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Chapter 5: Currents Status and Predicted Developments and Trends in the Resource and Environmental Industries

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CHAPTER 5 CURRENT STATUS AND PREDICTED DEVELOPMENTS AND TRENDS IN THE RESOURCE AND ENVIRONMENTAL INDUSTRIES

Much of Canada's wealth has been generated from the exploitation of earth resources, and much of today's public concern for the environment has spawned an explosion of the environmental industry and a search for alternative fuels. In this chapter, the industrial applications in the earth sciences are covered in four sections: mineral exploration industry, petroleum exploration industry, environmental industry, and alternative energy industry.

5 (a) Mineral Exploration Industry

Current Status

Economic significance

Over the last hundred years, following the decline of the fur trade, the economic development of much of Canada was greatly influenced by the mining industry. There is a common thread through Samuel Hearne's journeys to the Coppermine, the Klondike gold rush, Horne's discovery of Rouyn-Noranda, the development of the Labrador iron ranges and Diefenbaker's "roads to resources".

The commodities may have changed from gold to base metals, from uranium to diamonds but the discovery and exploitation of Canada's mineral wealth has, until very recently, been viewed by most Canadians as an unmitigated good.

The mining, metals, and minerals sector remains one of the cornerstones of the Canadian economy, and it is especially important in the more remote and peripheral regions of the country. On an overall basis the industry represented approximately 5% of Canada's total GDP in 1993. It contributed a total of $27.7 billion to the economy and the total net export earnings for the sector were $17.7 billion. In the highly competitive global market, Canada's standing as a world class producer of metals and minerals is clear (Fig. 5.1, see also Table 2.1). This eminence is a reflection both of the excellence of the orebodies and of the skills utilized in their exploitation.

Direct employment in the mining industry is 84,000, but an overall total of 435,000 persons are directly or indirectly involved in the entire sector. The minerals industry operates at 500 sites across Canada and at least 150 remote communities are directly dependent upon it. No other economic activity, except Tourism and Government Services, has a greater geographic spread in Canada (Fig. 5.2). This positive regional impact is illustrated by Table 5.1 and Figure 5.3.

Present-day mining and minerals processing in Canada are high-technology industries with most jobs requiring high levels of diverse skills and expertise. Hence, the average annual earnings are $47,000 for those directly involved in the industry, an amount which continues to make mining by far the best paid industrial activity. This is also a reflection of the success of the Canadian work force, enabling the cost per unit extracted to be more than competitive with much less well paid workers elsewhere in the world.

In 1993, direct mineral production in Canada was worth $14.7 billion. This is a considerable decline from previous years, a result of weaker metal prices world-wide.

Table 5.1 The 1993 value of mineral production by Province

PROVINCE	$ MILLION	NUMBER OF MINES
Ontario	4,392	119
Quebec	2,544	178
British Columbia	2,414	46
Saskatchewan	1,362	33
Alberta	882	33
Manitoba	833	14
New Brunswick	782	29
Newfoundland	728	12
Northwest Territories	403	7
Nova Scotia	398	26
Yukon	117	2
Prince Edward Island	2	-
TOTALS	14,680	499

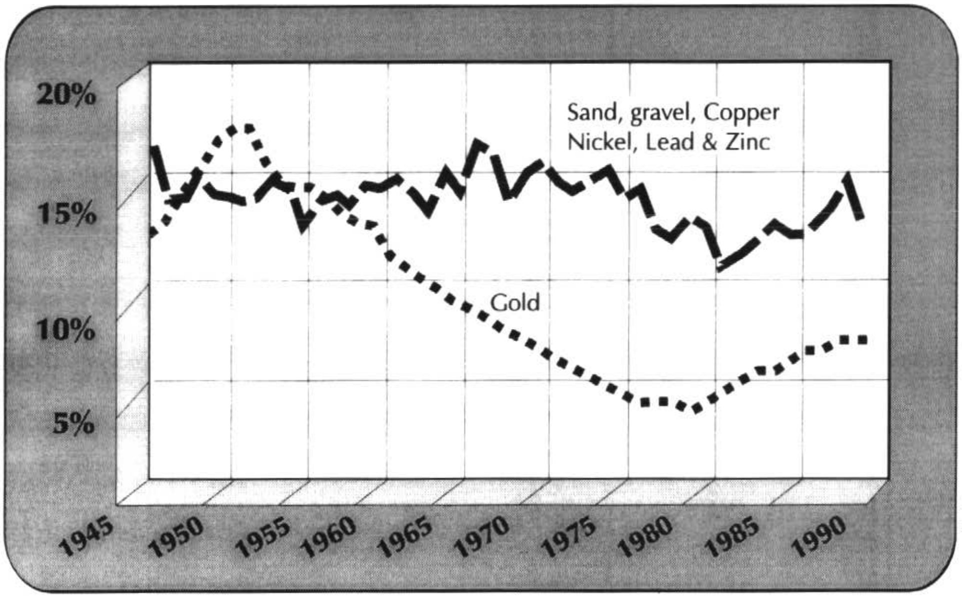

Figure 5.1 Canada's share of aggregate value of world mine production, selected metals. (Source: Metallgesellschaft, Metallstatistik, American Bureau of Metal Statistics, International Lead-Zinc Study Group, International Nickel Study Group, World Bureau of Metal Statistics, and Gold Field Services Ltd.)

In 1993 direct exports of metals and minerals totalled $26.1 billion. This represented 14.8% of Canada's total exports. The USA imported 66% of this material, with the remainder going mainly to Europe and Japan. The historical importance of mineral exports to the Canadian economy is shown in Figure 5.4. In 1993 Canada imported $16.2 billion worth of metals for smelting, refining, and fabrication, resulting in a total positive trade surplus in this sector of $9.9 billion.

The export-import trade in metals and minerals has a very large impact on Canada's national transportation network; 54% of total railway freight revenue and 65% of the volume of all products loaded at Canadian ports are mineral related.

Currently more than $400 million a year is spent on mineral exploration in Canada supporting a wide range of R & D activities.

Mineral exploration in the Global Context

Although the intensity of Canadian mineral exploration has passed through a number of significant cycles since the end of World War II, at least 1650 mineral deposits were discovered in Canada between 1946 and 1990. Thus the (unstated) premise has remained that Canada is blessed with a very significant mineral endowment and that new mines will continuously be found. On this (unchallenged) premise much government, academic, and R & D infrastructure has developed and remains in place. There is a web of symbiotic relationships in geology, geophysics, geochemistry, mineralogy, *etc.*, between CANMET/GSC/Provincial Surveys and Research Councils, the Universities, and entrepreneurial industrial R & D companies, all of which is focused on the present (and future) needs of the presumed continued growth of the exploration/mining industry in Canada.

Yet the reality is that the discovery rate of Canadian mineral deposits discovered between 1945 and 1979 was halved between 1980 and 1994, while the cost of discovery has approached an average of ±$100 million for a new significant large deposit. Thus the premise of uniformitarianism for the future of mineral exploration in Canada is under strong challenge.

Despite increased recycling of metals and construction materials, the world demand for minerals in continuing to increase. This is due to the increasing world population and rising standards of living (Fig. 5.5). This demand for more metals will be successfully met because most explorationists believe that there are still great orebodies to be found and that the will to find them will continue.

In a global context, the mineral exploration industry has become an open business. This has happened because countries long closed to exploration, principally in Asia and South America, have become available for prospecting as a result of political stability and changing tax laws. Currently, and even more so in the future, exploration money will go where the combination of geological prospectiveness, incompleteness of prior exploration, and confidence about future regulatory stability are most inviting. There is no guarantee that this shall be Canada.

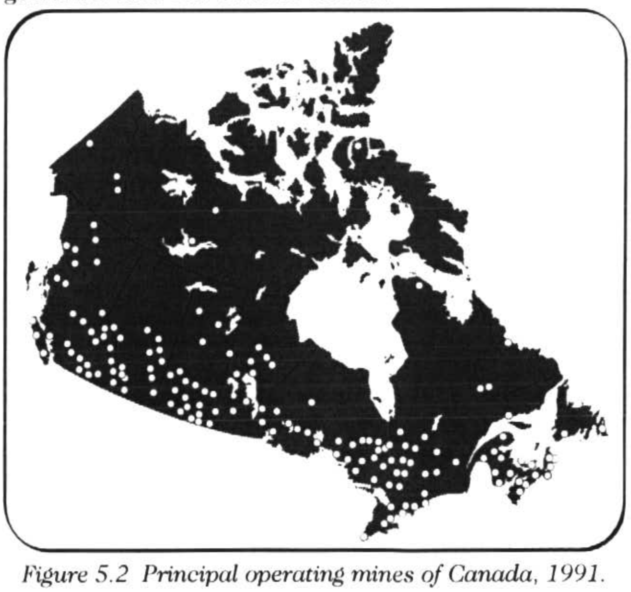

Figure 5.2 Principal operating mines of Canada, 1991.

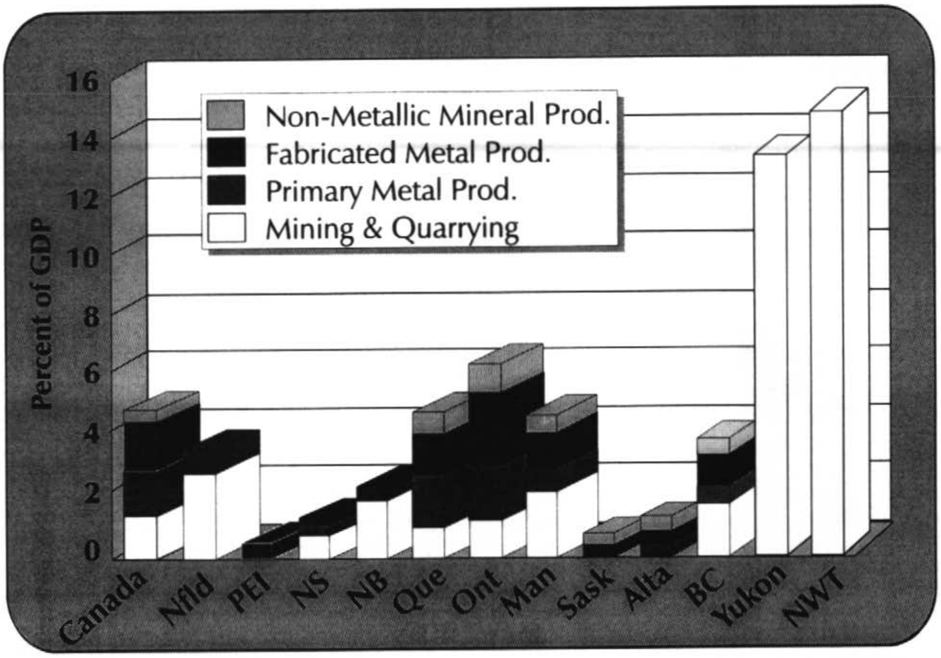

Figure 5.3 The minerals and metals industry in Canada as a percentage of Provincial/Territorial GDP (1987). Due to confidentially, 1986 figures for NF (non-metallic mineral products), Yukon and NWT were used. The following figures were not available: Mining Sask. and Alta; Primary Metal Prod. NS, NB and Sask; Non-Metallic Min. Products NS and NWT.

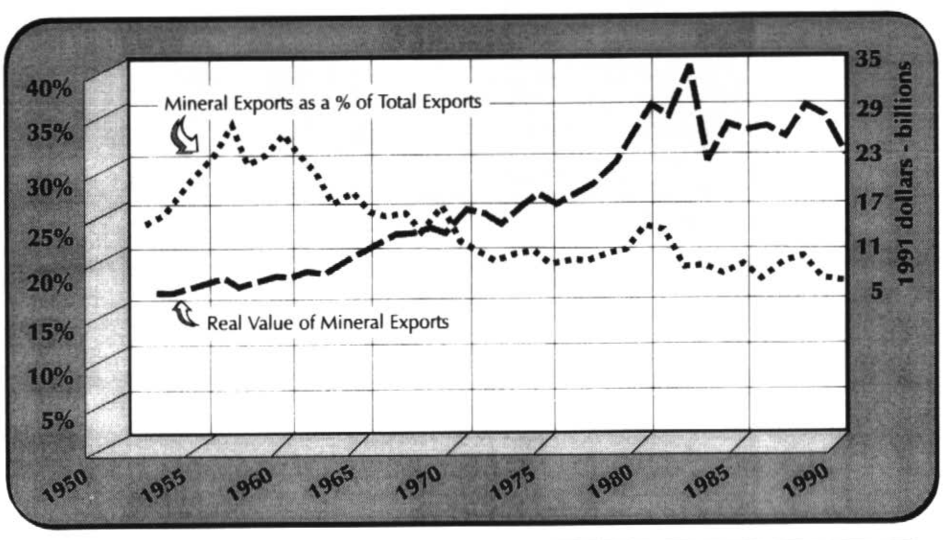

Figure 5.4 Mineral exports from 1951 to 1990 (excluding petroleum and natural gas).

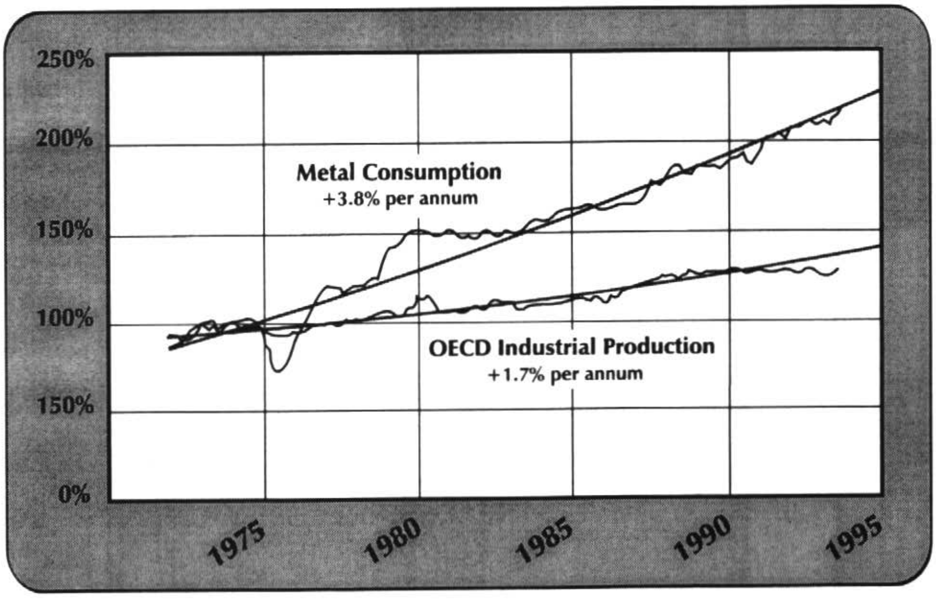

Figure 5.5 OECD production index and global consumption of base metals from 1972 to 1994; 1993=100. Trend lines indicate growth rate predicted to 1995.

Table 5.2 Current Canadian proven/probable mineral reserves versus current production rates for some metals

METAL	CURRENT MINEABLE RESERVE (tonnes)	CURRENT PRODUCTION RATE (tonnes)	"APPARENT LIFE") (years)
Gold	1,400	15	29
Zinc	11,000,000	700,000	16
Copper	1,500,000	1,000,000	15
Molybdenum	163,000	10,000	16
Silver	16,000	1,000	16
Lead	4,300,000	187,000	23
Nickel	15,600,000	180,000	31*

*(Mining Association of Canada, 1994)**

**These numbers represent a moment in time in what is a very complex and dynamic situation which reacts to changes in metal prices, exchange rates, technology, new discoveries. It does not account for Canadian deposits in the exploration or delineation stage, or those known for many years but currently uneconomic.*

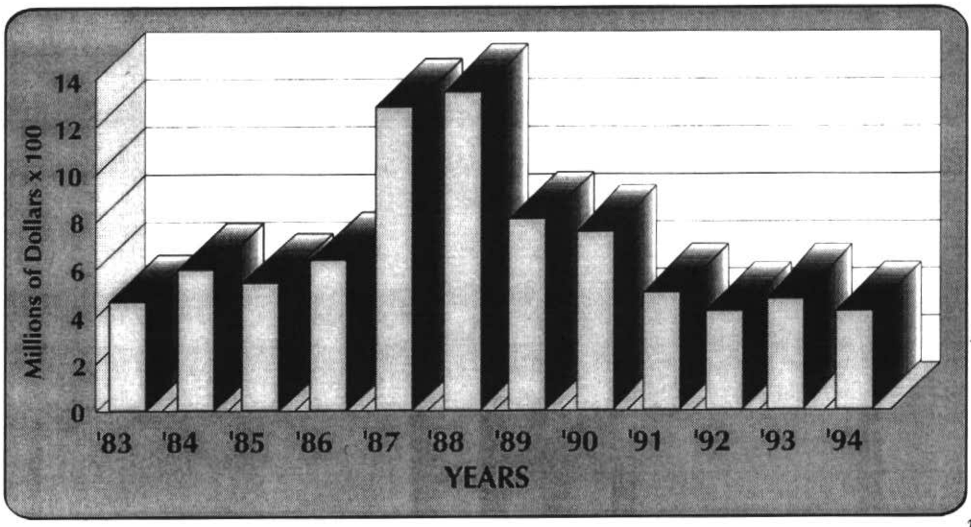

Figure 5.6 Canadian mineral expenditures from 1983 to 1994. The value for 1993 is preliminary and the value for 1994 is estimated (source: Intergovernmental Working Group on the Mineral Industry, Report on Exploration Expenditures and Flow-Through Share Funding, Sept. 1994).

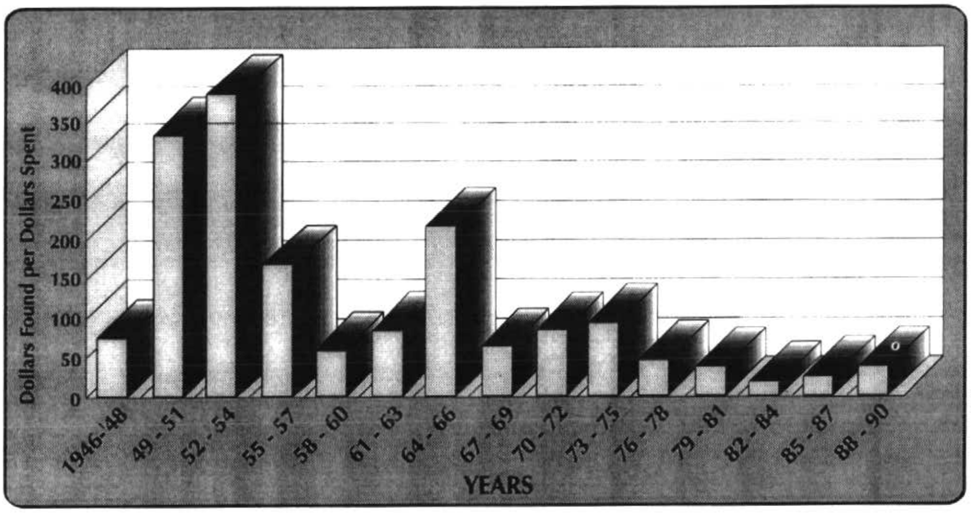

Figure 5.7 A histogram showing the gross "in-ground" value of metals discovered in Canada per dollar spent on exploration from 1946 to 1990. Dollar values were based on a 1987-91 average price.

In a global marketplace, new medium or large metal mines will tend to be developed only if the capability of sustaining that production lies in the lower half of the production cost curve, so as to be competitive in periods of low metals prices. Canada will have to provide a competitive environment for exploration through to mineral extraction.

Canada has numerous competitive advantages: a diverse prospective geological endowment, skilled labour force, dependable and highly competitive exploration services, excellent infrastructure, and abundant water. Hence, in Canada one receives reasonable value for the exploration dollar spent. It could return to superior value.

Presently, however, there are numerous structural problems in Canada which have had a strong cumulative negative impact both on sustaining the high level of expenditure needed to maintain a stream of newly-discovered orebodies and on encouraging the development of known deposits into successful mines. An example of current difficulties are the various Provincial Mining Acts. These have historically implied an ability to stake mineral claims on crown land, to provide a right to explore, and the ability to extract under certain reasonable conditions. In many cases they no longer reflect the current reality of: aboriginal land claims; the processes of land use designation; the attainment of a Protected Areas Strategy at ±12% of the land mass; the complexity of environmental impact processes; and the liability of previous mining activity and the uncertainty of future abandonment/reclamation procedures. After the "Windy Craggy affair" in British Columbia, tenure may have become outmoded in some jurisdictions while compensation for expropriated claims is not yet routine. Meanwhile on the horizon there loom issues of biodiversity, ecological integrity, buffer zones to parks, all of which promise further problems an delays in permitting.

Potentially this combination of internal and external forces on the Canadian mineral exploration industry has profound implications for the balance of activities within Federal/Provincial Surveys, for the geoscience curriculum in universities, and for the strategy of independent mineral exploration R & D companies.

Canada has a justifiable claim to be a world leader in: mineral exploration, as an applied science; mineral exploration services and; environmental management. Currently all are facing an uncertain future. However, in the highly competitive global mining industry, Canada has to remain at the leading edge of R & D in all of these areas to be able to stay ahead of the worldwide challenge.

Future Trends in the Mineral Industry

Domestic deposits

The mining industry depends on new discoveries to ensure that production and employment is sustained into the future. In recent years mineral exploration in Canada has failed to replace ore mined out, especially in the case of base metals. For example, from 1981 to 1993, domestic reserves of nickel and copper dropped by almost one third, zinc by over 40%, and lead by half. The current situation is shown in Table 5.2. Though this failure to replace reserves is due in part to a decrease in overall exploration expenditure (Fig. 5.6), in reality it is more a reflection of the declining success rate of that expenditure (Fig. 5.7).

Through the last twenty years the Canadian mineral exploration industry has matured and predictably (inevitably?) followed the well established path of other industries/commodities through the growth-peak-decline curve (Fig. 5.8). The question arises "where does Canada lie" on this well known "Skinner" diagram?

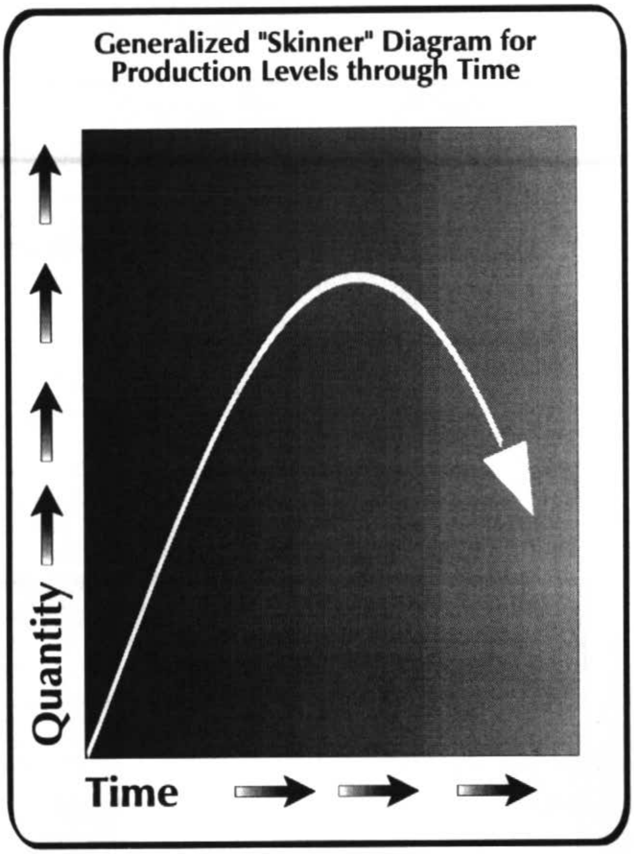

Figure 5.8 Generalized "Skinner" diagram for production levels through time.

Presently, however, this disturbing trend does not seem apparent to many of the active participants in recent Canadian mineral exploration due to two unrelated circumstances. Firstly, the internal Canadian fiscal policy that initiated the flow-through share, tax write-off scheme, resulted in approximately \$500 million a year in additional funds being available for mineral exploration through the period 1984-89. Flow-through funding allowed Canadian exploration expenditure to reach the giddy heights of ±\$1.3 billion a year in 1987-88 (Fig. 5.6). With this level of expenditure someone had to inevitably stumble into ore. Secondly, external events allowed Canadian explorationists to move sequentially from new commodity to new commodity, apparently sustaining their enviable success record while ignoring the much more difficult task of replacing the base metal inventory established in the 1950s and 1960s with the help of the new airborne and ground electromagnetics technology. The initial uranium discoveries of the 1970s were followed in the 1980s by the world class deposits at Cigar Lake and McArthur River. The gold boom followed with discoveries at Hemlo, Casa Berardi, Hope Book, Eskay Creek and then propitiously in the 1990s the focus on diamonds followed with success at Lac de Gras and most recently the nickel-copper discovery in Archean rocks at Voisey's Bay in coastal Labrador. However, few of these discoveries were made with new technological advances or into new geological terrains. Certainly good sense and persistence were needed but no radical new directions were involved.

As a result of emphasis on uranium, gold and diamonds, the development of new concepts or technology to sustain the discovery rate of Canada's traditional metals (copper, zinc, and nickel) was neglected. It is these commodities (with a gross annual value of $6 billion) that actually underpin Canada's mineral industry due to their large downstream multiplier effect in transport, smelting, refining, fabricating and metal product stages.

Incremental additions were made to existing mining camps - Sudbury (Victor), Timmins, Thompson (Deep Pipe), Matagami (Isle Dieu), and stepouts have occurred at Flin Flon (Hanson Lake) and along the extension of the Thompson Belt under Paleozoic cover. However, only four significant new and or large base metal deposits have been found or delineated lying well beyond existing headframes,. These are Windy Craggy, Louvicourt, Cominco's Kudz Ze Kayah project in Yukon, and the Voisey's Bay discovery in Labrador

Windy Craggy (±300 million tonnes of ±2% Cu) is now an environmental monument in a World Heritage Park. Louvicourt, though coming into full production in 1995, is no longer the large deposit its proponents once anticipated. Intensified exploration in the geological belt that contains Kudz Ze Kayah may locate other ore bodies. Voisey's Bay exploration is still in its infancy but is being touted as one of the largest discoveries in 30 years.

None of the copper-gold porphyry's (Mt. Milligan, Mt. Polley, Taseko, Kerness, Casino) are currently slated for development, and Quebec's Ungava nickel belt still remains at the exploration stage.

Meanwhile, no new significant or large Sedex or carbonate-hosted Zn-Pb-Ag deposits have been discovered in Canada in the last twenty or so years.

A key element to ensure successful mineral exploration in Canada is information handling. There should be a major thrust to produce standardized and regularly updated, unified national databases of both land use, and of geological, geochemical and geophysical information. These databases should be constructed in the most efficient and effective way with the minimum of duplication of government cost. One of the most important facets of these databases will be their use in providing the basis of "good science" for use in land planning, definition of environmental background, monitoring , *etc.*

It is important that these databases are readily available to the wide range of interested clients by providing user-friendly, single window access in order to encourage widespread, prompt and efficient use. They should not be marketed on a purely cost recovery basis. Successful cost recovery will be the discovery of an orebody.

These geoscience databases should be integrated on a national scale in order to stimulate new and original interpretations of the Canadian landmass, and to act as the basis for new integrated, thematic regional research programs that study geological entities unconstrained by jurisdictional boundaries.

There should be a proactive effort to encourage integrated, multidisciplinary, multi-agency developments of new exploration concepts and technologies for the discovery of blind or buried deposits. These new thrusts should define clear roles for the various federal/provincial/academic/industry research groups in order to eliminate duplication and to encourage productive interaction.

An example of two efforts in the last five years by the Canadian exploration industry to help itself (in Canada) is the establishment of the Mineral Deposits Research Unit (MDRU) at The University of British Columbia (UBC) and the Exploration Technology Division (ETD) of the Mining Industry Technology Council of Canada (MITEC) in Toronto. Both of these agencies provide integrated "Academic-Federal/Provincial-Industry" exploration research. These are usually funded adequately (±$250,000 per program) and end after 2-3 years to ensure that they will make a significant impact. MITEC-ETD currently has firm commitments that are in excess of $1 million for the next three years. A noteworthy component of this research is its multidisciplinary nature; a real effort has been made to integrate geology/geochemistry/geophysics data and then highlight whatever is the most appropriate signature to find new orebodies.

The major thrusts of present MDRU/MITEC-ETD cooperative programs are directed at specific deposit-types which are both well-known and plentiful in Canada and in which Canada is well endowed.

A different thrust would be R & D for major deposits ("elephants") currently not known or mined in Canada, that might occur but have not yet been discovered, especially those hosted within major sedimentary sequences. However, basic science into low temperature basinal fluids in considered too basic, and too long range. Yet some feel that this is where the real future and rewards lie. This field of basic research is possibly an area for future cooperative, jointly funded GSC/academic/industry research.

Exporting Canadian expertise

Canada's airborne, ground and downhole geophysical expertise in magnetics, electromagnetics, and radiometrics is world class. The expertise has developed in response to the challenge of the huge scale of the Canadian landmass and the complexities of the overburden cover. Currently Canada has captured 70% of the world market for airborne surveys and 60% of equipment, software and data interpretation in airborne geophysics.

Canadian geochemical analytical laboratories have well deserved reputations for analytical accuracy and precision, for rapid turn around time, low cost, and dependability. The laboratories have been innovative in dealing with a wide variety of sampled media, and in assisting in the collection of samples. At the same time, drilling companies have provided innovative methods of sampling till quickly and effectively, with rotary and sonic methods,.

These continuing advances have mainly been a response to the needs and demands of the Canadian mineral exploration industry. When this industry spent between $800 million and $1.3 billion per year, it was quite prepared to fund much of the relevant R & D itself. Likewise the R & D industry was prepared to undertake the risk because of the ready demand for a successful new product. Now that the annual Canadian mineral expenditure is only at a ±$400 million level, neither of these sources of risk capital is as available. Yet the problem of declining reserves means that the need for innovative R & D to look at or through the overburden cover, or to look deeper into the crust is more acute than ever.

Hence, the present challenge for Canada's mineral exploration service industries is twofold. Firstly, they need to be able to compete aggressively and effectively in the global exploration marketplace in order to retain their current dominant position. They can then continue to generate sufficient revenues both to serve and to fund the new and radical R & D necessary to produce the innovative technologies and exploration tools that will overcome the second challenge which is the need to find the next generation of orebodies in Canada.

There have been a number of proactive steps made by various federal government departments to assist in the continuing development and sale of Canadian expertise abroad. It is hoped that these small entrepreneurial companies do not become lost in a maze of federal departments (Industry Canada, Natural Resources Canada, Canadian International Development Agency, Foreign Affairs, etc.) as they attempt to establish their presence in the booming exploration marketplaces like Asia, Africa and South America. Potentially, there is a ±$5 billion per year worldwide exploration market available for Canadian expertise.

Hence, there is a clear need for a single-window government agency to assist in this technology transfer/income earning opportunity for the Canadian exploration service industry.

In mineral exploration, mineral exploration R & D, and reclamation R & D there are many exciting challenges for multidisciplinary, multiagency earth science research. All are vital for the future of Canada's mining industry both at home and abroad, where there exists the potential for aggressive sales. It is hoped that fiscal realities will drive the interested parties into effective, cost benefit research partnership.

5 (b)Petroleum Exploration Industry

Current Status

In preparing this chapter it became apparent that, unlike other sectors of geosciences, there are very few forward-looking reports on the interaction between this industry and the earth sciences. Most of the statistics quoted here are taken directly from a report on the Upstream Petroleum Industry in Canada (1994) and the Statistical Handbook for Canada's Upstream Petroleum Industry (1994), both produced by the Canadian Association of Petroleum Producers.

Amongst Canadian earth scientists and students, there currently is a strongly held perception that the Canadian petroleum industry, and especially its exploration component, is a sunset industry. Many who hold this opinion have never worked in the industry. Although the last decade was quite tumultuous, as the oil and gas industry had to adjust to economic realities in order to survive. Reports of its imminent demise, however, are greatly exaggerated. In fact, as funding cutbacks force universities and government geological sectors into the cauldron of change, the Canadian petroleum industry emerges as one of the better organized sectors to meet current fiscal and political realities.

The oil industry in Canada began in the last century in the Petrolia area of southwestern Ontario, but the modern era commenced with the discovery of oil in a Devonian reef at Leduc, Alberta in 1947. Since then, while there have been rounds of frontier and offshore exploration, most of the exploration and production has been concentrated in the Western Canada Sedimentary Basin. To the end of 1993, over 206,000 exploratory and development wells were drilled in this basin. Approximately 12,000 additional wells were drilled in 1994.

Economic significance

Canada is the third largest producer of natural gas and the ninth largest producer of crude oil in the world. In 1993, 665 million barrels of crude oil and equivalent were produced, along with 4.6 trillion cubic feet of natural gas. The value of these products was $21.2 billion. The petroleum industry is a major contributor to the support of Canada's high quality of life and directly employed 62,000 people in 1992.

In 1992 the estimated remaining established reserves of conventional and non-conventional crude oil were 8.1 billion barrels. The estimated natural gas ultimate potential was 255 trillion cubic feet, with estimated remaining established reserves of marketable natural gas of 94.8 trillion cubic feet. Natural gas and crude oil exploration and production is concentrated primarily in the large Western Canada Sedimentary Basin. Overall the industry is mature, as production has exceeded additions to reserves each year since 1987.

In addition to conventional light oil and natural gas, Canada's non-conventional resource base of oil-sands deposits in northern Alberta and Saskatchewan is among the largest in the world. Today about 16% of Canada's oil comes from Cretaceous oil sands in Alberta. Overall, these non-conventional resources are estimated at 2.5 trillion barrels of which 300 billion are ultimately recoverable. This is equivalent to approximately one third of the world's entire oil supply. The oil sands give Canada a competitive advantage that is unique in the world and has earned it a reputation as a pioneer in non-conventional production.

Canada produces about 1.67 million barrels of oil per day. Production is composed of conventional light oil, heavy oil, bitumen, and synthetic oil from Alberta's oil sands. The Panula/Cohasset field located offshore of Nova Scotia came into production in mid-1992 and currently produces 25,000 barrels per operating day. Canada produces about 4.6 trillion cubic feet per year of natural gas. Up to the end of 1993, Canada had produced over 162 million tonnes of sulphur and had about 5.5 million in its stock piles. This sulphur was recovered from natural gas resources and developed synthetic crude-oil reserves. To date no natural gas reserves have been assigned to coal bed methane resources. To the end of 1992, in the Western Canada Sedimentary Basin, 15.0 million barrels of conventional oil and 76 trillion cubic feet of marketable natural gas had been produced. This represents 54% of the oil and 30% of the gas known to exist in Canada. Crude oil and natural gas represent 7.5% of all merchandise exported by Canada.

Canada produces more crude oil and natural gas than it requires for domestic use and this situation is expected to continue over the next decade. All consumption of domestic production is in Ontario and the western provinces. All imported crude is used in Quebec and the Atlantic provinces. While Canada is nominally self-sufficient in liquid production, it would not be possible to deliver the desired feedstock to all Canadian refineries in the case of an emergency. Canada exports about 920,000 barrels of oil per day primarily to refineries in the central and western United States. Canada also imports about 590,000 barrels per day of oil to central Canada and the Atlantic provinces. Approximately 60% of this imported crude oil comes from the North Sea. In 1993, Canada exported about 2.3 trillion cubic feet of natural gas to the United States. A surplus of $9.2 billion contributed to Canada's position as a net exporter in 1993.

In summary Canada has huge, undeveloped energy resources for future exploitation, including major oil and gas deposits in offshore areas and massive reserves of bitumen and oil sands in Alberta and Saskatchewan.

The oil industry in Canada

The Canadian oil industry has matured to a margin industry in which companies have been forced to control costs in order to remain profitable. In the mid-1980s declining commodity prices and escalating operating costs, among other negative economic factors, caused the industry to consolidate, re-organize, and adapt to change. With this restructuring and consequent downsizing, thousands of geologists and geophysicists lost their jobs becoming consultants, contractors, or simply leaving the industry. This consolidation process also forced the large multi-national oil companies to focus on reservoir management production of core properties and to sell many marginal properties. The result has been one of the greatest transfers of private business assets in Canadian history. The multi-nationals chose to concentrate on exploitation of their reserves and to de-emphasize exploration programs which must compete for internal funds against exploration opportunities elsewhere in the world. One outcome of this reorganization and down-sizing is that the multi-nationals are no longer the training factory for young geologists and geophysicists as previously these professionals would have migrated into smaller companies as their careers matured.

The process of consolidation continues. Companies which were established through the acquisition of previously delineated reserves have few new acquisition opportunities and are now forced either to explore, sell, or merge. Because it was financial and not exploration expertise that built these companies, it is anticipated that 1995 will be a year of further mergers (due to rising interest rates and falling natural gas prices).

Even with continued consolidation, the demand for geophysicists and proven explorationists exceeds supply. More companies are now looking to hire additional summer, co-op, and graduating students. Unfortunately, many of these companies do not have in-house resources, time, or financial resources to train entry-level geologists. Professional and technical organization, colleges, and professional training organizations are currently trying to solve this problem.

Most geologists and geophysicists explore for petroleum in the Western Canada Sedimentary Basin. Frontier exploration has continued to decline, and about 20 companies maintain a relatively modest international exploration effort. The first federal land sale in recent years in the Northwest and Yukon Territories and the has created new interest in exploring north of 60°. Former expertise and knowledge of this area no longer resides in many oil companies. The Institute of Sedimentary and Petroleum Geology (GSC) in Calgary now has a unique opportunity to promote their considerable Arctic expertise in the petroleum industry. Because of relatively excellent economic factors, 1994 was a record drilling year in the Western Canada Sedimentary Basin, with approximately 12,000 wells drilled. However, significantly lower natural-gas prices are expected to cause a decline in the overall number of wells drilled in 1995.

Future Trends

The future of exploration in Canada

The Canadian petroleum industry is a commodity business and therefore its activities reflect the price of conventional oil, gas, and heavy oil. Marketing of the product is a key issue and Canadian producers are well positioned to respond to new market opportunities because of two fundamental strengths related to deliverability and infrastructures. Crude oil and natural gas in Canada are transported to market through extensive and sophisticated gathering, transportation, distribution and refining systems that meet domestic demand and provide access to export markets. This system includes more than 180,000 miles of pipeline.

In the Western Canada Sedimentary Basin, the reserves life index (based on current production of remaining reserves, other discovered resources, and undiscovered recoverable resources) for light oil is approximately 24 years, heavy oil 31 years, bitumen 2200 years, and natural gas 36 years. How much of the ultimate reserve is produceable will depend mainly on economics (commodity price, finding and developing costs, *etc.*), and new technology leading to significant advances in finding and recovery methods. There are geological caveats on future exploration. For example, according to the GSC's (1993) resource assessment of Devonian natural gas, most of the remaining potential is attributed to conceptual plays. The last significant conceptual play discovered, however, was West Pembina in 1979. Obviously this presents a major challenge to future explorationists!

Critical to any future petroleum exploration is the availability of suitable land. Land usage has, however, become a major issue in the 1990s. This is well illustrated along the slopes of the Rocky Mountains, in the deeper western portion of the basin, where much of the undiscovered natural-gas reserves are believed to occur, and where operating costs for seismic and drilling are the highest. This same region has become the focus of environmental, native, societal, and governmental concerns for alternate land use. In some areas resource development has been denied as illustrated by the recent Whaleback decision.

Although exploration will continue for smaller pools, in mature plays, rank wildcat exploration will focus on new conceptual plays and exploring the deeper, Lower Paleozoic portion of the whole basin. Efforts will continue to prove the viability of coal bed methane production. Horizontal well technology, with its mining approach, will evolve, and new drilling methods, such as pad drilling, will be used to minimize surface damage. Increased extraction efficiencies from better enhanced, and secondary oil recovery techniques, including improved lift technology for in-site heavy oil, will be required to minimize finding and development costs. Canada has always been at the forefront in the development and application of enhanced oil recovery techniques. The 65 billion barrels of crude oil and bitumen that we cannot recover provides a high incentive for the development of new or modified tertiary oil recovery techniques.

Frontier and offshore exploration in the 1960s through to the mid-1980s revealed significant reserves of oil and natural gas for future exploitation. The northern areas have been dormant in terms of exploration until last fall when native land settlements permitted the acquisition of new leases in certain areas. The first leases were acquired in the Liard Basin area, and this may signal another significant round of exploration. Much of the success of this effort will depend on developing truly cooperative and long-term agreements with the native peoples.

Any future exploration in the Frontier and offshore areas will obviously depend on positive economics relative to finding and actually developing the resources. It is unlikely that the Federal Government can afford to offer new fiscal incentives for exploration in these areas in the foreseeable future. The resources therefore, will have to be large enough to justify their own development.

Research and technology to support exploration

Successful petroleum companies concerned with maintaining success recognize the value of new technology and research and incorporate these into their strategic and business plan. The trend now is away from in-house R & D, so that most new technologies will be acquired from outside sources and will be modified or enhanced by expert users. Identifying, acquiring, and implementing new technologies remains problematical. Larger Canadian oil companies have been looking for possible strategic research synergies in all sectors within Canada and with industry research companies abroad.

The trend is also towards using external research consortia by joint ventures, cost-benefit analysis, and accountability, especially on longer-term projects. There appears to be little proprietary advantage in keeping research exclusively in-house. This realization should promote research relationships between oil companies, service companies, governments, and universities. The very nature of most complex research problems today requires multi-disciplinary approach to their solution and, therefore, the sharing of resources and knowledge in cooperative research efforts. On the other hand, it requires a different type of researcher, one who can be innovative and creative in an environment in which application and short-term goals need to be achieved. Companies still recognize the need for some research that will be long-term and fundamental in nature.

Cooperative research between sectors is not without its challenges. The Canadian economy has forced universities and governments to look more and more to industry for alternate research funding. The petroleum industry is not a cash cow and will not subsidize research it does not need. Many companies are looking to research to solve both short- and long-term problems, and most are looking for a "win-win" situations for all partners in a consortium.

Another challenge is to promote cooperative research between sectors. Regardless of whether the research is fundamental, radical, or incremental there must be a relative appreciation of each other's notions of time and its management. Global economic competition has accelerated the business clock. With the shift to a margin business, efficiency becomes paramount. The value of research to the industry becomes critical. Hence less fundamental research is being done. The management of R & D then changes from an intuitive, ad-hoc style to a purposeful exercise thereby exacerbating the differences for doing research between the oil companies, service companies, governments, and universities (Roussel *et al.*, 1991).

Exploration research will focus on better funding techniques; more refined facies and depositional models in a high-resolution sequence-stratigraphic framework – particularly in carbonates, mixed carbonates, and siliciclastics; development of conceptual plays; diagenesis and the prediction of resulting reservoir porosity and permeability; structural, thermal, and evolution of fluids within basins; integration of detailed geology into reservoir modelling and computer-simulation modelling of reservoir performance; re-examination of reservoir quality and sensitivity analyses related to new sequence defined facies models; advancing the petrophysics of carbonate rocks to develop more accurate formation-evaluation methods; developing evaluation and testing methods for the H_2S rich pools and understanding and predicating fractured reservoirs. There are, in fact, no end of geological research opportunities in petroleum exploration.

Production advances, from the perspective of earth sciences, will focus on reservoir management, reservoir quality and sensitivity for improved enhanced and secondary recovery techniques to get more of the remaining oil out of proven fields. New geological models will be applied in planning reservoir optimization.

R & D will continue to enhance the resolution of the seismic tool. Improved 3D imaging will be used in complex geologic areas and seismic application in fractured rocks. More work needs to be done on elastic measurements instead of acoustic so as to focus on the rigidity of the rock, its compressibility which is affected by fluids, and to better resolve changes in lithology. There is a need to bridge resolution gaps in seismic through cross well experiments, high bin 3D seismic; and better acquisition through improved channel instruments, more intelligent geophones, faster readouts and more accurate surveys through GPS. Again this is just a sampling of some of the R & D activities which must occur in seismic to advance exploration.

The petroleum industry needs to work with other sectors in doing multidisciplinary and multi-agency research. Although primarily needs driven, there is a recognition that it will be part of a total geoscience system in order to operate in a harmonious fashion with society.

The Canadian industry still has a future with many challenging and exciting opportunities to apply science and technology. Where else can geological theories be so thoroughly tested?

5 (c) Environmental Industry

As mentioned in Chapter 3, topics in this field have some characteristics that are different from those of traditional geology. Environmental earth science generally involves surface or near-surface processes (both terrestrial and marine), and generally these have the potential to affect a large number of people. Conversely, the activities of our growing population have an increasing impact on these "natural" processes.

The environmental industry can de divided into 3 broad categories:

- consultants who study and analyze environmental problems and recommend solutions;
- investigative and analytical service companies (*e.g.*, drilling and soil contaminant testing laboratories); and,
- companies that provide mitigative services.

The environmental earth sciences industry is small and is likely to remain so. The following are some examples of

Table 5.3 Estimates of liability distribution of acid mine drainage

INCIDENCE OF LIABILITY AND TIMING	TAILINGS $ million	TAILINGS percent	WASTE ROCK $ million	WASTE ROCK percent	TOTAL $ million	TOTAL percent
Crown (Provinces & Canada) now	270	8.5	170	8.1	440	8.4
Companies (0-10 yrs. from now)	1,200	37.7	1,270	61.3	2,470	47.0
Companies (10-20 yrs. from now)	750	23.6	630	30.6	1,380	26.3
Companies (20 yrs. from now)	960	30.2		-	960	18.3
TOTALS	**3,180**	**100.0**	**2,070**	**100.0**	**5,250**	**100.0**

(Feasby and Jones, 1994).

how the geosciences can continue to support environmental earth sciences industry.

Of necessity, Canada has developed an expertise in landslide investigation, analysis, and mitigation. For example, with the passing of the *British Columbia Forest Practices Code Act*, geoscientists trained or experienced in slope stability are in very high demand, as most areas of future logging will have to be studied in some detail before road building or logging permits are issued. At the present time, the related consulting industry is extremely overworked. Increased landslide investigations will continue to drive an increase in service companies such as drilling, geophysical, and analytical software companies. Geotechnical engineering firms, for example, will continue to find that many of their projects are associated with the design of landslide mitigation structures. New techniques and products for slope stabilization will continue to be forthcoming as in the past when stabilization techniques using reinforced earth, reinforced retaining walls, and soil nailing were developed.

It is too late just to protect our groundwater resources. We now have to be "proactive" and begin to clean up the contamination of the past 100 years. These efforts will be based on the basic knowledge of the interaction of the chemical, physical, and biological aspects of the groundwater with the rocks and soil through which it is flowing. Remediation is a growth industry. An estimate of the total dollars required to clean up the hazardous waste problem in the United States, is $1 trillion (Bredehoeft, 1994). Under current policies, the cost of a Canadian clean-up, given a 10:1 US to Canada ratio, is estimated at roughly $100 billion and the time estimate to clean up the hazardous waste produced over the past 100 years is 100 years.

As an example of industry spin off, the University of Waterloo's Centre for Groundwater Research has resulted in the formation of six associated groundwater service companies which are involved in all aspects of groundwater, including remediation. In British Columbia alone, the number of groundwater remediation firms has increased in the past 5 years from 2 to more than 40.

Earth science is closely linked to aspects of urban environmental science (e.g., radioactive soils, lead and cadmium bearing soils, high levels of metals in urban waters, *etc.*) and with the recycling and waste management industries. All of these have exciting, interesting and beneficial earth science research components. There needs to be a concerted effort to avoid overlap and duplication, to ensure a multidiciplinary approach and to set the basic framework in terms of the appropriate earth science components, especially those that relate to the dynamics of rate processes, suitable time frames and three dimensional space. Once again it is hoped that the sound science evolving from this research would influence the development of relevant and sensible regulations and policies.

Acid mine drainage is the largest single environmental problem facing the mining industry today (Cherry, 1993). It has been a product of many mines since minerals were first extracted, although the problem has only been fully recognized in the past several decades. Commonly, long after a mine shuts down, acid mine drainage will continue to be produced and travel through the subsurface impacting both groundwater and surface water. Continued research, by geoscientists of the federal and provincial governments, universities, and the mining industry, is required to better understand the phenomenon and to provide efficient methods of remediation. The present methods are effective but costly, as many clean-up operations have to remain in place for many years after the closure of a mine. To date it has cost the Canadian mining industry $3 to $5 billion in research, consulting fees, and remediation (Industry Canada, 1994b). Table 5.3 indicates the order of magnitude of mining site restoration and reclamation that needs to be accomplished in Canada. Regardless of exactly how this work will be paid for, it represents an exciting challenge and opportunity for environmental earth science research.

Such research topics include the relationship of the original (prediscovery) signature of the deposit to the local or regional geochemical background; delineation of the extent of natural buffering by the local biota, overburden and groundwaters; measurement of the rates and magnitudes of natural acid-mine drainage processes of both of tailings and waste rockpiles in different climatic and permafrost regimes. These and many others topics represent large and stimulating areas of multidisciplinary earth science research that need to be addressed now.

There are obvious social and environmental benefits to Canada. Equally important are the remedial techniques and technologies that would evolve and be transferable to the vastly more deleterious situations such as "Russia-CIS", in northern Asia and to the high altitude mines of the USA and South America. There is a huge market for the transfer of this remedial technology if Canadian R & D evolves rapidly in this area.

One of the brightest lights in the recent advances of engineering site investigation has been the development of the Cone Penetration Test at the University of British Columbia. This development, used to provide *in situ* geological and engineering properties of soft soils, has lead to several new companies and a whole new facet in the site investigation industry.

More than 6 billion tonnes of aggregate (sand, gravel, and crushed rock) are mined and used throughout the world each year. This is more than all other mined commodities combined. In British Columbia alone, there are 2,600 active sand and gravel pits producing over 50 million tonnes annually, with an approximate value over $170 million. The sand and gravel produced in Canada in 1993 was worth over $700 million (see Table 2.1). The fact that aggregate is a high volume, low unit value commodity necessitates that it be located relatively close to its location of end use. To ensure adequate supply in the future, geoscientists need to:

- inventory remaining near surface resources; develop better methods to locate more deeply buried resources;
- continue to evaluate marine sand and gravel deposits; investigate methods of using marginal resources;
- devise methods to develop existing, but presently sterilized, resources near large urban centres;
- evaluate and establish transportation methods, other than traditional trucking;
- address environmental concerns associated with extraction;
- investigate alternative, possibly recycled, materials that can be use to replace traditional materials.

In the future a great deal more money will be spent in locating and extracting this diminishing resource. It is likely the lead agencies will be the larger aggregate producers and users. In addition, the value of other building materials, such as building stone and cement, is likely to increase as supplies dwindle and demand rises.

5 (d) Alternative Energy Industry

Throughout history there has been a progressive evolution in the mix of energy sources used by humankind - from wood, animals, water, and wind through coal, oil, gas, nuclear, geothermal, and solar - as technologies developed and needs demanded. In the future this mix will continue to evolve, but now in response to concerns over the environment as well as to changing availability of some fuels. At 1993 rates of production, known world oil reserves (conventional) will last between 40 and 50 years and natural gas reserves about 70 years (Fig. 5.9).

Global climate change predictions, linked principally to energy-related, greenhouse-gas emissions (especially CO_2 and CH_4), have led many nations and international organizations to specify emission targets ranging from stabilization at 1990 levels (United Nations Conference on Environment and Development, 1992), to 20% reduction from 1988 levels by 2005 (current Canadian position), to 60% reduction (Intergovernmental Panel on Climate Change, 1992). While most of these reductions are cost-effective and can be realized through energy efficiency measures, none can be fully met without a substantial change from the current mix of fuels.

Many different proposals have been put forward suggesting an appropriate mix of fuels in the twenty-first century to address the above climate change concerns. Most of these proposals share several attributes: a shift from oil and coal to gas and renewable fuel (especially biomass); a modest increase in hydroelectricity; a gradual increase in alternative energy sources such as geothermal, solar, wind, and photovoltaics; and, an elimination of nuclear power. In transportation over the longer term, most scenarios call for alcohol fuels, derived from biomass, and hydrogen, produced ultimately with solar electricity, to replace current fossil fuels. In the shorter term, natural gas, direct electricity (batteries charged from hydroelectric sources), and hydrogen from hydroelectricity or natural gas would be used. Alternative models suggest that there would be a modest use of new renewable energy sources (e.g., direct solar) supplemented by a significant shift from oil (and an elimination of coal) to natural gas. Gas would be used in integrated energy systems in buildings and for cogeneration in industry. All of these models of sustainable energy for the next century emphasize that, if even the most conservative emission targets are to be achieved, all approaches would have to be within the context of an overall reduction in energy demand globally, met largely through energy efficiency and conservation measures.

The implications for the geosciences in Canada if such trends were to come about are clear, both in terms of domestic energy supply and international markets for Canadian energy and fuels:

- growing reliance on natural gas domestically
- increased markets for Canadian gas

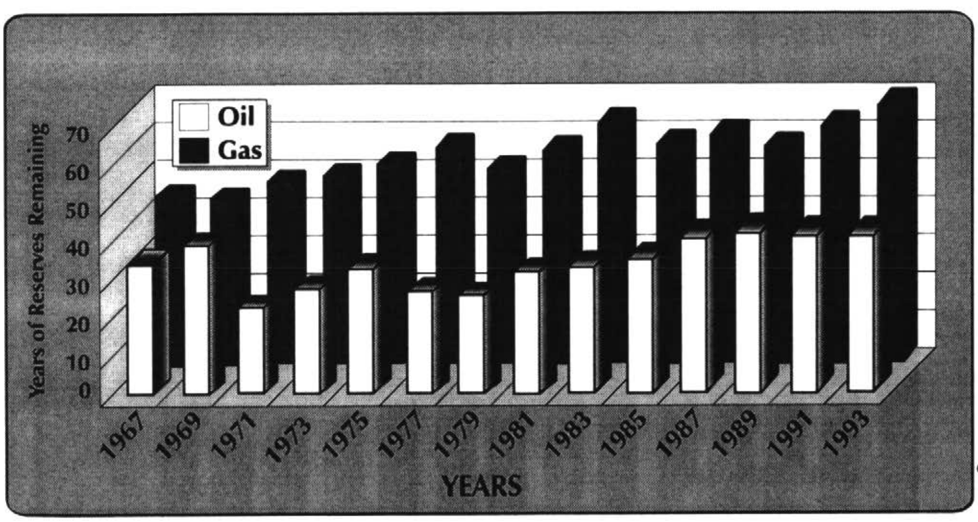

Figure 5.9 Estimates of years of world oil and gas reserves remaining (British Petroleum, 1994).

- decrease in oil and coal use domestically
- diminishing markets for Canadian coal
- increase in hydroelectricity, particularly in response to U.S. needs
- no new development of nuclear energy in Canada
- decreased market for Canadian uranium
- substantial increase in both high- and low-temperature geothermal energy, for space heating in Canada and for electricity generation to meet domestic and U.S. demands.

As rational, desirable, and achievable as these suggestions are for sustainable energy, few really believe that they will materialize, at least in the stated (and required) time frame. Political will is absent. The juggernaut of "traditional" laissez-faire economics will alter course very slowly toward a more "steady state economic system". The political and financial power of the nations and corporations which control fossil fuels internationally will ensure their continued undiminished exploitation. The rapidly rising expectations of the developing world, and their dependence on new energy (largely from available, abundant, and cheap coal), will far outstrip the ability of the developed world to effect the philosophical, technical, and economic shifts necessary to promulgate more sustainable energy utilization on a global scale.

The Intergovernmental Panel on Climate Change (IPCC) predicts that fossil fuel utilization will continue to account for about 85% of the primary energy until about the year 2025, at which point it will begin to decline to 57% in 2100. It will be replaced by commercial biofuels and nuclear, hydroelectric power, and solar energy.

Thus reality would suggest that the future for Canadian energy resources is, in fact, bright. Canadian coal will continue to grow in importance, conventional oil will steadily diminish (at least from the Western Canada Sedimentary Basin) into the middle of the next century and some new reserves will be exploited in frontier areas; natural gas will continue to grow ever more important to Canadian trade with the U.S.; nuclear power will grow at a modest pace in the developed world and more rapidly in the developing world, opening new markets for Canadian uranium; and, Canada will develop and export more hydroelectricity to the U.S.

The most significant new opportunities for Canadian geoscientists are expected to be related to geothermal energy in its many forms. There is a known potential for high-temperature geothermal energy in the Garibaldi Range of southern British Columbia, with three companies currently making application to develop various sites. The electricity derived from these areas would initially serve the Californian demand for non-fossil fuel generated power. Lower temperature geothermal energy is currently used to heat recreational swimming pools, provide warm water for fish hatcheries, and warm community water systems in northern Canada. As well, geothermal heat pumps are slowly penetrating the Canadian market for domestic and institutional heating. Carleton University has been using this source for many years, and several homes in the Greater Victoria and Vancouver areas are now heated in this way. The most manageable and predictable type of geothermal resource for power generation is hot dry rock. Whereas considerable research and analysis has been undertaken in the U.S. with respect to exploration, technologies, and economic feasibility of exploitation, little has been undertaken in Canada.

Canada has both the potential to develop geothermal energy sites throughout the country (to offset current reliance on fossil fuels) and an expertise (from its groundwater, geophysics, and basin analysis specialists) to establish an international position in geothermal exploration methods and technologies.

There will also be continuing pressure for Canada to develop its remaining hydroelectric power potential. In eastern Canada, for example, it has been estimated that untapped hydroelectric generating capacity is 237% of the present capacity (98,000 megawatts versus 41,000 megawatts), ranging from 80% in Newfoundland and Labrador to 280% for Quebec. Similarly, abundant remaining potential exists in British Columbia and the Yukon. Although it is doubtful that much of this remaining capacity will be exploited, particularly for environmental reasons and native land claims, it is inevitable that a significant portion will come on-line within the next fifty years in response to U.S. energy demands and Canadian commitments to shift to non-fossil fuel energy sources. Climate change scenarios also suggest that many currently exploited hydroelectric generating sites in eastern Canada (particularly in the Great Lakes System) will have significantly reduced output by early in the next century, requiring other areas to be developed. Geoscientists will be called upon to fill a variety of roles related to this expansion in Canada's hydroelectric generation capacity (e.g., reservoir analysis, hazard assessment, geotechnical evaluation, rock mechanics, environmental assessment, and monitoring.