1886-2000



Source: Statistics Canada.

Petroleum was discovered not only in Alberta, but also in Saskatchewan, British Columbia, the Northwest Territories, Manitoba and the Yukon. Recently, discoveries have been made for the first time ever on the island of Newfoundland portion of the province of Newfoundland and Labrador and on Prince Edward Island.

In Alberta, the production of synthetic crude oil from the Athabasca oil sands commenced in 1967. In 1997, production from the various oil sands operations in that province amounted to 87 000 m^3 (550 000 barrels) a day, about one-quarter of Canada's total daily crude oil production. Declining reserves and production in Canada of crude oil from conventional sources is being more than compensated for by increasing production of synthetic crude from oil sands operations; in 2000, Canadian crude oil production reached a record total of 128.4 million m^3 (Figure 8.1). Planned new oil sands projects and major expansions at current oil sands operations are expected to result in rapidly increasing Canadian synthetic crude oil production. Canadian natural gas production has been increasing rapidly, reaching a record 172 billion m^3 (6.07 trillion cubic feet) in 2000, valued at $27.8 billion,[1] (Figure 8.2), as has the production of natural gas by-products (Figure 8.3). Recently constructed new pipeline capacity to growing markets for Canadian natural gas in the United States and eastern Canada can be expected to support even higher levels of natural gas production. Canada is third in the world (after Russia and the United States) as a producer of natural gas, although only eleventh in terms of natural gas reserves.

The values of production of crude oil (Figure 8.4), natural gas (Figure 8.5) and natural gas by-products – excluding sulphur – (see Figure 8.6) have also increased, but as the increased values have depended not only on production volumes but also on ever-changing prices, the increases in values have been more erratic than the production increases have been.

ATLANTIC OFFSHORE

Offshore exploration on the Atlantic coast began about 1960. The first discoveries of oil and gas were made in 1971, off Nova Scotia, in the vicinity of Sable Island, and discoveries of gas were made in five locations on the Labrador Shelf about 100 km offshore.

Sable Island petroleum was produced from 1992 to 1999 when the field was exhausted after the recovery of 7.067 million m^3 (44.452 million barrels) of crude oil. Natural gas production commenced in January 2000 with production expected to continue until 2025. A total of more than 85 billion m^3 (3 trillion cubic feet) of gas is expected to be produced.
Exploration of the Grand Banks, southeast of Newfoundland and Labrador, commenced in the mid-1960s. The Hibernia field was discovered in 1979, Hebron in 1981, Terra Nova in 1984-85 and White Rose in 1985-88. Another 14 oil, oil and gas, and gas fields have been found on the Grand Banks, most of them small, but some may have potential for eventual production.

At present, there do not appear to be any current plans for the production of gas from the Grand Banks area. Recoverable (if economic) gas reserves total 142.2 billion m^3 (5 trillion cubic feet). Most of that gas is contained in the Hibernia, Terra Nova, White Rose and Hebron fields and so will not be produced until the oil is recovered. Additional gas will have to be discovered before the reserves threshold required for pipeline construction is reached.

According to Canada's National Energy Board, at the end of 1997, the Grand Banks area had crude oil reserves of 106 million m^3 (667 million barrels) and estimated natural gas reserves of 935 billion m^3 (33 trillion cubic feet). Estimated undiscovered recoverable resources of oil and gas on the Grand Banks are several times these amounts (National Energy Board, 1999, Table 5.1, p. 43). However, current crude oil reserves for the Hibernia field alone now exceed the NEB estimate. The Canada-Newfoundland Offshore Petroleum Board estimated in May 2000 that discovered oil reserves and resources for the area are 336 million m^3 (2117 million barrels).

The Hibernia field, including the adjacent Avalon reserves, both of early Cretaceous age, is the largest offshore discovery made to date and the fifth largest oil field ever discovered in Canada. Crude oil production commenced in December 1997 at a cost of C$5.82 billion. Hibernia has recoverable reserves of 140.5 million m^3 (884 million barrels) of oil, 38.7 billion m^3 (1.375 trillion cubic feet) of gas, and 23 million m^3 (145 million barrels) of natural gas liquids. Crude oil production at Hibernia is expected to have a life of 20 years and an estimated lifetime production of 15 900 m^3 (100 000 barrels) a day, over a 20-year period, and peak production that may be as large as 31 800 m^3 (200 000 barrels) per day. Natural gas removed from the crude oil is being reinjected to conserve it and to help maintain field pressure.

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[1] For recent years there are differences in natural gas production values published by Statistics Canada ("values reported by producers" - $27.8 billion in 2000) and Natural Resources Canada ("producers' plant gate reveues" - $32.4 billion in 2000). As Statistics Canada data are the only data covering the entire production period 1912-2000, for consistency purposes, only Statistics Canada values are shown in the graph.

The Terra Nova field, developed at a cost of $2.8 billion, commenced production of crude oil in January 2002. Terra Nova has recoverable reserves of 64.6 million m^3 (406 million barrels) of oil, 7.6 billion m^3 (269 billion cubic feet) of natural gas, and 2.2 million m^3 (14 million barrels) of natural gas liquids. Terra Nova is expected to have a peak production of 19 870-23 846 m^3 (125 000-150 000 barrels) a day.

The White Rose field is being developed to produce by the end of 2005 a total of 32-40 million m^3 (200-250 million barrels) of oil over a 10 to 15-year period, with a peak production rate of 15 900 m^3 (100 000 barrels) a day.

The Hebron field, with recoverable resources of 51.6 million m^3 (325 million barrels) of oil, is currently not economically viable, in part because up to 75% of the recoverable crude oil consists of heavier oil, making production more costly than at Hibernia, Terra Nova and White Rose.

MACKENZIE RIVER DELTA-BEAUFORT SEA

In the 1970s, substantial reserves of oil and gas were discovered in the Mackenzie River delta area of the Northwest Territories and to the north in adjacent areas of the Beaufort Sea. Recoverable gas reserves are estimated at 255 billion m^3 (9 trillion cubic feet) and recoverable oil reserves at 161 million m^3 (1 billion barrels). Ultimate recoverable resources for the entire Mackenzie Beaufort region, discovered and undiscovered, are 1.8 trillion m^3 (64 trillion cubic feet) of natural gas and 1.066 billion m^3 (6.705 billion barrels) of oil (National Energy Board, 1999, Table 5.1, p. 43, and Table 7.1, p. 62).

Natural gas, discovered in 1980, has been produced since 1999 from two wells in the Ikhil gas field, 50 km north of Inuvik, Northwest Territories. A pipeline provides Inuvik with gas for electric power generation and for heat. Reserves at the Ikhil field are about 510 million m^3 (18 billion cubic feet).

In the 1970s, permission to construct gas and oil pipelines to the south was refused because of objections made by the Aboriginal people who live in the general area in which the oil and gas would be produced or through which the pipelines would pass. However, these people have recently indicated that they favour pipeline construction and oil and natural gas production. Consequently, if current relatively high crude oil and natural gas prices continue, such activities may commence in the foreseeable future. In fact, an oil pipeline has subsequently been constructed as far north as the Norman Wells oil field (which had been in limited production since 1920). With higher oil and gas prices in 2000, oil and gas exploration resumed in the Mackenzie delta. The eventual construction of pipelines from the Mackenzie River Delta-Beaufort Sea region depends on long-term future North American market demand for crude oil and natural gas, and on future oil and gas prices.

ARCTIC ISLANDS

Oil and gas were discovered in Canada's Arctic Islands (Ellesmere Island, Melville Island, Ellef Ringnes Island, King Christian Island, Cameron Island) in Nunavut and in offshore areas in the vicinity during the 1970s and early- to mid-1980s.

A total of at least eleven gas fields, five oil fields, and four oil and gas fields were discovered. Two of the gas fields are among the largest in Canada. Estimated proven, probable and possible reserves total 509 billion m^3 (17.983 trillion cubic feet) of gas and 31 800 000-79 500 000 m^3 (200 million-500 million barrels) of oil, plus about 9 700 000 m^3 (61 million barrels) of natural gas liquids. At that time, consideration was being given to construction of a pipeline to join the proposed pipeline to one from gas fields in the Mackenzie delta area, and to a natural gas liquification plant, but these possibilities do not seem to have proved to be economic to the present. One or two shiploads of crude oil were shipped annually from a well in the Bent Horn field on Cameron Island beginning in 1985 and ending in 1996 when crude oil prices declined. Cumulative production amounted to 449 000 m^3 (2.8 million barrels).

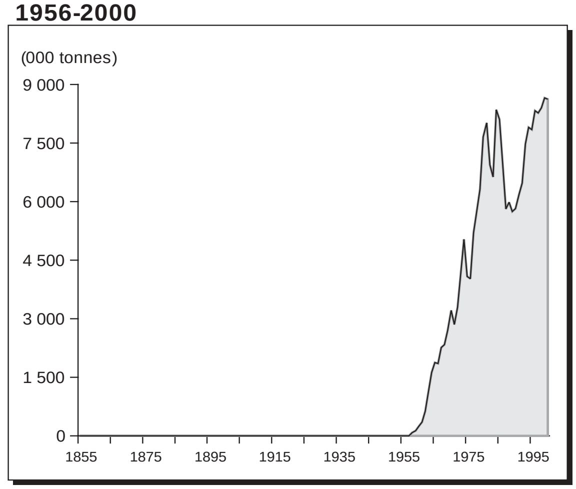
Large-scale production of gas and oil from the Arctic Islands seems likely only at some future time when market conditions are more favourable.

9. Sulphur Production in Canada

Canada is the world's second largest producer of elemental sulphur, supplying 21% of the total world elemental sulphur market in 1999. Elemental sulphur is produced in Canada not by mining, but is mostly recovered at plants that remove highly toxic hydrogen sulphide gas from natural gas and convert it to elemental sulphur so the gas can be marketed. Elemental sulphur is also recovered during the refining of high-sulphur crude oil (5% of Canada's production) and from oil sands plants (8% of Canada's production). In 2000, Canada produced 8.6 Mt of elemental sulphur and another 831 000 t of sulphur contained in sulphuric acid and in liquid sulphur dioxide, both of these products produced from smelter gases recovered at base-metal smelters. Canadian production of elemental sulphur, most of it recovered from natural gas, commenced in 1956 and increased rapidly (Figure 9.1).

With increasing production of natural gas and increasing production of synthetic crude oil from oil sands, Canada's output of elemental sulphur can be expected to continue to increase.

Figure 9.1
Canadian Elemental Sulphur Production, 1956-2000



Sources: Natural Resources Canada; Statistics Canada.
Note: Production of SO_2 in smelter gases, and in pyrite and pyrrhotite concentrates, is not included.

10. Principal Mineral Areas of Canada

Natural Resources Canada publishes *Map 900A, Principal Mineral Areas of Canada* each year. (This map is also available in French.) The map, at a scale of 1:6 000 000, presents a simplified version of the geology of Canada; locations of Canadian mines (on January 1, 2001) and the mineral commodities each mine produces; the names and locations of each of Canada's oil and gas fields; routes of major crude oil and natural gas pipelines; the locations of nonferrous smelters and refineries in Canada and the commodities each of them processes; and the locations of iron ore pelletizing plants, pig iron plants, reduced iron plants and ferroalloy plants in Canada.

Copies of the most recent edition of Map 900A can be obtained from:

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Map 900A does not show the locations of Canadian steel plants. Detailed information about primary Canadian steel plants is provided in the annual publication entitled *Metallurgical Works in Canada: Primary Iron and Steel*, which is prepared by the Minerals and Metals Sector, Natural Resources Canada.

Additional information concerning mining and mineral processing operations in Canada is available in the annual publication entitled *Mining and Mineral Processing Operations in Canada*, which is prepared by the Minerals and Metals Sector, Natural Resources Canada.

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[1] Now the federal Department of Natural Resources.