	 		Chapter IV				
	 	Mineral Resource					
	 		Development				
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"For a miner must have the greatest skill in his work, that he may know first of all what mountain or hill, what valley or plain, can be prospected most profitably, or what he should leave alone..."

# Georgius Agricola, 1556

# **IV.1** Synopsis

The importance of the mining and petroleum industries in Canada's economic development was stressed in Chapter II. The main purpose of the present chapter is to assess the actual and future contributions of earth sciences in relation to the industry's growth expectations, the most appropriate rate of mineral exploitation, the apparent inadequacy of the past discovery rate to meet anticipated production objectives, and the measures that will increase the effectiveness of earth science activities in mineral exploration.

Mineral resource development involves a unique responsibility in that it relates to the exploration for and the exploitation of non-renewable resources. Decision makers in business, industry and government should possess adequate quantitative and qualitative information on mineral resources so that the location, kind, timing and scope of mineral recovery operations will be in the nation's best economic interest, with regard to present and future mineral requirements.

The present expenditures on exploration activities - close to \$90 million a year for metallic and non-metallic minerals, and \$300 million a year for mineral fuels - indicates the magnitude and importance of earth science activities. Any improvement in the state of the art and its application in the discovery of new sources of minerals and fuels could have far-reaching benefits, not only in improving exploration technology but also in increasing mineral reserves for our national needs and enabling Canadian industry to remain competitive in world markets.

The earth science role must advance inasmuch as all signs point to a doubling in mineral requirements every 15 years and the record shows that the process of making new discoveries is becoming increasingly difficult and costly. Furthermore, mineral resource development affords practically the only means of effectively occupying much of the Canadian territory through the establishment of economic enterprises contributing to the nation's income and well-being; indeed, practically all productive activity in Canada north of the main population centres is based on mining and petroleum industry activity and power development. Progress in earth sciences will be an important determinant of the industry's ability to continue its historic role of pushing back the frontier, opening up new areas to productive economic activity and promoting Canada's development.

Sustained growth of the mineral industry should remain a major preoccupation of government, and a major concern to earth scientists in industry, government and universities. Intensification and optimization of mineral exploration are major keys to the industry's growth and diversification. Earth science research must be fostered so that new principles of mineral discovery may be found and applied to this endless search for new sources of mineral commodities.

It is in the national interest that mineral exploration research be particularly encouraged, and that better co-ordination in the orientation and support of this research be achieved. It is important to develop national multi-disciplinary and mission-oriented projects leading to new thought in geology and new applications of science. National efforts should be oriented particularly towards the following goals: a) major improvements in exploration drilling technology and drill hole surveying instrumentation and techniques; b) the miniaturization and automation of borehole geophysical instruments; c) the development of geochemical instrumentation for the automatic logging of boreholes, drill core and cuttings, and rock exposures; d) the establishment of central core storage libraries and laboratories in a number of mining districts; e) the development and use of a national computerized system of earth science data storage and retrieval; and f) the creation of a number of regional field research units.

Canadian universities must continue to provide broad basic training in the earth sciences, but with a greater emphasis on field problems than at present. Earth science student enrolment should be increased appreciably in order that industry's professional manpower requirements may be met. The mineral industry should improve its image among students, faculty and the general public.

Furthermore, industry should provide more challenging work for its scientists and engineers, with greater scientific or professional rewards, higher remuneration and better compensation for isolation from main population centres and other difficulties associated with field work. To encourage the development of the North, the federal government could well provide substantial personal income tax incentives to personnel working north of a certain line, as done in Australia, or alternatively, and jointly with industry, provide substantial financial incentives of some other kind to these people. Finally, the prosperity of Canada's mineral industry is very much dependent on the amount and quality of the scientific services provided by federal and provincial government agencies. It is in the best national interest that these services be increased at a rate at least parallel to that of industry's exploration expenditures. Provincial departments of mines and natural resources in particular ought to increase their earth science activities by at least 10 per cent a year during the next 10 years to provide the basic framework of scientific information needed for efficient mineral exploration.

science is not regarded as a thing in itself but rather as a means to an end. In general, particular scientific projects are not examined on their own merits but rather as components of programs which have defined objectives".1 Likewise, the mineral industry regards earth sciences as a means of increasing the effectiveness of mineral exploration, for lowering the unit cost of mineral discovery. The mineral industry being by far the largest employer of geoscientists (Table II.5) and the largest spender on earth science activities (Table II.1), it is a matter of national concern that these activities contribute increasingly to Canada's economic and social development.

Mineral exploration is inextricably linked to the well-being of the mineral industry. It is thus appropriate at the beginning of this chapter to emphasize the importance of the mineral industry in Canada's economy in terms of both broad patterns and growth trends.

### **Broad Patterns**

As outlined in Chapter II, the essential features of the Canadian mineral industry include:

1. An output value of \$4.7 billion in 1968 (Table II.11).

2. A ninefold increase in output value in the period 1945-68 (Figure II.4).

3. A fourfold increase in the physical volume of output in the period 1950-68, compared with less than three times for the industrial economy as a whole (Figure II.5).

4. During the period 1946-68 the real domestic product index for the mining sector of the Canadian mineral industry grew at an annual average rate of 8.7 per cent, compared with 5.5 per cent for manufacturing, 2.3 per cent for forestry, and 1.7 per cent for agriculture.

5. In 1968 the mineral output value was equivalent to 7 per cent of Canada's GNP, compared to 4 per cent in 1945 (ex-

# IV.2 General Perspective

"In the eyes of the Treasury Board,

<sup>&#</sup>x27;Senate of Canada. The Treasury Board. Proc. of the Special Committee on Science Policy, No. 26. Ottawa, 1969. pp. 3693-3796.

cluding in this percentage the appreciable value of manufacturing activities based on mineral supplies, as well as the multiplying effect in transportation and various service industries).

6. Minerals and metals currently account for about 30 per cent of all Canadian merchandise exports, compared with 20 per cent in 1950 (Figure II.7). Canada's position as fifth largest world trader is in good part due to these exports.

7. Total wages and salaries paid by the mineral industry are almost double those paid in forestry, and well over three times the income to labour in agriculture.

8. Corporation profits, before taxes, of mining and petroleum companies constitute about 11 per cent of the corporation profits of all industries.

9. Mining, petroleum and related companies pay almost one-fifth of all federal income taxes, and are major contributors to provincial and municipal treasuries.

10. The mineral industry has had a major impact on regional development throughout the country; indeed, it is the only major factor in economic development of the North.

11. The mineral industry has contributed significantly to the growth of secondary industry.

12. Finally, the expansion of the mineral industry has been a major factor in extending Canada's transportation network and communications system.

# Growth Trends in Earth Science Activities

An affluent society cannot exist without an adequate supply of domestic or foreign minerals and metals. In Canada the mineral industry cannot be sustained without a very substantial national investment of manpower and expenditure in mineral exploration.

## Earth Science Expenditures

The following patterns, obtained largely from our questionnaire survey, are most revealing:

 In 1968 the mineral industry spent
\$392 million on earth science expendi-174 tures (Table II.1), almost all in mineral exploration. This amount represents 8.3 per cent of the gross value of mineral production in 1968; it is 7.3 times larger than all government expenditures on earth science activities (for all purposes), and 20 times larger than provincial government earth science expenditures.

2. While the federal government collected \$185 million from mining and petroleum companies in 1967 in the form of income tax at the primary production level, and \$8 million in 1968-69 from mineral rights and royalties, it spent only \$12 million in 1968 on earth science activities related to mineral exploration.

3. All the provincial governments combined received an estimated \$349 million in the form of taxes and royalties from the mineral industry in 1968, and spent in return an aggregate total of \$7 million on earth science activities.

4. The mineral industry spent \$42 million on earth science research and development, compared to \$13 million by the federal government and \$4 million by all provincial governments (only a fraction of these government expenditures relates solely to the mineral industry).

5. Industry spent \$345 million on earth science data collection, compared to \$15 million by the federal government and \$11 million by all provincial governments (much of this federal government expenditure does not relate directly to the mineral industry).

6. Industry spent \$5 million on earth science information, compared to \$6 million by the federal government and \$2 million by all provincial governments (Table II.4). These government expenditures are largely drafting and printing costs of publications.

7. Of the \$345 million spent by industry on data collection, \$172 million were for exploratory drilling (Table II.16), representing 44 per cent of industry's total earth science expenditures.

8. Of the \$392 million spent by the industry, 14 petroleum and mining companies alone spent \$153 million, or 39 per cent of the total (Table II.10). These 14



Source: Our survey and the Dominion Bureau of Statistics



Source: Our survey and the Dominion Bureau of Statistics

major companies spent \$18 million on earth science research and development in 1968, or 43 per cent of the industry's total earth science R & D. These same companies alone spent \$135 million on earth science data collection in 1968, or 39 per cent of the industry's total.

9. The petroleum industry is the major performer of earth science activities. In 1968 it spent \$299 million, compared to \$88 million by the mining industry (Table II.17).

10. Geology expenditures represent 5.9 per cent and 20.8 per cent of total earth science expenditures of the petroleum industry and the mining industry, respectively, whereas the equivalent percentages for geophysics are 37.2 and 13.1 per cent, and for geochemistry 0.2 and 5.1 per cent (Table II.17).

11. During the period 1964-68, the petroleum exploration expenditures increased from \$165 to \$299 million a year, whereas the mining exploration expenditures grew from \$48 to \$88 million (Table II.17).

12. This unprecedented activity in Canadian mineral exploration is well illustrated by Figure IV.1, which shows the growth in annual exploration expenditures from 1950 to 1968, as well as the growth in output value of annual mineral production during the same period.

13. The annual growth of exploration expenditures by Canadian metallic mining companies and oil-gas companies during 1950-68 is shown in Figure IV.2.

14. Finally, we estimate that during the period 1964-68 alone the Canadian mineral industry spent a total of \$1.5 billion in mineral exploration in Canada. About 84 per cent of this colossal sum was actually spent on field activities (including exploratory drilling).

These facts speak for themselves and it should not be necessary to elaborate further on the importance of earth science activities in the mineral industry, except to indicate the past, present and future contributions of earth sciences in Canadian mineral exploration, particularly from the point of view of research and development. However, before doing so, we should also analyse the industry's manpower patterns.

# Earth Science Manpower in the Mineral Industry

Before this study was undertaken there were no reliable estimates of the numbers of geoscience professionals in the mineral industry. A national professional manpower survey was carried out in 1967, but the results were never published. We had to conduct our own survey, and our main findings are:

1. We estimate that in 1968 the earth science manpower in the mineral industry totalled about 4 000, including 457 consultants (Table II.19).

2. Of this total, 30 per cent had degrees higher than the bachelor's level (Table II.19).

3. Geologists and geophysicists combined form 82 per cent of the earth science personnel in the mineral industry, or about 56 per cent of all earth science professionals in Canada (Tables II.6 and II.18).

4. The proportion of geologists to geophysicists is  $2\frac{1}{2}$  to 1 in the petroleum industry, and 21 to 1 in the mining industry (Table II.18). These ratios are in direct relation to expenditures, which in geophysics are 10 times greater in petroleum than mining exploration, while geological expenditures are about the same in the two industries (Table II.17).

5. Geochemists form less than 1 per cent of the earth scientist population in industry, whereas mining and other engineers represent 13.5 per cent (Table II.18).

6. On a national basis, the average professional engaged in mineral exploration in 1968 was responsible for \$110 000 worth of earth science activities (Tables II.1 and II.5), compared to \$87 000 in 1964.

7. Allowing a 3 per cent replacement rate (retirement, death, etc.), the average annual increase of earth science manpower in the mineral industry in 1964-68 was 365, or a 9 per cent average annual increase (Tables II.9 and II.19). 8. Canadian universities provided only one-third of industry's manpower requirements in the earth sciences during 1966-68, and industry has had to rely heavily on immigration to fill its requirements (in 1968 alone, 336 geologist immigrated to Canada, compared to an output 220 B.Sc., 62 M.Sc. and 38 Ph.D. geology graduates from all Canadian universities).

9. If the last five years' activity in Canadian mineral exploration is maintained (Figure IV.1), exploration expenditures may exceed \$1 billion a year by 1985, which is about 10 per cent of the predicted value of annual mineral output. On the basis of the industry's geoscience manpower during 1964-68 and the level of exploration activity during this period, we estimate that industry may employ more than 8 000 earth scientists in exploration by 1985, compared to 4 000 in 1968 (Table II.5).

As discussed in Section III.6, we believe an earth science manpower problem exists in Canada, which is most serious in the case of mining engineers.

# IV.3 Importance of Earth Science Activities in the Mineral Industry

Earth science activities are of foremost importance in mineral exploration, for it requires a good knowledge of the earth's materials, processes and history to find the coveted economic mineral deposits. Whereas in the past many deposits were found by grass-roots prospecting (even today some may still be found by this method, especially in the northern regions of Canada) the fact is that mineral exploration has now become a generally sophisticated and very costly business. It is increasingly based on scientific methods of geology, geophysics, geochemistry, and to some extent on the use of geomathematics, computer technology and operations research in exploration methodology.

## **General Statement**

# Oil and Gas Exploration

Nowhere is the degree of exploration sophistication more apparent than in the major petroleum companies. For example, a major oil company operating in Canada may have a permanent earth science staff of 50-190 professionals, including 30-100 geologists, 10-60 geophysicists, 1-3 geochemists, and 5-25 computer programmers. Its exploration expenditures may range from \$10 to \$25 million a year. It may have an integrated system of data collection, scientific information, and earth science research and development operated by a staff of, say, 40 scientists and 80 support personnel; its annual budget for earth science research and development alone may be in the order of \$2 million a year.

The well files maintained by this company may contain more than one million individual documents, representing 100-200 man-years of file collection, service and inventory. It may have on microfilm some 600 000-700 000 seismic records. Its computer-oriented well-data files, which are outlined in Appendix 7, may contain data on 50 000-60 000 wells across Canada.

Geological and geophysical techniques have played a very significant role in the discovery of oil and gas fields in Canada. Geophysical exploration in particular has been intensively and extensively applied, as shown by the fact that in western Canada alone the industry has done some 21 650 crew-months of seismic work, which in terms of seismic lines amount to 1 300 000 miles. Also in this part of Canada about 2 000 crew-months of other geophysical work, such as gravity and magnetic surveys, have been performed.

In the initial stages of petroleum exploration in Canada, geologists applied the simple anticlinal theory of entrapment that had been so successful in the United States and other parts of the world. Through mapping of the surface geology several significant discoveries were made, including Canada's first major oil field at

### Turner Valley.

As exploration moved to the Plains area, simple reflection seismology became the principal tool, and was the basis for the discovery of most of the large Leduc reef fields in 1947-55. Later on, the same tool was used to locate the giant Beaverhill Lake fields, such as Swan Hills, Judy Creek and Virginia Hills.

Between 1955 and 1958, industry again focussed its attention on the Foothills region where a combination of reflection and refraction seismology, together with detailed surface geological mapping, led to discoveries of major gas fields like Waterton and Lookout Butte.

In the late 1950s and early 1960s, exploration geophysics underwent a tremendous advance through the development of magnetic tape recording, common-depth point shooting and digital processing. These developments have led to much better seismic data which, in turn, have resulted in several important new discoveries. The first of these was the Rainbow A pool in 1965. This discovery was rapidly followed by other finds in the same area, and led to the successful exploitation of the Pinnacle Reefs of the Zama and Virgo areas also situated in northwestern Alberta. More recently, in late 1968, these new seismic methods led to new Leduc Reef gas discoveries in the Strachan and Ricinus areas of west-central Alberta. These discoveries would not have been made were it not for these newer seismic techniques.

Probably the most significant advance in stratigraphy in the last decade has been the improved techniques of describing and interpreting carbonate rocks. These advances have been particularly significant to western Canada, where 56 per cent of the oil-gas reserves occur in carbonate rocks. The very large extension of the Kaybob South Beaverhill Lake gas field in 1968 is one example of a discovery resulting from the application of these improved geological techniques.

Well logging and reservoir engineering technology have produced many new tools and analytical techniques, which have almost eliminated the hazard of missing profitable reservoirs penetrated by exploratory drills.

The advances made in oil exploration on land are also applicable to offshore exploration. With increased offshore activity throughout the world, much attention is now directed to Canada's 1.5 million square miles of submerged continental margin, which is equivalent in size to about 40 per cent of its total land area. Since the first offshore permits were issued in 1960, the petroleum industry has already spent about \$40 million for geophysical surveys and about \$20 million for exploratory wells on the Canadian continental shelves. During the next decade industry expects to spend as much as \$1 billion in probing these areas. The major oil discovery at Prudhoe Bay in Alaska has of course boosted industry's expectations of finding major oil fields in the Canadian Arctic. This high activity in offshore exploration will require extensive application of the earth sciences and marine technology.1

## Metal and Non-metallic Mineral Exploration

Whereas much petroleum exploration deals with relatively continuous geological variables, with geophysics being a major tool to ascertain the subsurface geology, mineral deposits mostly occur within geological discontinuities, e.g. faults, breccia zones, intrusions, alteration zones, certain sedimentary structures and lithologic facies, etc. Mining geophysics is used extensively to pinpoint drilling targets in drift-covered areas, and to locate possible orebodies at shallow or intermediate depths. Unfortunately, many geophysical anomalies are found to be barren when drilled and it is usually uneconomical to test drill all of them systematically. A combination of airborne geophysical methods may allow better differentiation between anomalies and provide strategic locations for exploratory

<sup>&#</sup>x27;In 1969 the Science Council of Canada initiated a Special Study of Marine Science and Technology in Canada, which will deal extensively with this subject.

holes at relatively lower cost. Geochemistry can be used to advantage in restricted areas, but here again there is a high element of risk involved, and no assurance that even with the best technique a valuable deposit will be found. Of one thousand prospects of mineralization, perhaps only one or two will yield a mine. It is the particular function of earth scientists and mineral engineers to make this search successful at the least cost.

Geology. Numerous examples illustrate the importance of geology in mining exploration. Geological mapping carried out by the Geological Survey of Canada, provincial departments of mines, and mining companies, have led to several important mineral discoveries or provided the essential framework for many highly successful exploration programs. Geology has been an essential element of many important mine discoveries, as indicated by the following examples:

-the development of the geological theory that focussed new attention on the Pine Point district and led to the discovery, by drilling, of major lead-zinc deposits just south of Great Slave Lake;

- the geological concepts that guided the exploration for massive sulphides in the Archean rocks of the Noranda and Timmins areas, with the resulting discovery of the Vauze, Lake Dufault, and Delbridge mines, and the finding of the fabulous base metal orebody of Texas Gulf in Kidd township;

-the definition of the stratigraphic and sedimentological controls affecting the uranium mineralization in the Blind River area:

-the geological concepts that guided the geophysical exploration for massive sulphides in the Matagami area of northwestern Quebec and the Bathurst area of New Brunswick;

-the geological hypothesis that guided the discovery of the copper deposit of Madeleine Mines in Gaspé peninsula;

-the geological concepts that led to the exploration for nickel in the Thompson area of northern Manitoba;

-the geological knowledge that provid-180

ed the basis for the discovery of the world's largest deposits of potash in northern Saskatchewan;

-the structural hypothesis which led to the discovery of the Campbell shear zone in Yellowknife;

-the geological studies which guided the discovery by drilling of new coppernickel orebodies, and large extensions of known orebodies in Sudbury;

-the definition of the structural, lithological and textural guides to iron ore exploration in the Labrador Trough of New Quebec-Labrador, etc.

In addition, geology is used continually in finding lateral and depth extensions to orebodies in operating mines. Although less glamourous perhaps than new deposits, these finds contribute important additions to ore reserves.

Exploration geophysics. In terms of orebodies found and tonnage developed, Canadian mining geophysics has achieved success to a degree unparalleled in any other country of the world. In 1967, Canada accounted for 34 per cent of the Free World expenditures in mining geophysics (\$32 million U.S.), or almost as much as the activity in the United States and Europe combined.' In airborne geophysical methods, it accounted for 37 per cent of the Free World expenditures, compared with 17 per cent for the whole of Africa and 16 per cent for the United States. Canada also ranks first in the Free World in regard to research in mining geophysics.1

In contrast with petroleum geophysics, which is dominated by the seismic method, mining geophysics utilizes mostly airborne and ground magnetic and electromagnetic measurements for reconnaissance. The electromagnetic and the induced polarization methods are considered to be the most diagnostic of massive and disseminated sulphide mineralization, respectively.

Aerogeophysical methods have had an enormous impact on mineral explora-

<sup>&#</sup>x27;Hood, P., World expenditures in mining geophysics during 1967. CIM Bull. 61 (680): 1453-1459. December 1968.

tion in Canada, owing to their enormous speed and relatively low cost. Many new Canadian mines in recent years have been located by such methods. Geophysical ground surveys are also carried out extensively in Canada.

To list all the Canadian geophysical mine discoveries is clearly beyond the scope of this report. The following examples should suffice to illustrate the importance of mining geophysics in this country:

-the first Canadian geophysical mine discovery was made at Buchans, Newfoundland, in 1926, as a result of an equipotential ground survey;

-the multimillion-ton iron deposit at Marmora was found exclusively by an aeromagnetic survey in 1949, under a thick capping of sedimentary rocks and glacial drift;

-although the Horne Mine at Noranda had been in production since 1927, it was not until 1945 that the large deposit of Quemont Mine was found by drilling on the adjacent property, as a result of ground magnetometer survey;

-the Texas Gulf discovery a few miles north of Timmins, one of the most spectacular Canadian finds, was made in 1964 as a result of an airborne electromagnetic survey of a favourable volcanic horizon, some 50 years later than the start of mining production in the Timmins area;

-entirely new mining camps were developed in the Bathurst area of New Brunswick and the Matagami area of Quebec as a result of discoveries made in the 1950s from aeromagnetic surveys combined with airborne and ground electromagnetic surveys;

-the use of induced polarization was directly responsible for the discovery in 1966 of the large Pyramid lead-zinc deposit at Pine Point, Northwest Territories;

-the discovery of a major nickel belt in the Thompson-Moak area of northern Manitoba was brought about by airborne and ground magnetic and electromagnetic surveys during 1947-56; -in 1969, major base metal finds were made from aerial electromagnetic surveys of favourable rock formations at Ruttan Lake, Manitoba and Uchi Lake and Sturgeon Lake, northwestern Ontario, and a uranium deposit was indicated in the Wollaston area of northern Saskatchewan from an airborne scintillometer survey.

*Geochemistry*. In the last 15 years or so, geochemistry has become a major tool in the search for new metalliferous deposits in Canada. In spite of a ubiquitous glacial drift cover, which is locally very thick or impermeable to metal dispersion, the increasingly sensitive techniques of geochemical prospecting are becoming widely used in conjunction with geological and geophysical methods.

Geochemical methods are particularly useful in mineral exploration in the sense that they provide both discrimination and focus. One major problem associated with geophysics is the frequent lack of discrimination, that is, of the capacity to indicate precisely which elements are present in the rocks underlying a geophysical anomaly. On the other hand, geological exploration methods-while of inestimable value-generally lack focus or the capacity to pinpoint concealed ore deposits.

Geochemical prospecting was introduced into Canada by H. Lundberg in 1940, but it was not until 1945 when Professors H. V. Warren and R. E. Delavault of the University of British Columbia began their research, that geochemistry became an exploration tool in this country. It was through geochemistry that the tin mineralization at Mount Pleasant, New Brunswick was discovered in 1954 and that the Newman Lake copper orebody was found. The large molybdenum deposit of Endako, British Columbia, was pinpointed long ago by one of Professor Warren's biogeochemical surveys, although the actual discovery by drilling was made much later. Also in British Columbia, geochemistry has been of direct assistance in locating the Stikine Copper and Boss Mountain orebodies. The Portage Lake lead-zinc orebody in

the Bathurst area, New Brunswick, was a geochemical find, as was the recent discovery of the large Anvil lead-zinc-silver deposit in the Yukon. Although not economic, the lead-zinc mineralization found in the Bruce Peninsula of Ontario is directly attributed to geochemical exploration. These few examples suffice to show geochemistry has definite potentialities in Canada, in spite of our very widespread glaciated terrain and the modest amount of geochemical exploration research done to date on Canadian problems. Glaciated terrains do impose severe restrictions on the use of soil and stream sediment geochemical methods in large regions of Canada, but there is really no limit to the possibilities of using rock geochemistry in exploration.

There is also a real need to refine the techniques of sampling glacial till in an effort to pick "trains" of metal values that may be traced back to their ultimate source, in the same way as the Steeprock iron orebody and the Lynn Lake coppernickel deposit were found in Canada and base metal deposits have been discovered in Scandinavia. Finally, it is pertinent to mention that Ireland's mining revival is directly attributed to the success of Canadian-conducted geochemical exploration.

## Relative Importance of Exploration Methods

A prominent feature of Canadian mining exploration is the team approach used in most exploration programs. Figure IV.3 illustrates the combinations and sequences of scientific methods commonly used in the exploration of large areas. The selection of areas, which is a critical feature of exploration programs, is based on geological studies and hypotheses. The combined geological-geophysical approach has resulted in many spectacular discoveries, e.g. the copper-zinc-silver deposit of Texas Gulf Sulphur north of Timmins, and the Thompson-Moak nickel belt in northern Manitoba. Geochemistry is now used fairly extensively in conjunction with geological and geophysical methods to define new areas of

interest and pinpoint drilling targets.

The relative importance of various exploration methods in the discovery of Canadian non-ferrous mines since the early 1900s is documented in studies by Lang<sup>1</sup> and Derry<sup>2</sup>. Although recognizing that many deposits were actually found by a combination of two or more different methods, Derry has gleaned historical records to find the key feature of each discovery. His main findings are:

1. Of the 75 non-ferrous metal mines found before 1950, 85 per cent can be credited to conventional prospecting, and the remainder to geological deductions;

2. Of the 75 mines discovered during 1951-66, only 37 per cent can be credited to conventional prospecting, whereas those credited to geophysics rose to 33 per cent, and geology to 29 per cent (geochemistry accounting for one discovery in 1961-66);

3. The peak in geophysical discoveries was in the 1956-60 period when 14 new mines were discovered by this method (in 1969 four major finds were made through geophysical exploration).

These patterns reflect the increasing dependence on scientific methods in mining exploration. Considering the diminishing proportion of Canada's surface that remains to be examined or geologically mapped, we may assume that geophysics and geochemistry will continue to play a major part in mine discovery. With the development of methods still in the experimental stages, such as airborne very low frequency methods, aerial trace-element "sniffing", infra-red air photography, mercury halo technique, geochemistry of glacial soils, etc., we may assume that until 1985 or so geophysics and geochemistry will account for 60-70 per cent of all new mine discoveries in Canada.

It should be realized that the present penetration depth of mining geophysical methods is only a few hundred feet,

<sup>&</sup>lt;sup>1</sup>Lang, A. H. Discovery methods of post-1955 new producers. Can. Min. Jour. 88 (1): 47-50. 1967.

<sup>&</sup>lt;sup>2</sup>Derry, D. R. Exploration-targets and the choice of weapons. Mining Mag. 120 (3): 151-163. 1969.

Figure IV.3-Combinations and Sequences of Scientific Methods Commonly Used in Mining Exploration of Large Areas in Canada



whereas mining can proceed under ideal conditions to depths greater than 10 000 feet. It can be surmised, therefore, that the challenge for the rest of this century is to explore efficiently this "geophysicalmining" gap.

By 1985 or so, geology could well become the major factor in mine discovery. We will be searching, for example, for buried strata-bound deposits by using geological methods somewhat like those used in the exploration for oil and gas. Canadian explorationists will then be working essentially in the third (vertical) and fourth (time) dimensions of geological features. They will conduct "wild-cat drilling" programs based primarily on stratigraphy, lithology, and structure. Concurrently, deep-seated deposits will be searched in and around buried intrusive stocks, requiring a conjunction of geological, geochemical, and geophysical methods. Major programs will be oriented towards the testing of promising geological theories. Metallogenic analysis and operations research, using sophisticated mathematical techniques and conceptual geological models, will become the major tools.

We may also predict that we will rely in the future on large, low-grade, metalliferous deposits at surface or relatively shallow depth, which will become economical as a result of mechanization and other technological advances in largescale mining, such as the use of atomic power as an energy source for breaking and moving rock. Research will also discover new means of extracting valuable minerals. The search for such low-grade deposits will require an increasing interdependence between geology, geophysics, geochemistry, mineral science and technology.

There is also the likelihood of a considerable increase in the cost of discovery, because we will be searching in more remote areas, or at greater depths, using advanced and more expensive techniques. We must face the fact that in Canada the discovery cost per ton of ore will increase, and so will the difficulties 184 of finding new bonanzas. Therefore exploration expenditures may be expected to increase in relation to the general growth of the mining industry (see Figure IV.1).

### **Research and Development**

The Canadian mineral industry spent \$41 million on earth science research and development (R & D) in 1968 (including data interpretation), of which 77 per cent was spent by oil and gas companies (Table II.2). Of this total \$8 million was spent on basic and applied research, of which 70 per cent was spent by oil and gas companies (Table II.16). Significantly, \$5 million of all this research and development was spent on field activities.

In both the petroleum and the mining industries, earth science R & D is singularly important because, apart from instrumentation, it relates to non-repetitive processes and no two mineral deposits or oil fields are exactly alike. A sample of rock taken from a natural sequence can never be taken again. An analysis cannot be repeated if, in the process, the original material is destroyed. Most earth scientists know very well nature's intricacies and appreciate the complexity of earth's phenomena, but few scientists of other disciplines realize how time can affect even the most sluggish chemical reaction and what the forces of nature can produce on a global scale. Finally, even with the best brains in the country, the best scientific method and the best instrumentation, there can never be complete assurance that certain minerals will be found beneath the surface, owing to unsuspected geological conditions. Earth science R & D must relate to earth's materials and processes in their natural environment, and depending on the nature of the problems, a substantial portion of R & D activities must be carried out in the field.

The importance of R & D in petroleum exploration stems mainly from the fact that exploratory drilling is very expensive. A 15 000-foot wild-cat well in the Mackenzie Delta may cost more than \$2 million to drill, and the decision to drill this well must be based on sound inductive geological reasoning supported by good geophysical definition of structure and stratigraphy to great depth. Before development of the reflection seismograph, the success ratio for wild-cat wells was 1 to 20. With the wide application and refinements of this method the ratio has now improved to approximately 1 to 7.

The very costly nature and degree of sophistication of petroleum exploration have been instrumental in the formation of large international companies. It is understandable therefore that several of the major oil companies operating in Canada depend on their U.S. parents' large research facilities for research on Canadian problems. We estimate that in 1968 some \$20 million (175 man-years) was spent in the United States on research related to Canadian problems, compared to \$6 million spent in Canada. This situation may be very beneficial to the individual Canadian oil companies themselves but we are of the opinion that more of this research should be carried out in Canada (see Section IV.5).

The importance of earth science R & D in petroleum exploration is also brought out by the following considerations.'

1. The analysis and interpretation of lithofacies and biofacies are needed to interpret the history of sediments and predict favourable reservoir trends.

2. Applied paleontology is essential to age determinations of potential petroleum-bearing strata, to biostratigraphic correlations between different rock units, and discrimination of different depositional environments.

3. Geometric analyses of rock masses supplemented by a study of their chronological development is of fundamental importance in petroleum exploration. Analytical comparison of broad Canadian structures with orogenic belts in other parts of the world is very much also a theoretical and practical necessity.

4. The technology of fracturing or crushing rock formations is of great importance in well drilling, and its improve-

ment requires expanded research in rock mechanics. In addition, rock mechanics studies are most pertinent to a better understanding of such features as thrust terrains or evaporite diapirs, which could be studied on the analog principle as have been the salt domes on the Gulf Coast.

5. Maximum ultimate recovery from any reservoir must be based on sound geological knowledge of the conditions which resulted in the formation of a reservoir, including knowledge of structural deformation, organic activity, diagenesis, hydrodynamics, sorting, facies changes, porosity and permeability changes, etc. With high-speed computers it is now possible to develop programs that consider the effects of an almost infinite number of variables and result in improved primary, secondary and possibly tertiary recovery from reservoirs. Good knowledge of the porosity and permeability values relative to depth of burial, pore geometry, and capillary pressures, is important for improving petroleum exploration and extraction.

6. It is now possible to compute extremely accurate porosity values from sonic logs once some information on the rock types has been obtained. As research continues, it may be possible some day to make reliable estimates of the degree of permeability. The digitizing of logs and use of electronic computers now permit development of models designed to relate log responses of several devices directly to lithology or other specific elements in various rocks. The resulting computerized lithologs lead to improved stratigraphic correlation and better interpretation of such complicated factors as depositional environments.

7. The development of synthetic seismograms from sonic logs has permitted much better velocity control in exploration geophysics and a resultant improvement in seismic interpretations.

<sup>&#</sup>x27;Mostly abstracted from the briefs submitted by the Canadian Association of Petroleum Geologists and the Canadian Well Logging Society.

8. The development of the microlog, laterolog and induction electric methods of measuring electrical resistance in boreholes has provided means of determining fluid distribution (oil or water) at depth, whereas gamma-neutron and gammadensity techniques of natural and induced radioactivity have been used to measure pore structure and identify rock types.

9. Research has shown that organic and inorganic geochemistry can play an important role in defining and evaluating the four prerequisites of a petroleum deposit, that is, source, reservoir, trap, and preservation:

a) the evaluation of the *source* can be accomplished by the analysis and correlation of chemical and isotopic properties of oils and sediment extracts;

b) the effectiveness of petroleum *reservoirs* is in many cases greatly influenced by processes such as leaching, cementation, and dolomitization, which alter both the pore volume and the pore geometry; an understanding of the timing and controls of these chemical processes is important in evaluating known deposits and predicting areas of favourable reservoirs;

c) the locating of *traps* can usually be done with sufficient geological and geophysical information; however, the relative timing of petroleum migration and the relative efficiency of the seal provided by different rock units at various stages of compaction are still poorly understood;

d) the physical and chemical *pres*ervation of petroleum in an environment which results in a producible product is the final prerequisite of an economic deposit; physical processes such as erosion into a trap and faulting of a trap are obvious and predictable destructive agencies; however, chemical processes such as thermal and bacterial alteration and water-washing are also extremely important, but not at all obvious or predictable without the extensive use of geochemistry.

10. Finally, the improved estimation of ultimate reserves of oil and gas and 186

related substances in a sedimentary basin requires better knowledge of the area and the configuration of the basin, the volume and types of sediments within it, the presence or absence of source beds and their potential, the types of traps, the ages and types of structures, and the unconformities; the comparison of these data with those from similar basins having producing wells provides yardsticks to estimate ultimate petroleum reserves.

In the metallic and non-metallic mineral exploration field, earth science R & D plays an increasingly important role as mineral deposits become harder to find, existing reserves become depleted, unit discovery costs increase, and the national and world demands for metals and nonmetals continually grow.

Geological R & D in the Canadian mining industry has generally been rather haphazard and fragmented, and dependent largely on personal interests of individuals. Yet in the early 1900s, the formulation of geological hypotheses to explain ore discoveries and locate new deposits played an important part in the exploration of the Sudbury and Cobalt mining camps. Similar or other hypotheses have, spasmodically, played an important role in many Canadian mineral discoveries.

The importance of research into the genesis of ore deposits is underlined by the fact that rarely in nature do we see mineral deposits in the making. Whatever we can find are only small bits of evidence relating to only a few types of mineralization. There is indeed no such thing as a general theory of ore deposition akin, say, to the theory of magnetism. It is not surprising therefore that ideas concerning the genesis of mineral deposits have been based largely on field observations, which have been supplemented by microscopic and chemical measurements made in the laboratory on natural samples and artificial systems.

The practical importance of metallogenic research resides in the need to define the environment in which mineral deposits occur and the conditions that

gave rise to their formation. Largely owing to European, particularly Soviet, geologists, it has been recognized that ore deposits are related in space and time to the geological environment in which they occur and that the key to their genesis lies in these rocks, not in some hypothetical plutonic source presumably existing at great depth. It has also been recognized, albeit rather slowly, that ore deposits and their surrounding rocks are chemical systems; hence the need for research on the conciliation of field observations and physico-chemical or thermodynamic relations obtained from experimental systems.

Metallogenic research is also important for learning the temperature-pressure conditions of ore formation, as well as the nature of ore-forming fluids. Studies of both the stable and the radioactive isotopes provide important insight into the geology of mineral deposits, because these have been formed almost throughout the geologic time scale and in various geochronologic or structural provinces.

Research in mining geology is of particular significance as it provides new knowledge on mineral deposits that become fully exposed in three dimensions, with consequent opportunities for studying their most intricate features. When it is realized that competent and experienced mine geologists must log in detail thousands of feet of drill core, and at times relog them two or three times in order to unravel complex geological settings, it is obvious that research is needed and sufficient time must be allocated to mine geologists for these essential studies. If this work is not done, valuable geological information is irretrievably lost, to the detriment of not only science itself but also, and importantly, the effective search for new ore in or near these mines.

Non-metallic minerals and structural earth materials are consumed at an accelerating rate. The value of Canadian production of sand, gravel and building stone in 1968 was about equal to the value of the combined Canadian production of gold, platinum-group metals, uranium, antimony, bismuth, calcium, cadmium, cobalt, columbium, selenium and magnesium. The main problem of the industrial minerals and structural materials industries is one of marketing, but geological research in these fields is important in locating larger sources of better quality material closer to consuming areas. At the same time, the growing pressures for landscape conservation within or close to Canadian metropolitan centres provide geologists with an important role in finding new sources of industrial minerals sufficiently close to these centres to safeguard the part of their economy based on such products.

The importance of geophysical research and development in our vast country is most evident from the impressive Canadian record of geophysical ore discoveries (see Section IV.3). Certainly Canadians have been ingenious and creative in developing new geophysical methods and equipment. Modern geophysical equipment as employed in Canada incorporates generally the latest in electronic circuitry design. As a result, Canadian geophysical instruments are light, sensitive, reliable and portable, permitting low-cost and dependable surveys to be undertaken year-round.

Canada's geophysical successes are attributable not solely to the ingenuity of Canadian geophysicists but more generally to a combination of favourable factors characteristic of the Canadian scene. These include geological, geophysical, geographic, political and economic factors which combine to stimulate an intense competition in the search for mineral deposits in Canada. This competition has in turn stimulated the growth of mining geophysics in this country. In the post-World War II period, Canadians made important advances in this field, and both new methods and new embodiments of old methods have been achieved. Advantage has been taken of developments in mathematics, physics and, most important, the rapidly changing field of electronics. Access to the wonderful world of U.S. electronics has been

most valuable in Canadian geophysical instrumentation advances. The continuing trend is towards more and more complex functions performed by geophysical instruments in smaller packages and with smaller power requirements.

All airborne geophysical methods are undergoing a major revolution. First, recording methods are being changed from the traditional analog or strip chart methods to computer-oriented digital magnetic tape, and second, the sensors themselves are being improved considerably. The high resolution airborne magnetometer has a sensitivy approximately 50 times better than the conventional fluxgate or proton magnetometer. In addition, several new airborne electromagnetic developments are under way using a much wider range of frequencies than heretofore.

Through these various developments, a highly successful Canadian mining geophysical industry has been achieved, which includes the manufacture of the finest exploration instruments available anywhere in the world and the provision of full services utilizing these instruments and others in the search for mineral deposits. As emphasized in Chapter VIII, these instruments and services are also profitable export commodities.

Activity in exploration geochemistry is now widespread in Canada but still very modest in comparison with geology and geophysics, representing only 5 per cent of all earth science expenditures (exploratory drilling included) of the mining industry in 1968 (Table II.17). Research and development in this field are minimal in Canada at present and limited essentially to work by the Geological Survey of Canada and very few mining companies. Apart from modest efforts in three departments of geological sciences, there is a conspicuous lack of research in geochemical prospecting in Canadian universities, in very strong contrast with the centres of excellence of the Royal School of Mines in England and the Colorado School of Mines in the United States. Yet, as emphasized by Boyle', there are 188

major problems that demand solution in order to find new deposits, as well as lateral and depth extensions of known deposits. These problems include:

1. definition of geochemical provinces and their relations to mineral deposits;

2. development of methods for discovering large low-grade ore deposits;

3. development of methods for discovering deeply buried ore deposits;

4. further development of methods to outline primary haloes;

5. elucidation and formulation of techniques to relate the size and trace element intensity of haloes and dispersion trains to grade of deposits;

6. development and refinement of biogeochemical methods, especially those based on indicator plants, chlorotic or toxic effects, and microbiological techniques;

7. delineation of the nature and extent of geochemical and biogeochemical haloes associated with oil and gas fields.

Since most mineral deposits and their host rocks are largely the result of chemical processes, it is conceivable that developments in modern chemical science and geology will eventually lead to the discovery of any type of deposit in any given geological setting.

In summary, experience shows that earth science research and development is an important factor of economic development. The successful conduct of mineral exploration depends largely on a combination of methods adapted to local conditions. We thus submit:

#### Conclusion IV.1

The mineral industry should support more research on the usefulness of various combinations of geological, geophysical and geochemical methods in a variety of geological conditions and Canadian terrains.

<sup>&#</sup>x27;Boyle, R. W. Geochemical prospecting-retrospect and prospect. Proc. Symposium on Geochemical Prospecting, GSC Paper 66-54, pp. 30-43, Ottawa, 1967.

### Conclusion IV.2

To take full advantage of the wealth of scientific knowledge that could be obtained from operating mines where orebodies are exposed in three dimensions, mining companies should post a research geologist at each of their major mines or mining districts to systematically gather and carefully analyse the geological data that could otherwise be irretrievably lost.

### Conclusion IV.3

The Canadian Government should adopt measures to encourage the mineral industry to carry out or support more earth science research in Canada.

### Conclusion IV.4

Science policy makers and research-funding organizations in Canada should recognize that research and development in mineral exploration must be encouraged as a means of promoting economic development, and accept the fact that this R & D is frequently and necessarily performed in the field.

### Conclusion IV.5

Canadian universities should increase their level of mineral exploration research and, before the year 1975, double their present level of research in economic geology and triple that in exploration geophysics and exploration geochemistry.

One way to encourage "practical" research in the universities is to promote a system of industrial research fellowships and institute sabbatical leaves whereby a number of scientists from industry and government agencies pursue their research in universities for certain lengths of time. The establishment of a system of well-remunerated "research" leaves could be highly beneficial to all parties concerned. It would bring academic researchers into closer contact with people having a wealth of practical experience, allow the latter to become more conversant with the latest developments in science and "refurnish" their minds through research in the academic atmosphere and through intensive study.

It is perhaps with these objectives in mind that the National Research Council established in 1967 a system of industrial research fellowships though its PIER program. In 1968, a total of 18 fellowships of about \$6 000 each were awarded. In 1969, the total was 28, of which 15 were renewals of fellowships granted the year before. Of these 28 fellowships, it is noteworthy that soil mechanics and mining engineering each have only one, while geology, geophysics or other fields of mineral exploration have none. Hence we conclude:

### Conclusion IV.6

Industry and government agencies should institute sabbatical leaves for their scientists to pursue earth science research in universities for certain lengths of time. The mineral industry should avail itself of the PIER program of industrial research fellowships of the National Research Council.

### Scientific Data Collection

The Canadian mineral industry spent \$345 million on data collection in 1968 (Table II.16), of which \$173 million was allocated to exploratory drilling. Significantly, during the period 1964-68 exploratory drilling expenditures rose from \$85 to \$140 million in the petroleum industry, and from \$18 to \$33 million in the mining industry (Table II.17). The other costs of data collection (geological, geophysical, geochemical surveys and related routine laboratory work) similarly increased almost twofold in these five years.

Scientific data collection (exploratory drilling included) represents about 88 per cent of the total costs of all earth science activities in mineral exploration, the remainder being research and development and scientific information in earth sciences. Obviously, it is a major feature of exploration activities. In contrast with the \$172 million spent by industry on earth science surveys and related routine laboratory work, all government agencies combined spent a total of \$27 million (Table II.3) on *all types* of earth science data collection (including soil surveys, groundwater inventories, etc.). In other words, the ratio of industry to government expenditures on this activity is greater than 8 to 1, which is in strong contrast with the situation prevailing in other Canadian primary industries.

The importance of data collection in mineral exploration is brought out by the necessity of knowing *where* and *how* to look for economic concentrations of minerals or fossil fuels. We could have the best theories in the world, but if we do not know the basic *facts* about Canadian rocks, their properties and their distribution in space and time, we may as well resort to the divining rod. Given the 3.8 million square miles of Canada, plus its 1.5 million square miles of continental shelves, there is obviously no end to earth science data collection in this country.

Within the broad framework of basic earth science information provided by federal and provincial government agencies, mineral exploration must be carried out in a necessarily restricted number of areas. It is the major role of Canadian earth scientists to point to areas offering the best possibilities at a given time. For example, it has been recognized that Archean volcanic belts are favourable loci for strata-bound deposits of base metal sulphides and it is important from an exploration standpoint to know the distribution, lithology, stratigraphy, structure and chemical composition of these volcanic rocks.

Industry generates each year a very large amount of new earth science data on Canada. It must be recognized that most of these data are proprietary in nature; however, means must be found to encourage industry to release a larger proportion for regional syntheses and publication (see Sections IV.5 and IV.6).

#### Scientific Information

According to our survey, the Canadian mineral industry spent \$5 million on earth science information in 1968, of which \$4 million was spent by the petroleum industry (Table II.16). In comparison the federal and provincial government agencies spent \$7 million (Table II.4), mainly on publishing geological maps and reports.

The industry's expenditures on earth science information represent 1 per cent of their total expenditures on earth science activities in 1968. Included in these expenditures are the cost of company earth science libraries, the purchase of computer programs for processing earth science data, and attendance at scientific meetings.

Some of the larger Canadian petroleum and mining companies have now developed their own scientific information services departments. Imperial Oil Limited in Calgary spends \$150 000 a year on this activity, with a staff of 12 operating a library of some 38 000 books and reports and 450 subscriptions to periodicals. Such departments have resulted from: a) the increasing awareness of the importance of information, and of systems for handling it; b) the increase in the volume and flow of information within the companies themselves; and c) the new technologies available, including computers and systems, better copying equipment, better communications between libraries, and microfilming.

Our national ability to cope with the ever-expanding knowledge becoming available will in large measure determine our greater efficiency in mineral exploration. Computer storage and retrieval of earth science information provides very powerful means of coping with this increase in knowledge. It is our hope that the Canadian mineral industry will subscribe fully to the national program recently initiated in this field (see Section IV.5).

Many companies have expressed their general satisfaction about the quality of federal and provincial earth science publications (see Appendix 6). However, several requested that government agencies speed up the delivery of their scientific results. These agencies should find new ways of cutting down the delays between manuscript and publication time (see Section II.5).

# IV.4 Prognosis of Future Canadian Mineral Production

Having analysed the importance of earth science activities in Canadian mineral exploration, we now turn in this section to a discussion of what our mineral production may be in the next 10-15 years. After this, we consider what should be the most appropriate rate of mineral development, and we discuss the adequacy of the present mineral discovery rate which, in turn, has a very important bearing on the future level of earth science activities in Canada.

# Production Expectations in Relation to Reserves

While mineral reserves, in the "measured" and "indicated" categories, have noticeably increased in recent years as a result of accelerated exploration activities (Figure IV.1), the growth in reserves for several minerals has not been proportionate to increases in production. Indeed, the relationship of reserves to annual production in 1967 was less for several minerals than it was in the mid-1950s. For example, while the measured and indicated reserves of copper increased by almost 40 per cent from 1956 to 1967, the annual production growth rate was such that the years of supply on hand at the end of 1967 had declined almost 20 per cent compared to 1956. Similar trends, of comparable magnitudes, are apparent for gold, lead, zinc, nickel, and asbestos. Rapid development of some mineral reserves however, such as iron ore, molybdenum and potash, has exceeded market build-up and resulted in a major improvement in these reserves in relation to anticipated production.

The need to pursue active mineral exploration and development programs is well illustrated by Table IV.1, which gives cumulative production for certain minerals for the 18-year period 1950-67 and the estimated cumulative production for the 18-year period 1968-85. Estimates of production expectations for the latter period are based on a forecast of annual

Mineral	Cumulative Production, 1950-1967	Measured and Indicated Reserves, 1967	Estimated Cumulative Production, 1968-1985
Copper (million tons)	7.0	19.5	13.9
Lead (million tons)	3.8	12.1	6.0
Nickel (million tons)	3.5	7.1	6.0
Zinc (million tons)	9.2	31.1	30.0
Platinum (million ozs.)	6.6	13.3ª	9.3
Iron Ore (million tons)	389	33 106	1 151
Molybdenum (thousand tons)	40	614	425
Asbestos (million tons)	20.2	1 192	31.4
Gypsum (million tons)	87.2	?	137.2
Potash (million tons K <sub>2</sub> O)	7.5	6 400	90.0
Sulphur (million tons)	11.3	134.8	63.1
Crude Oil (billion barrels)	3.3	8.2 <sup>b</sup>	11.5
Natural Gas (trillion cu. ft.)	10.6	45.7	51.0
Sand & Gravel (billion tons)	2.8	very large	5.5
Stone (million tons)	818	very large	2 131

Source: Mineral Resources Branch, Department of Energy, Mines and Resources, Ottawa.

• Based on 1967 reserves of nickel, which have been prorated according to the 1950-67 ratios of nickel and platinum production (platinum being a by-product of nickel ores in Canada).

<sup>b</sup> Does not include the very large potential crude oil reserves of Canadian tar sands.

production growth similar to that experienced in the earlier period. The 1967 reserve estimates which are provided as a basis for comparison do not include the "inferred" nor the "potential" reserves and are therefore not a measure of Canada's ultimate mineral reserves. They clearly indicate, however, the need to continue to apply the best available earth science technology to find new reserves and to meet anticipated mineral requirements.

For several mineral commodities measured and indicated reserves of 1967 are rather small in relation to the production expectations for the next 18 years. In the case of copper, cumulative requirements to 1985 are 14 million tons as against available reserves in 1967 of 19 millions tons; it should be noted however that the (1967) copper reserves have increased substantially during the past two years as a result of large discoveries in British Columbia, Ontario, Manitoba and the Yukon. Comparable figures for lead are 6 and 12 million tons, for nickel 6 and 7 million tons, for zinc 30 and 31 million tons, for crude oil 11 and 8 billion barrels, and for natural gas 51 and 46 trillion cubic feet. None of these reserves are very large in relation to expected requirements through to 1985. Should the rate of mineral demand through to 1985 exceed the growth rate experienced in 1950-67, the present (1967) reserves would be inadequate, especially in the face of any appreciable decline in discovery rate or Canadian exploration activity or both.

Uranium has not been included in the above table since it is only in recent years that this metal has begun to play a significant role as an industrial fuel. Production grew from less than 1 000 tons of uranium oxide concentrate (U<sub>3</sub>O<sub>8</sub>) a year in 1952 to 15 900 tons in 1959. Thereafter, because of the decline in requirements of uranium for defence purposes, production decreased to about 4 000 tons of U<sub>3</sub>O<sub>8</sub> a year in 1968. It is presently estimated that Canada's "reasonably assured reserves", recoverable at \$10 a pound U<sub>3</sub>O<sub>8</sub> or less, are about 200 000

tons of U<sub>3</sub>O<sub>8</sub>, or some 29 per cent of the free world total. Further, it has been estimated' that based on these reserves, *Canada's total production capability is only* 11 000 tons of U<sub>3</sub>O<sub>8</sub> a year, and that productive capacity beyond this level must be supported by newly developed reserves.

The European Nuclear Energy Agency (ENEA) has estimated that installed nuclear power capacity in the non-communist world will climb from 26 000 MWe in 1970 to between 233 000 and 328 000 MWe in 1980, requiring a cumulative total between 492 000 and 668 000 tons of U<sub>3</sub>O<sub>8</sub> over the 10-year period. To supply this quantity of uranium the non-communist world will need to produce between 73 000 and 106 000 tons of U<sub>3</sub>O<sub>8</sub> a year by 1980. Based on ENEA's median forecast of annual uranium requirements to 1980, and allowing for an 8- to 10-year forward reserve, it is apparent that new low-cost world reserves of at least 1 000 -000 tons of U<sub>3</sub>O<sub>8</sub> must be outlined before 1980 if production levels expected by that time are to be adequately supported. Although Canadian requirements for uranium as a nuclear fuel will be small compared with the world total, they will be appreciable. Clearly, if these requirements are to be supplied from domestic sources and if, at the same time, Canada is to maintain its position as a major world-supplier of uranium, it is essential that exploration programs for uranium be encouraged.

### Production Expectations in Relation to Past Trends

A general indication of the magnitude of Canadian mineral production by 1985 can be obtained by comparing the mineral industry's growth with that of our Gross National Product (GNP). In 1950-67, the average growth rate of the GNP was 4.5 per cent in real terms, that is without including the inflationary content of the increase. This growth rate provided for a doubling of our GNP. During the

<sup>'</sup>ENEA. Uranium production and short term demand. Paris, January 1969. same years the average growth rate of mineral production value, in constant dollars, was 6 per cent per annum. If the mineral output grows at the same rate during the next 18 years, the 1968 value of \$4.7 billion will increase to \$12.7 billion in 1985. On the other hand, if the mineral output value should grow at a rate comparable with that of the economy as a whole since 1950, that is at 4.5 per cent-an annual rate considered by economists as an acceptable objective for the future'-then the 1985 mineral output value in terms of 1968 dollars would be almost \$10 billion. These criteria would indicate good expectations for a mineral production value in the range of \$10-\$12 billion in 1985 (in terms of 1968 dollars), or as much as 2<sup>1</sup>/<sub>2</sub> times the 1968 output of \$4.7 billion. It is of interest to note that the extrapolation of the "production value" curve in Figure IV.1 leads also to \$10 billion for 1985. In view of the fairly good correlation between production output value and mineral exploration expenditures (Figure IV.1), we can estimate that at the present rate of growth of exploration expenditures, and in view of the anticipated difficulties of finding new sources of minerals in Canada to sustain the increase in production, exploration expenditures may reach \$1 billion a year by 1985 (in terms of 1968 dollars). This is assuming, of course, no radical change in taxation policies that would hamper the normal progress of our mineral industry.

### Production Expectations in Relation to Anticipated World Requirements

Inasmuch as Canada is the world's third largest diversified source of minerals, we can expect that demands on Canadian mineral production will grow at a rate similar to world demand. *It has been esti*- mated by several world authorities that in the year 1985 the world will require at least twice the quantity of minerals that was consumed in 1967, and by the year 2000-when the world's population will likely be double the 1967 level-mineral requirements will be increased almost four times.

The urgency for a greater and more effective national mineral exploration program is strikingly illustrated by examining the supply-demand situation of specific minerals in a world context. In copper, Canada has been accounting for almost 10 per cent of world output. Assuming a similar relationship to the year 2 000, as well as an average annual increase in world demand comparable with that of the past 20 years, the demand placed on the Canadian copper mining industry in the next 30 years would approach 35 million tons. Even making allowance for the considerable increase in our copper reserves during the latter part of the 1960s, the average discovery rate of the past 20 years would fall far short of meeting the requirements for new reserves to the end of the century. There is therefore a need for increased exploration activity for copper as well as for a number of other Canadian mineral commodities, particularly the base metals and uranium.

Mineral production expectations in Canada can be visualized in terms of the gargantuan American appetite for materials, which seems insatiable. According to a recent study' by the National Academy of Sciences, the consumption of minerals in the United States is expected to reach \$45 billion (constant 1966 dollars) in 1985, compared to about \$27 billion in 1968. A substantial part of the U.S. mineral supply may be expected to come from Canada. Thus, to take full advantage of market opportunities, we must continue to discover mineral resources in increasing amounts.

Consequently, and in view of the estimates made in Section IV.2, we submit:

<sup>&</sup>lt;sup>1</sup>In its *Sixth Annual Review* of September 1969, the Economic Council of Canada has estimated for the year 1975 a GNP at potential of \$100.7 billion (in constant 1967 dollars), which would, if achieved, represent an average annual increase of 5.5 per cent over the 1967 GNP of \$65.6 billion compared to an anticipated rate of growth of 4.5 per cent per annum for the real output of the 21 OECD countries as a group.

<sup>&#</sup>x27;National Academy of Sciences. Mineral science and technology. Washington, D.C., 1969. 129 p.

### Conclusion IV.7

Assuming that new fiscal regimes will not hamper the normal progress of the mineral industry and the tempo of mineral exploration, it is estimated that in 1985:

a) the gross value of Canadian mineral production will reach \$10-12 billion a year compared to \$4.7 billion in 1968;

b) exploration expenditures may attain \$1 billion a year compared to about \$400 million in 1968; and

c) the number of geoscientists in mineral exploration may exceed 8 000, compared to 4 000 in 1968.

Conclusion IV.8

For several of our major mineral commodities, including uranium, the "life index" of the 1967 "measured" and "indicated" reserves is too low in relation to anticipated market demand and Canadian production expectations to 1985; thus, mineral exploration must continue to be vigorously pursued in Canada.

# The Most Appropriate Rate of Mineral Resource Development

While the relationship of existing mineral reserves to projected requirements to 1985 (based on past trends) points to a condition of deficiency in several minerals unless exploration programs are increasingly successful, two very basic questions remain to be considered. First, what is the most appropriate rate of exploitation of our mineral resources? Second, does the discovery record of the past, say, 18 years give confidence that a discovery rate sufficient to sustain this optimum exploitation rate could be achieved? The second question can, of course, only be answered in terms of the first; in turn, its answer must depend on a judgment of the optimum contribution of the mineral industry's growth to the attainment of broad national goals. How can the mineral industry contribute best to national goals such as regional development, full employment, high and sus-194

tained economic growth, reasonable price stability, a favourable balance of payments, and an equitable distribution of rising incomes?

We believe that the mineral industry will make its best contribution to these goals if it grows at the fastest possible rate commensurate with the greatest economic return and maximum social benefits. The objective entails maximum mineral development as well as maximum productivity of capital and labour. Because minerals are worthless unless they are exploited, the objective also includes the production of new wealth through the sale of mineral commodities abroad and their use to satisfy national needs. Naturally, this concept is somewhat elusive in the sense that it can hardly be defined in quantitative terms; however, the following guidelines provide some clues as to the optinum role of mineral exploitation in Canada.

Our mineral resources do not form a neatly limited package but rather an inventory in which the size of the resource depends ultimately on costs and prices. The more one can afford to pay to recover valuable minerals from a block of rock the larger the reserves become. However, if Canadian mineral development costs become too high we could find ourselves priced out of world markets. The main force that serves to prevent this and to retard the depletion of our economic mineral deposits is technology. It is a well-known fact that mineral technology can alter supply relationships and make what were once inferior resources equal to those of higher quality in terms of this essential criterion: the unit cost of producing a given mineral commodity.

The old concept of "running out of resources" must be replaced by the concept of "resource availability at a cost". Mineral deposits have always been considered as non-renewable resources with ghost towns being the ultimate fate of most mining towns. This social catastrophe and economic loss is not necessarily inevitable; many mineral producing districts are capable of producing for generations

as long as they are recognized and receive the proper treatment from industry and government. These long-lasting resource areas (such as Sudbury) must have large mineral potential, preferably with a large initial tonnage of high-grade ore. As development proceeds, the tonnage of ore in these areas generally increases almost exponentially as grade decreases. Further requirements include economies realized through large-scale production and related major fixed capital investments, continually improving technology, availability of well-trained labour, and a government which understands the peculiarities of the mineral industry and the nature of economic mineral deposits. A mineral district of this kind can remain competitive with foreign producers of higher grade ore because advanced technology and large, fixed, paid-up capital investments lead to economies of a scale that can create large tonnages of ore from "mineralized waste" simply by a relative lowering of production costs.

The copper deposits of Arizona and the iron deposits of Minnesota are examples where this concept has operated successfully. The taconite reserves of Minnesota appear almost unlimited; technology and progressive taxation policies combined with a large resource base have made its ores of 30 per cent iron competitive with foreign ores containing 60 per cent iron. Arizona has continually increased copper production over several decades because its low-grade copper resources have been made competitive with high-grade foreign ores through advanced technology in mining and treatment methods, and by large fixed capital investment in mining, smelting and refining, which permit economies of scale.

Partly comparable situations exist in Canada. The iron of the Labrador Trough and the nickel of the Thompson belt in Manitoba are examples. Labrador Trough iron can compete with higher grade foreign ores because of the timely development of this iron district and the huge capital investment in plants and transportation made in the past 20 years. It is most doubtful that the Knob Lake iron district could be developed today in competition with foreign direct-shipping ores, and there may be some doubt as to whether the other iron ores of the Labrador Trough could likewise be developed today in competition with beneficiating or direct-shipping foreign ores. The Thompson nickel belt has the geological requirements for long-term production of nickel. Large plants can be paid off with its high-grade ore, and production can be supplemented by large tonnages of low-grade mineralization. By enlightened government policies and sustained mineral exploration, as well as research, this district can realize its full potential and remain competitive with foreign ores, even if they are of higher grade. The huge low-grade copper and copper-molybdenum ores in British Columbia may constitute another district where development is made possible through economies of scale.

The optimum rate of production therefore calls for immediate large-scale production consistent with maximum net profits and maximum benefit to the nation. Our unmined reserves may become useless if other products take their place, or if major industrial countries develop an iron-aluminum economy based essentially on these metals which are most abundant in the earth's crust. Valuable minerals can and must be located by exploration, but earth scientists must also recognize areas where ore reserves can be increased by advances in technology and enlightened government measures.

In relation to net profits mentioned above it must be remembered that the money for mineral resource development is available only if the investor, whether a large international company or an individual, is convinced that there are no significantly better investment opportunities elsewhere. The fact that some Canadian mining companies have diversified into other industries at various times reflects the need for spreading the financial risks and the decision to take advantage of better investment opportunities in other fields. Similarly, within the mineral industry there has been a flow of investment funds back and forth among the various sectors, particularly between the metal and oil-gas sectors. If the profit to the producer is not maximized, there is little point in setting maximum production as a goal because with a low rate of return, benefits to the country through income tax and foreign exchange earnings, as well as benefits to the company and its shareholders, would be lessened.

In the case of crude oil, Canada could produce at a higher rate but has been restricted by lack of markets due to international competition and U.S. government restraints on oil imports. Our uranium production growth has been hampered by international factors such as the delayed realization of nuclear reactors and the U.S. embargo on Canadian uranium. Canada could also have produced iron ore and potash at much greater rates had world markets been available. World market competitive factors and international producing-marketing arrangements or contracts between companies have thus somewhat restricted our mineral production growth.

In the case of nickel, however, our resource development has not kept pace with market opportunities. The Canadian nickel production curve of the past several years has been one of maximum growth in terms of production capacity. Lead and zinc developments on the other hand have proceeded at a pace closer to world market demand growth.

The planning of any major mineral development is determined in the first instance by the medium- to long-term prospects for marketing the mineral concerned. However, if a decision is made to open up a large deposit, and similar decisions are taken elsewhere in Canada or in other countries, there can be a surplus capacity by the time these deposits start production. This surplus situation can be compounded if, in the meantime, a downturn in economic activity should occur in the major consuming countries. 196 On the other hand, an unexpected economic upturn can cause the same situation to be maintained despite new sources of production, such as is predicted for uranium in the mid- or late 1970s.

Canada is in competition with worldwide mineral resources under a variety of economic, technological and political factors. Industry and governments by their policies and actions can change the cost of production and create or eliminate vast tonnages of mineral reserves. The effect on low-grade ores, which are the great metal resource of the future, is an excellent example. Equally serious is the competition of foreign ores on a normal commercial basis. For example, lateritic nickel deposits ore in tropical countries are in direct competition with our nickel sulphide ores, from which all our nickel is derived. Higher costs in Canada could accelerate an already apparent trend to greater utilization of the vast reserves of lateritic nickel ores, which we do not possess in Canada, and bring a decline in our important nickel industry.

It follows that we must have as good a knowledge as possible of the location, magnitude and physical characteristics of our mineral resources, to avoid wasteful underdevelopment or overdevelopment. It is in the national interest that the mineral industry continues to expand at a rate similar to that of the past two decades. New mineral discoveries being essential to this growth, we must raise the question of whether or not the past mineral discovery rate, if maintained, will be adequate to sustain this growth.

# The Adequacy of the Canadian Mineral Discovery Rate

The following analyses were undertaken to measure the adequacy of the past discovery rate.

### Analysis A

Study' of the histories of the 81 mines (precious metals, base metals, asbestos, and gypsum only) brought to production

'Source: Mineral Resources Branch, Department of Energy, Mines and Resources.

in 1958-67 indicates that 53 per cent of these mines were old deposits and 47 per cent were new discoveries. Of the total production from these mines during the 1958-67 period, 66 per cent of the value of mineral output was obtained from the new deposits, due in considerable part to recent increases in large-scale open-pit production.

In this analysis, the discovery of an orebody was considered as having been confirmed only after sufficient work had been done to justify the decision to exploit it. Furthermore, a mineral deposit was considered to be a new discovery if exploratory assessment leading to a decision to produce had proceeded without major interruption. An "old deposit", on the other hand, was one in which there had been a period of suspended activity of 10 years or more between the time of discovery and the time of actual decision to go into production.

On the basis of this analysis we can only conclude that while industry has not placed undue reliance on old mineral discoveries, exploration activity at the level of recent years is the absolute minimum necessary to maintain a rate of discovery commensurate with the existing and projected consumption of mineral products. This conclusion is supported in terms of the following observations:

1. Even if the inventory of potential mineral targets is being replenished to a considerable degree by new discoveries, the fact remains that 53 per cent of mines started in the last 10 years were based on old discoveries;

2. Current rates of production of minerals in Canada are the highest in the history of the industry and production is expected to at least double in 10-15 years; even at the current rate of production it can be noted, for example, that a discovery of a copper orebody of the size of Granduc in British Columbia (32 million tons averaging 1.93% Cu) is required every 18 months to balance the rate of copper production in Canada; a rising rate of production will naturally require an increase in the frequency of discovery.

### Analysis B

This analysis was based on a study of discoveries dating from the 1920s, with particular emphasis on the discovery rate and record of production since 1955. For the purposes of the analysis, the following discoveries were excluded:

1. Iron ore mines, because with a few exceptions most of these resulted from long-known iron-bearing formations, with mines being brought into production as a result of changing demand relating to iron and steel technology;

2. Bedded non-metallic mineral deposits, such as potash, because such mines were brought into production due mainly to new economic factors;

3. Deposits belonging to small marginal operations.

In all, a total of 160 mines that started or re-started or were planned for early production in 1955-68 were analysed. From this analysis it was concluded that 47 per cent of these were first discovered before 1950 and nearly 20 per cent before 1920. For the deposits that were viable for early production after 1950, the average discovery rate was about five non-ferrous metallic deposits per annum as compared with an average of nine production commencements or recommencements per annum. This means that an average of four out of nine new mines per annum have depended on old showings, in spite of the fact that the analysis has included new production starts in New Brunswick in 1952, the nine uranium mines discovered at Elliot Lake in 1953-55, three major nickel discoveries made by INCO in Manitoba in 1956, and three major discoveries of base metals at Matagami in 1957.

Thus, the results of these two analyses provide additional support to our previous conclusion that in parallel with the ever-increasing demand for mineral commodities and the need to locate sufficient new reserves for the future, the onus is on Canadian earth scientists and engineers to continually improve mineral exploration technology and establish new concepts or principles for guiding mineral exploration. The application of new science and technology is the greatest hope for the future.

# Exploration Costs as a Function of Value of Mineral Production

It is apparent from Figure IV.1 that Canadian mineral exploration expenditures during the period 1950-68 have amounted to about 10 per cent of the gross value of Canadian mineral production. The growth curve of exploration costs shows an almost exact 10 per cent relationship during 1950-57, a constant level of exploration expenditures during 1957-64, and a relatively high level of exploration activity in 1964-68. In other words, the 1957-64 plateau is now being compensated by the increased activity since 1964 and, once again, the curve of exploration costs for the last five years is converging towards the curve of mineral output value, that is towards the 10 per cent relationship.

Since the exploration growth curve shown in Figure IV.1 includes the earth science expenditures of non-producers (representing 5.5% of the industry's total in 1968) and combines the expenditures of both petroleum and mining companies, we show in Figure IV.4 the relationship between individual company exploration costs and value of mineral output in 1968. The compilation includes the 88 mining and oil-gas producers who participated in our survey, whose value of mineral production in 1968 amounted to \$3.2 billion. The log-log statistical correlation supports the following conclusions:

1. Petroleum producers spent about 22 per cent of the gross value of their oil and gas output on exploration, whereas mining producers spent 3 per cent (in both cases, the proportion of exploration expenditures to net profits is considerably higher than the percentages given); in other words, in relation to gross value of individual annual mineral output, oil and gas producers spent about 8 times more on exploration than mining producers;

2. There are 6 mining companies, with an individual mineral production value of \$1-7 million a year, which spent about 198 21 per cent of their production value on exploration, compared to the average of 3 per cent for the whole mining industry;

3. In contrast, there are 11 mining companies, with an individual mineral production value of \$1-55 million a year, which spent only an average of \$25 000 a year on mineral exploration; in the petroleum sector only 3 companies spent such negligible amounts (their output value was \$1-5 million a year); these "poor corporate citizens" represent 16 per cent of the producers surveyed in this study.

It is quite evident, therefore, that there is a direct relationship between the amount of mineral production and the level of mineral exploration necessary to replenish mineral reserves. The conclusion is inescapable that a continually increasing exploration effort is needed to sustain further growth of the mineral industry.

## Statistical Distribution of Mineral Exploration Expenditures of Petroleum and Mining Companies

Figure IV.5 is a log probability plot of the exploration expenditures of 123 mining and petroleum companies (including 31 non-producers) included in our survey. In this graph, the cumulative percentage frequency of companies is plotted on the probability scale in relation to the individual mineral exploration expenditures incurred in 1968. The graph reads as follows. To find the percentage of companies spending more than a certain amount in exploration, select this point on the frequency distribution line, read the corresponding percentage on the ordinate, and subtract the latter from 100 per cent. This graph supports the following conclusions:

1. the 1968 mineral exploration expenditures of these 123 companies follow an excellent lognormal law of distribution;

2. the probabilistic average of exploration expenditures of these companies in 1968 was \$600 000 per company;

3. of these companies, 5 per cent spent more than \$10 million, 39 per cent more

Figure IV.4-Log-Log Scattergram of the Annual Exploration Expenditures of 88 Canadian Mining and Petroleum Producers, as a Function of the Value of their Mineral Production in 1968 (Aggregate Total of \$3.2 Billion) (The oblique dashed lines in the diagram represent proportions of exploration expenditures to mineral production value)





than \$1 million and 25 per cent less than \$200 000 on mineral exploration in 1968.

# IV.5 Means of Increasing the Effectiveness of Canadian Mineral Exploration

In this section we discuss a series of measures which, in our opinion, could improve substantially the effectiveness of earth science activities in mineral exploration. The emphasis is on present shortcomings and areas for improvement. Our main concern is that the best use is made of existing research facilities and scientific capabilities, which in large part can be accomplished through better research co-ordination and more generous financial and manpower support to mineral exploration research in existing laboratories.

#### Tax Incentives for the Mineral Industry

Canada's progressive taxation policies have attracted more exploration money than any other country in the world and have, in turn, spurred the spectacular growth of our mineral industry. Because this industry is vital to our economic, social and regional development (see Section IV.2), and so much of our national earth science activities are related to mineral exploration (see Table II.1), we are concerned about the government's recent proposal<sup>1</sup> for tax reform and its possible effect on the tempo of mineral exploration in Canada.

In our brief<sup>2</sup> to the government, we have advocated that:

1. Pre-production exploration and development expenditures are a normal business expense to earn a profit, and we agree with the government's proposal of not changing this fiscal measure;

2. If the three-year tax exemption for new mines is to be eliminated, government should provide a major incentive (much more substantial than the interest factor of tax deferal through fast writeoffs) to encourage risk capital into mining exploration, such as allowing repayment of 1<sup>1</sup>/<sub>2</sub> times the capital expenditure before the imposition of taxes;

3. The government's proposal of relating the depletion allowance directly to exploration and development expenditures is logical and in the nation's interest; however, the government's proposal of a depletion allowance of \$1 for every \$3 spent on exploration and development is insufficient incentive for replenishing mineral reserves, and we recommend instead a depletion allowance of \$1 for every \$2 spent on exploration and development.

# Incentives for Mining Exploration Research

The need for increased research in mineral exploration is well illustrated by our data in Tables II.13 and II.17, wherein it is indicated that in the 1964-68 period exploration expenditures increased by 82 per cent compared to a rise of 40 per cent in the annual gross value of mineral production. As noted in Section IV.4, the mineral discovery rate for several important metals is generally inadequate in view of the projected market demand, notwithstanding the major increase in exploration activities of recent years (Figure IV.1).

Furthermore, the element of scientific uncertainty in mineral exploration warrants special consideration from the point of view of research incentives. As emphasized in Section IV.3, even with the best "brains" and the most advanced technology, there can be no assurance that an economic deposit will be found at a particular place in the earth's crust. The problem is compounded by the great complexity of geological phenomena, the presence of an ubiquitous cover of glacial drift over the bedrock surface, the insufficiency of data in many areas, the

<sup>&</sup>lt;sup>1</sup>Proposals for tax reform, by Hon. E. J. Benson, Minister of Finance. Ottawa, 1969.

<sup>&</sup>lt;sup>2</sup>The possible effect of proposed tax reforms on mineral exploration in Canada. Brief to the House of Common's Standing Committee on Finance, Trade and Economic Affairs, by the Solid-Earth Science Study Group of the Science Council of Canada. February 26, 1970. 39 p. mimeo.

size of Canada, and the remoteness of several areas of interest.

The element of risk should not be underestimated. Canadian experience shows that out of thousands of mineral showings only a few become profitable ventures. Thus, the risks must be spread over a large number of ventures and research is very much needed to diminish the risks. The following simple calculation illustrates the nature of this problem. Suppose that out of 1 000 targets examined, 10 prospects warrant a detailed surface investigation and each has a 1 in 100 chance of being an economic deposit. The probability of success is then:

Table IV.2-Probability Success	y of	Mineral	Exploration	
Result	_	Ch	ances	
0 deposit		9 ii	n 10	
1 deposit		9 ii	n 100	
2 deposits		4 ii	n 1 000	
3 deposits		1 in 10 000		
4 deposits	2 in 1 000 000			
	_			

Research in mineral exploration is thus a practical necessity. The question is how much and what kind of research must be done. The answer to the second part of this question may be found in Section 5 of this chapter, whereas the answer to the first part lies in part with the industry. We may surmise that industry knows best what research should be done, and that the present level of industrial research in this field (\$5 million in the petroleum industry and \$2 million in the mining industry in 1968) is the effort that industry considers to be appropriate at present. However, several mining and petroleum companies have indicated in our questionnaires that industry was not doing enough research in mineral exploration and that not enough research in this subject was being done in Canada. In universities and government agencies, there is general agreement that industry is not doing enough research, except for the "major" companies (but most of the research done for the "major" petroleum companies is done outside Canada-about \$18 million a year being spent on Canadian problems, compared to \$5 million spent in Canada). The problem is then to find ways and means of encouraging industry to do more research on mineral exploration. One partial solution lies in the industrial research incentive programs of the government.

The principal programs of interest in this connection are the Industrial Research and Development Incentives Act (IRDIA) and the Program for the Advancement of Industrial Technology (PAIT) of the Department of Industry, Trade and Commerce, and the Industrial Research Assistance Program (IRAP) of the National Research Council. The first two are essentially designed to promote research and development in the manufacturing industries and are not adapted to the primary resource industries such as mineral exploration, except for the development of exploration hardware such as geophysical instruments. IRAP, on the other hand, does not include assistance for hardware, and applies exclusively to support for additional R & D personnel required to carry out research projects that have received the approval of the National Research Council.

The PAIT program is specifically designed for productivity improvement in the manufacturing industries and applies to specific projects for a specific purpose. About \$7-8 million are spent annually on this type of incentive. Apart from relatively minor and occasional assistance to a very few geophysical instrument companies, the PAIT program has not been applied to the mineral exploration industry.

The IRDIA program is somewhat more useful than PAIT for encouraging research in mineral exploration, but its application is very restricted because-as said in the Act-it "does not include activities with respect to ... (vii) prospecting, exploring or drilling for or producing minerals, petroleum or natural gas". IRDIA assistance allows a 25 per cent tax-free grant only to research expenditures (research as defined in this Act and not according to

our definition - see Chapter I of this report) which exceed the average of the preceding five years. Even for eligible projects, the effect of this Act is such that it encourages the petroleum and mining companies to continually expand their research centres or, alternatively, to maintain research laboratories outside the country where conditions may be more advantageous. The present Act, while serving the expansion of research in the manufacturing industries (about \$35 million being spent annually on this program), provides no incentive to mineral exploration research. Consequently, we suggest that:

#### Conclusion IV.9

To encourage the mineral industry to develop research centres in Canada and increase their level of mineral exploration research, consideration should be given to tax abatements calculated on the total yearly research budget spent in Canada.

On the same subject, note should be taken of our conclusion in Chapter I, where we recommended revision of definitions of earth science research and development to make these definitions more applicable to mineral exploration.

We recognize that a fundamental problem exists in the matter of secrecy codes and proprietary rights of mining and petroleum companies. This problem is almost insurmountable in our free-enterprise system, but we must face the fact that a tremendous amount of earth science data collected in Canada never reaches the Canadian public. This situation leads to duplication in research and expensive exploration activities, thereby increasing the unit cost of mineral discovery. Government and industry must seek a practical solution to this important problem. One partial solution is to encourage industry to undertake research in fields in which it has particular interests and special capabilities and publish the results.

### **Mining Exploration Research Institutes**

In keeping with the "centres of excellence" concept outlined and discussed in Section III.12, we recommend the establishment of two centres of excellence in mining exploration research in Canada, one in the east and one in the west. The reasons for this recommendation are as follows:

1. Mining exploration is typically a Canadian endeavour (highest level of activity in the free world), a field in which our country has many natural advantages (see Section III.3), a major factor of regional development (through the finding of new mines in "depressed" or remote areas), and an essential element of northern development (in conjunction with petroleum exploration).

2. Multidisciplinary research in mining exploration has a high potential yield, both in terms of innovation (e.g. better instruments for mineral exploration) and a higher rate of discovery of new mineral deposits (see Section IV.3).

3. The level of research in this field is relatively low (see Section IV.3) in industry (Table II.2), in universities (see Section IV.6), and government agencies (see Table II.2 for all earth science R & D of these agencies).

4. There is at present no top-ranking Canadian university department covering the major aspects of mineral exploration (economic geology, mining geophysics, exploration geochemistry, statistics, computer technology and operations research). The present university capabilities in this field are limited and widely scattered. No Canadian university approaches the mining exploration excellence of some American or British schools of applied geology.

5. As stated by one director of the Prospectors and Developers Association of Canada, "It seems strange that in a country like England particularly devoid of metallic mines, it is possible for a mining company to engage in conjunction with academic interests in a research project specifically tuned to the company's problems...Regretfully our Canadian universities appear to be dropping mining courses, geological and geophysical courses and holding only to the pure science aspect". Even if this statement from a well-known Canadian economic geologist is somewhat overstated, the fact remains that the mining exploration industry has no particular university to go to for getting mining exploration research done and getting problems solved. It is thus not too surprising to hear industry deplore the excessive emphasis on pure earth science research in Canadian universities, when in fact industry does not dispute the desirability of having much fundamental research in earth sciences done in the universities. What industry deplores is the insufficiency of research activity in fields directly related to mineral exploration.

6. This Study Group has received no less than eight briefs recommending increased research in mineral exploration, including the creation of mineral exploration research institutes (see Appendix 3).

7. We estimate that mineral exploration research will require increasingly large expenditures and manpower, and it is unlikely that individual companies or consulting firms will come forth with major new developments on their own initiative and with their own funds, except for a very few large mining companies.

8. Most of the industrial research in new exploration methods is conducted in secrecy, and this leads to some duplication of efforts.

9. Any new technique of mine finding will benefit all companies equally and enhance their worldwide position in discovery and production.

10. The need definitely exists for centres of excellence which could answer to the various requests for expertise in mineral exploration. If these centres are not established, there will be a rising flow of research money leaving the country and less Canadian capabilities for solving exploration problems.

Although the following list of objectives is not exhaustive, we recommend 204 that centres of excellence in mining exploration research be established according to the following principles:

1. The centre(s) of excellence should be established on a university campus, or close by, to take full advantage of the training component that the centre should have and to make full use of the existing research facilities at the university(ies), including earth science libraries and large computer facilities.

2. In the first few years of operation, the centre should operate essentially with the existing facilities. In other words, the centre should be built with scientists rather than bricks. As the centre demonstrates its usefulness, and its scientists prove their ability to solve practical problems, then a physical plant should be built to accommodate personnel and equipment, and radiate additional prestige. If the centre fails to accomplish what it is supposed to do, the original arrangements should be terminated after a trial period of five years (but no less than five years).

3. The centre must operate on a cooperative basis with a firm commitment from the local university(ies), the local provincial government, the federal government, and the mining industry. The commitment should imply both manpower and financial resources. For example, the co-operating university should provide computer facilities at nominal cost.

4. The original request for a centre should originate from the university group(s) interested and be supported by the necessary documents, including clear evidence of support by mining companies and the local provincial department of mines.

5. There could be two such centres of excellence, one in the east and one in the west.

6. It is suggested that each institute be a privately incorporated, non-profit organization financed jointly by government and industry.

7. In addition to carrying out research projects sponsored by the Mineral Resources Research Committee (see Section II.5), each institute would carry out contract research for individual government agencies, mining and petroleum companies, and consulting firms.

8. The personnel of each institute would consist of fellows (appointed by the board of directors), associates (appointed by the director of the institute), technical and clerical staff. The fellows would be appointed for a period of one to five years, whereas associates could be appointed for a period of six months to one year (with the possibility of consecutive re-appointment). The associates would normally be researchers who would stay at the institute for relatively short periods to pursue mineral exploration research projects of their own choice, and whose salary would be paid in part or in total by their respective regular employers or by government research fellowships.

9. It is visualized that an institute of this sort would have a professional staff of 15 (including 6 faculty members half-time); and about 19 support personnel.

10. The annual budget for the institute might be in the order of \$600 000 a year (including rental of office space).

11. For the first three years of operation, the institute could be funded as follows: \$250 000 by the federal government, \$50 000 by the local provincial department of mines, and \$300 000 by the mining industry.

12. Funding in later years could be established mainly on the basis of anticipated revenues from contract research, using as a reserve the contract revenues obtained during the first three years of operations.

13. The major functions of the institute should be to:

a) execute research projects aimed at improving mining exploration methods;

b) test new instruments and new techniques of mining exploration;

c) devise improved methods of ore reserve estimation;

d) compile case histories of Canadian mineral deposit discoveries;

e) disseminate information of metallo-

genic and mining exploration interest;

f) organize from time to time mining exploration symposia and workshops;

g) co-operate with the Canadian International Development Agency in programs of external technical assistance to developing countries.

In the light of the aforegoing, we recommend:

#### Conclusion IV.10

An eastern and a western centre of excellence in mining exploration research should be established with the close cooperation and support of industry, government and some universities.

## Mineral Exploration Research Orientation and Co-ordination

As emphasized in Section II.5 of this report, there is a need to establish a committee to provide the necessary orientation and co-ordination of major aspects of mineral resources research in Canada. One of the major missions of this committee should be to foster research in mining and petroleum exploration as a means of promoting Canada's economic development. It is visualized that this national forum could do much to restore the balance between basic and applied research in universities by making available substantial grants for earth science research relating to mineral exploration. Grants could also be made available to researchers in industry to take full advantage of their special capabilities and research facilities in finding solutions to important practical problems, and to encourage the publication of earth science data in company files.

The proposed National Advisory Committee for Mineral Resources Research could also provide the necessary degree of co-ordination of earth science research in the academic, governmental and industrial sectors. Another important function of this committee should be to indicate major areas for future research, such as those indicated below in the field of mineral exploration.

# Major Earth Science Research Objectives in Mineral Exploration

The following research objectives are based on our judgment and the opinions of authors of background papers and briefs submitted to us. For simplicity, the objectives are categorized according to geology, geophysics, geochemistry, and other disciplines. It should be stressed that the topics are *not* listed in order of importance.

The effectiveness of mineral exploration is a function of strategy, money, personnel, tactics, and good evaluation. The research objectives listed below are primarily aimed at improving the strategy element of exploration.

## Geology

In the exploration for mineral deposits (excluding mineral fuels) in Canada, the following research objectives appear most relevant:

1. Perhaps the most important objective is to obtain a better understanding of the distribution patterns of mineral deposits in time and space, particularly in relation to the total geological environment of these deposits. For example, the massive sulphide deposits found in volcanic rocks must be studied in relation to the geochronology, stratigraphy, structure, lithology, petrology and geochemistry of the lavas in which they occur. It follows that the relations observed in the field constitute an essential element of this research.

2. Of subordinate national importance is the objective of seeking fundamental *physico-chemical knowledge of the constituents of mineral deposits* to interpret field relationships better and shed more light on their genesis. With the large amount of this type of research being done in the United States, which is freely available to Canadians, and in view of the relatively high costs and degree of sophistication of this work, it would be wise to encourage this type of research in only a few Canadian academic institutions.

3. There should be an *accelerated program of age dating of mineralization* 206

and associated rocks to refine metallogenic interpretation and improve exploration strategy.

4. A comprehensive research program should be initiated to *determine the physi*cal and chemical characteristics of a great number of Canadian rocks and minerals to guide geophysical and geochemical interpretation.

5. Structural studies of mineral deposits and their host rocks should be continued, with special reference to those which experienced more than one period of folding, and with the view of finding orebodies at greater depths than can be detected by present geophysical methods.

6. Research into the distribution, mineralogy and geochemistry of glacial deposits should be much more actively pursued to improve mineral exploration technology.

7. There should be more *joint drilling projects by government and industry* to outline important subsurface geological features which may provide a new base for exploration at depth.

8. There should be more geological research on deposits being mined to obtain better information on their properties and surroundings, and to decipher their probable origin.

9. Metallogenic research should be expanded, based on:

a) a detailed appraisal and systematic compilation of all the pertinent earth science data available from government, university groups, and industry, on mining districts and other regions of potential interest;

b) broad regional studies such as continental drift, continental structure, metamorphic belts, basic history and development of geological provinces;

c) new knowledge of geosyncline anatomy and evolution.

10. Research in new methods of geological mapping of broad areas, including remote sensing, should be actively pursued for the purpose of speeding up the geological coverage of Canada and providing the base for future mineral exploration.
Several objectives for geological research in Canadian oil and gas exploration have been outlined in Section IV.3. These and others can be briefly summarized as follows:

1. Much additional research is required on the *detailed ecology of bioclastic carbonates and reef environments*, with increased attention on internal morphology and growth stages.

2. Increased research into sand-shale *sedimentological mechanics and geometry* should be forthcoming, particularly as a result of the Alaskan Prudhoe Bay-Sag River discoveries, the exploration activity in the Mackenzie Delta as well as in the Sverdrup Basin of the Queen Elizabeth Islands.

3. Further research is needed into the *typological identification of stray sands*. The early recognition of type of sand mass (beach, bar, channel, sheet, etc.) and its probable geometry relative to basin morphology is important for predicting trends of favourable host rocks.

4. The analysis of paleostructure should be more widely studied, as its influence on subsequent sedimentation patternseven for relatively minute changes in structural conditions-is often dramatic.

5. The earth's crust is a vital, mobile skin whose pulsation and fragmentation depend very largely on subcrustal forces. Basement structure and deep-seated geophysical phenomena reveal many features pertinent to Phanerozoic sedimentation and petroleum geology. The current emphasis on continental drift and sea-floor spreading is but one aspect of a wide spectrum of studies important to the economic stratigrapher.

6. The development of reliable absolute or relative age dating by some sort of time-dependent geochemical or radioactive parameter within the sedimentary section, in relation to paleontological and palynological studies, would be an enormous boon to facies studies.

7. The problems of diagenesis in general, and of dolomitization and silicification in particular, should receive increasing attention because of the influence of these phenomena on petroleum reservoirs.

8. The entire subject of evaporites deserves special attention, in relation to both petroleum and non-metallic minerals such as potash, common salt, etc. Avid proponents of both a shallow-water and a deep-water origin for the same salt body can often be found among groups of experienced geologists. When such a fundamental concept as this is still being debated, there is obviously ample scope for expanded research.

9. The recent impetus in Canadian offshore activities will focus much more attention on the *structure and stratigraphy* of the continental shelves. If one accepts the modernized concept of continental drift, part of the answer to local stratigraphic and shelf problems may well lie thousands of miles across the Atlantic. Geophysical studies and a program of critically located deep offshore wells (such as that provided by the Joint Oceanographic Institutes Deep Earth Sampling) will help provide the answers.

10. Little is yet known about source rocks although much is assumed. The whole field of source rocks, formation waters, hydrodynamics, oil migration and petroleum geochemistry in general is pregnant with research challenge.

11. The predictable trends of research directly or indirectly related to stratigraphic problems are most numerous. It is in the field of *computer processing* that the greater advances can be foreseen. This will include everything from storage and access to the routine processing of vast quantities of data and to complex multivariate factor analyses.

12. Future research in paleontology should be directed towards systematic, taxonomic studies employing modern concepts of population statistics and aimed at providing more reliable taxonomic identification for successful petroleum exploration.

13. Kinematic analyses of the modes of development of geologic structures throughout the Phanerozoic Eon should be actively pursued for understanding

hydrocarbon migration into or out of structural traps and defining the effect of structural development on contemporaneous sedimentation.

### **Exploration** Geophysics

Although generally more costly than geological research, developments in exploration geophysics are expected to play a very important role in Canadian exploration for years to come. In our opinion', the major objectives of Canadian research in exploration geophysics should include:

1. Geophysical orientation surveys, or applied research into geophysical responses over known mineral deposits, to allow differentiation of anomalies and improve methods of interpretation.

2. Methods of geophysical differentiation between graphite and sulphide conductors.

3. Research on topographic effects and overburden effects on electrical methods.

4. Research into the causes of induced polarization (IP) effects and improved techniques in IP detection of less than one per cent disseminated sulphides.

5. Research into the geophysical *detection of economic sulphides* relative to barren sulphides.

6. Research into *high sensitivity magnetic methods* applicable to mapping of soils and sedimentary rocks of low magnetism.

7. Research into the cause of conductivity and magnetic properties of ores and rocks.

8. Improvements and innovation in geophysical instrumentation, methodology and automation of instrumental logging of diamond drill holes in mining exploration, e.g. nuclear geophysics (as practised in the U.S.S.R. and Poland), recording magnetic susceptibility meters, radio frequency "shadow" methods, etc.

9. Development of geophysical instruments for the rapid and accurate measurement of various physical properties of drill cores.

10. Development of new geophysical instruments for ore search to depths of 500 feet or more yielding similar confidence 208 as for shallow search techniques.

11. Research into the *drill* hole logging signatures for various rock types frequently encountered in mining districts.

12. Studies on the geological utility of very low frequency surveys.

13. Studies on the usefulness of *earth* resource satellites and parametric studies for ground truth follow-up.

14. Studies on the applications of *re*mote sensing to mapping of exposed rock structures (folds, faults, etc) and trace element distribution (e.g. outlining of uranium districts in Canada).

15. Geological field studies providing the follow-up to government regional aeromagnetic, gravity and seismic surveys.

16. Research into the utilization of aerogeophysical surveys for providing reliable interpretation of the geology to depths of 2 000 feet or more.

17. Development of *improved radiome*tric instruments.

18. Research to evaluate *seismic energy sources* and to determine their most effective use.

19. Research to *improve seismic energy receiving conditions*, including geophone array effectiveness for noise cancellation, remote controlled geophones, and high frequency recording.

20. Research in *digital processing* to improve data handling procedures.

21. Study of the problems of accurately measuring the parameters of *nearsurface variable velocity layers*. These layers create problems in the construction of accurate seismic structural maps.

22. Research into the effect of changes in the subsurface density, porosity and lithology on the reflected seismic energy.

### Exploration Geochemistry

In addition to the major problems for future geochemical research outlined in Section IV.3, Canadian research in applied geochemistry should include the

'Most of these objectives have been recognized by the Subcommittee on Exploration Geophysics of the National Research Council's Associate Committee on Geodesy and Geophysics, as well as by other groups of Canadian geophysicists. following objectives:

1. Geochemical orientation surveys, or applied research into the distribution of metals in bedrock and overburden in the vicinity of known mineral deposits.

2. Definition by geochemistry of *small* areas in favourable regions which have the best chances for ore discovery.

3. Development of *instrumental meth*ods of continuous chemical analysis in boreholes and on outcrops.

4. Development of methods of *rapid* chemical analysis of sludge from non-core drilling.

5. Studies to find out how far metal values released since glaciation may penetrate a layer of till.

6. Continuing studies on the *distribution of various metals in various types of soils* in Canada, with particular reference to the distribution of soils as provided by the Canadian Soil Survey.

7. Continuing research on the diagnostic trace elements found in the iron sulphides accompanying economic sulphides as opposed to barren sulphides.

8. Increased research on the *applica-bility of the mercury halo technique*.

9. Geochemical studies to find *native* gold mineralization.

10. Research into the geochemistry of halogens as an exploration tool.

11. Additional research in *organic geochemistry* to provide a better understanding of the chemical or chromatographic effects on oil composition caused by migration through various types of rocks and, most important, the factors that control the efficiency of primary migration and accumulation of oil.

12. Studies in *inorganic geochemistry* to contribute a better understanding of diagenetic processes that affect reservoirs. More knowledge is also needed of the interaction between organic components and inorganic components such as clays, brines, sulphur, and uranium.

*Research in Related Fields* Other research objectives relating specifically to mineral exploration include: 1. Mathematical studies of the *distribution in space of metal values within mineral deposits* to improve the techniques of ore reserve estimation and to provide mathematical parameters of metallogenic significance. Too often the distribution of metal values within these deposits has been incorrectly assumed to conform to the law of random variables when in fact standard statistics do not apply to these phenomena unless mathematical artifices are used. More studies should be made in Canada of the kriging techniques successfully developed and applied in South Africa.

2. Based on the above, research to improve hole to hole correlation and design of optimum drilling patterns.

3. There should also be more research in Canada on *conceptual mathematical models to guide regional exploration*.

4. One hopeful avenue for research in Canada is the *application of operations research to mineral exploration systems* whereby the relative costs and applicability of various methods to terrain and geological conditions would be considered, based in good part on previous case histories of mineral discovery. With the use of computers, and with good basic data to start from, it should be possible to optimize mineral exploration efforts to an extent never achieved before in Canada.

5. There is also very little doubt that our ability to find mineral deposits and oil fields in the future will depend to a large extent on our use of *electronic data-processing techniques* to store and retrieve rapidly the necessary information, and to process effectively a great number of variables for filtering out anomalous features and refining the interpretation. Computers will be used increasingly for solving complex problems, such as:

a) the fitting of formal mathematical surfaces to structural data;

b) Fourier analysis of structural data, combined with various filtering devices, to determine the nature of subtle structures not otherwise easily separable from the regional "grain"; c) computer "modelling" of hypothetical structures for the comparison with actual field examples;

d) development of computerized methods of statistical analysis of structural data to determine the nature of the significant structural elements;

e) computer determination of mineralogy on the basis of physical and chemical features obtained from geophysical well logging;

f) development of models to relate digitized log responses of several devices directly to lithology and other specific elements of potential oil reservoirs;

g) further improvements in the digitizing and the interpretation of aerogeophysical data, etc.

6. An important subject of research closely related to mineral exploration is the field of *mineral economics*. There is an increased need for research on resource-engineering-economic-political matters to arrive at the most intelligent policy regarding the exploration for and the development of our nation's mineral resources. This research could include the following activities:

a) studies on the economics of mineral development in northern regions;

b) detailed assessment of the impact of mineral development in correcting regional economic disparities and in promoting economic growth;

c) studies on transportation systems as a vital key to mineral development;

d) case histories of the factors that have led to new mineral discoveries;

e) based on marketing and other economic criteria, studies of the measures that would ensure the best opportunities for mineral resource development, such as the finding of rare mineral commodities which have excellent present or future market potential;

f) appraisal of the impact of government incentives on mineral development;

g) study of factors influencing Canada's position in international mineral trade;

h) study of the optimum exploitation of our mineral resources; 210 i) studies of the rate of new mineral discoveries in relation to rising exploration costs and levels of anticipated mineral demand;

j) studies of the effects of price changes and technological advances in mining, milling, and metallurgy on mineral development;

k) technical assistance to developing countries.

# Improvements in Exploration Drilling Technology

With the \$172 million currently spent on exploration drilling in Canada (see Table II.16), the increased difficulties of finding new ore deposits (see Section IV.4), the need to explore more actively (Section IV.4), and to greater depths, it is apparent that one of the most fruitful avenues for improving mineral exploration is through improvement of our drilling technology.

It is rather anachronistic that space-age technology has not yet engendred a revolution in exploration drilling technology akin, say, to the invention of the tricone bit or drilling mud many years ago. Although there have been some major improvements in the diamond drilling industry, such as the use of wireline core barrels and drills equipped with hydraulic heads, by and large the Canadian drilling companies are too small, or are in too competitive a business to allocate major funds to exploration drilling research.

Millions of feet are drilled each year in Canada and yet there is as yet no national program to improve the exploration drilling technology, particularly that of diamond drilling. The need for improving drilling equipment and methods is especially brought in focus by the attractive possibilities of using diamond drills in petroleum exploration. Furthermore, diamond drilling is an important export item. Canadian diamond drillers are renowned around the world for their ability and yet we do very little as a nation to build on this expertise. Therefore, we submit:

### Conclusion IV.11

A national program of research and development to improve Canadian exploration drilling technology should be undertaken jointly by the National Research Council and Canadian-owned drilling contractors, and with the co-operation of the mineral industry.

### Improvements in Down-Hole Surveying

At a time when laser beams can measure the distance between the moon and the earth with an accuracy of a few inches, we still have great difficulty in surveying the exact location of diamond drill holes at a few hundreds or thousands of feet in depth. Instruments are available which can give the azimuth and dip of a borehole, but these are unreliable in the presence of magnetic rocks (which are encountered frequently in sulphide orebodies and elsewhere). There is a need to develop a portable and inexpensive instrument for accurately surveying small-diameter diamond drill holes, and we submit:

### Conclusion IV.12

A national program of research should be initiated by the National Research Council to develop better instruments and improved methods of borehole surveying.

# Establishment of "Hard-Rock" Core Storage Libraries'

There has been over the years an appreciable loss of potentially valuable earth science data as a result of the discarding of diamond drill core once it has served its initial economic purpose. There is no question that drill cores provide the most valuable data collected in any exploration program. In 1968, exploratory drilling accounted for 37 per cent of the \$88 million spent on mining exploration in Canada (Table II.16) and was by far the largest expense in this exploration.

It is in the national interest to encourage industry to preserve drill core and submit drilling records. The establishment of core storage libraries under the aegis of government agencies would be a useful measure to improve the conduct of mineral exploration in Canada. By making drill cores available to all researchers, this measure would provide the necessary material for extended subsurface geological studies, for restructuring the third dimension of geological features, for appraising the causes of geophysical conductors, and for conducting geochemical investigations.

Reasons for Establishing Core Libraries Cores provide a unique and finite record of the third (vertical) dimension. They are also invaluable in the absence of outcrops. As drill holes probe thousands of feet into the crust, their importance becomes even greater in deciphering the third dimension and locating deeper mineral deposits. Benefits from preserving drill core include:

1. the drilling of many new holes could be avoided if previously obtained cores are available for inspection and study;

2. in areas of glacial drift and muskeg, drill core is the only material which will provide an absolute clue to the local geology;

3. drill core provides at present the only source of data for carrying out three-dimensional geochemical studies;

4. drill core provides important study material for defining the causes of geo-physical anomalies;

5. a drill core log is basically a record of the observations of the geologist who logged the core; the geologist is often unable, because of limited time and facilities, to make a thorough study of the core, especially from a scientific point of view; competence and bias on his part must also be considered: new theories and techniques may outdate a drill log whereas core specimens do not

<sup>&#</sup>x27;This discussion is based extensively on a paper prepared by David R. Francis and published in *Background Papers on Earth Sciences in Canada*, Edited by C. H. Smith, G.S.C., Special Paper 69-56, 1970.

change; the relogging and restudy of drill core can change previous concepts, and improved tests made on this core could contribute to improved ore-finding methods.

### Survey of Opinions and Current Practice Regarding Core Storage

Our survey of mining companies, which covers about 70 per cent of the mining exploration activity in Canada, has revealed that:

1. Most diamond drill core from exploratory drilling is logged and retained as long as it has immediate economic use, while mineralized sections are usually removed for assay and future reference;

2. If the area is remote, the cores are usually left on the property in an orderly fashion at the end of the field season, commonly in their boxes; where boxes are scarce or expensive, the cores are dumped directly on the ground; several companies indicated at this point that the government should provide the necessary facilities and personnel to gather this material which would otherwise be lost, and stressed the waste of time and expense involved in unnecessary duplication at a later date;

3. If the property was optioned, the cores would be turned over to the owner;

4. The cores from drilling at operating mines are retained for longer periods, at least as long as the volume of material, the inconvenience of collecting and maintaining it in a central location, and the cost of core boxes and storage do not become overpowering;

5. The principal means used by many companies to solve the core storage problem are to photograph the core, commonly in colour, and (or) to retain only representative sections, such as several inches for every 10 feet of core or change of lithology;

6. Many companies indicated, however, that they have no common policy, their core handling varying considerably in relation to the circumstances;

7. Our survey indicates that the Canadian mining industry overwhelmingly 212 supports the principle that the establishment and maintenance of central core storage libraries would improve the conduct of future earth science research and mineral exploration in Canada; the same opinion is shared by government agencies and university departments engaged in earth science activities;

8. However, industry's positive response includes several qualifications: 25 respondents specified that gathering all cores would be prohibitive and that only "condensed" or "telescoped" core should be stored; another 8 suggested that core storage libraries should be established on a regional basis; 7 indicated that only the drilling records and geological logs should be kept; and 4 others recommended the maintenance of photographic records of all core;

9. Seven mining exploration companies referred to the need for more stringent government regulations forcing the disclosure of drill logs, records and core samples by all mining companies.

A Proposal Regarding Drill Core Storage It is in the national interest that government adopt a policy concerning the retention and storage of diamond drill core resulting from mining exploration. In our opinion, this policy should be established on the following principles:

1. It is neither practical nor desirable to gather and store all core from all exploratory holes;

2. Any workable system of core acquisition and storage would have to be carried out by government agencies, that is by provincial resident geologists or their federal equivalents in the Yukon and Northwest Territories;

3. A standard system of collection and storage would be highly desirable;

4. A standardization of forms and terminology for drill logs would also be most useful;

5. Since almost all exploratory drilling has a proprietary aspect, mining companies should have the right to withold drilling information (including drill core) for a definite period of time to be negotiated with industry;

6. Government representatives must have the right to examine all cores taken at any time;

7. All cores should be subject to filing and storage in central core libraries in a condensed or "telescoped" form: at least 5 per cent of the core should be retained, with a minimum 3-inch piece from every significant change of lithology and at intervals of no more than 10 feet;

8. Generous assessment work credits should be provided for the core donated to these core libraries, with a built-in escalation clause for core brought from remote areas;

9. All cores submitted should be accompanied by the geologist's core log and the full particulars on the drill holes, such as exact location, collar elevation, azimuth, dip, etc.;

10. All core submitted should be individually indexed according to the National Topographic System and be given a number; a card index system for these numbers should be maintained with all the necessary information; the data format should be adaptable to techniques of electronic data storage and retrieval;

11. The central core libraries should be established in convenient centres of mineral exploration activity.

#### Cost Considerations

Total "hard-rock" exploratory drilling in Canada was of the order of 4 million feet in 1968. If five per cent of this core is retained, the core to be stored in government facilities will amount to about 200 000 feet per year. On a basis of 20 central core libraries across Canada, one library can be expected to receive about 10 000 feet of condensed core per year, which is a manageable amount even if doubled.

The capital cost of a central core library with a capacity of 200 000 feet (Armco-type steel building erected on a concrete slab, with steel rod racks) should be in the order of \$150 000. If we add to this amount the capital cost for ancillary facilities such as grinding and thin-

sectioning equipment, benches and office space, the capital cost may be \$200 000, or about \$20 000 a year for capital depreciation. Maintenance costs may be \$5 000 per year, and operating costs about \$25 000 (salaries of a junior geologist, core technician and clerical staff, plus supplies), for a grand total of about \$50 000 a year (excluding the resident geologist's salary). If this library receives 20 000 feet of condensed core per year, the acquisition cost to the government would be \$2.50 per foot of condensed core. This may seem to be a high amount, but it should be remembered that the expense in getting the core is 200 times this amount.

If the government core storage facilities were to contribute to only one find in 20 years, the economic activity and tax revenues engendered would more than compensate for these government expenditures. While revenues to the provinces and territories accruing from the mineral industry have increased substantially over the past several years (see Figure II.14), the total earth science expenditures of provincial government agencies have generally remained at a low level. It may be argued that a larger proportion of mineral revenues should be plowed back to increase the effectiveness of mineral exploration and to promote research in mineral exploration.

The establishment of these core libraries must meet a need. Industry and university researchers should be consulted on the desirability of establishing these libraries at particular locations and on the kind of services to be provided. Special consideration should be given to possible trends of future research and the methods of mineral exploration which may be in use in 1980 or 1985. Finally, the principle should be established whereby the "core laboratories" would own the thin-sections, powders, etc. of any material taken from these cores with the authorization of the geologist in charge, and would also own a copy of all results arising from the study of the material physically removed from the core.

### Conclusion IV.13

Government-funded and operated core storage libraries should be established to improve the effectiveness of Canadian mineral exploration and to promote earth science research on Canadian problems.

### Earth Science Data Storage and Retrieval

One of the most powerful means of increasing the effectiveness of mineral exploration activities in Canada is the use of computer technology in the storage, dissemination, exchange, and retrieval of earth science data. In fact, many Canadian earth scientists claim that a systematic input of present knowledge into electronic data-processing systems should be considered the single most important common objective of agencies of government, university departments, and companies engaged in mineral exploration. The growth of earth science data in Canada is so tremendous, and the need to retrieve these data rapidly so urgent, that we see no alternative for coping with the "information explosion". Increased use of computer technology offers almost unlimited opportunities.

Canadian earth scientists have a lead in the world in this field. With commendable foresight, the National Advisory Committee on Research in the Geological Sciences commissioned in 1965 an ad hoc committee of Canadian scientists to develop a concept for a computeroriented national system for storage and retrieval of earth science data. Its final report1, published in 1967, received widespread Canadian and international recognition. The leadership is illustrated by the fact that the American Society of Petroleum Geologists immediately adopted the coding method recommended in the report. The chairman of the ad hoc committee later assumed chairmanship of an international (IUGS) committee in this field, and another committee member was invited to serve on a United States (AGI) project to develop a national information program for the earth sciences in that 214

country.

The Canadian System for Geoscience Data has been fully endorsed by both federal and provincial government agencies, by universities, and by a number of mining and petroleum companies. The implementation of this system will require major re-adjustments in current practices of handling earth science data and there will be a cost to all concerned in setting up local data banks on a uniform basis. However, unless some such system is speedily established, there will be a great waste of the massive amounts of earth science data accumulated in various sectors, which are awaiting research utilization.

To this end, a further study sponsored by the National Advisory Committee has recommended the establishment of a Canadian Geoscience Data Institute. The institute would work toward the increased effectiveness of earth science activities relating to natural resource data. While the owners of data banks will retain the full and exclusive property of their data, the institute would develop a Canadian Index to Earth Science Data to enable scientists and other users to rapidly locate and retrieve data of interest. Another objective for the institute is to disseminate information regarding the design, development, operation and management of computerized data systems in the earth sciences, and to assist in and coordinate the establishment of necessary standards to enable development of the Canadian System for Geoscience Data. The proposal for this institute was discussed at length at the Provincial Ministers of Mines Conference of September, 1969. The Ministers of Mines accepted in principle the concept of a co-ordinated nation-wide system of Geoscience Data Storage and Retrieval, and recommended that the Government of Canada, through the Geological Survey of Canada, maintain a National Index for that purpose.

Brisbin, W. C., and N. M. Ediger, eds. A national system for storage and retrieval of geological data in Canada. National Advisory Committee on Research in Geological Sciences. Ottawa, 1967. 175 p.

The establishment of this national system of data handling has been endorsed by several companies, some of whom have contributed substantially to its present development. However, several other companies have questioned the system because of their fear that there would not be adequate safeguards to protect their proprietøry interests. However, it should be made clear that the system does not impinge on their proprietary rights. All the system does is to make known where field reports and research syntheses are located, without knowledge of what is actually contained in these documents. The system is based on the principle of uniformity in coding and filing. If a person or company wishes to obtain the data from any of the data banks that are part of the national system, he can only obtain it by negotiating the release of these data with the agency holding it, since no one else would actually have the data on file.

The practical applications of computerized data files have been outlined by Sharp and Burk.' In summary, "the objective of computer storage of earth science data is to make data available to more scientists, in larger volumes, in faster time, in more readily usable forms, and at lower unit cost, than other methods."

We are convinced that the economic benefits to be derived from the national system of earth science data storage and retrieval are potentially extensive and far reaching, and we conclude:

### Conclusion IV.14

The mineral industry should co-operate fully with government agencies and universities in establishing the Canadian System for Geoscience Data and contribute to the formation of a Canadian Geoscience Data Institute.

### IV.6 Role of Various Sectors in Earth Sciences Applied to Mineral Resource Development

Government, universities and industry all share the responsibility of keeping Canada in the forefront of modern technology: In such a broad area as mineral resource development, the earth science component must be appraised in terms of the contributions to be expected from each major sector. The following treatment is far from being exhaustive, but it provides some measure of the improvements that each sector should provide to increase the effectiveness of mineral exploration.

### Industry

Industry must make the most efficient use of knowledge, manpower and natural resources for the short- and long-term benefit of itself and the nation:

1. Industry's contribution to knowledge is essentially in the field of applied research and data interpretation.

2. Considering the very large sums spent by industry for drilling and other forms of data collection (Table II.3), we believe that industry should do more research in mineral exploration (in 1968 this research amounted to only two per cent of the expenditures on data collection). The research resources of individual universities and government agencies are far more limited than industry's, in both manpower (Table II.7) and financial means (Table II.1 and II.2). Furthermore, universities and government agencies must assume research responsibilities that encompass more than the needs of the mineral industry alone.

3. Industry, petroleum companies in particular, should carry more of their research in Canada compared to that done in other countries for their account.

4. We believe that industry would better serve the nation if it liberalized the publication of its research and relevant background data. We recognize that companies must preserve their competitive position, but in some instances valu-

Sharp, D. A., and C. F. Burk, Jr. Computer storage and retrieval of earth science data. *In* Background papers on earth sciences in Canada. Edited by C. H. Smith, GSC Special Paper 69-56, 1970.

able earth science data and research results lie dormant in corporate files because of an overly conservative attitude toward its confidentiality. Company geologists, geophysicists and geochemists should be encouraged to publish all results which would not endanger their competitive position. Perhaps the best way to achieve this is for industry to take a more active part in technical meetings of Canadian scientific societies, not only in discussions but also in the presentation of papers.

5. Industry should help sponsor institutes of applied earth science research at selected universities, for the following reasons:

a) by contributing financially to these institutes, industry can exercise leadership in defining major problems to be solved and guide the orientation of relevant research;

b) companies will be the major beneficiaries of this applied research;

c) with a minimum capital investment in additional research facilities, and adequate technical support, centres of excellence in mineral exploration research could be developed in universities (see Section III.12);

d) these contributions would promote better training of graduate students.

6. Industry should take an active part in national advisory research committees, particularly the National Advisory Committee on Mineral Resources Research (see Section II.5).

7. As the largest employer of earth scientists in Canada, industry should improve its image in the universities to attract more of these professionals into its cadres, and to help motivate more students toward earth sciences. This can be achieved by:

a) more industry scientists taking part in university visiting lecturers programs;

b) more active participation of industry scientists in the annual regional conferences of students;

c) greater attention to summer student employees in terms of responsibilities assigned, working conditions, and remun-216 eration;

d) better opportunities for students to undertake research projects;

e) increased career guidance by industry representatives, to explain what industry is doing and the opportunities it offers;

f) increased employment opportunities for female geologists.

8. One major difficulty in earth science manpower is the "feast and famine cycle" that so often characterizes mineral exploration. During the "famine" periods, industry should make a better effort to allocate its "surplus" staff to long-range studies and, for the most qualified perhaps, to increased research. It could also take advantage of these periods to send a number of its professionals to universities for additional training and specialized research.

9. Earth scientists working for industry in mining communities or in the "bush" should receive substantially higher remuneration than professionals of equivalent qualifications stationed in metropolitan centres.

10. It is also apparent that earth scientists working for industry in isolated communities have great difficulties in keeping up-to-date on new scientific and technological developments. Better opportunities for attending technical meetings and university courses are required. Likewise, industry should provide its staff with more challenging scientific or technological opportunities, as well as better technician support.

### Federal Government

Regarding mineral resource development, the earth science role of the federal government should remain missionoriented towards the country's economic development. Federal government agencies should continue to bear the prime responsibility for long-range fundamental studies and inventories consistent with their mission of promoting the overall economic progress of the country, correcting regional disparities, and co-ordinating scientific activities in the best national interest.

While the administration of mineral resources in provincial lands, and the prime responsibility for development related thereto, clearly lie with the provinces, there is almost unanimous opinion among Canadian earth scientists for the need to maintain strong scientific capabilities and a high level of earth science activities in the federal government, particularly in the Geological Survey of Canada. Our country is so large and its geology so complex that a strong earth science federal organization is vital to Canada's mineral resource development. It is of interest to note that 44 of the 92 companies that commented on federal services made specific reference to consultations with officers of the Geological Survey of Canada on a frequent or regular basis, while 6 others used this service occasionally. The value of open files, libraries, and other reference materials in the federal agencies accounted for the rest of the replies (see Appendix 5 for a description of earth science activities of federal government departments and agencies). Our survey further indicates that the geological and geophysical publications of the federal government are considered to be of high quality and are used extensively by the mineral industry (see Appendix 6).

There has been some confusion at times about the earth science role of federal agencies in mineral resource development. In our opinion, this role should be polarized essentially on the functions of national interest, including:

1. Regional geological mapping, at a scale greater than one mile equals one inch, by the Geological Survey of Canada. The more detailed systematic geological mapping should be carried out by the provinces, except in the territories where this mapping should be done by the Geological Survey of Canada. The general consensus is that the Geological Survey should expand its reconnaissance mapping of the country and provide national compilations and regional correlations.

2. Studies of broad geological units

within provinces or straddling provincial boundaries.

3. All topographic and photographic mapping.

4. Regional aerogeophysical surveys. Where a large provincial component is included, the surveys should be carried out on a cost-sharing basis with the provinces.

5. Specialized research investigations requiring expensive laboratory facilities and very specialized personnel, including the establishment of national standards of chemical analysis, reference collections of rocks, minerals and fossils, pilot studies of new geophysical methods, research investigations of the mode of occurrence of specific mineral commodities, etc.

6. Basic and applied research in related fields, such as mineral economics (an essential function which should be expanded), ore dressing, etc.

7. National systems of earth science data storage and retrieval, including coordination with provincial agencies, universities, and industry.

8. Earth science representation at the international level.

9. Co-ordination of the national earth science effort in programs of technical assistance to developing countries.

10. Financial and technical support of research in fields related to the federal mission, but performed in universities, provincial research councils and industry.

11. Financial and technical support of centres of excellence in the earth sciences (see Section III.12).

Specific areas for improved conduct of federal earth science activities include:

1. A speeding up of the publication process. Many companies have remarked that the time elapsed between the actual field work and the publication of the results is much too long.

2. A greater degree of regionalization of research personnel and facilities, in keeping with the "centres of excellence" concept elaborated in Section III.12.

3. Increased emphasis on mineral economic studies, including an expansion of research relative to rare minerals for which there is good marketing potential.

4. Better co-ordination with provincial agencies in priority setting of long-range earth science programs.

5. Development of a national program of earth science information based on computer methods:

a) integrated with the proposed national system of scientific information:

b) abstracting the pertinent earth science information from all the technical and scientific journals currently published;

c) improved facilities for translating the earth science literature that is not in English or French.

6. Establishment of good regulations and sample storage facilities to ensure that the records obtained in offshore exploration are fully utilized and preserved.

7. Increased activity in satellite mapping of natural resources and research into remote sensing techniques, including application of space and military research to mineral exploration. This work, needless to say, should relate to the whole field of natural resources rather than to mineral exploration only.

### **Provincial Governments**

Provincial agencies concerned with mineral resource administration and development play a major role in earth science activities, which may be summarized as follows:

1. In addition to resource administration, one of the prime responsibilities of these agencies is the geological inventory of provincial territory, with systematic geological mapping at a scale of one inch equals one mile or less. This involves the collection and cataloguing of earth science field data for their own account or as submitted for assessment work purposes.

2. One very useful role played by some provincial agencies consists of detailed geological surveys, compilations and syntheses of mining districts. Industry considers this work invaluable.

3. Another important function is production of metallogenic maps of certain <sup>218</sup> regions which are based on all the earth science data available, including information submitted for assessment work.

4. Provincial agencies have to apply major efforts to areas not under active exploration, in order to provide basic earth science information from which industry may more intelligently commence an exploration program. These agencies should be prepared to limit their activities to that level necessary to establish industry programs and, at some point, withdraw from certain fields and enter others where needs are more urgent.

5. Mining companies have repeatedly stressed to us the value of the services provided by provincial resident geologists and, as suggested below, this constitutes one particular area for increased earth science activity.

6. Provincial agencies also have a role to play in earth science research. The level of this research, and in fact the level of all earth science activities, varies tremendously however from one province to the next (see Section II.6).

7. Some provincial research councils are engaged in earth science research, but their activities in mineral exploration research are minimal.

The major areas for improvement in the earth science activities of provincial agencies appear to us as follows:

1. There is a real need and good justification for increasing the level of these activities in most provinces, particularly in Newfoundland and British Columbia. The provinces are in an excellent position to provide invaluable scientific services to the mineral industry, but because of limited staff, general lack of technician support, and insufficient budget (increased provincial revenues from the mineral industry are channelled to other provincial priorities), many important projects of value to the mineral industry have not been pursued. We think that until 1975 at least, the provincial agencies should increase their earth science activities at a rate equal to a 10 per cent annual increase in expenditure.

2. As recommended in Section IV.5,

provincial agencies should establish public core storage libraries (only Alberta, British Columbia, Nova Scotia, and Saskatchewan have such libraries at present).

3. As recommended in Section IV.5, provincial agencies should co-operate fully with the Geological Survey of Canada in establishing and operating the National System for Gesocience Data; they should convert their files of earth science data to computer-processable form.

4. It would be in the best national interest for the federal and provincial ministers of mines to establish jointly a functional mechanism, perhaps analogous to that of the Canadian Council of Resource Ministers, for continuing studies and discussions on resource matters of interprovincial interest. In the earth science field, these matters could include:

a) interprovincial and federal-provincial co-ordination of earth science programs on a sustained basis, for improved long-term planning and budgeting, and best use of manpower and financial resources;

b) development of improved legislation in the best interests of the nation;

c) mineral policy for Canada;

d) level and effectiveness of Canadian mineral exploration;

e) development of a better system than claim staking for establishing mineral exploration rights (the large sums spent on cutting trees and branches would be better spent on drilling holes in the ground);

f) improved systems of earth science information;

g) improved resource survey systems, including resource satellites;

h) shortage of manpower in the mineral industries;

i) establishment of standard map scales;

j) industrial pollution and land conservation measures;

k) ways of speeding up the preparation and publication of reports and maps;

1) continuing education for their scien-

tific and technical personnel;

m) formal communication between government and industry (in the June 12, 1969, issue of the *Northern Miner*, the Prospectors and Developers Association expressed concern about lack of communication between the mining industry and government channels);

n) formal communication between universities, government agencies and industry concerning trends in undergraduate and graduate earth science education.

5. The Department of Mines of Ontario, Quebec and New Brunswick have reported difficulties in obtaining qualified geologists in sufficient numbers from our universities. This opinion is generally prevalent in other government agencies and industry. Provincial government agencies should do more to attract qualified candidates. This can be achieved by a number of measures, including:

a) providing more scientifically rewarding work opportunities for their scientists;

b) providing adequate technician support for routine jobs;

c) developing regional research units in major mining districts under the direct supervision of the local government resident geologists.

# What Government Should Do for the Individual Worker in the North

Many earth scientists and engineers spend a good part of their life in northern communities and contribute to "pushing back the frontier." In a just society, one would think that they would get special recognition from their compatriots for contributing to Canada's development and for accepting the hardships associated with their work. Yet, in fact, they are *penalized* for living in the North: more rigorous climate, less sunshine, isolation from their relatives and friends, isolation from the scientific community, isolation from cultural centres, absence of highways, very limited opportunities for leisure occupations, often inadequate

schooling for their children (especially at the high school level), etc. These people generally do receive a higher rate of remuneration than their southern colleagues, but this increase in salary is rapidly consumed by the higher cost of living in these communities, the occasional trips to "civilization", and the cost of higher education for their children. To make matters worse, these people pay the same rate of income tax as if they were enjoying all the facilities of life farther south, i.e. as if they were using the highways, national parks, etc.

We think that people working in the Far North should receive special recognition from the Canadian government. The most effective recognition would be to reduce income tax for all people working north of a certain line. Many people in government will argue that such a program would be almost impossible to administer, yet Australia is providing this kind of personal incentive. The major problem would be to establish the line between the Far North and the rest of Canada, but this difficulty is not insurmountable. In any event, industry and government have a responsibility to provide incentives for northern employment.

#### Universities

The role of universities is discussed at length in Chapter III and need not be repeated here.

#### **Technological Institutes**

Generally speaking, there has been far too much emphasis on university funding compared to the funding of technological institutes. These schools provide excellent training for geological and geophysical technicians, who are in great demand in the industry. Experience has shown for example that many graduates of the Northern College at Haileybury have reached key positions in the mining industry because of their competence acquired largely through practical experience.

Unfortunately, we have not been able to survey the technological institutes 220

which provide training in fields related to the mineral industry. However, many people have remarked on the excellent quality of the graduates from these schools, and industry is anxious to have more of them. Consequently, we suggest to provincial governments that instead of establishing more university departments of geology, the emphasis should be on strengthening present departments which offer the best possibilities of becoming top-ranking institutions, and on establishing new technological institutes to meet industry's demand.

# Chapter V

Geotechnique and the Physical Environment "In all things success depends upon previous preparation and without such preparation there is sure to be failure."

### Confucius, 551-478 B.C.

### V.1 Synopsis

The Canadian construction industry, with an estimated value of \$13 billion in 1969, constitutes a major and one of the fastest growing sectors of the Canadian economy. Since every land-based engineering structure involves contact with the solid earth, those earth sciences concerned with civil engineering, collectively known as *geotechnique*, assume a particularly important role.

The 1968 expenditures by industry on geotechnical activities amounted to \$33 million. Ever-increasing expenditures in this field can be anticipated as the needs of increasing populations impose growing demands for construction and as increasingly difficult construction sites are utilized.

While geotechnical development in Canada is essentially a post-World War II phenomenon, and the numbers engaged in this work are relatively small (just over 500), such engineering works as the Gardiner Dam, Red River Floodway, Steep Rock Mine and Churchill Falls power development are important geotechnical contributions to Canadian development.

Canada's vast size, extremes of climate, and diversity of geological terrains pose particularly severe problems in terms of transportation and resource development. In the rapidly expanding urban areas, terrain disturbances and natural hazards confront planners and developers. These and other earth sciencebased problems must be solved to arrive at safer and more economic construction.

Our industry, universities and government organizations have developed much competence in many aspects of geotechnique. However, there is insufficient manpower in several fields, particularly in 222 urban geology, muskeg and permafrost engineeering. Anticipated needs for construction and resource development in the various parts of the country require additional geotechnical research on typical Canadian problems.

# V.2 Definition of Geotechnique and Related Activities

Geotechnical activities comprise the practical application of knowledge, techniques and methodology derived from geological and physical sciences and engineering to the study of earth materials and processes. These activities do not constitute a single branch or discipline of the earth sciences but form, rather, a broad earth science-based mosaic of multidisciplinary nature, which is particularly related to civil engineering.

A relatively new term, geotechnique, is being increasingly used in this regard. In Canadian usage<sup>1</sup> it includes activities in engineering geology, soil mechanics, rock mechanics, muskeg, permafrost, snow and surface ice studies. Other important contributions involve such fields as geomorphology, hydrogeology and geophysics as applied to engineering problems.

Snow and surface ice studies are, for the most part, beyond the terms of reference of the present study. However, the special importance of water in its frozen form to this country, scientifically and economically, is clearly recognized. It is, therefore, hoped that a special study of this challenging field can soon be initiated.

Throughout history man has contended with the natural hazards of his environment such as earthquakes, seismic sea waves (tsunamis), hurricanes, floods and landslides. Indeed, through his own activities, man has increased the consequences of these hazards in terms of loss of life or property. While their definition, their prediction, and the calculation of

<sup>&</sup>lt;sup>1</sup>Legget, R.F. Geotechnique and national development. *In* The earth sciences in Canada. Edited by E.R.W. Neale, Roy. Soc. Canada, Spec. Publ. No. 11. pp. 186-202. 1968.

the risks involved are the concern of scientists of many disciplines, the prime objective of geotechnique is the assessment and control of these hazards as they relate to and are influenced by construction.

From the standpoint of construction economics, particularly in the predesign phases of engineering, geotechnique serves to minimize or eliminate the excess project costs that result from "overdesign", that is, from the use of excessive safety factors to overcome uncertainties in the engineering performance or behaviour of earth materials. This is in contrast with earth science activities directed toward mining or petroleum exploration in which the prime objective is the discovery of deposits of commercial value.

Geotechnical expenditures, therefore, are directed toward reductions in capital costs rather than direct capital gain. To derive maximum benefits from geotechnique, studies must be carried out in advance of construction so that the results can be fully utilized in the planning and design phases of engineering.

# V.3 Importance of Geotechnique in Canada

### Historical Development of Geotechnical Activities in Canada

The historyof geotechnical activities in Canada is intimately associated with the development of formal geological studies, which were initiated with the founding of the Geological Survey of Canada in 1842. At that time the emphasis on geological activity was directed toward the discovery of natural resources in the form of coal, metallic minerals, agricultural lime, building stone, and lime for mortar, to serve the needs of the rudimentary society. Studies of construction materials in this early period marked the beginning of geotechnical investigation.

Increases in the population of the country produced commensurate increases in the size and complexity of the urban areas, and it is worthy of note that several descriptions of the geology of urban areas in Eastern Canada were published at the beginning of this century.<sup>1, 2</sup> Investigations by Ells<sup>3</sup> of landslides in the Ottawa Valley-St. Lawrence Lowland area, and the examination of foundation borings and abutment conditions for the Quebec City Bridge<sup>4</sup>, are other examples of early geotechnical contributions.

By 1915 the automobile had assumed a prominent place in Canadian transportation and brought with it a demand for improved roads. The response of geologists of that time to the need for road-building materials is contained in reports of the Geological Survey of Canada.<sup>5, 6, 7, 8, 9</sup>

Numerous other examples might also be cited of the participation of Canadian geologists and engineers in activities that relate geology to engineering and demonstrate the application of geological knowledge to groundwater development. Much of this early work, although of value then, was of a qualitative and descriptive nature, and thus was not of the type that could ultimately evolve into a

<sup>2</sup>Ells, R. S. Report on the geology and natural resources of the area included in the map of the city of Ottawa and vicinity. Geol. Surv. Canada, Summ. Rept. 1899, Vol. XII, Pt. G. 1901.

<sup>3</sup>Ells, R. S. The recent landslide on the Lièvre River, Québec, Geol. Surv. Canada, Summ. Rept. 1903. Vol. XV, Pt. AA, 1904.

<sup>4</sup>Ami, H. M. Notes on drillings obtained in six diamond-drill boreholes in the bed of the St. Lawrence River at Victoria Cove, Sillery, eight miles above Québec City and in vicinity of the Quebec bridge. Geol Surv. Canada, Summ. Rept. 1902, Pt. A. pp. 328-338, 1903.

<sup>5</sup>Reinecke, L. Road material surveys in Ontario and Quebec. (Character of deposits of bedrock and gravels between Ottawa and Prescott and results of tests on stone available for the Montreal-Ottawa road.) Geol. Surv. Canada, Summ. Rept. 1915, pp. 147-155. 1916.

<sup>6</sup>Reinecke, L. Road material surveys in Ontario and Québec (Rideau Canal route.) Geol. Surv. Canada, Summ. Rept. 1916, pp. 193-194. 1917.

<sup>2</sup>Clark, K. A. Road materials available for the Toronto-Montreal road between Trenton and Napanee, Ontario, Geol. Surv. Canada, Summ. Rept. 1916, pp. 195-198. 1917.

<sup>8</sup>Gauthier, H. Road materials in Two Mountains and Argenteuil Counties, Quebec. Geol. Survey Canada. Summ. Rept. 1916, pp. 198-201, 1917.

<sup>9</sup>Picher, R. G. Road materials in Soulanges and Vaudreuil Counties, Québec. Geol. Surv. Canada, Summ. Rept. 1916, pp. 201-206. 1917.

<sup>&#</sup>x27;Ami, H. M. On the geology of the principal cities in Eastern Canada. Trans. Roy. Soc. Canada. 2nd ser., Vol. VI. Sec. IV, pp. 125-164, 1900.

scientific activity based on the principles of mechanics.

It was not until 1936 that soil mechanics became generally recognized as a scientific discipline in its own right. Throughout the 1930s the development of quantitative analytical methods for groundwater studies provided further impetus to the application of earth sciences to engineering. The greatest acceleration in geotechnical development occurred during World War II in response to urgent demands for military construction and terrain analysis.

The most rapid acceleration in growth of geotechnical activities in Canada, as well as in other technically advanced countries, has occurred during the past 20 years. The construction and resource industries, particularly the energy sector, have demanded increased knowledge of terrain and the engineering behaviour of earth materials. This, in turn, has stimulated the development of refined instruments for measuring interactions between earth materials and structures, necessitated the use of computers for stress/strain and other complex geotechnical analyses, and led to increased sophistication in geotechnical studies.

### **Economic Aspects**

The construction industry constitutes one of the major areas of expansion and capital expenditure in the Canadian economy.

In the five-year period prior to 1961, the value of new building<sup>1</sup> and engineering construction<sup>2</sup> (Figure II.10) ranged between \$5 billion and \$6 billion a year. Since 1961, however, the annual value of new building and engineering construction has increased rapidly to an estimated level in 1969 of \$13 billion.

During the period 1962-66, the average value of engineering construction plus the industrial, commercial and institutional sectors of building construction, all of which have a significant geotechnical component, amounted to approximately two-thirds of the total construction expenditures. Thus, in 1969, the value of <sup>224</sup> construction to which geotechnical activities relate will be about \$9 billion, an amount that appreciably exceeds the present annual value of Canada's mining and petroleum production.

Geotechnique is important in the design of foundations for buildings. It is particularly significant in engineering construction for highways, railways, dams, marine facilities and other aspects of both construction and mining in which the excavation and placement of large volumes<sup>3</sup> of earth materials are involved.

### **Terrain and Climatic Factors**

Canada, with its areal extent of 3.85 million square miles, is second in size only to the U.S.S.R. Distance, therefore, constitutes a major economic factor in the development of surface transportation and communication links between the widely separated areas of resource development and industrialization.

Superposed on the basic fact of distance, however, are a great diversity of terrain and climatic conditions which, from the geotechnical standpoint, exert significant influence on economic development.

A unique aspect of our terrain is that it contains the largest expanse of glacial soils of any country.<sup>4</sup> These Pleistocene materials, which cover 97 per cent of

<sup>2</sup>Engineering construction as reported by the Dominion Bureau of Statistics comprises marine works, road, highway and aerodrome, waterworks and sewage systems, dams and irrigation, electric power construction, railway, telephone and telegraph, gas and oil facilities, and other engineering works. Expenditures for both new construction and repair are included.

<sup>3</sup>As examples:

Red River Floodway, excavation and placement-100 million cubic yards;

Gardiner Dam, earth embankment-27 million cubic yards;

Mica Dam, earth embankment-40 million cubic yards; Canadian mining industry, volume of rock excavated annually-200 million cubic yards;

(100 million cubic yards = 1 square mile x 97 feet deep). <sup>4</sup>Legget, R. F. ed. Soils in Canada. Roy. Soc. Canada. Spec. Publ. No. 3, pp. 3-5. 1961.

<sup>&#</sup>x27;New building construction as reported by the Dominion Bureau of Statistics comprises residential, industrial, commercial, institutional and other construction such as farm buildings, passenger terminals, bunkhouses, camps, etc. Expenditures for both new construction and repair are included.

Canada, are both beneficial and detrimental to construction. Sand and gravel are extensively used as construction materials, with a production value of \$128 million in 1968. At the 1980 level of construction, estimated at \$20 billion, the value of sand and gravel would be approximately \$200 million.

Relatively large areas of marine or lacustrine clays (Figure V.3), while often excellent for agriculture, cause serious foundation problems and slope instability in engineering construction (Figure V.1).

In addition, some 500 000 square miles of Canada are covered by muskeg or organic terrain which poses peculiar problems in road and railway construction or renewable resource development. Although organic terrain occurs at almost any latitude in Canada (Figure V.3), it is most abundant over the Canadian Shield, particularly in the northern latitudes.

Additional engineering problems associated with both mineral and organic terrains of northern Canada are caused by the high ice content of the subsoil in many permafrost areas. Disturbance of the ground surface by construction or other activities in permafrost terrain commonly leads to a change in the thermal equilibrium, to melting of ground ice (thermokarst), and to complete structural failure or accelerated soil erosion which, locally, may be very costly.

The scope of Canadian geotechnical activities, however, is not confined to earth materials of Pleistocene age but, in fact, encompasses all geological materials. Excavations in solid rock for mining or hydroelectric development, or the construction of dams or bridges founded in swelling clay shales of Cretaceous age in western Canada (Figure V.3), are further examples of geological environments where geotechnical activities have played an essential role.

In the Cordilleran region of western Canada the rugged terrain and climatic factors strongly influence the construction and maintenance of access routes, as exemplified by massive landslides along the Hope-Princeton and Squamish highways and avalanches in the Rogers Pass area. Geotechnical studies to control or reduce these hazards are, therefore, of particular importance.

In spite of no serious earthquake damage in recent years, the country possesses two areas in which possible severe damage could occur (Figure V.4). These areas are the Pacific Coast and the Lower St. Lawrence Valley, one of the most populous areas of Canada.

While the evaluation of the intensity and probability of earthquakes on a regional basis is an important task of the seismologist, the influences of dynamic loadings, such as produced by earthquake shock, on the behaviour of various soil types is of concern to the soil mechanics and foundation engineer. Earthquake provisions of the present National Building Code with respect to soft compressible soils, for example, specify that buildings be designed to resist 1.5 times the loads due to earthquakes. The multiplication factor is arbitrarily applied regardless of building height, soil depth or topographic location of the building because more precise knowledge of the reaction of the soil to earthquake loading under various stratigraphic and topographic conditions does not exist. It is estimated' that the cost of the use of the earthquake loading factor is \$500 000 per year for the City of Ottawa alone, and that substantial reductions in this cost could be attained through an adequate knowledge of the behaviour of soils under dynamic loading.

The importance of geotechnique is, therefore, in its essential assistance to safe and economical operations on or within Canada's diverse terrains.

<sup>&</sup>lt;sup>1</sup>National Research Council, Associate Committee on Geotechnical Research, and Geotechnical Engineering Division. Engineering Institute of Canada. Report on the geotechnical sciences to the solid-earth science study group of the Science Council of Canada. NRC, Assoc. Comm. Geotech. Res., Tech. Memo. No. 95, 1969.



Figure V.2-W.A.C. Bennett Dam from the Right Abutment, November, 1968 (Photo courtesy of the British Columbia Hydro and Power Authority)







# V.4 Geotechnique and Resource Development

Natural resources in the form of minerals, fossil fuels and water constitute an essential base for the Canadian economy. Accordingly, the discovery, management and exploitation of these resources to obtain maximum benefits for both the present and the future is the concern of all sectors of the economy.

The role of geotechnique in resource development is primarily to provide the basic data on terrain conditions and on the mechanical and physical properties of earth materials. This knowledge is fundamental to the economic and safe design of structures founded on, excavated in, or constructed of, earth materials.

An excellent example is the Portage Mountain (W.A.C. Bennett) Dam, an earthfill structure 600 feet in height on the Peace River near Hudson Hope, B.C. (Figure V.2). The location of earth materials for construction<sup>1</sup>, evolution of the design of the dam<sup>2</sup>, and quality control of earth materials during construction<sup>3</sup> were all based on geotechnique, without which the project would not have been possible.

Many geotechnical problems, such as slope stability, groundwater control and rock breakage, are common to both the mining and construction industries. Inherent in the continuing requirement for mineral resources is the increasing utilization of near-surface, low-grade ore deposits, or deposits of higher grade but at greater depths. The problems of slope stability and economic slope design for open-pit mines, and the prediction and control of surface and groundwater in mining operations, are part of the fabric of Canadian mining operations.

Open-pit mines commonly measure thousands of feet across and a few hundreds of feet in depth; consequently, millions of cubic yards of waste rock are removed along with the ore. Economic operation of these mines dictates the use of the steepest possible pit slopes commensurate with safety. Since steepening 230 of an open-pit slope by only a small percentage can eliminate the removal of millions of cubic yards of rock, the modest sums spent on rock mechanics research related to open-pit slope stability can produce enormous savings in mine operating costs.

Whenever excavations are extended below the water table, control of groundwater becomes essential for both the stability of the excavation slopes and the operations on a dry pit bottom. In foundation construction, dewatering is commonly a temporary measure required only during the period of open excavation. In open-pit mining, however, it is a continuous operation during the life of the mine; the daily quantities of water discharged may be of the order of millions of gallons as, for example, at Knob Lake<sup>4</sup> where the daily discharge from the open-pit iron mines exceeds 23 million gallons of water per day.

The design of effective and economical dewatering systems can be made only on the basis of a thorough knowledge of the water-bearing characteristics and distribution in space of the geological materials, which is a specialized geotechnical activity in both mining and construction industries. A fundamental geological feature of particular concern not only in geotechnique but also to the migration and accumulation of oil and gas is the spatial geometry and magnitude of pore spaces. Thus, geotechnical studies are concerned not only with the properties of earth materials themselves but with the discontinuities as well, which influence the mass behaviour of the materials.

Canadian resource development is commonly characterized by contemporaneous yet widely separated activity in both the mineral and energy sectors. For

Ripley, C. F. Portage Mountain dam: an outline of the project. Can. Geotech. Jour. IV (2): 125-141. 1967.

<sup>&</sup>lt;sup>2</sup>Morgan, G. C., and M. C. Harris. Portage Mountain dam, materials. Can. Geotech. Jour. IV(2): 142-183. 1967.

<sup>&</sup>lt;sup>3</sup>Low, W. I., and A. P. Lyell. Portage Mountain dam, development of construction contol. Can. Geotech. Jour. IV(2): 184-228. 1967.

<sup>&</sup>lt;sup>4</sup>Stubbins, J. B., and P. Munro. Open-pit mine dewatering-Knob Lake. CIM Bull. 58(640): 814-822. 1965.

example, construction of the W.A.C. Bennett Dam on the Peace River in British Columbia was, in part, simultaneous with the development of potash resources in Saskatchewan. The present high level of activity in petroleum exploration in the Arctic is contemporaneous with hydroelectric development at Churchill Falls, Labrador, and on the Columbia River in British Columbia. Thus, we submit:

### Conclusion V.1

Knowledge and evaluation of the engineering significance of a wide variety of terrain conditions and earth materials and processes are essential to resource development. A high level of Canadian competence in geotechnique must therefore be maintained.

# V.5 Geotechnique and Transportation

The political union of the provinces and territories of Canada in 1867 was heavily dependent upon the provision of transportation facilities and, in fact, was a prerequisite for the entry of the Maritimes and British Columbia into Confederation. Since Confederation, transportation systems have been the most important single element in the economic development of the country. This condition still exists and can be expected to continue in the foreseeable future.

Our modes of transportation have been greatly influenced both by technological advances and by the types of material requiring transport. During the period 1850-1925, railway track mileage increased from 66 miles to 40 000 miles. Since 1925 the operational mainline trackage of railways has remained about 43 000 miles. Included in this total, however, are approximately 2 500 miles of new railways constructed since World War II over some of the most difficult terrains, in response to mineral developments such as the lead-zinc deposits at Pine Point, Northwest Territories, and the iron ore deposits of Labrador-New Quebec.

Before 1900, intercity roads and highways were few in number and most roadbuilding was concentrated in and around cities to facilitate local traffic and economic development. The demand for more and better roads, which began about 1915, has continued to the extent that we now have about 450 000 miles of highways and rural roads, of which approximately 15 per cent are paved, the rest being gravel or earth surfaced. Also, there are approximately 45 000 miles of urban roads and streets, of which 65 per cent are paved.

The postwar period has brought a tremendous increase in air travel, with an attendant requirement for airport facilities at all of our centres, as well as at smaller centres, particularly in the North. The most striking development of a transportation mode in the postwar period, however, has been that of pipelines. Pipeline mileage was negligible in 1950, but by 1968, 42 companies were operating 14 457 miles of trunk and gathering lines for the transport of oil. Also, at the end of 1967 there were 48 295 miles of gas pipelines of which 11 per cent were gathering lines, 32 per cent transmission lines, and the rest distribution lines. In the 17-year period since 1950, the pipelines' share of materials transported on a ton-mile basis (Figure V.5) has risen to about 22 per cent, which is twice that of road transportation and almost equal to that of water transportation.

In terms of ton-miles of materials transported, the transportation modes in Canada rank as follows: railways, 43 per cent; water, 26 per cent; pipelines, 22 per cent; roads, 9 per cent. While air freight shipments on a ton-mile basis are only a fraction of 1 per cent of the total, this mode of transport is experiencing the fastest rate of growth; in terms of passenger-miles it exceeds both road and rail forms of commercial transportation.

While future changes in relative importance of the various transportation modes can be anticipated, it is significant from the geotechnical standpoint that all





Adapted from Weir, T.R.-Population Change in Canada, 1867-1967, Can. Geog., Vol. XI, No. 4, 1967

of the modes are beneficiaries of geotechnique, either throughout their routes or at terminal facilities.

Canadian expenditures for roads and highways in 1967 were approximately \$1.7 billion, and the two major railways spent \$351 million on track. When combined with expenditures for pipelines, canal systems and airports, the annual expenditures for construction and maintenance of transportation systems are well over \$2 billion. On a per capita basis these costs amount to over \$100 per Canadian per year, which is more than in almost any other country.1 A substantial portion of these costs is due to problems of a geotechnical nature.

Our terrain and weather conditions combine to make the economic construction of surface transportation systems difficult. As the need for transportation and communication systems expands northward, particularly into areas of muskeg and permafrost, the economic effect of terrain and weather conditions gains importance. Increased geotechnical activity is therefore needed to reduce the capital and maintenance costs of these systems.

### V.6 Geotechnique in Urban Planning and Development

Canada's population at the time of Confederation was 3.5 million, and since then the population has increased sixfold to the present level of 21 million. Throughout this period, significant changes have occurred in the regional patterns of population growth.

At the beginning of this century approximately 60 per cent of Canada's population was living in rural areas, and 40 per cent of the labour force was employed in agriculture. In the succeeding decades, in particular those following World War II, the process of urbanization continued, to the extent that 70 per cent of the population are now urban dwellers and only 10 per cent of the labour force is engaged in agriculture.

On a geographic basis, the distribution 234

of population (Figure V.6) has been characterized by concentrations in the major urban areas, particularly in the St. Lawrence Valley-Lower Great Lakes areas of Ontario and Quebec, and by more widely scattered populations in the principal agricultural and mining areas of the Maritimes, eastern Canada, the prairies, and British Columbia. Increases in population in the past 20 years have tended to intensify the distribution pattern rather than to create substantially new patterns. Consequently, almost 65 per cent of our national population is contained within a relatively narrow corridor that extends from Quebec City to Windsor. From a geotechnical standpoint this region is characterized by problems of foundation and slope stability in marine and lacustrine clays, as well as being one of the areas of highest seismic risk in the country.

It is anticipated that Canada's population will almost double within the next 30 years, which will require almost the same number of new buildings and public facilities that now exist. The Canadian urbanization trend, occasioned by the rapidly increasing development of manufacturing and service industries, is clearly established, and it can be logically predicted that future population growth will be within the urban environment. Unless this growth is directed toward new population distribution patterns, the present population centres will inevitably face increasing pressure to expand both laterally and vertically to cope with population growth.

Geotechnical investigations to evaluate foundation conditions and design parameters for major structures in urban areas are generally accepted in Canadian engineering practice. Such investigations are performed mostly by consulting engineers for a variety of clients in both private and public sectors.

Rational interpretation of the engineering results from specific site investigations requires a knowledge of the stra-

<sup>&#</sup>x27;Report on the geotechnical sciences, op. cit.

tigraphic and spatial arrangement of the earth materials at the site and their relationship to the areal geological framework. For most Canadian urban centres the stratigraphic and areal distribution of earth materials is imperfectly known at best. A great deal of valuable geological data of potential benefit is contained within construction excavations in urban areas. Much of this information, however, is never recorded and the opportunity for obtaining it is lost as the excavation is filled. Attempts by geologists or engineers to contribute to knowledge of the areal geology of urban areas have been all too commonly frustrated by a lack of financial support occasioned, in part, by the problems of jurisdictions of municipal, regional, provincial and federal government agencies. Also, Canadian earth scientists have failed to demonstrate to both the public in general and planning groups in particular the significance of basic geological data in urban and regional planning.

Under these conditions it is not surprising that earth scientists have shown a decided preference to concern themselves with research problems in the more remote areas of Canada, where an urgent need for their efforts of course exists, but where the complications of human organizational problems have much less of an influence on their scientific activities. Therefore we submit:

### Conclusion V.2

Each major city should have at least one geotechnical engineer, whose functions should include the systematic collection and compilation of earth science data from all available sources and the dissemination of this information for urban planning and construction needs.

Considerable effort is being devoted by various disciplines' to formulate concepts and methods to provide society with a rational basis for planning, which will provide an optimum relationship between community development, resources and economic development. While general agreement may not be reached on the exact geometry of a planning region, and on the best organization and methods for planning and implementation of planning within the region, it is nevertheless apparent that the trend of population distribution will dictate some form of urban-centred regional community as described by Gertler.<sup>2</sup>

Although planning for orderly urban and regional development and growth is based primarily on law and on the principles of economics, the execution of any such plans is inextricably involved with terrain conditions. Consequently, the prime role of geotechnique in urban and regional planning is the provision of basic data on terrain conditions and on the properties of materials. Such data are essential to the most efficient, economic and safe utilization of land, mineral, fuel and water resources, in view of the potential multiple use of these resources by the various sectors within the planning region.

Most construction activity for urban development-whether in the form of building foundations, transportation systems, utilities and services, or recreational areas-is contained within the upper few tens of feet of material beneath the earth's surface. In special cases construction may involve earth materials to a depth of 100 or 200 feet. These depths are relatively insignificant as compared with exploration depths of 10 000 feet in the mining industry and 17 500 feet in the petroleum industry. However, the increasing intensity of human activity within the near-surface zone demands a detailed knowledge of the distribution and properties of both the surficial and bedrock materials within this zone, and also an understanding of the consequences of disturbance of the earth materials on the bioliogical and hydrological regimes.

The potential users of geological data in urban areas include city and regional planners, municipal engineers, foundation engineers, suppliers of construction

<sup>&#</sup>x27;Resources for Tomorrow Conference. Montreal, July 1961. Background papers and proceedings, 3 vols.

<sup>&</sup>lt;sup>2</sup>Gertler, L.O. Regional planning and development. Resources for Tomorrow Conference. Background papers, Vol. 1. 1961, pp. 393-407.

materials, the geological community and the general public. Consequently, the geological data requirements in urban areas vary with the user. In order that urban geology studies are of maximum value to all potential users, the studies must integrate such elements as physical properties, engineering characteristics, erosion susceptibility, groundwater conditions and seismic stability with the basic geological framework of the stratigraphic and areal distribution of the materials. We therefore conclude:

### Conclusion V.3

Provincial governments should accelerate their detailed geological mapping (at scales of 1:50 000 or larger) of the urban and surrounding population growth areas, with particular emphasis on surficial materials, land forms and hydrogeological data. Federal government agencies should assist in these programs, particularly in individual pilot studies, and provide geotechnical compilations and analyses of national interest.

# V.7 Present Activities in Geotechnique

#### Introduction

In terms of diversity of activities, geographic distribution of effort and interrelationship with other sciences and engineering, geotechnique is one of the most complex components of the earth sciences. Activities are centred in industry, principally with consultants, in federal and provincial government agencies, and in the universities. An assessment of the present levels of activity in geotechnique has been made on the basis of questionnaire returns and background papers requested by this Study Group, and with extensive use of published information on support of research in the earth sciences.

Consideration is given in this section to the important questions of size and distribution of geotechnical manpower, level and types of geotechnical activities in the <sup>236</sup> various sectors, magnitude and sources of funding for geotechnical activities, and the influence and effectiveness of existing communication systems in the development of geotechnique both as a scientific activity and as an asset to national development.

Of the 93 questionnaires mailed to major consulting firms, contractors, and government agencies involved in geotechnical activities, 40 per cent were completed (Table I.2). The capital costs of the projects of these respondents were 64 per cent of the national value of non-residential and engineering construction reported by the Dominion Bureau of Statistics for 1968. We therefore consider that the data contained in the questionnaires are a useful guide for activity levels in the industrial and government sectors.

Levels of support and topics of research are well documented in publications of the National Research Council and the Geological Survey of Canada, from which it has been possible to obtain a clear picture of geotechnical activities within the universities.

An assessment of the effectiveness of communications systems within geotechnique is not amenable to direct forms of measurement. The background papers, questionnaires and briefs prepared for the Study Group, as well as published information on technical societies, conferences and related topics provide the basis for an informed overview.

Since geotechnique, as it is presently recognized, has developed in Canada primarily since World War II, and since the field comprises numerous activities, there are marked differences in the rate of growth of its various components. These disparities are attributable in part to the relatively brief history of the field. Perhaps more importantly, however, geotechnique is closely linked with the rapid growth and development in both the construction and mining industries. It has been used to meet the immediate requirements of these industries without consideration of the need for a planned and orderly development of the science

and its manpower.

### Expenditures

Expenditures on geotechnical activities are mainly in the industrial and government sectors, where they relate directly to construction projects, and the university sector, in which expenditures are for support of geotechnical research.

Expenditures Related to Construction The replies to our questionnaire provided some insight into the relationship between the capital cost of construction projects and the magnitude of related geotechnical expenditures. In 1968, geotechnical expenditures averaged 0.4 per cent of the capital costs of construction projects. Expenditures for any particular project, however, ranged from less than 0.1 per cent to 2.0 per cent of the capital cost, depending upon the complexity of the project and the interrelated influence of the geotechnical aspects. Drilling and sampling (Table II.20), which constitutes 44 per cent of total geotechnical activities related to construction, is the largest single item of expenditure in both industry and government sectors, followed generally in decreasing order of expenditure by laboratory and office activities, field activities such as mapping, research and development, and scientific information.

In 1968, total Canadian expenditures in geotechnical research and development were \$4 million (Table II.20), which is only 0.04 per cent of the value of construction to which geotechnical activities apply. This is in strong contrast with the mineral industry which, in 1968, spent \$42 million on earth science research and development, or close to 1 per cent of the value of mineral production. All of the examples of research and development carried out by industry were applied research and development related directly to the construction projects on which consultants were engaged. Thus, geotechnical R & D activities in the industrial sector appear to be related to specific construction projects and supported by fees for engineering services, with a negligible

amount of "overhead" research and development activity. The general lack of "overhead" research can, in part, be attributed to a lack of individual company resources for research and to a certain lack of interest or willingness on the part of some consultants who feel that they are not in the best position to conduct R & D. However, 71 per cent of the consultants who completed our questionnaire indicated a willingness to carry out contract research that was not directly related to a specific construction project.

### Government Expenditures

Examples of research and development activities within the federal and provincial governments provided by agencies that responded to the questionnaire were not sufficient to permit an accurate overall assessment of their expenditures on geotechnical research. An estimate of their level of expenditures, however, has been made on the basis of reported amounts of federal government support and unit costs' of research in science and engineering departments based on the number of faculty members.

University Research Expenditures The forecast unit cost of operating and minor equipment funds for research in science and engineering departments at Canadian universities for 1969 was \$20 400 per faculty member engaged in research.<sup>2</sup> There are approximately 70 faculty members of Canadian universities involved in geotechnique, so that the level of their operating and minor equipment research expenditures for 1969 would be \$1.4 million. Since operating and minor equipment funds constitute between two-thirds and three-quarters of total research fund requirements for engineering departments, the total level of present funding for geotechnical research at Canadian universities is probably of

<sup>2</sup>Loc. cit.

<sup>&#</sup>x27;National Research Council of Canada. Projections of manpower resources and research funds 1968-72: science and engineering research in Canadian universities. A report of the Forecasting Committee (Chairman: L. P. Bonneau). Ottawa, 1969.

the order \$2 million, derived almost entirely from government sources.

Grants in support of geotechnical research in the universities provided by the federal government in 1968 totalled \$763 000. As shown in Table II.27, the distribution of research support to the various geotechnical specialities is uneven, but this is a direct reflection of the research interests of the applicants themselves and not of the manner in which the funds were distributed.

#### Industry Expenditures

Present direct support by the construction industry of geotechnical research not directly related to a specific construction project appears to be virtually nonexistent. This at first sight may appear incongruous with the annual value of Canadian construction. It is recognized, however, that the design professions of the construction industry, which are the major direct users of geotechnical research results, comprise a large number of relatively small firms with heavy internal demands on their limited budget. Consequently, any surplus capital that these firms may have is directed toward their own business development. Similar circumstances exist for contractors in the construction industry and, to a lesser extent, for the manufacturers and suppliers to the construction industry. Furthermore, no industry-sponsored central organization exists that would represent the interests of all segments of the construction industry and through which any industry-contributed research funds could be allocated. Under these circumstances, the Division of Building Research of the National Research Council, through its central and regional laboratories, fills an important need. The services of this division might usefully be extended by the provincial research councils in co-operation with the construction industries in their area.

Manpower Distribution and Functions The distribution of geotechnical manpower in the industrial, government and university sectors in 1968 is given in Table V.1. This population has been calculated from completed geotechnical and government questionnaires submitted to the Study Group, and from the membership list of the Canadian Section of the International Society for Soil Mechanics and Foundation Engineering', with minor upward extrapolation of numbers in the industry sector to accommodate the probable manpower not reported by the questionnaires. We consider these estimates to be realistic.

Table V.1-Distribution of Geotechnical ProfessionalManpower by Sector, 1968

Sector	Numbers Percentage			
Industry	250	46		
Federal Government	123	22		
Provincial Government	105	19		
University	70	13		
Total	548	100		

The distribution of Canadian geotechnical manpower both by sector and by speciality based on the 1968 membership list of the Canadian Section of the International Society for Soil Mechanics and Foundation Engineering is given in Table V.2. This membership list contains 79 per cent of the manpower indicated in Table V.1.

It is apparent from both Tables V.1 and V.2 that soil mechanics is the dominant geotechnical speciality, followed by engineering geology and rock mechanics. Almost half the total geotechnical manpower is within the industrial sector.

The geotechnical manpower in industry is concentrated almost entirely in consulting firms. Besides filling domestic requirements for their services, almost half the firms who responded to our questionnaire had carried out work in 24 countries throuout the Caribbean, Central and South America, Europe, Africa, the Middle East, and Asia. Hydroelectric

<sup>&#</sup>x27;Eden, W.J., J. Butler, and D. Tremblay. Annual report of the Canadian section of the International Society for Soil Mechanics and Foundation Engineering for the year ending June 1968. Nat. Res. Council, Assoc. Comm. on Geotech. Res., Tech. Memo. No. 94. 1968.

 Table V.2-Distribution of Membership of the Canadian Section of the International Society for Soil Mechanics

 and Foundation Engineering for the Year ended June 1968

Geotechnical Speciality	Universities				Government				Industry	
	Faculty		Graduate Students		Federal		Provincial			
	No.	%	No.	%	No.	%	No.	%	No.	%
Soil Mechanics	56	12.9	32	7.4	83	19.2	54	12.5	174	40.2
Rock Mechanics	1	0.2	0	0.0	1	0.2	0	0.0	3	0.7
Engineering Geology	6	1.4	1	0.2	1	0.2	4	0.9	13	3.0
Geography	1	0.2	0	0.0	0	0.0	1	0.2	0	0.0
Geophysics	0	0.0	0	0.0	0	0.0	0	0.0	1	0.2
Biology	1	0.2	0	0.0	0	0.0	_0	0.0	0	0.0
Total	65	14.9	33	7.6	85	19.6	59	13.6	191	44.1

developments and transportation systems were the main types of projects in their overseas assignments.

In terms of academic qualifications of geotechnical manpower in the industry and government sectors, the questionnaire returns indicated that over 50 per cent of the personnel in both the industry and government sectors were trained at the bachelor's level (Table II.22). Further, however, the questionnaire returns indicated a definite trend during the past five years toward an increase in the numbers of personnel with postgraduate training, particularly at the master's level, and toward a decline in the percentage of personnel with bachelor degrees only.

### Training

The diverse character of geotechnical activities generates a requirement for professionals with a variety of academic backgrounds such as civil and mining engineering, geology, physical geography, soil science and biology. The present group of professionals, totalling over 500, that constitutes the Canadian geotechnical capability collectively possesses this variety of academic backgrounds. Many of these professionals obtained either a portion or all of their academic training at institutions outside Canada during the period since the Second World War but before the development of geotechnical capabilities at Canadian universities, which occurred primarily during the past 10 years.

Presently, soil mechanics training is offered at the undergraduate and gradu-

ate levels in at least fourteen of the major Canadian universities, and rock mechanics instruction and research is carried out at nine of the major universities. Most of the major universities also provide a small amount of instruction in engineering geology and hydrogeology. Instruction and research in these aspects of geotechnique are, therefore, well distributed geographically throughout Canada, and the faculty capacity (Table II.22) is available for undergraduate and graduate instruction. Only two or three Canadian universities have active research interests in muskeg. Permafrost studies are being pursued at a similarly small number of Canadian universities.

Instruction and research in the various aspects of geotechnique have developed primarily in engineering departments, but with significant inputs from departments of geology, geography, and soil science. Such a pattern characterizes the existing training capability at Canadian universities.

On the basis of our study we submit:

### Conclusion V.4

Adequate training of professionals in the various aspects of geotechnique should be supported at the postgraduate level on the basis of strong interrelations between university departments of civil engineering, geology, and other departments of earth science. Interdepartmental instruction and research in geotechnique should be fostered by the universities and encouraged through research grants.

#### Figure V.7-Distribution of Contributions to the Canadian Geotechnical Journal, 1963-69, according to Geotechnical Specialty and Geological Materials and Processes



### **Current Areas of Geotechnical Research**

The terrain and climatic factors pertinent to geotechnique, as described in Section V.3, provide the major focus for Canadian geotechnical research. The summary of current research activities as shown in Table V.3, although only a partial listing. provides an indication that geotechnical research is being done in all of the major geotechnical problems of concern to Canada. The present pattern of research activity, embracing geotechnical specialities, geographic areas, and materials of geotechnical concern, has been established for at least the past five years, as indicated by contributions, chiefly of Canadian origin, to the Canadian Geotechnical Journal (Figure V.7). Although papers on rock mechanics have not appeared in this journal, numerous Canadian papers in this field have been published elsewhere.1

Additional information on subjects of recent geotechnical research, contained in the reports of the National Advisory Committee on Research in the Geological Sciences, is summarized in Table V.3.

The variety of geotechnical subjects either published or currently undergoing research suggests that a Canadian geotechnical competence has been developed for the major areas of concern. Wide variations exist, however, in manpower capacity in the various aspects of geotechnique in all three sectors. For example, the manpower capacity in the permafrost, muskeg, urban geology and geophysical aspects of geotechnique are but a small fraction of the manpower capacity in soil mechanics and foundation engineering. These areas of geotechnical specialization are, for the most part, unique to Canada, and the manpower capacity requirements cannot be met simply by recruitment outside the country. It is further recognized that the re-

quired expertise in the various aspects

'Bibliographies of Canadian contributions in the field of rock mechanics, compiled by D. F. Coates and published in the *Bulletin of the Canadian Institute of Mining and Metallurgy*, list a total of 167 published papers for the years 1964-67 inclusive, in addition to 43 theses and 83 reports of the Mines Branch (Department of Energy, Mines and Resources) during the same period.

Subjects of Geotechnical Activities	Governm	ient	University	Industry	
	Fed.	Prov.			
Marine clays					
Engineering properties	5*	-	5	_	
Landslides		1	-		
Areal mapping					
Urban geology			1	_	
Regional and site	2	-		Хь	
Rock					
Physical and engineering properties	6	-	3	X	
Engineering classification	3	_			
Slope stability	5	_	1	X	
Stress measurements	7	_	1		
Lacustrine clays	2		1	XXX	
Clay shales	1	-	2	_	
Permafrost and frost action	3		1		
Muskeg and peat	1			X	
Foundation design and field testing		_	-	XXX	
Drilling and sampling methods	_			X	
Field instrumentation		-		X	

Table V.3-Summary of Recent Subjects of Geotechnical Research

Data Sources: 1. National Advisory Committee on Research in the Geological Sciences, Current Research in the Geological Sciences, 1966-67; Geol. Surv. Canada, Paper 67-58 1967-68; Geol. Surv. Canada, Paper 68-54.

2. Geotechnical questionnaire returns for this study.

<sup>a</sup> Numbers indicate the number of researchers involved with a given research project as reported in data source 1.

<sup>b</sup> Indicates frequency of citations from questionnaire returns.

of geotechnique is closely geared to demands from the three sectors in which geotechnical manpower is employed. Consequently, changes in the level of demand for geotechnical expertise, occasioned for example by accelerated construction in areas of muskeg and permafrost or increased industrialization in areas of sensitive marine clays, could readily overtax our present geotechnical manpower capacity.

#### Scientific Communications

The successful development of any sphere of scientific activity and the implementation of research results are both primarily contingent upon the effectiveness of scientific communications. A simplified model of the basic communications of any scientific activity is a tetrahedron, with three apices represented by the domestic sectors of industry, universities and government and the fourth apex by the international sector. From this basic tetrahedron, the communications network evolves with increasing complexity as the scientific disciplines, operational organizations, levels of government and methods of communication are added. Both within the model and in operational fact, the effectiveness of communications is directly related to the strength of the connection between the various components of the network. Many of the factors that influence quality of communications are centred in the behaviour of man himself and are thus a subject for intensive investigation by the social sciences. However, effective communication between scientists is commonly identified with motivation as well as dedication to common objectives unhampered by the necessary but arbitrary boundaries of administrative jurisdictions and scientific disciplines. The implementation of an effective communication system, whether in the form of publications, conferences, symposia or seminars, produces a requirement for an adequate level of financial and manpower support without which the best of human motivation and dedication becomes of little

avail.

The development of the various components of geotechnique in Canada is clearly the result of the impetus provided by several nationally organized and federally sponsored committees. The Associate Committee on Geotechnical Research of the National Research Council has been foremost in the stimulation and co-ordination of research on the engineering and physical aspects of Canadian terrain and in providing liaison with Canadian and international geotechnical organizations. Since its establishment in 1945, the Associate Committee and its subcommittees on Soil Mechanics, Muskeg, Permafrost, and Snow and Ice have sponsored conferences and research seminars in these various aspects of geotechnique. The proceedings of these conferences, published by the National Research Council as technical memoranda of the Associate Committee, constitute a valuable source of Canadian geotechnical information, which complements the geotechnical publications of the Division of Building Research of the National Research Council. Since 1962, the annual Canadian Soil Mechanics conferences have been sponsored by the Geotechnical Engineering Division of the Engineering Institute of Canada. In addition, the subcommittees, in conjunction with local study groups and universities, have sponsored national lecture tours by distinguished lecturers.

In 1963 the Associate Committee sponsored the establishment of the *Canadian Geotechnical Journal* which now has a national and international subscription list of over 1 000.

International relations in geotechnique are fostered by the Associate Committee through its provision of the executive and secretary of the Canadian Section of the International Society of Soil Mechanics and Foundation Engineering.

Development of communication in the field of rock mechanics has been aided by the establishment in 1963 of the Canadian Advisory Committee on Rock Mechanics, sponsored by the Mines Branch
of the Department of Energy, Mines and Resources. This committee is composed of members from the mining industry, universities, the Mining Association of Canada, and from the Mines Branch of the Department of Energy, Mines and Resources. Stimulation of interest, improvement in communications and coordination of research activities in rock mechanics are fostered by the committee through the provision of research funds, publication of bibliographies, and sponsorship of conferences.

Both the National Advisory Committee on Research in the Geological Sciences and the National Advisory Committee on Geographic Research (sponsored by the Department of Energy, Mines and Resources) and the Defence Research Board (Department of National Defence) provide additional avenues for communication between research workers in geotechnique and other aspects of the earth sciences.

We therefore conclude:

#### Conclusion V.5

Within the sphere of Canadian geotechnical activities, effective organizations exist to foster communication and to co-ordinate Canadian geotechnical research. Representative membership and continued financial support for the national advisory research committees are essential to effective communication and co-ordination of research effort.

Scientific activities in geotechnique, as in other aspects of the earth sciences, are carried out on a worldwide basis by countries whose scientific capacities in terms of manpower and financial expenditure vastly exceed ours. It is therefore not surprising that publications such as *Geotechnique*, published by the Institution of Civil Engineers of Great Britain, and the *Journal of the Soil Mechanics and Foundations Division*, published by the American Society of Civil Engineers, both of which contain papers of high quality, occupy a dominant place as reference sources for Canadian geotechnical activities, particularly in the fields of soil mechanics and foundation engineering. Manuals of exploration methods and construction procedures produced by various state and federal agencies in the United States are used constantly by the geotechnical design professions. Our geotechnical expertise has been greatly enhanced by the availability of these foreign publications, which give us the essential benefits of foreign research. While the ready availability of non-Canadian geotechnical information is an asset of which full advantage should be taken, this in no way reduces the responsibility for developing and maintaining the high level of competence necessary to cope safely and economically with Canadian geotechnical problems, and to maintain a manpower capacity in keeping with the demands of national and international markets.

Because of the close relationship between geotechnique and engineering, the main channels of communication in Canadian geotechnical activities have been through the engineering organizations and publications, with only a minor contribution to communications being made by Canadian geological organizations. In contrast, the Geological Society of America, with headquarters in Boulder, Colorado, has had an active Engineering Geology Division since 1947, while at present no division of engineering geology exists within the Canadian counterpart organization, the Geological Association of Canada. The lack of a formal organization for Canadian engineering geology is in large measure a result of the relatively small number of Canadian geologists (about 40) engaged in this activity, but it is also a reflection of the preoccupation of the Canadian geological profession in general with the more traditional aspects of the earth sciences, in particular those relating to the mineral industry. Nevertheless, changes within the Engineering Institute of Canada and the steady growth of geotechnical activity in Canada have combined to pave the way to the establishment, in the near future, of a Canadian Geotechnical Society to replace the existing Geotechnical Engineering Division of the Institute.

Apart from the continuing requirements for internal communications within and between the various professions and organizations concerned with geotechnique, we conclude that:

#### Conclusion V.6

Scientific and professional societies concerned with geotechnique should play a more active role in informing government authorities and educating the general public about the cost benefits of the use of geotechnique in the early planning stages of physical development to avoid terrain misuse and foster economic and safe construction.

# V.8 Geotechnique in the Future

#### Introduction

Future developments and growth of geotechnical activities in Canada are inextricably linked with the anticipated growth patterns for resource development and the expansion of the construction industry in response to growing population and industrialization. It is not possible to predict specific geographic locations in which mineral resource development may occur, or what demands on foundation conditions future industrial technology may impose. However, the general patterns of Canadian economic development and the existing gaps or deficiencies in our geotechnical activities do provide an informed basis upon which a prognosis of future requirements can be made.

#### **Areas for Research**

We have not attempted to compile an exhaustive catalogue of geotechnical research topics from the data contained in the background papers and briefs submitted during the study. An extract of the more important areas for future geotechnical activities in resource development, transportation, and urban and regional 244

planning is presented in Table V.4. The topics considered to be of highest priority in relation to national development are underlined. As we were compiling Table V.4 it was apparent that topics in one area, for example transportation, were equally applicable to resource development or urban and regional planning. Accordingly, the area for research was assigned to the column to which it primarily applied, with its relation to other areas indicated by arrows.

### **Implementation of Geotechnical** Activities

The major requirements for the implementation of geotechnical activities, such as those outlined in Table V.4, required for future Canadian economic development are:

1. Common recognition by governments, industry and universities of the need for these activities, and general agreement on the order of priorities;

2. A pool of competent manpower of sufficient capacity to undertake the task;

3. Adequate financial support from governments and industry;

4. Continued national and international co-operation and communication to avoid unnecessary duplication of research effort and to ensure maximum utilization of research results.

In our opinion, effective implementation of the geotechnical activities required for the development of the various Canadian geographic areas can best be achieved by the active participation of and cooperation among federal, provincial, regional and municipal government agencies.

Effective implementation of the geotechnical programs presented in Table V.4 will require the optimum use of all of the manpower capacity available within the industry, university and government sectors. The greatest population of geotechnical manpower is within the industry sector; the available capability of this sector plus the research capabilities of universities should therefore be fully utilized by governments in conjunction

#### Table V.4-Major Priorities in Geotechnique

Geotechnical Speciality	Subjects for Study in Geotechnique						
	Resource Development	Transportation	Urban and Regional Planning and Development				
Public and Construction Safety	-Development of guides and codes of practice for surface and underground soil and rock excavation to assist in minimizing loss of life and financial resources through failures of earth materials.	$\rightarrow$	$\rightarrow$				
	-Development of instru- mentation for warning of rock and soil slope failures and rock stress level build-up in underground openings.		-Increase public awareness of the economic value of earth science activity in regional and urban development with emphasis on recognition and abatement of natural and induced geological hazards.				
Earthquake Effects and Soil Dynamics	<del>~</del>	<del>~</del>	-Development of national methods of earthquake risk evaluation for Canadian geographic and soil con- ditions involving the co-operation of seismologists, soils engineers and civil engineers.				
	<del>~</del>	<del>~</del>	<ul> <li>Increase studies of soll/ structure interaction under dynamic loadings.</li> <li>Determination of the dynamic engineering properties of soils which</li> </ul>				
			influence liquification and slope stability.				
Permafrost and Climatic Factors	-Development of equip- ment and techniques for rapid exploration of permafrost areas.	$\rightarrow$	$\rightarrow$				
	–Increase activity in mapping and evaluation of permafrost terrain.	$\rightarrow$	>				
	· ~	-Develop technology for the design of pipelines, sewers and other struct- ures on or in permafrost.	$\rightarrow$				
		<ul> <li>Increase study of construction tion techniques and earth material beneficiation to minimize frost action in subgrades and earth fills and to facilitate cold- weather placement of</li> </ul>	>				
	~	soils. -Increase studies of the fundamental nature of ice lensing in porous earth materials. -Develop methods to	$\rightarrow$				
		improve frost depth predictions based on climatic moisture and soil type factors.	$\rightarrow$				
Muskeg	<i>←</i>	-Continued study of terrain/ vehicle trafficability for off-road access in muskeg and soft-ground terrains.					
	-Continued studies of physical properties of muskeg types and the potential utilization of peatlands.	→					

Water Resources	-Continued study of ground- water storage and movement under both natural conditions and as related to the operation of surface water reservoirs. -Continued study of the influence of rivers, reservoirs, lakes and associated groundwater flow phenomena in shore and slope stability.		
	<del>~</del> —		and geochemical impli- cations of surface and subsurface disposal of fluid wastes
	-Study of the migration of contaminants derived from mineral resources activities in surface and subsurface flow systems and the development of methods of contamination abatement.		vasits.
Terrain and Earth	-Improved techniques of terrain analysis by remote sensing.	$\rightarrow$	$\rightarrow$
Materials Studies	-Improvement in drifting, sampling and blasting techniques. -Improvement in surface and borehole geophysical	$\rightarrow$	$\rightarrow$
	techniques for subsurface investigations of soil and rock materials and for hydrogeology. -Continued study of the slope stability char- acteristics of Canadian	$\rightarrow$	$\rightarrow$
	earth materials, with reference to natural and cut slopes, and tills.		
	-Continued study of the relationship between the stratigraphy and engi- neering properties of Quaternary deposits.	-Study of the physical and mechanical characteristics of subgrade material and ballast. -Study of the skidding characteristics of pavement aggregates. -Continued activity to locate and evaluate	<ul> <li>Increased effort in geological mapping of urban and population growth areas with the results presented in a form to maximize multiple use benefits.</li> <li>Increased effort in the development of data storage and retrieval systems.</li> </ul>
	<del>~</del>	granular material resour- ces and to provide guidelines for the control of their development.	$\rightarrow$
	-Studies to determine economic methods of landscape restoration following open-pit and strip mining operations. -Continued study of the strength-deformation characteristics of problem soils and rocks.	-Development of effective economical means for controlling slope erosion. -Development of methods of benefication of earth materials for construction.	$\rightarrow$

with their own personnel in carrying out geotechnical programs supported by public funds.

The future demand for trained geotechnical personnel will be determined mainly by the government and industry sectors in relation to the requirements for national development. Thus, a continuing program of manpower training centred in the major universities, with emphasis on the multidisciplinary aspects of geotechnique, will be required to maintain and increase our national geotechnical competency.

Research in geotechnique at the universities is recognized as an integral part of the training program. While most geotechnical research is of an applied nature, and is likely to remain so, a balance of research support must be maintained, both among the various aspects of geotechnique and between applied and basic research. We believe that an appropriate ratio of support for applied and basic research in geotechnique is of the order of 5 to 1.

The present level of Canadian expenditures on research and development in geotechnique is 0.04 per cent of the value of construction to which geotechnical activities apply. When compared with the commonly proposed target level for R & D expenditures of 2 percent of the Gross National Product, a level which the Science Council' believes will need to be surpassed by future major Canadian R & D programs, the amount spent on R & D in geotechnique is pitifully small.

For present R & D expenditures to attain a level of 2 per cent of the pertinent value of construction, an immediate 50fold increase in funding would be required, with subsequent annual increases of 5 per cent or 6 per cent being required to maintain the level. While such an enormous increase is obviously beyond the bounds of both economic feasibility and desirability, it nonetheless indicates the extent to which present geotechnical R & D expenditures fail in reflecting the importance of the construction industry to the national economy. We believe that geotechnical R & D expenditures should be in proportion to the magnitude of construction expenditures; thus, the following analysis provides a means of establishing a realistic target level of geotechnical expenditures for 1985.

We estimate the 1985 value of construction to be not less than \$25 billion. Since geotechnique pertains to at least 60 per cent of the value of construction, we obtain \$15 billion as the gross value of construction having a significant geotechnical component. Engineering costs of construction which include direct expenditures for geotechnique commonly average 5 per cent of the total value of construction. Thus, the value of engineering for construction to which geotechnique applies directly would be \$750 million.

If we use an R & D expenditure level of 2 per cent, then the 1985 level of geotechnical R & D would be \$15 million, or approximately four times the present level of expenditures.

On the basis of this analysis, we submit:

#### Conclusion V.7

The 1985 target for geotechnical research and development expenditures should reach 2 per cent of the value of the engineering costs of construction to which geotechnique applies. This target will be of the order of \$15 million, or approximately four times present geotechnical R & D expenditures.

It is recognized that the attainment of this target will require an increase in present research and development expenditures of 10 per cent per year, exclusive of compensating rate increases for dollar devaluation and increasing R & D sophistication. Such an increase, however, is entirely consistent with the 10 per cent annual growth rate of the construction industry and the annual growth rate of

Science Council of Canada. Towards a national science policy for Canada. Report No. 4. Ottawa, Queen's Printer, 1968.

the Gross National Product of approximately 8 per cent.

We believe that it is unrealistic to assume that all increases in research support must come from the federal government through grants in aid of research provided by the National Research Council, the Department of Energy, Mines and Resources, or the Defence Research Board.

Since the construction industry, through the design professions, is the major direct user of the results of geotechnical R & D, we submit:

Conclusion V.8

The conduct of geotechnical research and development by the construction industry and the engineering profession should be encouraged through tax-incentive programs. These programs should be sufficiently flexible to foster co-operation in joint R & D efforts among the construction industry, the engineering profession, project users or owners, universities, and research establishments.

We believe that particular emphasis in future geotechnical research and development should be placed on those aspects of geotechnique pertaining to areas of resource development, transportation, and urban and regional development, especially in the Canadian North, as listed below:

Resource development:

- Slope stability studies;

- Economic methods of land restoration;

- Strength/deformation characteristics of earth materials;

- Guides of practice for earth material excavation;

- Rapid permafrost exploration methods;

- Groundwater movement and storage.

#### Transportation:

-Inventory of granular material resources;

- Beneficiation of earth materials for construction;

- Development of technology for construction in permafrost areas;

- Minimization of frost action in subgrades;

- Terrain/vehicle trafficability in muskeg and soft ground.

Urban and regional planing and development:

- Geological studies and mapping in urban areas;

- Development of earth science data storage and retrieval systems;

- Increased public awareness of the economic value of earth science data and methods in the abatement of natural hazards;

- Development of national methods of earthquake risk evaluation;

- Hydrodynamic and geochemical implications of surface and subsurface disposal of wastes.

Thus, while all aspects of geotechnique are of importance in these areas, urban geology, engineering geology, rock mechanics, muskeg and permafrost are particularly so.

At present, soil mechanics is the dominant sector of geotechnique in terms of both manpower and receipt of research grants. While it is expected that soil mechanics will continue to be the dominant aspect of geotechnique because of its broad and diversified application to other geotechnical sectors, we nevertheless conclude:

#### Conclusion V.9

The faculty of departments of civil engineering, geology and geography should pay more attention to the opportunities for research and development in urban geology, engineering geology, rock mechanics, hydrogeology, muskeg and permafrost, particularly as these fields relate to national development.

Since federal government funds for research in the earth sciences are granted in response to requests for funds by qualified applicants, it is only reasonable

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to expect that increases in the total amount of research support for geotechnique will be occasioned by a demand for funds in support of new research projects in the universities. We believe, therefore, that the university geotechnical community has both a responsibility and an important role in providing leadership in research in those aspects of geotechnique in which the need is greatest.

In our opinion, geotechnique receives a fair proportion of the total university earth science research grants provided by the federal government. However, we submit:

#### Conclusion V.10

The present level of federal government support for research in geotechnique in the universities is at a minimum and the annual growth of this support in proportion to the budget increases of the fund-granting agencies is sufficient only to maintain this minimum. Support of the present university research programs must be continued, and the federal government fund-granting agencies should be prepared to provide increased support for new research programs in urban geology, engineering geology, rock mechanics, hydrogeology, muskeg and permafrost.

Although support of university research is an important function of government agencies, their principal role should continue to be the implementation of government policy for national and provincial development in the best interest of the public. We submit:

#### Conclusion V.11

New geotechnical programs within the various areas of responsibility of federal and provincial government agencies should be directed toward providing new knowledge in the fields of urban geology, engineering geology, rock mechanics, hydrogeology, muskeg and permafrost, as an aid to national development and to increasing Canadian geotechnical competence and manpower capacity in these fields.

If future Canadian economic and scientific development is to obtain a full measure of the benefits to be derived from geotechnical activities, then the three operating sectors of industry, university and government in which geotechnical activities are carried out must devote their efforts in a co-operative manner toward the common geotechnical objectives of safe and economical engineering operations on or within our diverse terrains. Each operating sector has a role which it performs best, whether it be the provision of a high-quality service on a fee basis by consultants for the public or private sectors of the economy, the traditional role of teaching and research by the universities, or the provision of basic information by government agencies. It is inevitable that in some areas of endeavour and at various times some overlap of functions will occur among the several operating sectors. While outright duplication of effort is to be avoided, the emphasis must be placed on the major missions of the sectors, not on the areas of overlap.

Chapter VI
Renewable Resources and
 Land Planning

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"To skin and exhaust the land instead of using it so as to increase its usefulness will result in undermining in the days of our children the very prosperity which we ought by right to hand down to them."

### President Theodore Roosevelt

#### VI.1 Synopsis

In the many facets of this study the recurring theme is that of the contributions of earth sciences to economic growth, as well as physical and regional development. From an economic standpoint we can look forward with confidence to the continued contribution of the earth sciences to national prosperity, but we must bear in mind that our terrain resources are limited. The increasingly competitive use of the land, whether for extractive purposes, agriculture, forestry, hydroelectric development, industrial and urban development, or recreation and nature conservation, necessitates judicious use of natural resources and demands proper regard for preserving the quality of the natural environment. In this context, we discuss the contributions of earth sciences to the management of renewable resources and land use planning, with special reference to agriculture, forestry and water resources. Multiple use land planning is discussed in some detail and the significance of biogeochemistry in nutrition and welfare is emphasized. Although succinct, this chapter is important, as it completes the survey of earth sciences in the service of the nation.

The Science Council of Canada has already sponsored special studies in the important fields of water resources', agriculture<sup>2</sup>, and forestry<sup>3</sup>, each of which receives a significant input from the earth sciences, as does the rapidly developing field of land use planning. Because of these existing studies our approach has been to provide a perspective rather than an in-depth study of the applications of earth sciences to these fields. We have

attempted to demonstrate the interdependence between the earth sciences and these other disciplines, as well as to highlight the close relationship between land use planning, renewable resource development, and geotechnique.

# **VI.2** Introduction

The present public and political concern in North America over pollution of water and air, destruction of wilderness areas, urban sprawl, and other factors contributing to deterioration in the quality of man's environment, is a symptom of the acute need for much greater attention to the management of our natural environment and resources. Canadians not only face the challenge of achieving effectively the anticipated accelerated growth of urban centres, but are also responsible for the development and management of one of the largest and little disturbed wilderness areas remaining in the world. A concerted attack on these challenges and problems, although circumscribed by social, economic, and legal factors, must be based upon objective, factual, scientific information concerning land4 or terraininformation which is the essence of the earth sciences.

### VI.3 Relation of Earth Sciences to Land and Renewable Resources

Notwithstanding the progress of modern technology, the activities of man are circumscribed to a considerable degree by constraints imposed by the land: where man builds his cities; lays out roads, pipelines, and dams; grows crops and harvests timber: obtains the water neces-

Bruce, J. P., and D. E. L. Maasland. Water resources in Canada. Science Secretariat. Special Study No. 5. Ottawa, Queen's Printer, 1968.

<sup>&</sup>lt;sup>2</sup>Smallman, B.N., et al. Agricultural science in Canada. Science Council Special Study No. 10, Ottawa, 1970.

<sup>3</sup>Smith, J. H. G. and G. Lessard, Forest resources research in Canada. In press.

In the present context, "land" is considered to comprise the physical components of the surface of the solid earth. namely relief and landforms, rock. unconsolidated earth materials, soils in the pedological sense, and water.

sary for life and industry; and discards the waste products of his manifold activities. The ever-increasing complexity of and competition for land use in Canada today and that anticipated in the near future must be paralleled by increased and more effective land use planning for all purposes.

Knowledge of the nature and behaviour of the land, which is essential to effective planning and management of land resources, is based upon earth science information concerning relief and landforms, surface and near-surface bedrock, unconsolidated earth materials, soils in the pedological sense, as well as water both in and on the ground. Facets of geology, physical geography, soil science, and soil engineering are all involved.

# VI.4 Agriculture

Although occupied and potential agricultural land makes up only about 12 per cent of the land area of Canada, farms comprise one-third or more of the land area of several provinces and, in total, occupy some 270 000 square miles of the most valuable land in Canada. The soil on these farm lands is the essential base for the agricultural industry. Sound management of this most important resource, to maintain or increase the productivity of soil, is essential to the future well-being of our nation.

#### Soil Science and Pedology

The need to appraise and understand agricultural land and soil<sup>1</sup> has led to the development of soil science as a distinct and separate scientific field which is dependent upon agriculture for its existence, but nonetheless is closely tied to the earth sciences. The Canadian Soil Science Society glossary of terms (1967) defines soil science as "dealing with soil as a natural resource on the surface of the earth including soil formation, classification, and mapping, and the physical, chemical, biological and fertility properties of soil *per se;* and these properties in relation to their management for crop production". As the study of soils in their natural environment, pedology comprises those aspects of soil science concerned with characterization, genesis, classification, and mapping of soils.

Soil formation involves first, the accumulation of the parent material by geological processes, and second, the differentiation of soil horizons and development of the soil profile in the upper part of the parent material by pedological processes. Horizon differentiation in mineral soils is brought about by weathering of minerals in the parent material; accumulation and assimilation of organic matter; transformation, transfer and removal of materials; and development of structure. The essential elements in this process are vegetation, climate and time, but the soil is also influenced by a variety of parent and geological features, including particle size and sorting, chemical constitution of minerals, kind and amount of salts, permeability and drainage, landforms and topography.

The pedologist or soil scientist characteristically receives his university training in a soil science department of a faculty of agriculture, but his studies commonly include basic earth science courses.

Soil investigations fall into three categories: a) soil survey, including soil classification and genesis, and yielding an inventory in the form of reports and maps; b) basic soil properties of chemistry, physics, mineralogy, and microbiology; and c) soil fertility and other aspects of soil management.

# Present Activities in Canadian Soil Science

Investigation of soil and land comprises between 5 and 10 per cent of agricultural scientific activity in Canada. Research on soil and water takes up 8 per cent of the

<sup>&#</sup>x27;The term "soil" is used here for the natural medium for the growth of land plants. A more specific definition is "the collection of natural bodies on the earth's surface supporting or capable of supporting plants". (Leahey, A, The soils of Canada from a pedological point of view. *In* Soils of Canada, Roy, Soc, Canada, Spec. Publ. No. 3. p. 147. 1961.)

research time of Canadian agricultural scientists.<sup>1</sup> The Canadian Soil Science Society memberbership<sup>2</sup> of 300 is approximately 10 per cent of the number of agricultural scientists in Canada. In soils, as in other facets of agricultural research in Canada, almost all scientists are in the federal or provincial government agencies or at universities (less than 7 per cent of agricultural scientists are employed by industry<sup>1</sup>).

Soil surveys and related pedological investigations form a co-operative endeavour of federal and provincial departments of agriculture and soil science departments of universities. Co-ordination and standardization of nomenclature and classification are effected through the National Soil Survey Committee. Data summaries<sup>3</sup> provided by the federal Soil Research Institute indicate that the co-ordinated soil survey program (federal, provincial and university groups) currently involves an annual budget of somewhat over \$2 million and the time of some 86 professionals. Of the 52 professionals in the federal Soil Research Institute, 38 are directly involved in soil mapping and classification and the rest are engaged in research on properties of soils that bear upon genesis, classification, and land use. In terms of educational background, the federal group of 38 soil scientists includes 6 chemists, 3 mineralogists, 2 physicists, 1 geologist, 1 geographer, and 1 biologist.

The Canadian soil survey program was initiated in 1921 and to the present has covered 270 million acres at a reconnaissance scale (see Figure VII.4), 120 million acres at an exploratory scale, and 6 million acres at a detailed scale. The reconnaissance surveys provide a basic inventory of our soil resources and a base for interpretations on land use; the exploratory surveys give a preliminary assessment of the potential of a region for farming and the kind of soils occurring in it; and the detailed surveys produce the information required where intensive use of land may be made, such as urban development, intensive cropping, irrigating, etc.

Since 1962, soil survey maps and reports have served as a major source of data for the Canada Land Inventory of the Agricultural Rehabilitation and Development Administration (ARDA). In this connection, all lands for which soil survey data are available, plus an additional 60 million acres, have now been rated according to the ARDA soil capability classification for agriculture.

### **Relation of Soil Science to other Earth Science Fields**

All pedological investigations, whether concerned with basic soil properties, genesis, classification, or mapping, involve and incorporate information and concepts drawn from other earth science disciplines. Particularly important is geologic-geomorphic information on rock lithology; distribution, stratigraphy and origin of unconsolidated deposits; nature and origin of landforms; and late Quaternary history. To the degree that this sort of information is available, particularly as maps, it is used by the soil scientist as background for his work; where it is not available he is obliged to draw his own conclusions regarding essential facets of geology and geomorphology.

Some projects of federal and provincial geological agencies, and some investigations of individual geologists, have been designed specially to provide background information for soil surveys, but most of these arrangements have been set up on an individual *ad hoc* basis or have been self-generating through personal contact between scientists. More formal planning and co-ordination on a continuing basis would be more effective in providing geological-geomorphological support for pedology.

# Application of Soil Science Data

Soil science continues to fill the role, developed over many years, of providing

<sup>&#</sup>x27;Smallman et al., op. cit.

<sup>&</sup>lt;sup>2</sup>Includes some who are not agricultural scientists.

<sup>&</sup>lt;sup>3</sup>Ehrlich, W. E., and P. C. Stobbe. Brief on "Pedology",

<sup>(</sup>see Appendix 3 in this report); also letter and notes from P. C. Stobbe to the Chairman of the S.E.S. Study Group.

agriculture with essential information on land fertility and land management. On the other hand, additional and expanding needs for and use of pedological data and soils maps have developed in forest land evaluation (see below) and in multiple land use planning. Priorities for soil survey can no longer relate solely to agriculture but must take into account the needs of forestry in wilderness areas and the requirement for detailed land planning information where the demands of urban expansion or other intense land use are in competition with agricultural use of the land.

Pedological maps and reports contain information that is valuable in a variety of earth science fields. Thus the pedological maps are an aid in highway engineering and other similar engineering work, or in preparation of geomorphological or surficial geology maps. Soils information is useful in determining the nature, stratigraphy and history of unconsolidated materials, landscape history, and sequence of biological and physical changes in environment during the recent past. Soil chemistry, physics, mineralogy, and genesis yield information on the chemical and physical properties and weathering behaviour of earth materials that is potentially pertinent to geochemical and geophysical mineral exploration.

In view of the varied applications of soil science in a wide range of scientific fields we submit:

#### Conclusion VI.1

Soil science in Canada should be broadened, in terms of both training and research. In addition to fulfilling its traditional role in agriculture, soil science should meet the expanding needs of forestry, water resources, soils engineering, mineral exploration and regional planning.

# VI.5 Forest Land

Almost half of the land area of Canada is forested and approximately onequarter of the area of the country (about 960 000 sq. miles) is potentially productive forest land. Some 312 000 sq. miles of forest land is currently occupied, either by private ownership (30%) or by lease, license, etc. of crown land (70%).<sup>1</sup>

#### Land Classification

The approach of forestry to land and soil resources differs somewhat from that of agriculture and relates specifically to the essential focus of forestry on natural vegetation. Thus the ultimate objective of land classification for forestry is to distinguish components of the land that are ecologically significant in terms of tree growth. This approach is illustrated by the classification system of Hills<sup>2</sup> in which "classification is based on the perceivable features of both vegetation and physiography (i.e. landform<sup>3</sup> and climate) which are significant in the establishment and growth of crops". A similar scheme is the airphoto-based Australian reconnaissance classification, in which the basic mapping units are land systems, defined as areas with recurring patterns of landforms, soils, and vegetation.<sup>4</sup> An example of a land system, in terms of Canadian terrain, would be "a rolling, shallow till plain overlying granite bedrock, characterized by podzol soils and a yellow birchbalsam fir forest cover".

The factors pertinent to forest land classification can be expressed in terms of parameters that promote or limit tree growth, such as soil constitution, soil fertility, limitation of rooting depth by bedrock or other resistant substratum, deficiency or excess of moisture in the soil or in the earth materials beneath it, concentration of toxic elements or soluble salts, stoniness, slope, susceptibility to

<sup>&</sup>lt;sup>1</sup>Data adapted from Canada Year Book, 1968. <sup>2</sup>Hills, G. A. The ecological basis for land use planning. Ontario Department of Lands and Forests, Res. Rept., No. 46, 1961.

<sup>&</sup>lt;sup>3</sup>Land form or landform in the forestry context includes not only the physiographic land features of the geomorphologist but also the underlying rock and soil materials.

<sup>&</sup>lt;sup>4</sup>Christian, C. S., and G. S. Stewart. General report on survey of Katherine-Darwin region, 1946. CSIRO Aust. Land Res., Ser. No. 1, 1953.

erosion or inundation, atmospheric precipitation and temperature, and soil exposure. These parameters basically involve earth science knowledge in the fields of pedology, geomorphology, as well as bedrock and surficial geology combined with pertinent aspects of climatology. Ideally, as in the Australian mapping system, surveys by teams of specialists provide the range of information listed above.

The appraisal and classification of forest land to a considerable degree must be undertaken in the context of potential alternative uses, principally in such fields as agriculture, wildlife management, recreation, and water conservation. Thus forest land surveys commonly have a multiple land use function and provide overall land resource data.

#### **Present Activities in Forest Land** Classification

The concept that forestry is concerned not only with forest products but also with management of land per se is relatively new in Canada. Although land problems are intrinsically involved in day-to-day commercial logging activities, the forest industry, for the most part, takes land, soil, and attendant problems for granted as part of the natural setting within which it operates. Specific appreciation and application of land data, as such, and the use of a physical land system for classifying and evaluating forest resources, are largely confined to the forestry agencies of federal and provincial governments, university schools of forestry, and a few of the larger companies. Recent establishment of a tax-relief incentive for forestry land inventory work in British Columbia is evidence, nonetheless, of increasing concern over land management.

Some provincial forestry agencies make relatively little use of scientific data on land, whereas others have been involved in scientific land evaluation for years. For instance, the British Columbia Forest Service has a well-established classification program involving interrelation 256

of forests and soils, and Ontario has pioneered a forest-based, multiple-use classification involving ecology and landforms.

During the current decade, the Canada Land Inventory of ARDA has done much to promote Canada-wide involvement in a co-operative federal-provincial program of appraisal of land for forestry. The system also includes appraisal of land for alternate uses in the fields of agriculture, wildlife management, and recreation. These classifications are confined to the "settled" parts of Canada, comprising some 800 000 sq. miles. To date approximately 10 per cent of this area has been rated for forestry, by using a system based on physical land characteristics in which all mineral and organic soils are classified in one of seven classes, according to their inherent ability to grow commercial timber.1

Concern by foresters over the need for land planning data on wildlands outside the settled area covered by the Canada Land Inventory has resulted in planning for, and experimentation with, a biophysical land classification system under the aegis of the National Committee on Forest Land, with co-operative support from the federal and provincial forestry agencies. On the basis that wildlands offer possibilities for varied use, this system is designed to provide a base from which lands may be classified in terms of their capability for forestry, agriculture, recreation, wildlife management, water yield, and other purposes. The objective of the biophysical system is to differentiate and rapidly classify at a reconnaissance scale, mainly with aerial photographs, ecologically significant segments of the land surface. As in the Australian classification, the basic mapping unit is the land system, which ideally divides the land into areas suitable for mapping on a scale of 1:125 000. This classification is proposed as the base for a regional survey system,

McCormack, R. J. Land capability classification for forestry. The Canada Land Inventory, Report No. 4. 1967. but to date it has only been applied on an experimental basis.

# Earth Science Contributions to Forest Land Classification

Forest land classification, inventory and evaluation, as well as forest land management planning on a more detailed scale, are therefore heavily dependent on earth science knowledge from geology, physical geography, and pedology. Geologic-geomorphic information of particular pertinence involves bedrock lithology; distribution, thickness, stratigraphy and origin of unconsolidated deposits; nature and origin of landforms; and late Quaternary history, including palynologically determined forest successions.

To the extent that pertinent earth science information is available, it is used by foresters engaged in land investigations; where pre-existing earth science knowledge is not adequate for their needs, forestry officials must either make do without proper background data or generate the required information by using whatever talents or specialists are at hand. A team approach, in which specialists in several contributing disciplines work together in a forest land survey, is particularly effective in generating the information required for forestry. Even where some background information on pedology or geomorphology is available in advance, it may be desirable to include these specialists in a forestry land-study team.

Currently, pedological information required in forest land classification is provided by approximately a dozen soil scientists employed by the Canadian Forestry Service and, in several provinces, by co-ordination of soil survey activities with forest land classification programs. A particularly effective integration of forest land classification and soil survey has been achieved in British Columbia within the framework of the ARDA program.

Direct geological-geomorphological input to forest land investigations is provided by about eight scientists with training or facility in geomorphology who are

employed by the federal and provincial forestry agencies. Particularly noteworthy in this regard is the work of officers of the Ontario Department of Lands and Forests in northwestern Ontario, which not only has provided for the needs of forestry but also has contributed significantly to knowledge of the glacial geology of the region. Also warranting special mention is the full-time involvement of a geomorphologist in the forest land classification project being carried out by the Canadian Forestry Service north of Quebec City. Additional support comes from direct participation of a very few geologists and geomorphologists from other agencies, and from forestry-oriented mapping of surface materials and landforms by other groups. Almost all such mapping is done by the Geological Survey of Canada, which has initiated about 10 projects during the past five years specifically to meet requests from federal and provincial forestry agencies.

Despite the substantial earth science contribution, it is clear that far more information from the earth sciences could be of immediate and direct application to forestry in Canada. To date, the mapping has been sporadic in relation to the end use in forestry. Considerable planning will be required to match up land resource surveys and forestry application.' At present the survey information on surface materials, landforms, and soils in areas of present and potential concern for forestry is minimal.

Improved communications between the earth scientists and foresters are required. In addition to yielding mutual benefits at the working level, greater contact would provide for improved planning and better reviews of needs and priorities for land data in forestry and multiple land use.

In view of the dependence of forest land inventory and associated multiple land use planning on background earth science data, and anticipating a substan-

<sup>&#</sup>x27;Personal communication, P. J. B. Duffy, Forest Land Inventory Co-ordinator, Department of Fisheries and Forestry.

tially increased need for such data in the future, it is submitted:

Conclusion VI.2

In setting priorities for pedological and surficial geology inventory surveys, increased emphasis should be placed on forest lands, particularly in relation to forest land inventory.

# VI.6 Water Resources

Water resources research in Canada and its application in the management of this essential and vulnerable resource has been documented effectively and comprehensively in an earlier report to the Science Secretariat.<sup>1</sup> In the present study the subject of water is introduced to explore the relationship of the solid-earth sciences to water resources and water research.

Water is involved in many aspects of the natural landscape and in almost all of man's activities. Thus, unlike research in other resource fields which involve a narrow range of scientific knowledge, water resources research touches upon many fields of knowledge and draws scientific workers from a wide range of scientific disciplines. In the present context, investigations in geology or physical geography that are designed to further knowledge and management of water resources are part of water research. Thus, water research is defined in terms of purpose rather than discipline, and clear definition of its boundary with solidearth sciences presents some difficulties. In this section attention is simply directed to those aspects of the scientific study of the obviously "solid-earth" elements of rock, earth material, soil, and landforms (and associated processes) that involve or are pertinent in water research.

#### **Relationship to Solid-Earth Sciences**

Water in the hydrologic cycle is distributed throughout the hydrosphere in the atmosphere, on the earth's surface, and within the earth's surficial materials. In 258 most cases, the water is liquid and capable of altering earth materials and landforms with which it has contact by weathering, leaching, transportation and deposition. The properties of surficial materials are often a function of their former or present relationship to liquid water. In the Canadian Arctic and sub-Arctic, solid water may form locally as much as 75 per cent of the earth materials as ground ice. The properties of these ice-material deposits are little known.

To the geologist, the historical contact between his discipline and water resources has been through ground water and its exploitation for water supply. Other important categories of contact involve:

1. geomorphology and surficial geology of river basins;

2. groundwater flow systems and the hydrologic water budget in drainage basins;

3. snow and ice, particularly ice in the ground;

4. water and its relationship to agriculture and forestry;

5. geological history and contents of the natural environment as related to forecasting the effects of physical and biological changes induced by man in water bodies.

Table VI.1 outlines more specifically the solid-earth science input into various water resource categories.

In view of these varied contributions of the solid-earth sciences to water resources research in Canada, involving bedrock geology, surficial geology, recent geological history, geomorphology, pedology, hydrogeology, and landscape processes of all kinds, we submit:

#### Conclusion VI.3

The management of water resources must be based upon pertinent land data in addition to information on the water itself, thus requiring an important input from solidearth sciences.

<sup>1</sup>Bruce and Maasland. Water resources research in Canada. Science Secretariat. Special Study No. 5.

### Table VI.1-Solid-Earth Science Input into Water Resources Studies

Code	Subcategory	Solid-Earth Science Input or Involvement

Water	· Cycle (Hydrology)	
201	General	-Fluvial geomorphology as a component of basin analysis. -Data on rock and earth materials, soils, landforms, and geological history as background information bearing upor the behaviour of water in a basin system.
203	Snow and Ice	-Permafrost and ground ice are integral components of the earth materials and geomorphic features in which they occur.
205	Stream Flow	-Geologic-geomorphic data serve as background in analysis of river basins and in prediction of flood and drought frequency and duration.
206	Groundwater	-"There is no part in the study of groundwater that can be explained without intimate knowledge of geology." <sup>a</sup>
207	Water in Soils	-Soil moisture and water yields for forestry and agriculture. -Water movement into soils and through the soil profile is the link between precipitation, stream flow and groundwater.
210	Erosion and Sedimentation	-Soil erosion, development of slopes and valleys, river bank development, erosion and deposition in rivers, erosion and deposition along lake shores, sedimentation in lakes. -Solid-earth inventory data as background in all the above.
211	Chemical Processes	-Solution from solid sources and ultimate precipitation as solid material.
212	Estuarine Problems	-In deltaic areas sedimentation, geomorphology and hydrology are complexly inter-dependent.
Water	Quantity Management and Control	
401	Control of Water on Land	-Drainage of excess water and conservation of limited water both involve background earth science data.
402	Groundwater Management	-See groundwater.
403	Effects of Man's Related Activities on Water	-Many disruptive changes applied to the land have an ultimate effect on quantity and behaviour of water.
Water	Quality Management and Protectio	n
502	Source and Fate of Pollution	<ul> <li>Many pollutants enter water following a land phase, e.g. fertilizers, salt on roads, organic farm wastes, septic tanks, garbage disposal.</li> <li>Shore and bottom materials influence dispersion of pollutants in water bodies.</li> </ul>
503	Effects of Pollution	-Past history of environment and environmental controls in water bodies are aids in predicting consequence of induced changes.
505	Ultimate Disposal of Wastes	-Effective disposal on land requires data on earth materials as well as on groundwater.
Mey	boom, P. Background report on "H	ydrogeology" (see Appendix 4 in this report).
Note:	The code and category system in this	s table is that used in Science Council Special Study No. 5 Bruce

*Note:* The code and category system in this table is that used in Science Council Special Study No. 5, 1 and Maasland, *op.cit*.

#### Hydrogeology

The primary interface between the solidearth sciences and water resources development is in the study of the occurrence and movement of groundwater, a field of specialization which during the last decade has become known as hydrogeology. The contribution of hydrogeology to geotechnique has been noted in Chapter V. However, we are concerned here with the significance of the groundwater zone as a supplier of water and as a waste disposal medium, with the relation between the solid-earth sciences, hydrogeology and the other hydrologic sciences, and with the degree of involvement of the solidearth sciences in the future development of water resources.

# Groundwater as a Source of Water Supply in Canada<sup>1</sup>

Of the 21 million people living in Canada (1969), an estimated 5.5 million supply their own water from individual household or farm supplies. The farm population of 2 million distributed over 480 000 farms is 75 per cent dependent upon groundwater, and an estimated 50 per cent of the non-rural farm population uses groundwater as its sole water supply. It is also estimated that 65 per cent of all water used by livestock is derived from groundwater. Groundwater pumpage contributes approximately 20 per cent of the entire municipal and rural water supply. The value of this production was approximately \$80 million in 1967. Although the development of groundwater is concentrated in rural areas where it supplies farms, towns and small cities, it is also a major source of industrial water in several of the larger urban centres in Canada. For example, metropolitan Winnipeg derives approximately 17 per cent of the water supply from wells, with large increases in demand occurring in the last few years, particularly for air-conditioning.<sup>2</sup>

An indication of the probable future trend of groundwater usage in Canada can be derived from comparisons with groundwater usage in the United States. 260

In 1960, municipal water supply systems served 136 million people in that country, with one-third of the supply coming from groundwater. This compares with a onetenth contribution from groundwater to the municipal water supply in Canada. Thus, with regard to urban groundwater development, it is clear that Canada has not progressed as far as the United States. Even the province of Ontario is considerably below the American average, even though at 15 per cent it is well above the national average. Increased population, urbanization and industrialization will undoubtedly require an intensified search for suitable groundwater supplies in urban areas in the next decade. There is considerable evidence to indicate that intensified search and the implementation of optimal pumping schemes will successfully expand the availability of groundwater in most of our populated regions, providing that comprehensive investigations using modern techniques are used. Because many incorrect concepts are associated by water resource engineers and administrators with the occurrence and movement of groundwater, this resource is rarely integrated into the overall water supply system of urban areas or even, in many cases, subjected to preliminary feasibility studies.

It should also be noted that pollution of groundwater supplies caused by influx of surface and near-surface wastes is an increasingly common problem in Canada. This can be avoided only if the groundwater zone is considered within the overall framework of environmental engineering and management.

# The Groundwater Regime as a Waste Disposal Zone

As pressure to control and diminish pollution of lakes and rivers mounts, activity in the field of subsurface waste disposal

<sup>&</sup>lt;sup>1</sup>Much of this information is adapted from P. Meyboom, Hydrogeology: a decennial appraisal and forecast. *In* The earth sciences in Canada. Roy. Soc. Can., Spec. Publ. No. 11, pp. 203-221. 1968.

<sup>&</sup>lt;sup>2</sup>Render, F. W. Geohydrology of the metropolitan Winnipeg area as related to groundwater supply and construction. Can. Geotech. Jour. (In press).

technology has increased markedly, particularly in the United States. The locating of zones into which liquid wastes can be injected, without causing pollution of fresh-water aquifers or endangering the surface environment in future years because of groundwater movement, is essentially a hydrogeologic problem.

Most industrial areas in Canada are underlain by zones in the groundwater regime which may be well suited for waste disposal. To neglect this waste disposal option or to conduct injections in unsuitable zones would represent gross mismanagement of the Canadian environment. We cannot depend entirely on foreign technology to solve our hydrogeologic problems in this field because it is the geologic framework in each individual area which governs the groundwater system. In Canada, the option of subsurface waste disposal has received some attention in Ontario, but on a national basis the subject has received little or no attention from provincial and municipal governments. Unless this potential area of contribution to environmental studies by the solid-earth sciences is emphasized in the coming decade, little change from the status quo can be expected.

### Hydrogeology within the Framework of Environmental Management

The solution of problems related to groundwater development, subsurface waste dispersal and groundwater pollution requires contributions from hydrogeology, geotechnique, and hydraulic, sanitary and water resources engineering, as well as economics and other disciplines, all contributing within an integrated scientific and administrative framework. At present this framework is lacking or at best only partially developed in the public service of the federal, provincial, and municipal governments in Canada. The combined expertise of private consulting firms in these three areas, although developing rapidly, is also inadequate to meet the challenge of the next decade. One of the major factors inhibiting the development of this framework is

the deficiency of well-qualified personnel in many of the required disciplines. This deficiency has retarded national development of hydrogeology during the past decade, and will continue to do so unless educational facilities in this area are expanded. As indicated below, it appears that the responsibility for this expansion will continue to lie primarily with the solid-earth sciences.

#### Training in Hydrogeology

In recent years many hydrogeologists have tended to regard themselves primarily as hydrologists rather than geologists, even though they took their undergraduate training in geology or geological engineering.' In most cases contributions by hydrogeologists to hydrologic and water resource problems have been in areas where in-depth understanding of the geologic and geochemical framework has been required, in addition to a broad knowledge of other areas of hydrology. It should be recognized, however, that there are other specialists in hydrology who contribute to the study of groundwater and who do not regard themselves as hydrogeologists, such as hydraulic, sanitary, and agricultural engineers and soil physicists. Their emphasis is commonly on the physics of flow through porous media in terms of laboratory or mathematical studies.

Academic programs in hydrology are currently offered at the graduate level only in Canadian universities. This arrangement is considered to be desirable. A strong graduate program in hydrology requires broad training in many subdisciplines, but it is neither feasible nor desirable to train each hydrologist comprehensively in all the subdisciplines contributing to the field. Thus, it is the responsibility of each subdiscipline (i.e. hydrogeology, hydraulic, sanitary or agricultural engineering, soil physics, hydrometeorology, etc.) to maintain an area of emphasis or specific competence, both in research and in graduate education. It is

<sup>&#</sup>x27;Meyboom, 1968, op. cit.

the responsibility, therefore, of the solidearth sciences, through departments of geology or earth science in Canada, to foster the development of the subdiscipline of hydrogeology and to encourage the necessary interaction of hydrogeology with other elements of the interdisciplinary hydrologic framework. We therefore submit:

#### Conclusion VI.4

Canadian universities should foster and expand graduate programs in hydrogeology through both specific training-in an earth science context-in subjects specific to hydrogeology, and provision of a broad base in hydrological sciences, environmental sciences, and water resource management.

#### Conclusion VI.5

Continuing increase in the use of the groundwater zone, as both a source of water supply and a medium for disposal of liquid and semi-liquid wastes, requires effective application of concepts and techniques of hydrogeology as well as administrative co-ordination of relevant aspects of environmental and water resource management procedures. All levels of government should recognize this need for co-ordinated action.

#### Prospecting for Groundwater

In Canada, potable groundwater is generally obtained from depths within a few hundred feet of the surface. Efficient search for groundwater thus necessitates the ready availability of reliable nearsurface geologic and hydrologic data, such as those provided by provincial and federal water-well catalogues and consultants' reports on municipal and industrial groundwater supplies; reliance is also placed on the surface information provided by topographic maps, soil-survey maps and aerial photographs.

These background data serve to identify probable aquifers and to estimate their depths, thicknesses and areal ex-262 tents. The groundwater geologist also uses these data to infer order-of-magnitude permeabilities, and areas of groundwater recharge and discharge. The collection and analysis of this information may involve outcrop examinations, water-well surveys, visits to suspected recharge and discharge areas, sampling of surface and well waters for chemical analysis, as well as stratigraphic test-drilling programs and aquifer tests. The use of geophysics, primarily geophysical borehole logging, may be of great assistance.

Groundwater exploration in Canada during the past decade has tended to become sophisticated, in regard to both the variety of field methods used and the detailed analysis of the field data collected. Vegetation patterns in the vicinities of surface-water bodies can be used to help identify recharge and discharge areas; consideration of natural water levels and subsurface variations in various chemical parameters aids in the delineation of local, intermediate and regional flow systems. Knowledge of the probable distribution of flow systems in turn allows the general prediction of subsurface variations in groundwater quality and the identification of areas where there are better chances of obtaining good-quality water.

Geophysical exploration for groundwater has been undertaken extensively. Earth resistivity prospecting has been useful in detecting and determining the areal extent of near-surface alluvial sands and gravels; it has also served in the detection of salt-water intrusion into coastal aquifers in the Maritime provinces. The seismic refraction method has been utilized with good results in areas where good seismic velocity contrasts exist; it has been used with limited success in prospecting for buried preglacial valleys under the lower contrast conditions that characterize the Western Canadian geologic environment; however, where drilling costs are relatively low, it is generally more economical and quicker to test drill than to seek the same information by the seismic method. The gravity method has

been used with some success in delineating buried preglacial valleys.

Geophysical methods offering some promise for special purposes and still under investigation include the electrical induced polarization method and the airborne INPUT electromagnetic surveying system. Induced polarization may help to resolve some of the ambiguities encountered in the interpretation of earth resistivity data. The INPUT method has been used in the detection of a near-surface sand-gravel aquifer in Manitoba and also in the survey of a deeper lying sandgravel body in southern Alberta. In this latter case, data analysis is still in progress.

Borehole geophysics is increasingly used in the search for groundwater. Progress has been made to the point where self-potential and single-point resistivity logs are routinely run in many test holes and wells bored by federal and provincial groundwater organizations. As another example, some provincial agencies are encouraging the running of electric logs in all water wells. However, much research remains to be conducted in this promising field. Techniques under investigation include borehole photography, temperature logging, various types of radioactivity logging, as well as lateral and normal resistivity logging. It is anticipated that use of these techniques will provide valuable information on fracture flow of groundwater, on water quality, and on porosity and permeability.

Of the remote-sensing methods, infrared scanning has been demonstrated to have some value in the location and detection of subaqueous springs, thus providing information on discharge areas. With further research it may find application in the identification of springs and seepage areas at the earth's surface. Other remote-sensing methods do not appear at this time to have any immediate utilization in groundwater exploration.

Future advances in groundwater exploration in this country will probably depend in large measure on the development of refined instrumental techniques and computerized methods of processing the relevant data. With regard to scientific development, the new field of acoustical holography appears as particularly promising. Acoustical holography could, in theory, be utilized to produce threedimensional images of formation and aquifer boundaries. This application is reportedly under investigation.

### VI.7 Land Use Planning

In practice, application of earth sciences in the management of renewable and other natural resources is considerably more complicated than is evident from the foregoing discussion, because of interaction and competition between land use requirements for various resources in any given area, plus the universal need to minimize harmful disruption of man's natural environment. Thus, in rural or wildlands areas it may be necessary to balance, one against another, land use needs for agriculture, forestry, recreation, wildlife management, transportation, hydroelectric power generation, and mineral development. On the fringes of our rapidly expanding urban areas, agricultural land use must compete with the land use requirements associated with high population, involving for instance sources of fill and aggregate, sites for waste disposal, water pollution problems and availability of domestic and commercial water supply, transportation routes, building foundations, recreation areas, and the need to retain open spaces.

Planning agencies, ranging from governmental departments with countrywide responsibilities to municipal planning boards, are increasingly being called upon to prepare recommendations relative to multiple land use problems of the kind listed above. Naturally, these recommendations are essentially based upon economic and social considerations. In this context, however, there is an urgent need for earth scientific information on land and environment relating to planning problems, thus ensuring that plans can be prepared in the light of, or in spite of, pertinent earth science factors.

Unfortunately, in Canada, earth science investigations designed specifically to provide background for multiple land use planning are all too few, except for the Canada Land Inventory of ARDA. It is rare indeed that our geological or other earth science reports can state their objectives in terms like the following1: "This study was undertaken at the request of the McHenry County Regional Planning Commission to provide geologic information for land use planning. Also participating in the program of investigation for the Planning Commission was the United States Department of Agriculture, Soil Conservation Service, who provided land use interpretations and small watershed evaluations on the basis of detailed soil maps of the county made in co-operation with the University of Illinois Agricultural Experiment Station."

To meet the urgent need for earth science data as background for multiple land use planning, particularly in and around urban centres, but also in rural and wilderness areas, we submit:

#### Conclusion VI.6

Geological mapping agencies in Canada, and particularly agencies of provincial governments, should increase markedly their output of geological work oriented specifically to environmental and land use planning. This work should be concerned with bedrock as well as unconsolidated earth materials and terrain.

#### Northern Terrain

Despite the pioneer state of development of its northern territories, Canada faces a critically important need for effective land use planning and environmental management in those vast areas in which terrain conditions are complicated by permafrost and muskeg. Here we are faced with the need to gain fundamental information on the behaviour of earth materials, land surface, and vegetation 264

cover under various conditions of development before effective planning can be done. A major increase in scientific and technical knowledge of permafrost and frozen ground is required to meet the problems of land development and environmental maintenance involved in the rapidly increasing activities of man in the North. Currently the number of Canadian specialists in this field is entirely inadequate to meet the needs of the country. We therefore submit:

#### Conclusion VI.7

To accelerate development of Canadian expertise and knowledge concerning northern terrain and permafrost phenomena, increased research funds should be made available at universities to encourage earth scientists and engineers to specialize in these fields. As recommended in Chapter III, a centre of excellence in northern terrain research should be one of our national priorities.

#### Importance of Inventory

Among the varied earth science investigations relating to renewable and other resources, those dealing with the inventory, classification and evaluation of land are of particular importance in the management of resources and environment and in land use planning. As noted before, land inventory and classification schemes vary greatly in purpose and degree of complexity. They range from simple plots of single, objective parameters, through so-called "natural" landscape classifications, to interpretative capability ratings based upon syntheses of basic inventory data. Effective land inventory involves much more than routine application of an objective scheme. Unless an inventory program is supported by research adequate to reveal the interdependence of the various landscape elements, the resulting maps will be of neither

Hackett, J. E., and M. R. McComas. Geology for planning in McHenry County, Illinois. State Geol. Suv., Circular 438. 1969. 31 p.

practical nor scientific value. Knowledge of genesis, land history and land dynamics is of critical importance as background for a land inventory and classification system if it is to be used as an effective base for extrapolations and predictions.'

Although some integrated land evaluation schemes (e.g. Australian and biophysical systems) incorporate all the scientific specialties needed to complete the inventory, most surveys concentrate on only one facet of land use and are dependent for their success upon the availability of other inventory data. Thus for instance, besides the topographic map required as a base for a forest land survey, it will be desirable or even necessary to have maps of bedrock geology, surface deposits, geomorphology, and (or) soils. Thus, the scientific effectiveness and administrative efficiency of land inventory depend on the order in which the component investigations are completed, with those of general applicability logically preceding those of specialized application. Unfortunately, specialized inventories are all too frequently undertaken to meet specific needs, while broader based "background" surveys are neglected. In view of the foregoing we submit:

#### Conclusion VI.8

General land inventories and associated land research providing scientific information for various purposes should be assigned priorities by appropriate government agencies (at the federal and provincial levels) on a basis similar to that used in assigning priorities for topographical mapping.

# Importance of Unconsolidated Earth Materials

Of particular concern in land use planning are the common unconsolidated earth materials that mantle the bedrock throughout more than 90 per cent of Canada. They serve as parent materials for agricultural soil, the growth base for forests, reservoirs for groundwater, pre-

ferred sites for cities and roads, sources of fill, aggregate and other commodities, and convenient "hosts" for disposal of garbage<sup>2</sup> and liquid wastes. Thus scientific knowledge of these materials and of associated terrain features is required in development and planning in the renewable resource fields of agriculture, forestry, recreation, and water, as well as in the geotechnical aspects of communications, construction, and urban development as discussed in Chapter V. In addition, knowledge of these materials is of increasing importance in the mineral industry, not only because they yield essential mineral commodities but also because of their role-in the glaciated Canadian terrain-in the interpretation of geochemical information, and in the use of both geochemical and mineral indicator data in the search for mineral deposits.

Despite the value of knowledge of these ubiquitous earth materials, they have received far less attention in Canada than the bedrock beneath them or the soils (in the pedological sense) derived from them. Thus, for instance, mapping of the surficial deposits and associated landforms has lagged far behind bedrock mapping; there are vast areas of Canada for which surficial materials maps are entirely lacking (see Figure VII.3).

In view of the above, a concerted effort must be made to bring knowledge of unconsolidated earth materials and associated terrain features up to a level appropriate to present needs for planning and development throughout the country for all purposes, and to progressively upgrade this knowledge to meet the needs of the future (see Conclusion V.3).

'Ruxton, B. P. Order and disorder in land. *In* Land evaluation. MacMillan of Australia, 1968. p. 29.

<sup>2</sup>As a measure of scale, it has been reported that about *10 million tons per year* of waste solids (excluding rubbish and floatable debris) are being delivered to the Atlantic Ocean by New York City, making this the largest single source of sediment from the continent to the Atlantic Ocean. (*Reference:* 1 January 1970 Newsletter of the Council on Education in the Geological Sciences. Washington D.C.).

#### **Importance of Land Dynamics**

Complementing the requirement for land information regarding the materials of the earth-whether rock, unconsolidated earth material or soil-is the fundamental need for knowledge of the dynamic processes and stability conditions of these materials and their environment. Such information is essential for predictions regarding the natural or man-induced geological hazards leading to such problems as slope failures, flooding, erosion, sedimentation collapse, cycling of pollutants, and thawing or freezing of ground.

The current level of earth science activity relating to land dynamics is low and is to a considerable degree fragmented into isolated inputs from geology, geography, soils engineering, hydraulic engineering, soil science and "water research". For effective land and environment planning, much additional quantitative information is required on the dynamics of processes controlling behaviour of natural materials at the surface of the earth. Hence we submit:

#### Conclusion VL9

Increased attention should be given to scientific investigation of land dynamics and geological hazards, combining basic concepts of sedimentology, hydrology, geomorphology, soil and rock mechanics.

# VL8 Communication and Effective Use of Earth Science Land Information

As is evident from the preceding sections, there is an urgent need for greater and more effective use of earth science information on rock materials, unconsolidated earth materials, landforms, and soils (pedology) in land use planning, in management of renewable and related resources, and in the maintenance of man's natural environment.

A basic problem that must be overcome, if the earth sciences are to contribute effectively in land planning, is the general lack of awareness of planners

and the public regarding the usefulness of earth science data in regional planning. The following quotation indicates the action required by earth scientists to meet this problem. "The success of geologic exploration for mineral resources be they liquid, gaseous, or solid-has been based on a mutual understanding and rapport between the exploration geologist and management. They both knew what they wanted to accomplish, and each learned to communicate effectively with the other. In order to do this effectively in the environmental area, you must learn enough about the problems of the planner and administrator to enable you to put geologic data into a form that can be used by those who need it. Happily, efforts are being made in these directions at many places across the country, but still far too many geologists are talking to each other rather than to the public, and, in management of the environment, the public is "management".1

Improved communication and coordination of effort is thus required between the various government agencies, mission-oriented groups, and scientific disciplines involved in gathering and disseminating scientific information about land, as well as in the application of this knowledge to management of renewable resources, regional and urban land planning, northern development, maintenance of man's natural environment, and engineering aspects of construction and communications. To assist in meeting this need we submit:

#### Conclusion VI.10

An ad hoc "Earth Science Committee on Land Information" should be formed by the Canadian Council of Resource Ministers and charged with the task of recommending measures and mechanisms designed to establish and maintain appropriate communication between providers and users of earth science "land" information,

Frye, J. C. Geological information for managing the environment, Illinois State Geol. Surv., Environmental Geology Notes No. 18, p. 12, 1967.

and particularly between the various provincial and federal agencies that are involved in this field.

# VI.9 Biogeochemistry in Health and Welfare<sup>1</sup>

Traditionally as well as historically the earth sciences have been applied to the mineral world, but with the exciting developments of biochemistry in recent years, they are now being linked with the life sciences and the biological world. As the science of the chemical relationships between the naturally occurring inorganic materials and all living matter, biogeochemistry offers much promise because of its potential contributions to the solution of nutrition problems, to epidemiology and to identification and control of natural and industrial pollutants.

Biogeochemistry is a young science, so young that in several quarters it is denied recognition as a science in its own right: in many Canadian universities it receives little or no support from geology, chemistry, hydrology, biology, or medicine, all of which have much to contribute to, and much to learn from, this integrating discipline. In common with several earth sciences, biogeochemistry was originally developed as a tool for mineral exploration, by using as a basis the abnormal concentrations of certain trace elements in vegetal matter above or near certain metalliferous deposits.

#### Scope of Biogeochemistry

A few of the problems falling within the present day scope of biogeochemistry are:

1. trace element deficiencies of food and drink;

2. natural and induced occurrences of toxic substances in soil;

3. chemistry of rocks, soils and plants as a support for organic life;

4. genesis of fossil fuels;

5. fertility of streams, lakes and oceans, and their threatened degradation by pollution. All of these problems encompass broad areas of scientific knowledge, and none can be dealt with competently by specialists of one discipline only. Advancements will continue to come largely from teams of researchers having the interest and ability to co-operate and communicate over a relatively broad range of human knowledge.

# Significance of Research and Development in Biogeochemistry

Research and development in this field are in a relative state of infancy because biogeochemical problems have been scientifically tackled only during the past two decades. The potential returns from this R & D are great, and far exceed the benefits accruing from geobotanical techniques as applied to mineral exploration. The problems involved embrace almost all facets of human ecology, including factors contributing to the health of plants, animals, and man.

The significance of biogeochemical research is illustrated by the following examples:

1. A team of medical doctors found that many deaths in a Japanese village had been caused by the eating of seafood with abnormal quantities of mercury derived from the waste products of a recently established synthetic fibre plant.

2. In Japan, several deaths from a bone disease were eventually related to an excess of cadmium in some rice. Water that had been in contact with old mine tailings had been pumped onto the rice fields.

3. By way of contrast, some communities over a long period of time have been accustomed to excessive amounts of some trace metals, and people who leave that community must supplement their new diet appropriately. For example, some people from the Alps cannot travel safely without arsenic supplements.

4. More generally recognized are areas

<sup>&</sup>lt;sup>1</sup>Mostly abstracted from Background paper on "Biogeochemistry", by H. V. Warren and R. E. Delavault (see Appendix 4 of this report).

of endemic anaemia and endemic goitre caused essentially by an insufficiency of iron and iodine in diets.

5. Although not statistically proved, highly suggestive correlations between excessive amounts of lead and zinc and multiple sclerosis have been noted by Warren et al.1 It was during these studies that some appreciation was obtained of the importance of biogeochemistry in tracing pollution. Obviously, a person eating potatoes is not concerned about whether the lead in his potatoes came from "natural" lead in soil or from automobile exhausts or the fly ash of coal. It is in the determination of unacceptable levels of pollution, as well as in the normal concentrations of trace metals in soils. plants and animals, that biogeochemistry now finds most challenging problems.

6. Biogeochemistry is a useful tool for measuring radioactive fallout.

One reason for agriculturists showing an increasing interest in biogeochemistry arises from the gravity of the various problems posed by pollution. Politicians are now becoming aware of pollution. They realize that the waste of cities may no longer be discharged into streams and rivers and they reason, with a measure of logic, that because much of our urban wastes come originally from the earth's crust, in the form of vegetal and mineral products, why not return these wastes into the ground whence they originated? The politicians suggest therefore that after removing major solids, all waste should be shredded, then sterilized and transformed into granules resembling vermiculite in texture, and spread on land which would thereby have its nutrients restored to their original concentrations.

It is a matter of concern that an important interdisciplinary field such as biogeochemistry does not fall among the stools of geology, chemistry, biology and medicine. Multidisciplinary research in biogeochemistry should be adequately supported in Canada in order that its potential applications to symbiosis, metabolism and pollution studies be fully explored for the benefit of the nation.

<sup>&#</sup>x27;Warren, H. V., R. E. Delavault, and C. H. Cross. Some geological factors in medical geography (in Spanish). Sociedad Mexicana de Geografia y Estadistica, Tomo VI. pp. 47-53, 1966.

Chapter VII
National
Earth Science
Surveys

"getting the facts of a situation before acting is of crucial importance, and...getting these facts is a continuous job which requires eternal vigilance."

### Bernard M. Baruch

# VII.1 Synopsis

The systematic mapping and interpretation of earth features (topographical, hydrographic, geological, geophysical, geochemical) are essential to the earth sciences. The resulting maps are indispensable tools for the economic and social development of a nation. Some maps display systematically collected data, and are classified under scientific data collection activities. Others, essentially geological, contain a large amount of interpretation and are considered to be research activities. Although a geological map must necessarily be presented in a two-dimensional (planimetric) format, it is in fact a portrayal of three-dimensional data and interpretations. The subsurface data are continually subject to revision in the light of newer data or ideas.

Methods of collecting earth science data have improved greatly in the past few decades, starting with the introduction of aerial photography, then the development of new and sensitive geophysical instruments, and the increased use of helicopters and other vehicles for logistical transport. Resource satellites are now in the offing as well as new computer methods to process very quickly huge quantities of data. The modern capability to generate certain forms of earth science data is continually increasing. Many geological parameters, however, are still not amenable to instrumental surveys and require several years of study, even in a single map-area.

We have no simple solution to the problems of estimating the quantity of systematic earth science data required, the speed of their collection, nor their required degree of precision. The urgency and quality vary from place to place and 270 time to time. Nevertheless we do consider that the present level of earth science knowledge for national development is below that of countries of comparable size (U.S.S.R. and U.S.A.); in general there is a need to speed up the rate of accumulation and summarization of basic regional data. The many users of these data in Canada consider that more should be made available (see Appendix 6). Additional funding is needed to increase the rate of data accumulation and the rising costs of publishing it. Improvements are also required in the standards of collection and presentation of the data, and in the coordination of activities between the various responsible groups.

In this chapter we summarize the earth science data for national development in terms of topographic, geological, geophysical and soil map coverage. We submit that there is a need to:

1. complete the topographic mapping at 1:50 000 by 1975;

2. complete the bedrock geological mapping at 1:250 000 by 1980;

3. complete the bedrock geological mapping to the 1:50 000 standard in areas of economic potential, urban and engineering development;

4. complete the mapping of surficial geological materials (including soils) to a 1:250 000 scale;

5. complete the mapping of surficial materials in urban areas to a 1:50 000 scale to meet the needs of regional planners, foundation engineers and suppliers of construction materials;

6. complete the national aeromagnetic coverage at current standards;

7. complete the systematic reconnaissance gravity coverage;

8. develop a program of systematic seismic surveys of sedimentary basins, with regard to the large amount of such data largely held in indívidual company files;

9. extend and complete the systematic geological and geophysical coverage to the continental shelves;

10. establish programs of systematic map revisions related to the changing



#### 272 Table VII.1-Percentage of Surface Covered by Topographic, Geological, Geophysical and Soil Maps in Canada, 1968

Province	Topographic Maps		Geology (bedrock) Maps		Geolog	Geology (Surficial) Maps			Aero- magnetic Maps	Gravity Maps			
	1:250 000	1:50 000	1″=1 mi.	1″=4 mi.	1″=8 mi.	1" = 2 mi. or less	1'' = 4 mi.	1″=8-16 mi.	Reconnaissance & Exploratory	(*)	Detailed (b)	Regional (•)	Reconnaissance
British Columbia	100	71	5	84	90	8.5	17	minor	21	15	minor	18	36
Alberta	100	64	7	82	95	3	34	-	100	28	minor	92	100
Saskatchewan	100	43	6 ½	37	100	2	35	_	67	64	minor	100	100
Manitoba	100	38	7 ½	63	99	-	11 1/2	25	26	85	minor	100	100
Ontario (north of 46°) (south of 46°)	{100	{ 39	{ 1	68 ½	{ 94	1 26	_ 74	71 100	{ 24	98	{minor	{ 70	{100
Quebec	100	52	22	44 ½	91	4	-	29	5	30	minor	72	86
Prince Edward Island	100	100	20	100	100	100	-	-	100	100	0	100	100
Nova Scotia	100	100	43	100	100	81	-	-	100	100	10	60	100
New Brunswick	100	100	49	100	100	12	27	-	59	100	20%	100	100
Newfoundland													
Island	100	1	23	88 1/2	100	-	24	-	11	70	minor	100	100
Labrador	100	52	0	53 1/2	91	-	13	7	_	5	-	75	75
Northwest Territories													
Franklin	100	1	(	ſ	(	-	-	79	ſ	20	-	60	60
MacKenzie	100	17	1/2	{ 27	{ 91	-	-	65	{<1	30	-	80	90
Keewatin	100	1	l	l	l	-	-	100	l	25	-		80
Yukon	100	42	2	65	90	-	11 1/2	23	-	45	-	3	8
Canada (Mainland)	100	37	7	48	92	3	8	39	19	41	-	64 %	78 %

a Line spacing of ½ mile and flown at 1000 feet.
b Station spacing ≤ 2 km.
c Station spacing ≤ 15 km.
d Station spacing ≥ 30 km.

	~		07
	%		~
U.S.S.R.	100	Cuba	100
United Kingdom	100	India	90
France	100	Spain	95
Japan	100	Pakistan	75
Italy	100	United States	74
Greece	100	Finland	60
Switzerland	100	Sweden	50
Norway	100	Central America	50
Thailand	100	Canada	20
Denmark	100	Africa	20
West Germany	100	Mexico	10
Benelux	100	South America	10
Portugal	100	Australia	10
Nationalist China	100		

 Table VII.2-Comparative Topographic Coverage at Scales of 1:63 000 among various Countries and Regions, 1967<sup>a</sup>

\* Based on information compiled by the U.S. Geological Survey and presented in hearings before the Subcommittee of the Committee on Appropriations (House), U.S. Department of the Interior and Related Agencies Appropriations for 1968.

features of urban areas, the increasing information collected by industry, and the new concepts of earth science.

# VII.2 Topographic Surveys

Topographic maps form the base for all other earth science maps. In addition, they are required to display administrative and legal information on properties and boundaries, and are essential for defence, all forms of transportation, planning and regional development, and many forms of outdoor recreation.

The conduct of national horizontal and vertical control surveys, and the preparation of the National Topographic Series, are the responsibilities of the Surveys and Mapping Branch of the Department of Energy, Mines and Resources. The concentration of topographic services in this branch is very beneficial, both from the uniformity of standards and economy of performance. Other federal government agencies depend fully on the services provided by this branch although, before 1966, the Department of National Defence also produced a considerable number of maps for the National Topographic Series. Provincial government agencies make extensive use of maps prepared on 1:50 000 and 1:250 000 scales in planning and resource administration. Several provinces conduct aerial surveys

and prepare local maps on larger scales (e.g. 1:10 000).

The present degree of coverage is shown in Figure VII.1 and is detailed in Table VII.1. The 1:250 000 scale mapping is now complete; 1:50 000 scale maps are available for 37 per cent of Canada (or 52 per cent of the area of the provinces). The comparative degree of coverage among various countries is illustrated in Table VII.2.

At the present rates of completion (approximately 2 per cent per year), the 1:50-000 series will not be completed before the year 2000. However, new construction causes maps in settled areas to become obsolete within 10 years, and hence an ongoing program of revision is necessary. A Federal-Provincial Map Users Conference held in 1966 "indicated a demand for mapping services now, and in the immediate future, far exceeding existing potential. Failure to satisfy this demand will aggravate a national emergency by wasteful retardation of economic development".1 The National Advisory Committee on Control Surveys and Mapping has estimated that the national topographic mapping program should be increased by an amount equivalent to an additional expenditure of \$4 million a

'1966 Map Users Conference, sponsored by the National Advisory Committee on Control Surveys and Mapping. year if the total demand for new mapping and map revision were to be satisfied. We conclude:

### Conclusion VII.1

Present topographic mapping at the 1:50 000 scale should be accelerated to ensure full coverage of all provinces and designated areas of the Yukon and Northwest Territories prior to 1975. Target dates and funding of 1:25 000 scale topographic mapping in urban areas should be established through federal-provincial consultations.

# VII.3 Hydrographic Surveys

Charting of the bathymetry of Canada's continental shelves is a prerequisite for commercial navigation, fisheries and defence. It is also essential to the search for mineral resources, natural resource administration and exploitation, and research on the origin and history of the oceans.

The Canadian Hydrographic Service of the Department of Energy, Mines and Resources is responsible for the national hydrographic coverage. Canada's continental shelves cover 1 452 000 sq. miles, approximately equivalent to 42 per cent of the land area. To date, accurate surveys are available for less than 10 per cent of the shelves. The principal government surveys programmed for 1969-74 are located in high-priority areas and include completion of the Gulf of St. Lawrence area, the shelf off Newfoundland and southern Labrador, the Viscount Melville Sound and waters adjoining Banks and Herschel Islands in the Arctic, as well as areas on the Pacific continental shelf. This will result, by 1974, in an adequate hydrographic coverage of 25 per cent of the Canadian continental shelves. It is essential that this rate of progress be continued.

# VII.4 Geological Surveys

Geological maps, like topographic maps, 274

serve multiple functions. In the mineral resource field, they form the basis for exploring and outlining the mineral and energy assets of the nation. In building and highway construction they indicate sources of natural materials, preferred sites for construction, and potential transportation routes. Agronomists, foresters, urban planners, conservationists and other specialists concerned with the environment use geological maps. Unlike topographic and hydrographic charts, a complete geological map includes an interpretation of the dimensions of depth and time. From surface exposures geologists predict subsurface structures and define the best locations for exploratory drill holes. Through determination of the age of surface samples (based on fossils, isotopic dating, or sequences of strata) and the laboratory identification of their various other properties, geologists interpret the history and evolution of the earth, and define in time and space those key horizons which may have particular economic significance. Hence, a geological map is commonly a result of geological research and is much more than a mere record of surface observations.

Most nations have found it advantageous to maintain a national geological survey to gather, classify, and make available the cumulative knowledge of the country's geology. In Canada this activity started with the Geological Survey of Canada and has, since Confederation, slowly evolved to become the function of a number of provincial agencies as well. There has been a threefold separation of efforts, related to: a) bedrock geology, of principal interest to the mineral industry; b) surficial material (all loose material above the bedrock), of principal interest to construction and transportation, land use and urban development; c) soil surveys, of primary interest in agriculture and forestry.

The personnel requirements for the conduct of these three types of geological surveys, the differing data recorded, and the differing users of the data require the following separate treatment.

Figure VII.2–Published bedrock geological maps on a 1-mile scale are available for 7 per cent of Canada. Maps on a 4-mile scale are available for 48 per cent, and on an 8-mile scale for 92 per cent of the country. Systematic coverage for the offshore areas is practically nonexistent.



#### **Bedrock Geological Mapping**

Bedrock geological mapping is performed by industry, government and university geologists. Industry is the largest spender on geological data collection, but because of its proprietary nature, little of this information reaches the public domain. The government agencies are the principal publishers of systematic geological maps, based to a considerable extent on the work of their permanent staff. University geologists contribute to the national coverage through field work for government agencies, as well as the preparation of maps and diagrams in theses and scientific journals.

Figure VII.2 shows the present coverage of bedrock geological mapping in Canada by federal and provincial agencies, and represents the sum of *over 125 years of work.*<sup>1</sup> Eight per cent of the landmass is currently unmapped (completion date estimated at 1975). Only 7 per cent has been mapped at a 1-mile scale (Table VII.1). Systematic bedrock mapping on the continental shelves has just begun.

Analysis of the quality of recent 8-mile reconnaissance geological mapping in the Northwest Territories indicates that although it provides broad targets for mineral exploration, there are only, on the average, two bedrock observations in each 100 sq. miles. Since mineral deposits very rarely measure more than a few hundreds or thousands of feet (if they outcrop at all), the meagre detail of coverage by 8-mile methods can be appreciated.

Forty-nine per cent of Canada is geologically mapped at a 4-mile scale. In the Northwest Territories this is based on approximately thirty bedrock observations per 100 sq. miles. The availability of aeromagnetic maps allows extrapolations to be made with greater confidence in areas of muskeg or overburden. They show quite clearly the weaknesses of existing maps based on surveys conducted before World War II and based principally on observations along canoe routes. In the Cordillera and certain provinces, higher relief and more abundant exposures result in maps of higher quality on the same scale. At current rates of mapping progress (Table VII.3), it is estimated that this scale of geological coverage will not be completed before the year 2000.

Geological maps on a 1-mile scale cover 7 per cent of the country.<sup>1</sup> They show the basic data for mineral prospecting and resource development, engineering projects and urban planning and environmental management. As interest in mineral and land resources intensifies. the need for maps on these scales is felt in ever-increasing proportions. However, the current rate of progress is small and it is unrealistic to estimate a date for completion on a national scale. In many provinces alone, the current rate of progress in surveying, compiling, and publishing new geological maps on this scale is insufficient to keep up with the changes in information which arise from urban or economic development or revisions in the topographic map base, or exploration programs conducted by industry, or changes in interpretation.

Table VII.3 summarizes the current rates of progress in systematic bedrock mapping by all government agencies. In view of the importance of this mapping in national development, and the presently inadequate rates of progress, we conclude:

#### Conclusion VII.2

The present rate of geological mapping at 1:250 000 (4-mile scale) should be accelerated to ensure complete national coverage by 1980, with uniform standards of information and precision. Goals for the sequence and rate of coverage of 4-mile studies, as well as follow-up investigations in economic areas on a 1-mile scale in the Northwest Territories and Yukon, should

<sup>&#</sup>x27;The total expenditures of the Geological Survey of Canada from 1842 to 1969, for mapping and all other services, have been \$100 million, or less than one-third the cost of the Appollo XII mission to the moon.

<sup>&#</sup>x27;India, for comparison, has a 61 per cent coverage at this scale.

# Table VII.3-Current Rates of Progress of Government Agencies Engaged in Bedrock Geological Mapping, 1968-

Agency	Rates c (map sl	Annual Coverage per year (at all scales)			
	1" = ½ mile	1 <i>"</i> =1 mile	1"=4 miles	1''=8 miles	sq. miles
B.C. Dept. of Mines & Petroleum Resources	minor	0	0	Xb	
Alberta Research Council	-	0	0	0	
Sask. Dept. of Mineral Resources	_	5	0	x	1 925
Manitoba Dept. of Mines & Natural Resources	_	10	0	x	3 850
Ontario Dept. of Mines	16	2	1	0	9 730
Quebec Dept. of Natural Resources	-	15	4	-	27 265
New Brunswick Dept. of Natural Resources	0.2°	0	x	x	40
Nova Scotia Dept. of Mines	0	0	x	х	<u>`</u>
Prince Edward Island Dept. of Industry & Nat. Resources	0	0	x	x	
Newfoundland Dept. of Mines, Agriculture & Resources	minor	0	0	0	
Geological Survey of Canada	minor	14	13	4	186 324
Total	16	46	18	4	229 134

• This table is based on information supplied by the organizations concerned. It represents the existing rate of progress by the organization concerned but not the preferable rate of progress.

<sup>b</sup> x = mapping completed on this scale.

• At <sup>1</sup>/<sub>4</sub>-mile scale.

be established co-operatively by the Department of Indian Affairs and Northern Development and the Department of Energy, Mines and Resources, and performed by the Geological Survey of Canada. Similar 10-year goals for systematic geological mapping should be established through co-operative agreements with the provincial governments.

It is a matter of concern that the amount of detail and accuracy of data on geological maps of the same scale can vary enormously. Some show out-crops and others do not; some show considerable vertical information and others do not; some are published on metric scale (e.g. 1:50 000) and others on English scales (e.g. 1 inch to 1 mile). Different symbols are used for the same feature. These differences reflect the fact that there are a number of separate agencies involved in the generation of geological maps (in contrast to topographic and geophysical maps). In addition, because of the interpretative nature of geological

data, maps frequently tend to reflect the special interests of the mapper.

It is also a matter of concern that the printing costs of geological maps are rising rapidly. Provincial and federal agencies see a need to develop newer formats to lower costs and speed publication while still maintaining acceptable standards.

#### Conclusion VII.3

The Department of Energy, Mines and Resources should convene a national conference of representatives from earth science mapping agencies in the federal and provincial governments and users in industry to:

a) summarize the current level of knowledge and rate of progress in completing the earth science map requirements of the nation;

b) review the present standards of data collection, data compilation (legends, etc.) and publication;

c) define the future national and provincial needs in terms of types of data (geological, geophysical, geochemical, topographic) and scales of publication;

d) develop detailed federal-provincial co-operative programs for the completion and publication of a national systematic map coverage on 1:250 000, 1:50 000, and detailed scales, and determine related funding on a cost-sharing basis.

#### **Mapping of Surficial Materials**

Mapping and interpretation of the unconsolidated surficial deposits' and landscape features is commonly referred to as "Quaternary geology", since the origin and history of these deposits have evolved during the past one or two million years (the Quaternary period). More than 90 per cent of Canada is covered by unconsolidated deposits that are directly or indirectly related to glaciation. Many elements of the landscape, including lakes, rivers, and coastal configuration, are the product of glaciation. From a practical viewpoint, the study of surficial materials serves the fields of agriculture, forestry, water resources, pollution and waste disposal, foundation and construction engineering, urban and rural planning, northern development, recreational land use, construction materials and mineral exploration.

Figure VII.3 and Table VII.1 indicate the current coverage of Quaternary maps produced by federal and provincial agencies. Because of the large variety of scales used, and the diversity in type and amount of detail shown on different maps, three main categories are shown, namely:

1. Eight- to sixteen-mile map coverage, resulting from reconnaissance surveys of landforms in the Arctic, northern Ontario, Manitoba and northern Quebec, as well as surveys by the Ontario Department of Lands and Forests and the Geological Survey of Canada in southern latitudes, the latter showing the distribution of materials on a reconnaissance scale.

2. Four-mile map coverage, involving the reconnaissance mapping of surface materials and landforms. This is divided 278 into "northern 4-mile" and "southern 4mile" classes on the basis of the amount of detail and the potential of the areas in regard to agriculture, forestry, power development and mineral resource exploration.

3. More detailed map coverage, consisting principally of 1- and 2-mile maps. One-mile mapping is confined largely to areas of high density population, and directed toward problems of environmental and urban geology, including both the potential uses and hazards of geological materials.

Maps of surficial materials are unavailable on any scale for 42 per cent of the country. There are 30 geologists in federal and provincial agencies who are engaged in this type of mapping, over half of whom are in the Geological Survey of Canada. The rates of this mapping, considering all facilities and all scales, total about 100 000 square miles, or 3 per cent of the landmass, each year.

#### Soil Surveys<sup>2</sup>

Soil surveys provide an inventory of our soil resources and the basis for agricultural development and land use.

The survey of soils in Canada is a cooperative undertaking involving the Canada Department of Agriculture, all provincial governments (except Prince Edward Island) and six universities. Within each province (except British Columbia), the federal and provincial units are accommodated together on a university campus (or college in the case of Nova Scotia). In Alberta and Saskatchewan, formal soil institutes have been established consisting of federal and provincial representatives with the federal government contributing 50 to 60 per cent of their cost.

#### The Canada Soil Survey was initiated

'Soil surveys, discussed in the next section of this chapter, refer only to the thin upper part of the unconsolidated cover, which is traditionally regarded as the natural medium for plant growth.

<sup>2</sup>Soil is used here in the sense of "the medium for the growth of land plants". Data provided in the brief on "Pedology", submitted to the Study Group by the Canada Department of Agriculture.

Figure VII.3–Published geological maps of surficial materials on a scale of 2 miles to 1 inch, or larger, are available for less than 3 per cent of Canada. Maps on a scale of 8 or 16 miles to 1 inch are available for 39 per cent of Canada. The surficial deposits of 42 per cent of the country are unmapped.


in 1921 and expanded after 1935. Ninety-four per cent of the agriculturally settled areas has been covered by broad reconnaissance surveys (Figure VII.4) and described in maps and reports, although a number of areas require re-examination. These surveys provide an inventory of soil resources and form a basis for land use interpretation and local detailed studies. Some of the unsettled or thinly populated areas have been covered by very broad exploratory surveys, which indicate the potential of a region for farming. For most of northern Canada, however, knowledge is based on isolated examinations. On a national basis, approximately 19 per cent of the landmass has been surveyed in some form (see Table VII.1). A soil map of Canada is now in preparation, depicting over 340 different soil combinations; it will be published on a scale of 1:5 000 000.

The information obtained from soil surveys has been used by the Canada Land Inventory of the Department of Regional Economic Expansion as one basis of land use classifications. A systematic series of coloured maps on a scale of 1:250 000 are being published to indicate land capability for agriculture and forestry, and land suitability for recreation and wildlife. These maps, which are supported through the ARDA program, will cover about 1 million sq. miles in settled areas.

## The Need for Closer Co-ordination of Soil and Quaternary Geological Mapping

There is a difference of opinion among earth scientists as to whether the term "soil" should refer to only those upper parts of the unconsolidated materials which support plant roots, or to the entire section of unconsolidated material. Engineers consider soils in the latter context. Agronomers have used the principles of soil science, following the former definition, to conduct the soil survey of Canada, and considerable benefits to agriculture have resulted. Interest in the importance of the entire section of unconsolidated materials has developed more slowly in Canada. As indicated by the Canadian Society of Soil Science in its brief to this Study Group:

"Soil science continues to remain oriented to agriculture, which is a strength and a weakness simultaneously. The strength arises through a sense of purpose in an application of the science. The weakness is that, because of the close association with agrology, the principles of soil science cannot be brought to bear on other areas of application. The various fields of geology, civil engineering, oceanography, forestry, wildlife management, urban planning and pollution are but a few fields of endeavour or disciplines which have not utilized efficiently the knowledge and principles of soil science."

Parallelling the disagreement in terminology is a difference in interest between the agronomer interested in soils as an agricultural resource and the Quaternary geologist interested in the source, transport and development of all unconsolidated materials. There is also a splintering of common interests in universities between the departments of agriculture, geography, and geology (the latter being interested in Quaternary geology). In fact, practitioners of soil and surficial studies become quite emotional about the merits and limitations of each other's work.

We feel very strongly that sharply increasing urbanization, problems of waste disposal and pollution, problems of land use and water resources, and demands for construction materials, indicate a need to re-orient the general purpose for study of surficial materials from a dominantly agricultural mission to an environmental mission, concerned with the entire section of unconsolidated materials, and aligned more closely to the needs of an urban society. Although this subject is not one for federal involvement alone, nevertheless in view of the use of federal funds and personnel for these purposes, it seems appropriate that initial steps for co-ordination be made at that level. Hence we conclude:

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Figure VII.4-Soil surveys of a reconnaissance or exploratory nature cover approximately 94 per cent of the farm and improved lands reported in the 1961 census.



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#### Conclusion VII.4

The Government of Canada should establish a task force to study its present allocation of financial and personnel resources to the national survey of "surficial geological" materials and to formulate a plan toward co-ordinating and accelerating the federal effort to meet rising needs of urbanization, groundwater resources, engineering construction, waste disposal and pollution, as well as the continuing needs of agriculture.

## VII.5 Geophysical Surveys

The ability of geophysical instruments and techniques to measure important rock properties has greatly influenced mapping and economic development of the country. Foremost in these methods has been the development and application of the airborne magnetometer, and this is being followed by the development of electromagnetic and radiometric methods. The speed of airborne surveys compared to ground methods, and the small number of trained men required, has been of considerable value in exploring our vast territory. Although airborne methods measure only a very few of the geological parameters which can be obtained from a rock outcrop, they penetrate swamps and overburden, providing a three-dimensional analysis of the underlying bedrock. Hence, their value cannot be overstated.

#### **Aeromagnetic Survey**

The Geological Survey of Canada has applied the airborne magnetometer to the systematic mapping of Canada over the past 20 years. In 1962 a federalprovincial aeromagnetic program was initiated. Recently the Bedford Institute of Oceanography initiated systematic shipborne magnetic surveys on the east coast. The present extent of coverage, using nuclear precision magnetometers, is indicated in Figure VII.5. Surveys are generally conducted at an altitude of <sup>282</sup> 1 000 feet and a line spacing of ½ mile, and published on a scale of 1 inch to 1 mile. At the present time 41 per cent of the landmass has been surveyed and the remaining areas are largely in northern or mountainous areas. *The program, exclusive of the western sedimentary basins, is scheduled for completion about 1975.* The western basins have been flown by petroleum companies, and are currently being resurveyed by using higher sensitivity magnetometers.

#### **Gravity Surveys**

Gravity data provide means of investigating the shape of the earth and the constitution of the crust. Development of the gravimeter was pioneered by the petroleum industry but the principal contributor to the national coverage has been the Dominion Observatory (Department of Energy, Mines and Resources). Recently the Bedford Institute of Oceanography implemented offshore surveys with a shipborne gravimeter on the east coast. The level of research on gravity in Canadian universities and provincial institutions is low and sporadic.

The present objective of the Gravity Division of the Dominion Observatory is to complete systematic gravity mapping of Canada at a station interval of 15 km or less. The results are published at a scale of 1:500 000. Figure VII.6 shows the present degree of coverage, and Table VII.1 summarizes the coverage by province. At present approximately 64 per cent of Canada is completed on a 15-km spacing. The present rate of completion involves the observation of some 7 000 new regional gravity stations annually. This is considered adequate to meet the general national needs. Regional mapping east of the Cordillera will be completed by 1975 but the mountainous areas of western Canada will require at least another 10 years to complete.

## VII.6 Earth-Oriented Resource Satellites

Earth-oriented resource satellites to be

launched in the United States offer an increased capability for the collection of earth science data. The major uses of these data will relate to management of renewable resources and environmental quality (agriculture, forestry, water, pollution) rather than to the mineral resources. Nevertheless, the availability of orthophoto imagery will be of considerable value in the identification of major lineaments on the earth's surface. At the present time, the development of remote sensing methods for use in high-flying aircraft appears to offer more potential for mineral exploration since greater penetration of the earth's surface can be obtained. This is a field in which Canada has made, and can continue to make, important contributions at a low cost. In the immediate future, the economic merits of using earth resource satellites over Canada for geological purposes will depend upon: a) the cost of participating in American or other programs to gain access to data pertaining to Canada; b) the extent of their usefulness in the renewable resource field; and c) the degree of urgency in gaining access to the data and technology. We propose:

#### Conclusion VII.5

It is essential to maintain liaison with the United States resource satellite programs to ensure access to resource data and technology of use to Canada. The Federal Government should ensure that the necessary international and national co-ordination is developed and that research is sufficient to ensure the fullest benefits to the nation. The planning and implementation of such an arrangement should ensure the fullest participation and data access by industry, universities, and provincial government agencies.

## VII.7 Earth Science Activities on the Continental Shelves

Solid-earth science activities hold the key to future exploitation of Canada's continental shelves, and if economically successful, could result in considerable national and regional benefits. A general absence of geological knowledge of the shelves has been both a handicap to the planning of efficient exploration programs and an attraction in allowing uncontrolled speculation on their potential. Cloud,' speaking of continental shelves in general, summarizes the situation succinctly as follows:

"A 'mineral cornucopia' beneath the sea exists only in hyperbole. What is actually won from it will be the result of persistent, imaginative research, inspired invention, bold and skillful experiment, and intelligent application and management-and resources found will come mostly from the submerged continental shelves, slopes and rises. Whether they will be large or small is not known. It is a fair guess that they will be respectably large; but if present conceptions of earth structure and of sea-floor composition and history are even approximately correct, minerals from the seabed are not likely to compare in volume or in value with those yet to be taken from the emerged lands."

The potential geological resources on Canada's continental shelves are: a) oil. gas and sulphur resources in thick sedimentary section; b) sand, gravel, and placer deposits (minor) which occur near shore and in lands considered to fall under provincial jurisdiction. The exploitation of these resources without proper planning can result in considerable damage to the coastal environment. Canada's prospective oil bearing offshore areas cover an estimated 650 000 sq. miles, or 40 per cent of the area of the continental margins. However "there is not enough information to establish a meaningful value for the offshore potential...and when we have completed a billion-dollar exploration program during the 1970s,

<sup>&#</sup>x27;Resources and man. Report of Committee on Resources and Man, National Academy of Science and National Research Council, Washington, D.C. W.H. Freeman & Co., 1969.

Figure VII.5-Progress toward magnetometer coverage of Canada. Published aeromagnetic maps of the landmass, on a scale of 1 inch to 1 mile, are available for 41 per cent of the country.



Figure VII.6–Progress toward gravity map coverage of Canada. Regional information (station spacing  $\leq 15$  km) is available for 64 per cent of the landmass.



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Augustantia and shorton "weat-protect" with harved will been off small grint with a standardine repairing the first man be reduced in an givent first and be reduced in an givent first at mit bigst off \$100 security of the standard bigst off \$100 security of the security we may begin to have a clue to the offshore hydrocarbon potential."1

The development of national policies on the use of Canada's offshore resources cannot be done "overnight". The provision of a geological framework (what is the resource potential in terms of type and size?), an environmental framework (what will be the impact of resource development on the environment?), an operational framework (extraction techniques, navigation aids, climatological data, etc.), a legal framework (national-international, federal-provincial, governmentindustry), an economic framework (what would be the impact of a major oil discovery in the Atlantic continental margin on the local, national and international economy?) all require careful consideration and considerable expenditure. The manyfold activities involved are dependent first on whether the resources exist, and then on whether they are economically exploitable without undue damage to the environment. This knowledge will define the scale and direction of further policy and operational development. It is a matter of concern, therefore, that no schedules have been set for acquisition of the basic earth science data which are so essential to the formulation of many other policies and activities.

At the present time, Canada's marine earth science program represents an agglomeration of the cumulative responses of industry, government and university groups to the immediate needs as they see them. Some are motivated by the search for resources in Canadian waters; others by basic problems of earth history on a global scale; others simply by the availability of funds to support research activities. No single group attempts to co-ordinate or direct the total effort and a "laissez-faire" attitude has developed among them. The need for broad planning was perhaps unnecessary a few years ago when offshore activities were growing slowly as an extension of onshore programs. With the rapid rise in the number of petroleum companies and government agencies concerned with 286

that the proposed National Advisory Committee on Mineral Resources Research (NACMRR) could logically undertake this role of planning a national program for the mapping of Canada's offshore continental shelves and their non-renewable resources, of setting the goals, of reviewing the progress, and of advising on problems or co-ordination and proper levels of activity. The Mineral Exploration Research Subcommittee of NACMRR could be charged with the responsibility of defining and monitoring the national mapping program, including the definition of standards of data collection, line spacings, and levels of activity between related disciplines (hydrography, oceanography, bottom sampling and drilling, seismology, magnetics, gravity, etc.). It could co-ordinate the activities of government and university groups with those of industry to ensure minimum duplication of expenditures and effort, and earliest completion and assessment of the exploration program. The Mineral Production Research Subcommittee of NACMRR would operate at a lower intensity in the early stages, since its main impact would occur after resources are identified. Nevertheless, it could act as a monitor of contemporary developments on a worldwide scale, especially in "cold water" exploitation, and could alert university and industry groups to the main problems of extraction requiring early research and development. The Mineral Policy Research Committee of NACMRR has an immediate role to play in providing advice on the regulatory, political and economic and environmental matters affecting resource exploration. We therefore submit: Conclusion VII.6

marine earth sciences, the need for plan-

ning becomes more urgent. We consider

The proposed National Advisory Committee on Mineral Resources Research should assume the responsibility of developing and

'Smith, D. W. The potential of Canada's offshore mineral resources. CIM Bull. 62(685): 507-509. 1969.

monitoring a national program for exploration, exploitation, and policy formulation related to the non-renewable resources of Canada's continental shelves.

In addition to the needs expressed above, there are numerous areas of earth science research which can be pursued. These include, to mention only a few:

1. correlations of offshore and onshore geology, with resulting economic implications, as well as scientific significance in relation to sea-floor spreading and global tectonics;

2. geophysical and geological studies of the transition zones between crustal blocks and ocean basins;

3. sedimentological studies on the shelf and continental slope;

4. Quaternary studies of the extent of glaciation and implications of post-glacial emergence;

5. geochronological and paleontological studies of the age and evolution of the continental margins.

A strong emphasis on a systematic geological and geophysical reconnaissance of our continental shelves will provide not only the basis for economic and policy development, but also a good foundation for future applied and basic research activities in the earth sciences.

# Chapter VIII

Technical Assistance to Developing Countries "The world is my family."

## Gandhi

## VIII.1 Synopsis

Although external aid is essentially the subject of political decision, with social and economic overtones. Canadian earth scientists should be concerned with the pressing needs of developing countries. By applying their expertise in science and technology to natural resource development, earth scientists can do much to improve the economy of emerging nations and help bridge the gap between these nations and the industrialized countries.

In this chapter we review briefly some of the major principles underlying Canada's technical assistance to developing countries and indicate the potential magnitude of earth-science-based programs in relation to the total aid effort. Furthermore, we outline Canadian capabilities in natural resource development and propose a series of guidelines for developing future earth-science-based programs of external technical assistance.

Canada is eminently capable of providing expertise in mineral resource development, ranging from broad reconnaissance surveys to detailed scientific and economic studies, and including assistance in the elaboration of mining and fiscal legislation to promote the exploration for, and exploitation of, mineral resources. Canadian scientists can also conduct soil and land use studies for agricultural development, including the search for and proper use of mineral fertilizers, as well as studies for locating adequate supplies of water, and geotechnical studies applied to large construction and other public works, and irrigation.

The Canadian earth science contributions to external assistance programs should be part of a fully integrated approach to natural resource development, with a well-directed, rational, effective and sustained national contribution. Adequate professional and technical support from various government agencies, uni-290

versities, contractors and industry should be provided. Technical assistance should be looked upon as a product that Canada is trying to market to the mutual advantage of the co-operating nations and this country. With good salesmanship abroad, Canada should provide "guided responsive aid" whereby it would make known the types of requests to which it would respond most readily.

Other measures to improve the efficacy of earth science programs overseas include better planning of, and prioritysetting in, assistance projects; mid-project reviews and post-project appraisals; concentration on education and training in the home country rather than in Canada; the development of counterpart institutions in the developing countries; the establishment of a Canadian cadre of earth science specialists for foreign work; the publication of the essential results of aid programs; and better communications between the Canadian International Development Agency (CIDA) and the Canadian earth science community.

Finally, it is believed that the earthscience-based programs in the resource field should amount to at least 5 per cent of Canada's direct assistance and reach a minimum of \$30 million by 1975 compared to \$5 million spent on such programs in 1968.

## VIII.2 General Considerations on Canada's External Aid Policy

Although motives are mixed and related to emotional reactions, the principles underlying Canada's technical assistance to developing countries are guided by humanitarian motives and affected by political, social and economic considerations. One of the primary objectives of foreign aid is to help in the economic development of the less fortunate nations and to bridge the economic gap between the "Third World" and the industrialized countries.

Canada's aid policy was stated in 1965 by the Honourable Paul Martin<sup>1</sup>, then Minister of External Affairs, who said:

"...the resources we allocate to foreign aid are intended to serve one overriding objective, which is to supplement the resources the developing countries themselves can manage to mobilize for their economic development". The present government's intent is "...to carry forward the plans and policies which Mr. Martin set in motion and to seek new ways in which the Canadian people can help to narrow the economic gap".<sup>2</sup>

In the development of these objectives, the Canadian government has so far considered that the individual assistance projects it sponsors are responsive<sup>3</sup> in nature. Canada's response is of necessity related to its ability and capacity to provide the required resources. Canadian assistance is concentrated, to an increasing extent, in those countries where it is believed that the most effective contribution can be made and where Canada has important interests.<sup>4</sup>

Science policy on assistance to developing countries is generally not specifically defined by aid-giving organizations. However, it has been and still is the subject of discussion by the Canadian International Development Agency (CIDA) and other organizations including the United Nations, OECD, the Ford Foundation and the World Bank. Policy related to earth sciences is mentioned only in the broadest terms, although a report of considerable significance on the utilization of earth sciences in developing countries was published by the United Nations in 1963.<sup>5</sup>

The need for establishing policies and defining scientific capabilities have been clearly outlined by the President of CIDA: "Our planning requires the best possible knowledge of Canadian scientific priorities. It is important that we know present and projected future Canadian capabilities in the fields applicable to the needs of the developing countries and the extent to which these capabilities may be available to us. It is equally important for those involved in Canadian science policy and planning to take into account the extent to which our programs are going to be drawing on these capabilities. As our programs will be growing at a significant rate and are likely to be a continuing feature of our national life for the foreseeable future, I believe that they must be taken fully into account in establishing our national science policies and priorities. This requires much closer co-operation between our Agency and the Canadian science community".<sup>6</sup>

In the light of the above, it is evident that our study of the solid-earth sciences in Canada would not be complete without a discussion of the role of earth sciences in Canada's foreign aid programs. The opinions expressed in this chapter are based on the collective experience and judgment of several hundred Canadian earth scientists, many of whom worked in developing countries for either CIDA or UN agencies, or for mining or petroleum companies.

## VIII.3 General Structure of Canada's International Assistance Program

As outlined by Mr. Strong<sup>7</sup>, Canada's program of assistance to developing countries has two main components:

1. Bilateral assistance, which is direct aid in the form of capital or technical assistance, or both, and indirect aid in the form of education and training given to personnel from developing countries. 2. Multilateral assistance, whereby Can-

<sup>2</sup>Canadian International Development Agency. Annual review 1967-68.

<sup>3</sup>By *responsive nature* is meant the inherent right of the developing country to determine and initiate its own aid requirements.

<sup>4</sup>Strong, M. F. Statement to the Senate External Relations Committee. Ottawa, December 14, 1967.

<sup>5</sup>United Nations. Science and technology for development; Vol. II. Natural resources. UN Publ. No. 63.1.22. New York, 1963, 243 p.

<sup>6</sup>Senate of Canada. The Canadian International Development Agency. Brief presented by M. F. Strong, Proceedings of Special Committee on Science Policy, No. 32. Ottawa, 1969. pp. 4485-4588.

'Senate of Canada, op. cit.

<sup>&#</sup>x27;Hon. Paul Martin. Principles and purposes of foreign aid. External Affairs, Vol. XVII, No. 3. Ottawa, March 1965.

ada makes contributions to the agencies that are primarily part of the United Nations system, such as the United Nations Development Program (UNDP), the World Bank, the Asian Development Bank, etc.

These programs are administered by CIDA. The Exports Credits, which are administered by a separate crown corporation, are not considered as part of the aid program, but they appear nevertheless in the "total aid flows".

The Canadian International Development Agency utilizes the service of other government departments and crown agencies. For example, aid co-ordination officers have been established in a number of government departments, e.g. the Department of Energy, Mines and Resources. Contracts are made with specific organizations for special studies, e.g. the Association of Universities and Colleges of Canada (AUCC), and advice on technical assistance is sought from many sectors of Canadian professional and academic life. Finally, CIDA supports the Canadian University Service Overseas (CUSO) and the Canadian Executive Service Overseas (CESO), both of these voluntary organizations employing a few earth scientists and geotechnicians. Other aspects of CIDA's organization may be found in Mr. Strong's brief to the Senate Committee on Science Policy.

## VIII.4 Magnitude of Canada's International Assistance Program

Basically, Canada's external assistance is in the form of grants-which are outright gifts-and loa'ns, which are generally on 50-year terms and carry no interest. This assistance involves government, industry, and non-profit or voluntary organizations. Industrial participation arises from government contracts, the majority of which in the earth science fields are engineering and resource surveys, and commercial ventures arising from work on a government project.

The funds allocated by the Canadian government to external assistance in 1965-70 are shown in Table VIII.1. For

the year 1969-70 it is estimated that \$228 million will be spent in direct assistance to 72 individual countries (Figure VIII.1) out of a total CIDA budget of \$398 million.

The official aid flows in 1968 were \$175 million compared to \$185 million budgeted (Table VIII.1). The earth-sciencebased programs included in this official aid amounted to \$6 million (Table 5.1, Appendix 5), or 3.5 per cent of the total official assistance.

If Canada follows the recommendation of the Pearson Commission, which calls for an 18.9 per cent annual rate of growth in Canada's official aid disbursements, CIDA's budget for grants and soft loans may be expected to reach \$590 million by 1975, or 0.7 per cent of our Gross National Income. The question that then comes to mind is how much of this budget might be allocated to natural resource development in the years to come and, accordingly, to earth-science-based programs. If our overseas earth science activities reach the minimum proportion of 5 per cent of Canada's total technical assistance, as recommended in Section VIII.11, we should expect CIDA's earthscience-based programs to reach \$30 million annually by 1975, almost a fivefold increase with respect to the year 1968-69.

## VIII.5 Role of Science and Technology in Canada's Foreign Aid

Science and technology figure very prominently in the requirements of developing countries, particularly in natural resource development. Not only must science and technology be applied to the particular technical problems of these countries; they must also be directly related to the "milieu", with proper appreciation of the cultural values, social conditions and political regimes that exist there. This is admittedly a very difficult task, especially since the co-operating nations often have difficulties in understanding their particular problems and identifying their special needs, let alone

	1965-66	1966-67	1967-68	1968-69	1969-70
	\$'000	\$'000	\$'000	\$'000	\$'000
Economic, Technical, Educational and Other Assistance (Vote 35, CIDA)	48 500	48 500	50 000	62 900	70 617
Multilateral Assistance Programs (UNSF & UNDP) (Vote 15, Ext. Affairs for 1965-69; Vote 35, CIDA)	7 325	9 500	10 750	10 750	13 500
Multilateral Assistance Programs (UNESCO) (Vote 15, Ext. Affairs)	746	757	966	1 035	1 136
Approved assistance projects by Canadian non-governmental organizations	_	-		5 000	6 500
Special loan assistance to developing countries and to recognized development institutions (Vote L35, CIDA)	50 000	50 000	90 000	106 000	137 000
All Fields of Technical Assistance	106 571	108 757	151 716	185 685	228 753
Source: Published Canadian government estim	ates.				

 Table VIII.1-Funds Allocated by the Canadian Government to all Fields of External Assistance to

 Developing Countries, 1965-70

the ways in which they can best help themselves.

The Canadian International Development Agency has made limited attempts to survey the needs of several developing countries and appraise the extent to which Canada could make its own special contributions. If CIDA is to be more than a post office for handling assistance requests, fundamental planning concepts must be scientifically elaborated. These concepts must be drawn in relation to Canadian policy in external affairs, the needs and aspirations of the co-operating nations, and the Canadian capacities to meet these needs and contribute significantly to these aspirations. However, to be really effective our aid program must be based on forward planning rather than on "responsive" accommodation.

In our opinion, priority setting and follow-through in program development are prerequisites to further expansion of Canada's technical assistance programs. In order to improve the decision-making process in the resource field, the most appropriate form and scope of foreign aid must be defined. This calls for the active co-operation of Canadian earth scientists and other specialists, and underlines the need for special studies such as this.

As indicated by Mr. Strong<sup>1</sup>, CIDA does not carry on scientific research per se in fields related to its mission. However, the Canadian government has introduced a bill to create a Canada-based International Development Research Centre.<sup>2</sup> It is understood that the objects of the Centre are to initiate, encourage, support and conduct research into the problems of the economically underdeveloped regions of the world and into the means for applying and adapting scientific, technical and other knowledge to the economic and social advancement of those regions. For example, one of the areas of special interest could be the development of new techniques for identifying and evaluating mineral resources.

"A possible additional objective is envisaged for the Centre in the field of assimilation, storage, retrieval and dissemination of information and data in various areas of the development field...The Centre is planned to complement the services performed by CIDA, and other bilateral and multilateral aid agencies".<sup>3</sup> The Centre would be a separate institution,

CIDA, op. cit.

<sup>&</sup>lt;sup>2</sup>Speaking during the second reading of the bill, Hon. Mitchell Sharp told the House of Commons on January 12, 1970, that he foresees early allocation of as much as 5 per cent of Canada's total aid budget to the Centre. With the aid flow expected to exceed \$500 million by 1975, this would put the Centre's budget at \$25 million a year within five years or so.

<sup>&</sup>lt;sup>3</sup>Peters, S.S. International Development Research Centre of Canada. Talk given at Banff, Alberta, September 8, 1969.



international in the scope of its activities but Canadian in its basic sponsorship.

## VIII.6 Earth Science Activities in Canada's Bilateral Assistance Programs

In this review we are considering only the CIDA-sponsored projects which are partly or completely based on earth science activites. In 1968-69 these particular projects amounted to a total expenditure of \$5 million (Table 5.1). In addition, Canada spent close to \$1 million on earthscience-based multilateral programs conducted by various United Nations agencies. Of the total of \$6 million, about 10 per cent has been allocated to advisers. 13 per cent to education and training, and the rest to scientific data collection in the form of various types of field surveys and natural resource inventories, and geotechnical studies related to power development.

The general nature and scope of the earth-science-based projects sponsored by CIDA during the period 1953-69 are shown in Tables 8.1 to 8.4, Appendix 8.

#### **Capital Assistance**

According to CIDA sources, the earthscience-based capital assistance provided to developing countries as grants or long-term loans during the period 1953-69 amounted to 33 projects totalling \$35 million (Table 8.1). Of these, 10 projects totalling \$10 million were completed before 1965. Table 8.1 includes most of the projects in natural resource development; however, because of the lack of reliable detailed information, it is impossible to apportion some of these projects in terms of personnel, equipment, funds, and exact type of scientific activity, and to determine total staff involved.

A second group of projects in the capital assistance category includes those related to the development of power and irrigation, for which geotechnical personnel and equipment are involved. In this case, it is even more difficult to allocate costs and personnel to the geoscientific component of these projects, several of which are multimillion-dollar expenditures. This group of projects includes engineering geologists, rock and soil mechanics engineers, structural geologists, hydrogeologists, geophysicists, and others in the field of applied geology and environmental studies.

#### **Technical Assistance**

This category of projects is aimed primarily at education and training. It consists in sending abroad technical advisers, teachers and professors, and in bringing to Canada a number of trainees in fields of science and technology. During the period 1953-69, a total of 92 earth science personnel were sent abroad (Table 8.2), representing a total expenditure estimated at \$2.7 million, i.e. \$20 000 per manyear. Of this personnel, about 27 completed their assignments prior to 1965, at a cost to the External Aid Office of about \$0.7 million. In June 1969 there were 19 earth science advisors overseas.

With respect to education and training given in Canada, there were 144 trainees in earth science and geotechnical fields in this country as of September 30, 1968, representing an annual expenditure of about \$2 million, i.e. \$4 500 per manyear (Table 8.3). There were in 1968 a total of 50 trainees in the field of "mining and surveys" (covering only part of the earth science fields), as compared to 894 in all other fields (Table 8.4). Of the 10 000 people from developing countries who received education and training in Canada during the period 1950-67, only 5 per cent were trainees in "mining and surveys".1

It is estimated that during the period 1952-69 the total aid expenditure by CIDA and its predecessor (the External Aid Office) in all fields of earth science activities abroad was as follows:

'CIDA, op. cit.

Table VIII.2-Canada's Earth Science Expendituresin Bilateral Assistance to Developing Countries,1952-69

1952-64 1965-69 1952-69

	\$'000	\$'000	\$'000
Advisers	640	2 040	2 680
Trainees, 1968		1 958	1 958
Trainees, 1965-67	-	1 350	1 350
Trainees, pre-1965	2 350		2 350
Projects	9 593	27 780	37 373
Totals	12 583	33 128	45 711
Source: Personal con	nmunicatio	n, CIDA.	

The above table shows very clearly that before 1965, Canada's technical assistance in the earth science field was minimal. While this aid has increased markedly during the last five years, this support is-in our opinion-far below the expectations of most developing countries. It is clearly inadequate from the point of view of both the importance of natural resource development in these countries and the Canadian capacities to provide this type of assistance.

## VIII.7 Canadian Earth Science Participation in Multilateral Assistance Programs

Multilateral agencies such as UNESCO and FAO frequently use Canadian services and geoscientists in carrying out their programs in developing countries. For example, of the 117 geoscientific projects sponsored by the United Nations Development Program and implemented by the executing agencies in 1959-69, there were 44 projects utilizing Canadian personnel and services (Table 9.1). Most of these projects were concerned with mineral resource development or groundwater development, or both. As shown in Table 9.2, a minimum of 51 Canadian advisers (excluding employees of the federal government) worked on UNDP projects during the period 1959-69, at an average estimated cost of \$25 000 per man-year.

In 1967, there were 215 Canadians engaged in all fields of external aid sponsored by United Nations agencies<sup>1</sup>, including 31 in earth science activities, <sup>296</sup> principally in geological mapping, mineral resource surveys, and drilling.

Multilateral agencies also support annually at least 100 fellowships in Canada in the earth scince fields and related technology.

Canada's participation in multilateral programs is particularly evident in the part played by Canadian firms specialized in aerial photography, airborne and ground geophysical surveys, and diamond drilling. Of a total of 32 mineral exploration contracts in progress or just completed under the United Nations Special Fund (UNSF) in 1968, 18 (56%) involved Canadian participation. Many mineral exploration programs in developing countries are staffed partly or entirely by Canadians, especially in the field of mining geophysics, although the larger part of this involvement is through the UN agencies rather than CIDA.

## VIII.8 Earth Science Activities Abroad of Canadian Voluntary Agencies

The earth-science-based activities of voluntary agencies in developing countries are small relative to those of government agencies, since their main efforts are in other fields. CUSO, CESO (see Section 3), the United Church of Canada, and the White Fathers of Africa utilize the services of a few geologists, some soil scientists, two hydrogeologists, some drillers, and one mining engineer. When CUSO was established in 1961, it sent 17 people overseas; in 1969, it sent 1 100, very few of whom were in earth science fields. CESO's role is to provide experienced and well-qualified Canadian volunteer business and professional men for short-term assignments to developing countries; here again, very few are in earth science fields.

'Personal communication, G. C. Riley, UNDP, New York.

### VIII.9 Earth Science Activities Abroad of Canadian Mining Companies

Although the activities of Canadian mining companies in developing countries are not part of the technical assistance programs, and should not be considered as such, the fact remains that they can contribute very significantly to the development of mineral resources. As shown in Appendix 10, a number of Canadian companies are currently engaged in important exploration and development activities in several developing countries.

Canadian mining companies have probably invested well over \$100 million in developing countries during the last five years, and more than 100 man-years of Canadian earth science personnel are currently engaged in these commercial ventures.

In any survey of the economy of a developing country, the presence of an operating company like Falconbridge Nickel Mines Ltd. in Uganda, Nicaragua and the Dominican Republic, or Alcan Aluminum Ltd. in Jamaica, Brazil and India, assumes considerable significance.

It is well to emphasize that for many developing countries mineral development is the most likely source of additional income. In many cases, this income may be very substantial and provide the major source for a nation's capital investments and social security, health and education programs. Furthermore, the sale of minerals produces large amounts of foreign exchange and provides an important base for new industries in the secondary sector.

Consequently, even though commercial ventures are not part of Canada's external assistance programs except for government-awarded contracts, they are very much part of the overall picture and must be discussed here. In fact, the situation is somewhat analogous to that prevailing in Canada, where government agencies provide basic services and at a certain stage of regional knowledge, the industry takes over the mineral development; both government and industry are partners in this development, and each must have regard for the responsibilities and capacities of the other. There is however the important difference that in developing countries the local government does not have the financial, technical and planning resources to provide the essential platform of information for attracting industrial ventures; this lack of resources must be alleviated through technical assistance.

It follows that planning and prioritysetting in the resource field of external assistance must be achieved in full consideration of the role to be played by industry. For example, there is no point in Canada sponsoring aid projects that duplicate the work of mining companies in these countries. Likewise, there is no merit in Canada undertaking mineral resource surveys in countries which are either incapable themselves of bringing mineral deposits to economic production or unwilling to provide foreign investors with the opportunities of obtaining adequate returns on their risk capital investments.

There is no question in our mind that in many developing countries the establishment of a prosperous mineral industry depends to a large extent on the mineral exploration and exploitation expertise that private enterprise such as Canadian mining companies can provide and, importantly, on the massive injection of foreign capital investments and the possibilities for exporting much of these mineral commodities. Understandably, private enterprise will hardly be interested in investing risk capital in countries with monopolistic or nationalization tendencies, or in politically unstable areas.

The general attitude of Canadian mining companies towards foreign investments is well stated in a recent paper' by a distinguished Canadian economic geologist, Dr. C. E. Michener, who said that

<sup>&</sup>lt;sup>1</sup>Michener, C. E. Political versus geological climate in global exploration. Paper presented at the Canadian Prospectors and Developers Association. Toronto. March 10, 1969.

when planning their investments in other countries, Canadian companies consider the following factors:

Political Factors:

- 1. Encouragement of free enterprise
- 2. Possibility of political unrest
- 3. Possibility of expropriation
- 4. Possibility of killing taxation

5. Possibility of artificial exchange rates

6. Restriction on repatriation of capital and profit

7. Free movement of personnel

8. Dishonesty in government and employees

Geological and Physical Factors:

1. Country's history of mineral discoveries and mine production

- 2. Geological potential
- 3. Transportation problems
- 4. Health hazards
- 5. Availability and cost of labour
- 6. Availability and cost of fuel
- 7. Availability and cost of supplies

8. Mining rights, and methods of tenure

By rating each of these factors on the basis of past experience and knowledge of the country concerned, Michener estimated, for example, that Australia ranks at the top with 72 per cent, Canada is a close second with 70 per cent, while Guinea rates at 9 per cent and Nigeria at 7 per cent. Although other persons might rate individual factors differently and use a more rigorous approach, based on computerized factor analysis for example, the general rating of countries would probably not vary significantly. The very large spread obtained in this method of rating, i.e. 72 to 7 per cent, provides private enterprise with an identification of countries in which they may plan to invest. It is most revealing that 90 per cent of the current Free World mineral production (oil and gas excluded) comes from the 24 countries which rank highest in Dr. Michener's rating list.

In a free-enterprise system mineral resource development is very much a function of technological and managerial efficiency, and availability of markets. 298 Furthermore, it involves balance between the advantages accruing to the nation as a whole and those guaranteed to the investors. Government legislation may kill foreign investments and thus delay mineral resource development indefinitely. At the other extreme, a government may be very liberal and provide give-away measures, but it will not then obtain its fair share of benefits arising from the exploitation of its mineral resources. Thus the matter of progressive mining legislation and realistic taxation measures are of utmost importance in these countries.

Although the political, social, economic and geographic conditions of developing countries are generally vastly different from those prevailing in Canada, we think that these countries would benefit from a careful study of government measures that have provided for the investment climate and made possible the highly successful mineral resource development in Canada. In giving this kind of advice, Canada must be particularly attuned to the needs and aspirations of the countries with which it co-operates. It should also recognize that in certain countries it may be best not to adopt the Canadian system. The nature of the services and financial incentives that a particular government should provide to attract foreign investments can only be decided by that government, but on request Canada should deliver the best possible advice.

Most mining is international and a particular mineral development cannot exist in a vacuum. It must be based on realistic planning based on the world needs and the country's ability to provide mineral commodities at competitive prices.

Two of the most significant factors for attracting foreign investments in mineral resource development are the adoption of progressive mining legislation and the establishment of an explicit mining code. In the usual capitalistic sense, minerals are of no value unless exploited at a profit. "To this end, mining legislation should be drafted in relation to the possibilities of national assets producing wealth in terms of a world market".1 In developing a mining code, many complex questions must be taken into account. Some of them have been outlined by Dewan.<sup>2</sup> They include regional disparities, distances from seaports, tax exemptions for certain minerals, the scale and rate of national participation in the financing and management of the operations, etc. Through Canadian assistance, the developing countries could establish good mining codes to protect their interests when dealing with the highly sophisticated international companies, while at the same time providing fair and equitable agreements or contracts with these companies. Canada could also offer its services to countries with restrictive laws and ordinances to help liberalize them so as to attract foreign capital.

With some "missionary" work done to build up the demand, this particular aid alone could require the services of at least three advisers for a minimum of 10 years. These specialists should work very closely with the Mineral Resources Branch and other groups within the Department of Energy, Mines and Resources, and with the provincial departments of mines.

On the other hand, the Canadian mining industry has special capabilities in mineral exploration, development, exploitation and processing (see Chapter IV). If this industry works to the advantage of Canada, there is no reason why it could not also work most effectively to the advantage of developing countries. Therefore, even in adhering rigidly to a "no strings attached" policy on foreign aid, and keeping as a foremost consideration the best interests of the co-operating nations, Canadian foreign aid officials should emphasize to these nations the particular capabilities of Canadian mining companies.

We are thus of the opinion that:

#### Conclusion VIII.1

The Canadian Government should financially assist Canadian-owned mining and petroleum companies with their commercial mineral exploration programs in countries eligible for Canadian aid, where it can be shown that such exploration programs will assist significantly in reaching aid objectives.

This conclusion stems from our conviction that Canadian companies can play a very important economic role in developing countries. The increased overseas activity resulting from the adoption of this fiscal measure could well have more impact for emerging nations than several Canadian programs of direct technical assistance. It should be stressed in this regard that the U.S. government provides financial incentives to American companies operating abroad. In contrast with the Carter Commission on Taxation which recommended the U.S. type of incentive, we advocate that this measure be provided only to Canadian-owned companies working in countries eligible for Canadian aid. Whether or not the cost of this program of "indirect aid" should be credited to CIDA's account is a question outside our field of competence.

### VIII.10 Canadian Earth Science Capabilities for Foreign Technical Assistance

In the natural resource field, Canada has a wealth of earth science expertise which, if properly developed and applied, could be most beneficial to developing countries. This expertise lies mainly in the following areas:

1. Aerial photography and air photo interpretation

2. Surveying and cartography

3. Government surveys of natural resources

4. Development of mining laws and ordinances

5. Mineral exploration technology

6. Drilling technology.

<sup>&</sup>lt;sup>1</sup>Harrison, J. M. Mineral resources in economic development. Speech given in Nairobi, 1969.

<sup>&</sup>lt;sup>2</sup>Dewan, H. R. Mining legislation. Paper A/176 presented at the UN Conference on Science and Technology for Development. Geneva, 1963.

In the field of earth sciences, Canada also has expertise in *soil science* as applied to agricultural development, and rather limited export capacities in groundwater geology and engineering geology.

In aerial photography, airborne and ground geophysics, and diamond drilling, the expertise lies mainly with contracting firms. The ability of Canadian-owned firms to perform major tasks in these fields is amply demonstrated by their achievements at home and abroad, and clearly illustrated by the numerous contracts they have been awarded by United Nations agencies. In view of this expertise and the desirability of encouraging the technological growth and financial status of these firms, we are of the strong opinion that CIDA's contracts in aerial photography, airborne and ground geophysics, and diamond drilling should be preferentially awarded to Canadian firms beneficially owned more than 50 per cent by Canadian citizens. This ownership clause is standard U.S. aid policy, and we suggest that CIDA simply "borrow a page" from the USAID manual, adopt a policy similar to that prevailing in the U.S., and make it known publicly.

In certain countries such as France and Germany, as well as in all of the socialist countries, there are government agencies or private organizations owned largely by the government (e.g. La Compagnie Générale de Géophysique in France, and Prakla-Seismos in Germany) which act unofficially as operational arms of governments in their external aid programs. In addition, these organizations attempt with varying degrees of success to act as contracting agents for private mining companies in executing mineral exploration programs in various countries. If CIDA would restrict its contracts in the above fields to majority Canadian-owned contracting companies rather than simply Canadian-domiciled firms, this would provide a comparable preferential treatment by Canada for its own firms. We feel that the enforcement of this policy for these three fields will in no way be of prejudice 300

to the co-operating countries. On the contrary, it would reinforce Canadian capabilities and capacities for external technical assistance, particularly in view of the program of earth science assistance recommended in Section 11 of this chapter.

Canada has strong capabilities in surveying and modern cartographic techniques. Canadian surveyors are well known for their physical endurance and their ability to work rapidly and accurately, even under difficult climatic conditions and rugged terrain. In this regard, we recommend that CIDA make more frequent use of Canadian contractors to train nationals in their home country. With proper planning, this on-job training in surveying could very well be part of the "integrated approach" recommended in Section VIII.12.

There is probably no country in the Free World that possesses as much experience in government resource surveys as Canada. The capabilities lie mainly with the Surveys and Mapping Branch of the Department of Energy, Mines and Resources, the Geological Survey of Canada, the Dominion Observatories Branch, the Soil Research Institute of the Canada Department of Agriculture, the provincial departments of mines and some provincial research councils. By drawing on these capabilities it should be possible to provide major help to emerging nations in carrying out their natural resource development and strengthening their national institutions.

Canada is well known around the world for its expertise in mineral exploration technology, especially in mining geophysics and economic geology. If career opportunities and one- to three-year foreign assignments were provided, with CIDA's requirements properly announced and known well in advance, it is our hope that a sufficient number of competent Canadian earth scientists would be found for overseas programs, perhaps as many as 200-300 a year by 1975. In regard to geochemical exploration it should be noted that many developing countries are situated in a tropical or semi-tropical climate, where chemical processes dominate. The use of geochemistry as an exploration tool in these countries offers great promise and the Canadian capacities to deliver this kind of service should be greatly expanded. In so doing, not only will we be helping the developing countries, but we would also help ourselves very much, since the experience and new knowledge acquired through foreign work would be beneficial to Canada as well.

In view of the importance of agricultural development in these countries, technical assistance and home training in soil science and land use should remain an important component of Canadian aid. Canada is far from having reached an appropriate level of external aid in pedology and it should become a major objective to increase capacities in this important field.

Expertise in hydrogeology is also extremely important to developing countries, but Canada can still offer very little in this regard because of increasingly important domestic needs and insufficient number of experienced specialists. In view of the importance of this specialty, both abroad and at home, we feel that major steps must be taken to increase the Canadian capacities in this domain.

Valuable aid assistance could be provided through geotechnique in foundation design, site selection for new buildings, road construction, earthworks, irrigation, etc. Furthermore, Canada could supply important expertise in theoretical, instrumental and practical seismology to the many developing countries situated in critical seismic zones.

There are, of course, many other Canadian capabilities in earth sciences but the above are, in our opinion, the most important areas for external technical assistance in the resource field. In summary, we conclude:

#### Conclusion VIII.2

Natural resource development, with an indigenous training component, should figure pre-eminently in Canada's external aid programs. To ensure the availability of suitable experts for resource development work abroad, CIDA should define its earth science manpower requirements for a fiveyear period to allow for the orderly training and recruiting of Canadians for Canada's bilateral and multilateral assistance programs.

### VIII.11 A Proposed Pattern of Canadian External Assistance in the Earth Sciences

We propose a pattern of earth science activities in foreign aid based on the following premises:

1. The Canadian government *and* the co-operating countries will recognize the importance of natural resource development and the significance of earth science activities in the resource field.

2. The Canadian government will endorse the Pearson Commission's recommendation to allocate foreign aid disbursements equivalent to 0.7 per cent of the Gross National Income by the year 1975, or about \$590 million in official assistance in the form of grants and soft loans.

Hence, the proposed pattern is as follows:

1. An amount equivalent to 5 per cent of the official aid assistance is the recommended minimum level for the earthscience-based programs of external assistance.

2. Thus, these programs should increase to \$30 million annually by 1975 compared to \$6.0 million spent in 1968.

3. Most if not all of these programs should be planned and implemented on a three-year basis, starting at the earliest possible date.

4. The programs could be initiated in as many as 20 countries, with equitable distribution in South America, Central America, Anglophone Africa, Francophone Africa, and Asia.

5. It would be desirable that the programs in South America take the form of direct bilateral assistance. 6. Although a blanket approach to resource development is not in any way advocated here (the needs and priorities varying from country to country), each program should be designed, planned, developed and implemented in an orderly manner (see Section 12).

7. We believe that the type of budget given in Table VIII.3 is fairly representative of the major fields and level of assistance that Canada should provide in the solid-earth sciences, even though the nature and extent of the aid will vary from country to country.

8. According to this concept, Canada's earth-science-based programs would re-

quire (apart from contractors) about 260 people by 1975, including 200 professionals (about 3 per cent of Canada's manpower in the earth sciences) and 60 technicians (Table VIII.3).

9. A cadre of earth science foreign aid specialists should be established as soon as possible to form the nucleus of this increased aid effort (see Section 12).

10. The major principles outlined in the following section are submitted as guides to future planning and implementation of resource programs.

Although somewhat idealistic and over-simplified, this proposed pattern provides nevertheless a reasonable target

Table VIII.3-Type Budget of Foreign Aid Earth Science Activities for 1975					
Major Field	1 Country	20 Countries			
	\$'000	\$ million			
1. Basic survey control, aerial photography, and air photo interpretation	225	4.5			
2. Aerial geophysical surveys	100	2.0			
3. Reconnaissance geological surveys	200	4.0			
4. Ground geophysical surveys	75	1.5			
5. Geochemical exploration surveys	35	0.7			
6. Soil surveys and land inventories	125	2.5			
7. Water resource inventories and test drilling	125	2.5			
8. Geotechnical investigations	75	1.5			
9. Mineral resources and feasibility studies	100	2.0			
10. Development of counterpart government agencies:					
Labour (Canadian cadres)	50	1.0			
Equipment and supplies	50	1.0			
11. Development of counterpart university departments:					
Salaries and scholarships	100	2.0			
Equipment and supplies	25	0.5			
12. Cost of publications (including drafting)	110	2.2			
13. Administrative overhead (10%)	140	2.8			
Total	1 535	30.7			

#### Table VIII.4-Manpower Requirements for Earth Science Aid to 20 Countries (excluding contractors)

200	rolessionals	ov recnnicians
200	Desfagionals	(A Tashrisians
20	University Professors of Earth Sciences	20 Instrumentmen
20	University Professors of Soil Sciences	20 Geological technicians
20	Cartographers and Surveyors	20 Mechanics
20	Pedologists	
10	Engineering Geologists and Soil Engineers	
10	Hydrogeologists and Hydrologists	
3	Accountants	
2	Lawyers	
20	I annuar	
10	Mining Engineers and Mineral Economists	
10	) Geochemists	
15	Geophysicists	
60	Geologists (including economic geologists)	
_		

for future earth science foreign assistance. It does not seem to us out of proportion with the earth science assistance provided by such countries as the United States, Great Britain and France (see Appendix 11), nor does it seem to be out of proportion with the potential Canadian capacities to provide an effort of this magnitude (see Chapter II).

If this pattern is accepted by CIDA authorities, we think that it should in turn be "sold" in principle to potential recipient countries. A first step would be to let these countries know of the policies, ideas and "concepts" underlying Canada's aid and to inform them of our special capabilities in natural resource development. With a good knowledge of the essential needs, priorities and local conditions within these countries, it should be possible to establish an effective dialogue with these nations to arrive at sustained aid programs specifically designed to meet important economic objectives and yet adapted to local conditions. We fully realize that each program must be tailored to each country and we also recognize that the recipient country has an important say in these matters. Nevertheless, we also believe that Canada should do all it can to interest the recipient countries in the best programs it has to offer and convince them of the importance of a sustained and well-integrated approach to resource development (see next section).

On the basis of this proposed pattern, we propose:

#### Conclusion VIII.3

A realistic target for the magnitude of the earth science aid to developing countries is \$30 million for 1975, involving 200 manyears of professional and 60 man-years of technical manpower allocated annually to earth science activities abroad (excluding manpower of contracting firms).

## VIII.12 Major Principles relating to the Future Role of Earth Science Activities in Canada's External Aid Programs

In keeping with our terms of reference, in all our questionnaires we have asked the following basic question: "What Canadian expertise in Earth Sciences would best benefit developing countries?". In addition to compiling and evaluating some 310 replies to this question, and discussing this subject in many of our hearings across Canada, we have had the benefit of the documented advice of 23 Canadian specialists of earth science foreign aid, some of whom are still overseas. It should be emphasized that many industrial respondents to our questionnaire survey have had extensive practical experience in developing countries. Our respondents have not only specified the Canadian expertise available but have also commented at some length on several related topics, ranging from basic philosophical aspects of foreign aid to the education being given in Canada to people from developing countries. It is this collective judgment that is presented here for the purpose of associating the Canadian earth science community to the development of improved external aid policies, better priority-setting and more effective follow-through in program development. Naturally, our objective is not to "pull the blanket" towards mineral resource development in particular or to earth science activities in general, but rather to indicate how these activities can contribute to the economic development of less fortunate countries.

#### The Need for "Guided Responsive Aid"

As stated by CIDA's president, Canada's *responsiveness* to requests from developing countries is more than an answer on a mail-order basis; it is based on an effective dialogue with the co-operating countries, and "out of that dialogue our input is basically our ideas and our assessments of the kind of resources that we might be able to make available to them. Their

input is their understanding of their own particular problems, of their own particular needs and, of course, of their environment, the cultural, physical, political and social environment in which the resources must be brought to bear on the needs."

However, in the field of science and technology, and in natural resource development in particular, we believe that Canada should exert a certain power of initiation which, for all intents and purposes, would amount to "guided responsive aid". Following this approach, Canada could make known the types of requests to which it would respond most readily. This approach is needed because in natural resource development, particularly that of mineral resources, few emerging nations can define clearly their basic requirements, because they hardly know what commercial development means or what it involves. For example, in mineral resource development most developing countries do not possess a mining code that is usable and workable.

In natural resource development Canada is in a particularly good position to provide technical assistance to the "Tiers-Monde", in spite of its relatively small population and limited financial resources. Extending the "guided aid" concept, we believe that Canada should actually exercise salesmanship and offer technical assistance in fields where it has particular competence to the countries where it feels that this competence could be most effectively applied. These offers should be based on a realistic assessment of a country's needs, determined in conjunction with the co-operating nation, a study of aid plans of other aid-giving organizations, and a good evaluation of Canada's ability to export specific kinds of expertise in terms of a fully integrated, rational and complete program designed to reach important economic and social goals.

We think that there is a real need to establish the basic criteria for the types of resource development projects that Canada should sponsor as part of its external aid policy, such as the criteria <sup>304</sup> presented in Section 10 and 11 of this chapter. In summary, once these criteria are established, Canada should actively promote the best natural resource development programs it can offer. Following a policy of "guided responsive aid" Canadian assistance should be concentrated in countries which will make the best use of it.

## The Need for an Integrated Approach to Natural Resource Development

Many developing countries have realized the importance, at least in principle, of an orderly and systematic sequence of development. There are, however, some major disagreements on what that sequence should be and what the priorities are. For example, industrialization has often been over-emphasized, and the socalled "green revolution" in agriculture has substantially reduced the need for major food donations. In its recent report, the Pearson Commission on International Development stressed that "the developing countries face problems both in increasing their earnings of foreign exchange and in the increasing claims on available foreign exchange of rising debt payments and other essential commitments". It also indicated that foreign exchange is a crucial resource in development planning.

We must recognize that unplanned application of science and technology can lead to many very serious imbalances in society. We must also recognize that technical assistance as an instrument of external affairs policy is subject to change from time to time. Nevertheless, certain principles must be followed in resource development in order that the assistance be as effective as possible from the point of view of both economic and social goals. The following principles deserve special consideration:

1. Specific technical assistance projects must be conceived as part of a concerted effort. This implies full mutual understanding and co-operation between the

'Senate of Canada, op. cit.

donor country and the recipient nation, as well as good co-ordination with other aid-giving organizations.

2. Technical assistance must be based on an integrated approach to natural resource development, implying an effective follow-through of programs to reach important economic and social goals. This approach requires a continued involvement and a sustained effort based on good original assessments and planning, and periodic project appraisals. In mineral resource development in particular, this approach requires Canadian aid to be maintained until the recipient country can assume the responsibility of a particular development project, with or without Canadian industrial participation. This principle also means that Canada should not undertake basic resource surveys in a country where there would be little chance for effective follow-up. For example, if geophysical anomalies are located through an aerial survey, there should be good ground follow-up to evaluate the significance of these anomalies so that the co-operating country may derive full benefits from Canada's assistance.

3. Canadian technical assistance should not be spread too thinly over too many countries. Perhaps direct technical assistance in the resource field should be provided to only one-third of the countries presently receiving Canadian assistance (Figure VIII.1). This concentration should materially assist in providing better services and more sustained aid to the recipient countries.

4. Canadian assistance in the resource field should be based on a series of individual multistage continuing programs instead of annual budgets. In view of the necessity of securing enough Canadian earth science manpower to contribute to natural resource development, we think that it is essential for CIDA to initiate this approach. The continuity of the programs (one to five years) should be assessed on the basis of performance. This brings us to conclude:

#### Conclusion VIII.4

In the resource field, Canadian technical assistance to developing countries should be part of a concerted effort, based on an integrated approach to natural resource development, and with good priority-setting. The individual programs should be multistage and sustained. Their performance should be assessed through midproject reviews and post-project appraisals.

## The Need for Priority Setting in Natural Resource Development

We recognize that many developing countries are presently passing through different stages of development and, as emphasized above, a blanket approach to development is not appropriate. However, in our opinion, the following general sequence of natural development is valid in most countries:

1. Basic inventory of natural resources. "The absolute prerequisite for intelligent development...is a survey of all actual and potential resources and it must be as systematic and thorough as possible".' This idea forms the basis for orderly planning and constitutes the objective of the first stage of technical assistance. In view of the Canadian experience in natural resource inventories and the great importance of natural resources in the Canadian economy, this is one major field in which Canada can provide invaluable help to developing countries.

The first step is to obtain basic survey controls and good aerial photographs of region of interest. These will serve many purposes in the conduct of geological, geohysical, agricultural, forestry, land use and other surveys, as well as the planning of transportation networks and urban development. In some countries all aerial photographs are classified as secret by military authorities and it is impossible to obtain prints for technical or scientific purposes; this problem must be overcome before Canadian aid is awarded.

<sup>&#</sup>x27;United Nations, op. cit.

The second step is to carry out the actual field surveys and prepare various base maps. In mineral development, the first surveys will generally be oriented toward the production of aeromagnetic and reconnaissance geological maps. All aerial resource surveys could be done most effectively by *Canadian-owned* contracting firms.

In the field of renewable resources, the initial surveys should likewise be directed towards the production of basic inventories, such as the nature and distribution of various types of soils, the distribution of water courses and their flow characteristics during various seasons, depth of the water table, etc.

This first stage of earth science activities requires selected teams of geologists, geophysicists, geochemists, hydrogeologists, soil scientists and engineers, agricultural experts, geodesists and cartographers, all supported by adequate technical staff.

We believe that the training of nationals should be initiated at the beginning of these projects so that they be given a tull opportunity to learn the Canadian techniques and become prepared to continue them for the benefit of their country.

2. Master planning. The next stage is to evaluate the results obtained from the basic surveys, in terms of the country's needs and priorities and the Canadian capacity to provide the required sustained assistance. This is very much part of the "integrated approach" advocated above and involves a thorough assessment of the natural resources and economic characteristics of the country concerned.

One important consideration before deciding on an elaborate development plan in a particular area is whether or not the co-operating country has *power for advancement*, which means that a necessary type of labour force, professional and technical skills must be expected to emerge at a satisfactory rate once incentives are introduced.

An essential part of this master planning is the drafting of progressive mining 306 legislation and the establishment of an explicit mining code, as emphasized in Section VIII.9. There is indeed little use in going through the exercise of expensive surveys, collecting and studying scientific data if, in the final analysis, the mining laws or tax levies make it impossible or unattractive for foreign mining companies to work in these countries and invest in their resource development or, *alternatively*, if the co-operating countries are not in a position to provide the necessary financing or assume *efficiently* the technical direction of operations.

Intimately related to this master planning is the absolute necessity that the cooperating country have a national mining and natural resources service, including a Geological Survey and some competence in mineral economics. "The importance of such a service is emphasized by the fact that the UN Special Fund will not accept a project for mineral exploration unless the country does possess a geological or mining service which can carry on the work begun with UN aid".1 Thus, an important objective of Canada's assistance should be to strengthen counterpart institutions in the countries where its aid is directed. Most developing countries have their own geological and mining department, and aid personnel must work more or less within the framework of such agencies.

3. Development of agriculture. In many developing countries, agricultural development ranks as a top priority, and one of the objectives of foreign aid is to make these countries self-sufficient in food. Canadian pedologists have been very much in demand in developing countries since the establishment of the Food and Agriculture Organization and similar organizations. They have made good contributions, particularly in assessing land for irrigation potential and in surveys for intensive land use purposes.

The major contributions of earth sciences in agricultural development include identification and mapping of soil

<sup>&#</sup>x27;United Nations, op. cit.

types; soil research relating to agricultural reform; land classification, particularly as it pertains to resettlement objectives; irrigation to improve soil fertility; the search for and use of local sources of mineral fertilizers, etc.

It would seem that one of the most useful contributions that Canada could make in this regard would be to send soil scientists to these countries, to teach and train students in their native country where they must recognize and solve their particular soil problems.

4. Development of water resources. Water is often a rare commodity in developing countries. It is essential to agricultural development and indispensable to all forms of life. Earth scientists can help these countries by locating adequate supplies of groundwater; this work involves geological, geochemical and geobotanical studies, geophysical methods, test drilling, pumping tests and borehole logging. The location of important aquifers calls for the services of hydrogeologists using the latest scientific techniques of water prospecting. This is one of the most important and least expensive applications of science and technology to the benefit of emerging nations, since ground water is usually of better quality, chemically and bacteriologically, than surface water, and it is constantly available, being protected from evaporation and being little affected by weather. The lack of application of earth sciences in the search for groundwater can only lead to the indiscriminate drilling of wells and result in waste of time, energy and money.

Surface waters should also be considered, as they provide a ready source for industrial requirements and irrigation purposes. The basic inventory referred to in stage 1 above should have provided the general outlines of water resources immediately available. This knowledge must be supplemented by detailed and systematic meteorological and hydrogeological observations, such as the amount of precipitation according to seasons in particular catchment areas, the loss

through evaporation and transpiration, the sources of pollution, the quality of the water (chemical composition, relative hardness, bacterial content), the rate of flow, etc. Drainage studies and investigations of the hydroelectric potential of rivers must also be considered. From a health and sanitation point of view, it should be recognized that waterborne diseases are still among the leading causes of death and debility in many parts of the world, and biogeochemical investigations of these diseases should be given much attention by donor countries. Several other aspects of water resource development could be outlined here, but due to limited space the reader is referred to specialized reports on the subject, such as the UN publication on natural resources1 and the Science Secretariat's study on water resources.<sup>2</sup>

5. Development of power and communications. Power, whether hydroelectric, thermal or nuclear, is essential to the basic economic infra-structure for industrial development. Development of communications, particularly roads, is also an early necessity. The earth science activities associated with such development are mostly in the field of geotechnique (see Chapter V), in which there are very few capabilities in most developing countries. Canada could provide valuable assistance in geotechnique, especially in rural and urban development, mainly through Canadian consulting firms.

6. Development of a mineral industry. It is obvious from Chapters II and IV of this report that mineral resource development can be extremely beneficial, particularly from an economic point of view. Perhaps the most beneficial aspect of this development for emerging nations resides in the large amounts of foreign exchange that it provides through the export of mineral commodities. The Pearson Commission on International Development has unequivocally stressed the need for

<sup>&#</sup>x27;United Nations, op. cit.

<sup>&</sup>lt;sup>2</sup>Bruce, J. P., and D. E. L. Maasland. Water resources research in Canada. Science Secretariat, Special Study No. 5, Ottawa, Queen's Printer, 1968.

developing countries to increase their earnings of foreign exchange. Significantly, it has also stressed the need for developing countries "to remove impediments to foreign investment and assure stability and improved administrative procedures affecting foreign firms."

Minerals and fossil fuels are of absolutely no value unless they are exploited. Some emerging nations have apparently decided to keep their mineral resources very largely to themselves; in view of their limited financial capacity to absorb the high costs of mineral development and their difficulty in getting into world markets at competitive prices, they have not produced as much as they could, had they liberalized their mineral legislation somewhat. Consequently, they are left with an abundance of relatively unutilized mineral resources in a very captive market. Although it is clearly the exclusive responsibility of governments to use their mineral resources as they wish, we question the wisdom of nationalistic attitudes which deprive them of the economic benefits of mineral exploitation. In the face of rapidly changing science and technology, shifting market supply, demand and prices, as well as in the increasing quantity of substitutes for metals, it may well be that a mining proposition that is economically attractive today may not be so 20 years hence. Emerging nations should be encouraged to develop their mineral resources as much as possible as a means of earning foreign exchange, developing an industrial economy, and obtaining the major funds needed for their social programs.

Before mineral development programs are implemented, there should be an economic assessment of production, processing and marketing opportunities in relation to international supply and demand criteria. The purpose of this assessment should be to determine whether the nature and timing of the proposed mineral development is feasible.

Canada is in a good position to help developing countries in natural resource development. Canadians have a good <sup>308</sup> reputation abroad, scientifically, technically and socially; they have no territorial ambitions and no past record of imperialism or political indoctrination; they are tolerant and understanding, and are developing bilingualism and biculturalism. All of these are important qualities that must be cultivated in our foreign aid effort.

In summary, organized natural resource development hinges on the following general sequence: basic inventory of natural resources, master planning, development of agriculture, water resources, power and communications, and mineral industries. All of these fields include important earth science activities.

#### The Need for a Publication Policy

In our opinion, the essential scientific and technological results arising from Canadian aid programs or Canadian participation in UNDP programs should be circulated as widely as possible, to ensure maximum scientific and economic usefulness. We also feel that the cost of publishing these results should be built into the assistance budget.

Where full publication is not warranted, the basic data should be placed on open file in the host country and in Canada. The existence of new information should be drawn regularly to the attention of the Canadian earth science community through mailed announcements (e.g. the GSC notification cards) and notices in Canadian mining journals. A subsidiary benefit of this procedure will arise from the scientific audit which the scientific community at large will be able to make of the aid programs. Accordingly, we submit:

#### Conclusion VIII.5

The Canadian International Development Agency should establish a policy whereby the major scientific results arising from Canadian aid programs are published in suitable journals, preferably in the recipient country and with due acknowledgment to Canada's contribution, and in Canada as well, where it should be filed both at CIDA and the Overseas Branch of the Department of Energy, Mines and Resources (see Conclusion VIII.7). The publishing costs should be built into the assistance budget.

#### The Need for Improved Communications Relating to Canadian Aid Programs

The Canadian earth science community in government, universities and industry should be kept fully informed of Canada's current activities in technical assistance abroad, so that this community will be able to respond to requests for advice or participation to the fullest extent. It has been our experience that apart from contractors and a few tens of individuals, Canadian earth scientists are generally not aware of CIDA's past, present and future projects in which they may have an interest, nor of CIDA's basic policies concerning natural resource development and the scientific activities related to this development.

We consider that it would be most useful if CIDA would publish regularly short articles on the existing and expected earth science manpower requirements for external aid, and provide summary accounts of current and proposed earthscience-based assistance projects. These articles could appear from time to time in newsletters of Canadian scientific societies and in Canadian mining and petroleum journals, e.g. the CIM Bulletin and the Canadian Petroleum Bulletin.

To create the much-needed growing awareness of Canadian earth scientists towards external aid, it would be useful if symposia would be held from time to time under the auspices of Canadian learned societies and with the full cooperation of CIDA. One very useful symposium was the Conference on Exploration Geophysics held at Niagara Falls in 1967, which attracted a large number of delegates from developing countries.

The need for improved communications also applies to the technical relations between CIDA and the Department of Energy, Mines and Resources, and some other government departments. If CIDA is to be the exporting agent for Canadian earth science activities, it must act with the continuing advice of the government's earth science authority, i.e. the Department of Energy, Mines and Resources, and with continuing, full and mutual co-operation and information exchange with that department at all stages, from policy, through planning and execution, to conclusion. Current arrangements seem to be that CIDA establishes and acts upon the policy and principles, with only *ad hoc* intermittent advice and participation being solicited from EMR.

To meet the continuing need for appropriate earth science advice and liaison, and the continuing need to develop and modify principles, policies and actions, it is suggested that CIDA accept a scientific adviser seconded from the Department of Energy, Mines and Resources at such a level that he could be supported by a reasonably high-level committee from EMR and elsewhere. This adviser should be fully knowledgeable on the nature and usefulness of earth science activities, from the point of view both of policies and objectives, and of operations. While an administrative vehicle has been established to improve liaison and invite participation, with a number of manyears for aid work given to various EMR branches and with an Aid Co-ordinator's post established in the Mineral Resources Branch, it appears to us that the present Aid Co-ordinator's role is little more than co-ordination and "trouble shooting". Thus, we submit:

#### Conclusion VIII.6

The Canadian International Development Agency should solicit more actively the cooperation of other government agencies in establishing the policies and objectives, developing the planning, and supervising the execution of earth science programs of foreign aid. The present post of Foreign Aid Co-ordinator in Geosciences should be upgraded to the level of a senior official, who would be attached to CIDA at the International Development Committee level. We visualize that this Aid Co-ordinator should continue to be responsible not only for earth science activities proper, but also for other closely related activities, e.g. surveys and mapping, mining legislation, drilling, economic studies relating to mineral development, mining, mineral processing, and such fields.

#### The Need for a Cadre of Earth Science Specialists for Foreign Work

Notwithstanding the continuing need for contractors and short-term help for overseas service, we urge government to establish a small permanent cadre of qualified earth science personnel to help in carrying out Canada's external assistance programs. As emphasized in the following paragraphs, foreign work is not for amateurs, nor for specialists who cannot adapt themselves quickly to new conditions. The need to establish a national corps of experts who could make a career of foreign work has been clearly recognized by the Pearson Commission on International Development. Knowing the excellent work of the American and British cadres of earth science foreign aid specialists, we have long subscribed to the view that Canada should have earth science cadres for overseas assignments. The cadres could help in the central planning and provide the supervision for earth-science-based projects overseas, whether done by cadre people, by contract under cadre management, by university people or by others. Consequently, we submit:

### Conclusion VIII.7

The Department of Energy, Mines and Resources should establish an Overseas Branch, with a permanent cadre of earth science specialists having the scientific or technological competence, proper attitudes, personal qualities and interest demanded for foreign work. This Branch should be financially supported by the Canadian International Development Agency.

If the Canadian assistance in natural resource development increases as we 310

recommend, it is essential to build this cadre rather than hiring people "off the street". This cadre would provide the backbone for overseas earth science activities, but it would not replace all the other specialists who are normally engaged in this type of activity.

### The Need for a Registry of Earth Science **Personnel for Overseas Assignments** An embryonic registry of professional personnel exists in the files of the technical recruiting office of the Advisers Division of CIDA. A few manpower surveys have been attempted to compile basic information, but the resulting professional and technical listings were neither complete nor kept up-to-date. In view of the anticipated increase in manpower requirements, we recommend that a computerized central registry of earth science personnel for foreign work be established and kept up-to-date by the "Overseas Branch" of EMR.

#### The Need for Project Appraisals

Mid-project reviews and post-project appraisals should be instituted to determine the economic and social impact of Canadian foreign aid and to appraise the technical performance of CIDA-sponsored programs. This is indeed the only way to improve the programs. Projects must be administered firmly but not inflexibly, and definite project termination dates specified and adhered to. All projects should have a training component, which should be clearly spelled out in the agreements with the co-operating countries. Functional projects should be separated from the so-called "education and training" programs.

The Need for Basic Research in Natural Resource Development Methodology Notwithstanding CIDA's analysis of its technical assistance programs, we believe that one of the most fruitful avenues for research in foreign aid in the resource field is the computerized mathematical analysis of the many variables affecting this development and the optimization of aid systems. As data from project appraisals become rapidly available, the building of conceptual models of sequential, multistage technical assistance could be undertaken to increase the value of Canada's programs.

## The Need for Personal Qualities and Good Attitudes

It is an inescapable fact that the success of even the most technical type of aid is very often a matter of human relations. The need for an understanding of the people in emerging countries and what "makes them tick" cannot be overstressed. There are persons capable of quickly grasping a foreign culture, and others incapable of it. Some people are quick to learn a foreign language, whereas others simply refuse to speak a language other than English.

Personal qualities and attitudes, with emphasis on flexibility, patience, political acumen, desire and ability to adapt to new social and cultural environments, are just as important as technical competence, if not more so, in ensuring the success of a technical assistance project.

Many of the foreign advisers overseeing or carrying out a particular assistance project tend to develop that project as if they were still working within the environment from which they came. The expert working in a developing country must be adaptable psychologically, politically and technologically to the environment in which his expertise is to be expressed. His preparation for the job should include a philosophy and understanding of the purpose of the aid, with an understanding that he must complete his assignment satisfactorily in as short a period as practical and not attempt to perpetuate the job unnecessarily.

#### The Need for Identifying Capacities for Overseas Assignments

Canada might well have the scientific and technical *capabilities* for doing certain things but because of domestic requirements and priorities, it may not have the *capacity* to export this expertise overseas. For example, we are currently importing more geologists and mining engineers than we train in Canada.

In the field of earth science activities, we have a good knowledge of Canadian capabilities but we hardly know our capacities for overseas assignments. We cannot discuss these capacities because we do not know what CIDA's requirements are in terms of numbers and specialties, the duration of the assignments, the countries requiring these services, the projects that are contemplated, the anticipated government-university-industry participation, etc. This is why we have concluded in Section 10 above that CIDA should define its earth science manpower requirements for a five-year period, to allow for the orderly training and recruiting of Canadians for these programs.

## VIII.13 Education and Training in the Earth Sciences and Related Techniques

Much of technical assistance involves a transfer of knowledge and technology. Thus, education and training constitute a vital part of any development hypothesis. Training plays a large part in Canada's aid schemes and this is indeed most desirable. However, we question the nature and distribution of the present training because we feel that with some major modifications it could be made much more effective than at present. When referring to training in the following paragraphs, we also include the education related to training in the resource field, but we are not discussing education per se, which is clearly beyond our terms of reference.

Training falls into three broad categories depending on where it is given: a) in Canada, b) in the co-operating country's institutions, and c) on-job training associated with a technical assistance project.

#### In Canada

Canada's educational, governmental and industrial institutions can provide excel-

lent training in the resource field, in almost every aspect of earth sciences and related technology. In fact, few industrialized countries can provide better earth science training in the resource field for personnel from developing countries.

The problem, however, is to determine to what extent the training should be given in Canada. The most obvious advantages of training in Canada are excellent teaching and academic research facilities, availability of highly competent staff, possibilities of training in government and industry, unlimited opportunities for field work and practical training, use of very advanced technology, learning of the mechanisms of a highly industrialized society, emphasis on natural resource development and regional economic development, etc. A very important feature of training in Canada is that the trainee may, by practical example, get the idea that successful private enterprise is synonymous with efficient work and that he must work, get his hands dirty, work on three-shift jobs, etc.

In spite of these advantages, there is a very strong feeling in all major segments of the Canadian earth science community that there are far too many people from emerging nations receiving education and training in Canada compared to what Canada provides abroad.

As of September 30, 1968, there were 144 geoscience trainees in Canada under direct government assistance alone (Table 8.3), plus more than 100 geoscience fellowships provided by UN agencies, plus more than 100 graduate students in Canadian earth science departments who came from developing countries on their own. In contrast, the total number of advisers sent overseas in all educational and technical assistance geoscience programs was about 14 per year (full-year equivalent); of these probably no more than 7 were fully engaged in education and training. At \$20 000 and \$4 500 per man-year for advisers and trainees, respectively, we estimate that about 90 per cent of CIDA's geoscience education and training program is spent 312

in Canada, whereas it should be the other way around. There is in addition the relatively large number of geoscience graduate students who are not supported by CIDA but who, nevertheless, are supported by the Canadian taxpayer through research assistantships and other means.

We know from our study that about 44 per cent of all graduate students in fields of geology, geophysics, geochemistry and physical geography in our Canadian universities are neither Canadians nor landed immigrants. This proportion also happens to be the percentage of all non-Canadian graduate students in Canadian schools of science and engineering in 1968.1 If we assume that in geosciences the non-Canadian graduate students are distributed geographically like their colleagues in other fields of science and engineering, with 42 per cent from the U.S.A. and European countries, 40 per cent from Asia, 3 per cent from Africa, and 15 per cent from other countries, we can surmise that 26 per cent of all graduate students in Canadian geoscience university departments are from developing countries. Direct and indirect costs for supporting these graduate students are estimated to total about \$2.5 million a year. In our opinion, a good part of this money would be better invested if it were spent in the developing countries themselves, particularly since the research there is much more likely to bear on these countries' problems, rather than tending to be somewhat esoteric with respect to the pressing technological problems of these countries.

The main reason for this relative abundance of foreign students seems to be due to the fact that the earth science university departments are much "undernourished" with Canadian students in the first place. This excessive import has also been encouraged by the policies developed for the National Research Council,

<sup>&</sup>lt;sup>1</sup>National Research Council of Canada. Projections of manpower resources and research funds 1968-1972. A report of the Forecasting Committee. (Chairman: L. P. Bonneau). Ottawa, February 1969.

which until July 1969 allowed any researcher to apply for and receive research funds that could be used in part or in total for employing graduate students of any country. However, beginning April 1, 1970, any graduate student supported for the first time under an NRC operating grant must be either a Canadian citizen or a landed immigrant. This is still a relatively generous measure, since a landed immigrant does not have to renounce his original citizenship; the "brain drain" affecting developing countries may still continue with this regime.

In all fairness to these students, it must be recognized that many of them do not wish to return because of the lack of job opportunities in their home country at the level of their talent and the additional training they have acquired in Canada. This kind of problem possibly cannot be totally avoided, but we feel strongly that in far too many cases the training given in Canada to these nationals-especially in the universities-is not sufficiently geared to the needs of the developing countries. For example, when a country needs intermediate-level practitioners of geology, the training given in Canada should be oriented directly to fulfilling this need rather than being directed at many doctorate students. Thus, aid training in Canada should be specifically and directly related to the most pressing needs of the developing countries.

Many people in Canadian government agencies, universities and industry have further brought our attention to the fact that the Colombo Plan training presently given in Canada is generally unsatisfactory, because trainees who have been recommended by their respective organizations have often shown little interest or little capacity to learn. In fact, the attitude of these trainees has caused several mining and petroleum companies to opt out of the program. Consequently, we feel that Canadian participation in the Colombo Plan and other foreign aid programs should consist essentially in sending experts to the developing countries to develop and strengthen counterpart institu*tions.* If trainees are brought to Canada they should be well selected; if successive trainees from a particular country are found to be disinterested in or unsuited for a type of training, the recipient country should be notified and, if appropriate, the agreement terminated.

It is suggested that the training being given in Canada should be exclusively oriented toward the strengthening of counterpart institutions in the developing countries, and nothing else. This would include regular and prospective employees of government agencies, universities and industry. We further suggest that the training be concentrated on senior individuals who have had and will continue to have extensive contacts with their fellow countrymen, and on outstanding students who have a keen interest and a partially demonstrated ability in applied research. Training in Canada should also aim at providing short courses and practical experience for middle- or junior-level technical personnel, such as provided by the Institute of Mining at Haileybury. In all cases, students and trainees from developing countries should be pledged to return to their native country.

As far as university training in Canada is concerned, we submit that the best scheme would be for some earth science departments to adopt a counterpart department in a developing country where Canadian aid is concentrated and where the indigenous people are interested, willing and prepared to accept Canadian expertise for a minimum period of three years. For example, the Department of Geological Engineering at Ecole Polytechnique in Montreal has a strong orientation and good capacities in mineral exploration and engineering geology, and several professors speak Spanish, in addition to French and English; this department could very well adopt a geology department in Central or South America. As another example, the Department of Geology of the University of Alberta has good capacities in petroleum geology; it could well adopt a department located perhaps in the Far East where the need

is felt for improved training in petroleum exploration. This adoption system has the following advantages:

1. Better possibilities of exchange of faculty and students for the purpose of strengthening the academic institutions in the recipient countries;

2. Greater attention paid to the total environment of the recipient country and its most pressing needs, owing to a better realization of the cultural and social values held to be important in that country;

3. Better opportunities for a *sustained* effort;

4. Better opportunities given to Canadian faculty to become expert in the natural resource development of particular countries and to apply their expertise to this development through research and the training of nationals;

5. Improvement of educational systems in the developing countries, and development of altruistic attitudes on the part of Canadian professionals and students;

6. Better selection of people who would come to Canada for further education and training.

If CIDA would endorse these principles and agree to fund such programs, it could bring the matter directly to the attention of the chairmen of Canadian earth science university departments at an early date, and provide them with the necessary guidelines and rules of procedures. The chairmen could submit detailed proposals to CIDA which, if accepted, could be forwarded by CIDA to the potentially interested individuals in the co-operating country. The exact mechanism of this scheme should be formulated by CIDA; the departmental chairmen will need to abide by CIDA's rules, including the submission of statements for project reviews and appraisals.

With regard to the financial support provided directly or indirectly by the Canadian government to students and post-doctorate research fellows from developing countries, we are of the strong opinion that it should become the responsibility of the 314

Canadian International Development Agency. Whereas the Macdonald committee1 recommended (p. 204) that "all support of foreign students under the auspices of the federal government become a responsibility of CIDA", we subscribe to this recommendation only insofar as it pertains to students from developing countries. The post-doctorate research fellows from developing countries included under the NRC operating grants should be supported by CIDA. In all cases the actual selection of these students and research fellows should be left to the Canadian universities, who would consult directly with the appropriate authorities in the co-operating country. Furthermore, CIDA should support these people only to the extent that training in Canada will contribute directly to strengthening counterpart institutions in the developing countries.

#### **Home Training**

As mentioned above, the major emphasis in education and training should be placed in the country where the nationals are to work. If teaching and laboratory facilities are not adequate, it should be an objective of Canadian aid to provide these facilities.

Proper emphasis must also be given to the training of technicians in these countries. Indigenous people must be shown by actual experience that success in natural resource development can only be achieved by efficient team work, sufficient technical support, and plenty of personal effort.

In order to attract a sufficient number of competent and dedicated instructors, Canada must provide generous remuneration and take full advantage of Canadian capabilities for optimum selection of qualified personnel. These instructors should be able and *willing* to learn and speak the country's language, whatever the language may be, adapt to local con-

<sup>&</sup>lt;sup>1</sup>Macdonald, J. B. *et al.* The role of the federal government in support of research in Canadian universities. Science Council of Canada, Special Study No. 7. Ottawa, Queen's Printer, 1969.

ditions, and work with students in order to train them in good field methods and philosophies. If these instructors work within a university department, care should be exercised to set up the program with enough independence that the regular faculty of the university does not feel inferior to the foreign staff, in either status or salary. Foreign assistance must respect the local customs but must be handled with a firm hand in order to avoid waste of time and effort on the part of instructors and advisers.

If training cannot be readily provided within the country, Canada would do well to support training of nationals through regional institutes supported by the United Nations family. In the field of earth sciences, these include:

*1. Philippines:* Institute of Applied Geology (attached to the University);

2. Iran: Geological Survey Institute (Phase I approved in December 1960; Phase II approved in January 1968; still operational);

3. India: Institute of Petroleum Exploration at Dera Dun (Phase I approved in 1961; Phase II approved in 1966; still operational);

4. Saudi Arabia: Centre for Applied Geology at Jeddah (approved June 1969);

5. Bolivia: Centre for Petroleum Development at Santa Cruz (approved June 1965).

Serious consideration should be given to the establishment of a Mineral Exploration Institute in one of the South American countries, for the purpose of providing training in Spanish or Portuguese in exploration technology relating specifically to metallic and non-metallic minerals. Because of its expertise in the field of mining exploration, Canada could well exercise leadership in promoting such an institute.

#### **On-job** Training

This practical training should be a major aspect of any aid project, because the aim of technical assistance should be to aid the developing countries to the point

where they can take over their own natural resource development. On-job training is particularly important during the development and exploitation stages of mineral resource development, where the indigenous people can be taught skills for lifetime careers. It is also important in the basic surveys phase of development, where the surveys are part of a concerted and integrated program designed to reach important economic goals. Therefore, foreign aid personnel should be told in their original terms of reference that the training of nationals is an integral part of their job. In fact, project appraisals should bear not only on technological efficiency but on the training rendered as well.

One of the most valuable forms of assistance that Canada could provide would be to assign experts in various fields of earth sciences to various government departments or agencies in the developing countries, to provide *in situ* training during the execution of development projects such as highways, irrigation, mineral exploration, geological surveys, soil surveys, rural and urban planning, and so forth.

On matters of education and training, we submit:

#### Conclusion VIII.8

The basic philosophy in Canada's education and training programs in the earth sciences should be: a) all training should aim at fulfilling the recipient country's most pressing needs; b) the major emphasis should be on training in the recipient country rather than Canada, or in the UN-sponsored regional earth science institutes; c) training in Canada should be specifically and exclusively oriented towards the strengthening of counterpart institutions in the developing countries; d) training in Canada should be reserved for really outstanding students, for senior people who have had and will continue to have extensive contacts with their fellow countrymen, and for instructors in technical fields.

Conclusion VIII.9 The Canadian International Development Agency should develop immediately a program of "pairing" of certain earth science departments of Canadian universities with their counterparts in developing countries, and also assume the financial support of all students and postdoctorate research fellows from these countries. The actual selection of these students and research fellows should be done mainly by the institutions concerned.
Appendices

#### Acknowledgements

A study of this scope and degree of complexity would not have been possible without the help of a great number of earth scientists in Canada. The Study Group is particularly gratified to have received excellent co-operation from all sectors, which testifies to the wide interest aroused by this investigation and demonstrates the desire of Canadian earth scientists to contribute to the formulation of Canada's science policy.

It would be impossible to list here the several hundred scientists, engineers and administrators who filled out questionnaires and provided essential data, valuable ideas, and useful discussions in the course of this investigation. However, the authors extend their special thanks to the many organizations who have fully cooperated in this endeavour by responding to various requests for specific and general information, to those individuals who have taken their valuable time to prepare and submit the 27 briefs which have been received (see Appendix 3), and to the authors of the 53 special background papers which have been prepared for the benefit of the Study Group. To the 2 560 reviewers of these papers and the 1 509 persons who have attended our meetings across Canada, we also extend our gratitude.

Although the whole community of earth scientists in Canada has contributed to this report in one way or another, this Study Group accepts responsibility for the views expressed and the conclusions presented, as well as the shortcomings and inaccuracies which may be found in this report. We have been especially aided in our work by our consultants, Dr. George C. Riley and Dr. John G. Fyles, who prepared special reports for us.

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### Organizations and Individuals Who Submitted Briefs

Organizations	Subject or title
Alberta Society of Petroleum Geologists	Petroleum geology
Associate Committee on Geotechnical Research, National Research Council, and Geotechnical Engineering Division, Engineering Institute of Canada	A report on geotechnical sciences
Canada Department of Agriculture	Pedology
Canadian Association of Geographers	Recommendations on the future devel- opment of geomorphology in Canada
Canadian Institute of Mining and Metallurgy, General Committee on Education	Views on research on solid-earth sciences in Canada
Canadian Institute of Mining and Metallurgy, Geology Division	Research in solid-earth sciences in Canada
Canadian Society of Exploration Geophysicists	Exploration geophysics
Canadian Society of Soil Science	Soil science
Canadian Well Logging Society	Well logging
Geological Association of Canada	The teaching of earth science in secondary schools in Canada
Geological Engineering Department, Ecole Polytechnique	Recommendations on the future of earth science research in Canada
Imperial Oil Limited, Exploration Department	Imperial Oil's earth science activities
Mineralogical Association of Canada	Earth science research in Canada
Société Québecoise d'Exploration Minière (SOQUEM)	A proposal for the establishment of an institute of applied research in mineral exploration
University of Guelph	Earth science at the University of Guelph

Individuals	Subject or title
J.B. Bird	The role of physical geography
Graduate students of the Department of Geological Sciences, University of Toronto	Views on research
P.F. Karrow	New directions in earth science
E. Mirynech, J. Terasmae, P.A. Peach, B.A. Liberty	The definitions and scope of Quaternary geology
E.W. Nuffield	The problem of geology departments in the university environment
D.T. Ower	Geophysical research-methods and applications
G.E. Pajari, Jr.	Research and development
J.E. Riddell	Proposal for a national mineral exploration research institute
G.K. Rutherford, R.H.M. van de Graaf	Soil science
H.O. Seigel	A proposal for a mineral exploration research foundation
D.E. Smylie	On the future of theoretical geophysics in Canada
G.F. West, D.W. Strangway, F.S. Grant	The case for increased research in mineral exploration technology

# List of Solid-Earth Science Disciplines<sup>1</sup>

#### **Geological Sciences**

- 1. \*Coal geology
- 2. \*Economic geology
- 3. \*Engineering geology
  - \*Muskeg
  - \*Permafrost
- 4. Environmental geology
- 5. General geology
- 6. ‡Geomorphology
- 7. Historical geology
- 8. \*Hydrogeology
- 9. \*Marine geology
- 10. \*Mineralogy and
  - \*Crystallography
- 11. Mining geology
- 12. Paleobotany
- 13. \*Paleontology
- 14. \*Palynology
- 15. Pedology
- 16. \*Petrology
- 17. †Petroleum geology
- 18. Photogeology
- 19. \*Quaternary geology \*Quaternary research
- 20. \*Rock mechanics
- 21. \*Sedimentology
- 22. \*Soil mechanics
- 23. \*Stratigraphy
- 24. \*Structural geology
  - \*Tectonics and geotectonics
- 25. \*Volcanology
- 26. Other fields

#### Geophysics

- 27. \*Exploration geophysics
- 28. \*Geodesy
- 29. \*Geomagnetism
- 30. Geophysical instrumentation
- 31. \*Gravity
- 32. \*Heat flow
- 33. \*Magneto-telluric studies
- 34. \*Marine geophysics
- 35. Physical properties of rock and minerals
- 36. \*Remote sensing
- 37. \*Seismology
- 38. \*Tectonophysics
- 39. \*Other fields (glaciology)

#### Geochemistry

- 40. \*Biogeochemistry
- 41. \*Exploration geochemistry
- 42. \*Inorganic geochemistry
- 43. Isotope geochemistry and \*Geochronology
- 44. \*Physical geochemistry
- 45. Organic geochemistry (cf. # 42)
- 46. Other fields

#### **Other Fields**

- 47. Mathematical geology
- 48. \*Computer applications to Earth Sciences
- 49. Physical geography<sup>2</sup>
- 50. \*History of Earth Sciences

'The groupings of disciplines in this table are arbitrary. This numerical coding of disciplines was used in the Solid-Earth Science Study.

<sup>2</sup>Physical geography is a multidisciplinary field involving geomorphology, Quaternary geology, glaciology, and other disciplines.

\*Indicates the fields for which a background paper was submitted. Most of these papers have been published by the Geological Survey of Canada, under the sponsorship of the National Advisory Committee for Research in Geological Sciences, as the following publication: *Background Papers on the Earth Sciences in Canada*, Edited by C. H. Smith, G.S.C., Special Paper 69-56, Ottawa, 1970.

†Brief submitted by the Canadian Association of Petroleum Geologists.

‡Brief submitted by the Canadian Association of Geographers.

#### Description of Solid-Earth Science Activities of Federal Government Departments and Agencies

The following summary is based on the government agency questionnaire circulated by the Study Group as well as meetings with the various departments or agencies.

#### **Canada Department of Agriculture**

The earth science activities of the Canada Department of Agriculture (CDA)are concerned with the study of soils-involving their distribution, mineral composition and alteration, and chemical and physical properties. Other soil studies, related to fertility and productivity, involve the agricultural and biological sciences.

The National Committee on Soil Survey-a national co-ordinating committee of the Canadian Agricultural Services Coordinating Committee (CASCC)<sup>1</sup>-guides the Canadian Soil Survey which is carried on under the joint auspices of the CDA Research Branch and the universities and departments of agriculture in each province. The federal and provincial units within each province, except in British Columbia, work together as a unit. Research activities are centred in the Soil Research Institute (staff of 135) of the Research Branch in Ottawa and Pedology Units located in St. John's, Truro, Fredericton, Quebec, Guelph, Winnipeg, Saskatoon, Edmonton, and Vancouver. At present there is a staff of 52 professionals in the field of pedology, of whom 38 are involved in soil surveys and correlation and 14 in research. The expenditure during 1967-68, exclusive of overhead, was \$1-2 million. Productivity for

'CASCC is an advisory and co-ordinating body which reports through the Deputy Minister to the Minister of Agriculture. It is chaired by the federal Deputy Minister and includes as members the 11 Deputy Ministers of Agriculture, the 10 Deans and Principals of Faculties and Colleges of Agriculture and Veterinary Medicine, the Director of the Agricultural Research Institute of Ontario, the President of the Quebec Agricultural Research Council, a representative from NRC and DBS, and eight senior officials from CDA. that year was 7 soil survey reports and maps, 30 papers in scientific journals, and 20 interpretative maps.

At the time of our survey, the Prairie Farm Rehabilitation Administration (PFRA) was under the Department of Agriculture and its expenditures are listed under CDA in our tabulations. Its geotechnical activities involved an intramural expenditure of \$850 000 and 17 civil engineers specialized in soil mechanics (one engaged in research). PFRA has subsequently been transferred to the Department of Regional Economic Expansion.

#### Canadian International Development Agency (CIDA)

Canada's aid program for developing countries is funded and managed through CIDA. a crown agency reporting to the Secretary of State for External Affairs. CIDA has 405 staff members and 10 seconded officers, none of whom are specifically engaged in scientific activities. Nevertheless, it makes extensive use of Canadian scientific and technical resources in its programs, approximately 23 per cent of the personnel sent to developing countries under its bilateral programs being qualified in one of the sciences or technical vocations.<sup>2</sup>

CIDA utilizes the services of Canadian industries, universities and government in the conduct of its programs. The Department of Energy, Mines and Resources assists CIDA in identifying, mobilizing and co-ordinating Canadian earth science resources for aid projects, as well as the placement of overseas students in Canadian universities and industry.

Of CIDA's total expenditure of \$185.7 million in 1968-69 for all fields of technical assistance, \$6 million involved solidearth science activities (Table 5.1). An estimated \$900 000 represents Canadian contributions to earth-science-based programs conducted by various UN agencies. The expenditures are directed toward inventory surveys for resource dev-

<sup>&</sup>lt;sup>2</sup>Brief of the Canadian International Development Agency. Proceedings of the Senate of Canada Special Committee on Science Policy. No. 32. 1969.

elopment and training in earth science techniques. No research expenditures are involved.

#### **Defence Research Board**

The solid-earth science activities of the Defence Research Board (DRB) are related to its responsibilities under the National Defence Act of "carrying out such duties in connection with research relating to the defence of Canada and development of, or improvement in, equipment as the Minister of National Defence may assign to it; and to advise the Minister on all matters relating to scientific, technical and other research and development that, in its opinion, may affect national defence".

Earth science activities are funded under three separate programs: an intramural research program, a university grants program, and an industrial grants program (Table 5.2). The total solid-earth science expenditure during 1968-69 under the three programs was \$800 000, of which 40 per cent was performed by university and industrial groups.

The intramural program, conducted by a professional staff of eight, involves field and laboratory studies in seismology, magnetics, crater studies, soil mechanics, glaciology, and terrain evaluation.

Under the University Grants Program, grants are made to members of university staffs to: a) acquire new scientific knowledge that may prove applicable to the solution of technical defence problems; b) develop and support an interest in defence science in the scientific community; and c) assist in staffing the various DRB establishments with promising young scientists. Twenty-five advisory committees and panels of experts review the applications. Applications related to solidearth sciences are referred to the Advisory Committee on Geophysical Research, composed of 12 members from universities and government. The Committee allocates grants in meteorology as well as solid-earth geophysics and geology. In 1968-69 the total allocation for geophysical research was \$290 000, of which 40

per cent went to solid-earth science projects. About half of the solid-earth science grants are in geology and geotechnical fields (Table 5.2).

The Defence Industrial Research Program provides grants to promote the research capability of Canadian industry in defence technologies. Financial assistance is provided in the form of non-refundable grants for specific research projects proposed by companies incorporated in Canada. Normally, the Crown and the company share equally the cost of the research; data, patents and equipment remain the property of the company. Under this program, \$155 000 was allocated to solid-earth sciences (Table 5.2) during 1968-69 from a total budget of approximately \$5 million.

#### Department of Energy, Mines and Resources

The Department of Energy, Mines and Resources is the earth science arm of the federal government. The statutory basis for its scientific research and investigations in earth science is included in the Resources and Technical Surveys Act, 1966, which provides for:

1. The collection and publication of data on the mineral industry;

2. The detailed investigation of mining areas:

3. Full and scientific examination and survey of the geological structure and mineralogy of Canada;

4. Chemical, mechanical and metallurgical research and investigation to aid the mining and metallurgical industry of Canada:

5. Management of astronomical observatories;

6. Collection and preparation of ore, rock and mineral specimens to afford a knowledge of geology and mineralogy and mining and metallurgical resources and industries of Canada;

7. Preparation and publication of maps to illustrate the above;

8. Measurements, observations and surveys for the preparation of maps. The Act also extended the functions of 

 Table 5.1-Classification of CIDA-Sponsored Activities in the Solid-Earth Sciences During the Year 1968-69 

 (Expenditures shown are approximations only, since the projects reported by CIDA extend over several years and may include more than one type of activity)

Type of Activity	Developmentb	Scientific Data Collection	Education and Training	Total Cost
	\$'000	\$'000	\$'000	\$'000
1. General purpose topographic and				500(G) °
photographic mapping	-	1 450	-	950(L) d
2. General purpose geological surveys and inventories	250	350	-	200(G) 400(L)
3. General purpose geophysical surveys	100	500	-	600(L)
4. General purpose land surveys	80	600	_	80(G) 600(L)
5. Specific mineral resources surveys and inventories	50	350	_	40(G) 360(L)
6. Hydrogeological surveys and inventories	50	440	_	240(G) 250(L)
7. Geotechnical studies	_	150		150(L)
8. Education and training	_	_	760	760(G)
9. Multilateral programs.	100	800	-	900(G)
Total	630	4 640	760	6 030 <sup>±</sup>

Source: Canadian International Development Agency.

• These activities include no research.

<sup>b</sup> Represents the cost of advisers.

• Grant.

d Loan.

• Represents Canadian contributions to UNESCO, UNDP, etc. calculated at 7 per cent of total funds.

<sup>1</sup> About two-thirds of this amount is in the form of Capital Assistance.

#### Table 5.2-Total Solid-Earth Science Funding by Defence Research Board, 1968-69

Earth Science Specialty	Total Expenditure	Total Intramural Expenditure Projects <sup>a</sup>		Extramural Projects		
			University <sup>b</sup>	Industry •		
<del>.</del>	\$'000	\$'000	\$'000	\$'000		
Seismology	172	61	61	50		
Magnetism	354	266	18	70		
Tectonophysics	6	-	6			
Soil mechanics	40	33	7			
Rock mechanics	14	-	14	_		
Glaciology	38	22	16			
Geomorphology	36	34	2	_		
Geochemistry	20		_	20		
Crater studies	91	91	-	_		
Photogrammetry	29	_	14	15		
Total	800	507	138	155		

Applied research, 20 per cent of which is performed in universities.

Basic research.

• Applied research.

the Department to include energy, water and other resources, as well as stating that "the Minister shall be responsible for co-ordinating, promoting and recommending national policies with respect to energy, mines and minerals, water and other resources".

The Department is divided into four sectors (Figure 5.1), each under an Assistant Deputy Minister. The Water and Renewable Resources Sector accounts for half of the departmental expenditure. Earth scientists are employed throughout the Department, the largest concentration being in the Mines and Geosciences Sector. The expenditures on solid-earth sciences, relative to the total budget of each branch, is depicted by a solid bar in Figure 5.1. The actual expenditures are shown in Table 5.4.

#### Geological Survey of Canada

The Geological Survey of Canada is the major earth science branch of the Department. Founded in 1842, its reputation is deeply rooted in the history and economic development of the nation (see Appendix 6 for comments by industry). It assumes the major federal responsibility for providing the geological basis for the search and evaluation of Canada's potential mineral resources, as well as for the planning of industries and governments concerned with northern and regional development, land use and urban development, conservation, recreation, engineering and residential construction, and national security.

The Geological Survey undertakes the following activities to meet its objectives:

1. Investigates, describes and interprets the geology (including geophysics, geochemistry, geomorphology and physical geography) of Canada, including the Continental Shelves, to provide a national and regional geological framework. This includes the correlation of geological knowledge between regions or provinces through total or partial surveys related to the capability of the province concerned;

2. Provides a research competence in various specialized disciplines to: 326

a) support the systematic investigation of the geology of Canada and add to its sophistication;

b) investigate problems relevant to its mission, such as the properties, identification, classification and origin of rocks, minerals, ores, fossils, structures and land-forms, and thus increase the effectiveness of its own activities and of other agencies and industry;

c) provide a national cadre of specialists, beyond the resources of individual provinces but available as a source of expertise to various federal and provincial government agencies, to industry, and to the public;

3. Erects reference standards, examines the applicability of theories, develops and tests new instruments and methods, and performs pilot projects and surveys as aids to geological surveys and the search for mineral deposits;

4. Disseminates to users the results of its activities through its own reports and maps, through scientific, professional and trade journals and conferences, official communications, and through participation in national and international scientific associations; maintains book, oil-well core and sample, mineralogical and paleontological libraries for reference by its own staff, by other government agencies and by industry; provides geological information to the general public, tourists, hobbyists and educators.

The Geological Survey is divided into five divisions (Figure 5.2), four with headquarters in Ottawa and one in Calgary. Their separate objectives are:

1. Crustal Geology Division. To investigate the bedrock geology of the Precambrian Shield, the Appalachian, Eastern Lowlands and Cordilleran regions (latter staff located in Vancouver), in support of which it also conducts research in paleontology, petrology, geochronology, coal petrology and stratigraphy; maintains an eastern library of oil-well samples in Ottawa, and a scientific information service in Vancouver.

2. Institute of Sedimentary and Petroleum Geology. To investigate the geology of

#### Table 5.3-Deployment of Professional Staff of Geological Survey of Canada according to Missions

Mission	Divisi	on					
IVII351011	<u></u>		cs		<u></u>		
	STS		iysi		ntaı olo <u>ş</u>	ų	
	arte	gy	hqc		C ec	ear c	
	nb	, olo	ŭ	087	m o	olo	
	ead	G <sup>A</sup> a St	u u	eole	f S. leui	y R Ph	
	Η̈́	log nic	atic	Ű	e o trol	nor	ls
	Jch	che nor	lor	stal	Pe	eo1	ota
	sraı	Geo Col	CX D	, Lui	nsti nd	k G	ubt
	ш		щ	0	аП	0.2	S
Managers	3	2	_1	2	1	1	10
Managers Staff	_1		1		1		4
Subtotal							14
Support Editorial & Information				1	1		
Librory				1	1		
Data							- 2
Analysis chemical and instrumental		4					<u> </u>
Mineralogy		3			1		
Subtotal					-		18
Special							
National Advisory Committee	1						ī
International Geological Congress	1						1
Data, National Index	1		_				1
National Mineral Collection		1					1
External Aid	2						2
Subtotal							6
National Overview				_			
Compilations	1	2	_			1	4
Geological overview of mineral		12		1	1		17
		12			12		
Correlation: paleontological				<u> </u>	12		
geochronological			-5			1	4
Subtotal							
Inventory							
Bedrock mapping by quadrangle							
(reconnaissance and follow-up)				34	9		43
Topical mapping				12	1		13
Sedimentary basins, surface and							
subsurface studies				2	11		13
Pleistocene and geomorphological			_				
mapping						18	18
Aeromagnetic			2				2
Seismic	_		2				2
Mineralogy		4					4
Subtotal							95
Development							
Applied Geochemistry		8					8
Magnetic Methods			3				
Electrical Methods			<u> </u>				4
Geophysical geomorphological			4				4
metallogenic data analysis		1	2			1	4
Pleistocene indicator geology and engineering						3	3
Subtotal							26
Total Staff	14	39	24	66	39	29	211





#### 330 Table 5.4-Total Solid-Earth Science Funding by the Federal Department of Energy, Mines and Resources, 1968-69

Branch <sup>a</sup> or Unit	Total Solid- Earth Science	Intramural				Extramural		
	Expenditure	Basic Research	Applied Research	Development	Scientific Data Collec	Scientific tion Information	Industry	Universities
	\$'000	\$'000	\$'000	\$'000	\$'000	\$'000	\$'000	\$'000
Mines & Geosciences Sector								
1. Geological Survey of Canada	11 686	1 092	4 035	1 140	1 777	2 072	1 307	263
2. Surveys & Mapping Branch	6 804	5	157	19	4 685	1 929	_	9
3. Observatories Branch	2 678	741	356	222	1 245	105		
4. Polar Continental Shelf Project	1 991	810	65	91	930	95	_	
5. Mines Branch	765	188	253	129	78	79		38
Subtotal	23 924	2 836	4 866	1 601	8 715	4 280	1 307	319
Mineral Development Sector								
1. Mineral Resources Branch	228		65	_	69	89		5
Water Sectorb								
1. Marine Sciences Branch	5 650	556	690	528	2 991	850		35°
2. Inland Waters Branch	377	12	373	72	416	64		40
Subtotal	6 627	568	1 063	600	3 407	914	-	75
Energy Sector								
1. Resource Administration Division	100		_	_	100	-	-	_
Departmental Total Amount	30 879	3 404	5 994	2 201	12 291	5 283	1 307d	399°
%	100	11	19	7	40	17	4	1

Departmental administration costs are prorated among branch expenditures.
Oceanographic and water activities excluded.
Includes estimated cost of ship time provided on recommendation of Canadian Committee on Oceanography.

<sup>d</sup> Data collection.

· Basic research.

the sedimentary basins between the Precambrian Shield and Rocky Mountain Trench and into the Arctic Islands; carry investigations and research in petroleum geology and geochemistry, sedimentary petrology, clay mineralogy and paleontology; maintain book and oil-well core and sample libraries and a laboratory building for its own and other departmental units in Canada.

3. Exploration Geophysics Division. To conduct geophysical surveys that further the geological description of Canada (including the federal-provincial aeromagnetic survey program); conduct investigations in paleomagnetism and rock magnetism; to develop instruments and methods for prospecting, with particular emphasis on remote sensing and aerogeophysical methods; conduct field trials of newly developed equipment; conduct research into the computer analysis and interpretation of geophysical data; to provide geophysical advice to government agencies, industry and the public.

4. Geochemistry, Mineralogy and Economic Geology Division. To systematically survey the concentration levels and geological habitats of elements of economic interest and the nature of deposits in which these elements occur; to study the provenance and genesis of mineral deposits, the geochemical cycles of elements, and the identification and classification of minerals; to develop geochemical means of prospecting and the application of mathematical and statistical procedures to geology and to mineral assessment.

5. Quaternary Research and Geomorphology Division. To systematically investigate, describe and explain the unconsolidated deposits and land-forms of Canada, including studies of stratigraphy, chronology and Quaternary paleontology; to develop and test methods of using the unconsolidated "drift" as a prospecting medium; to document the properties, behaviour and dynamic processes that are of significance or concern to foundation and construction engineering.

The Branch administration forms a

fifth "division" which provides the overall direction and pooled administrative, personnel and technical services. It also provides the secretariats for the National Advisory Committee on Research in the Geological Sciences, the Geoscience Data Institute, and the International Geological Congress. The Geological Survey is also responsible for Canada's membership in the International Union of Geological Sciences and the Geological Liaison Office of the British Commonwealth Scientific Conference. In addition, it provides grants for university research in the geological sciences amounting to \$263 000 in 1968-69 (Table II.27).

The professional staff of the Geological Survey numbers 211 (163 geologists, 11 geophysicists, 10 geographers, 7 geochemists, 5 engineers and 15 other physical scientists). Of these, 88 per cent hold an advanced degree (66 per cent at the Ph.D. level) and 49 per cent received their highest degree outside Canada (compared with 67 per cent in the geology departments of Canadian universities). Their deployment according to the divisional structure of the Survey is shown in Figure 5.2, and their deployment according to specific missions in Table 5.3. Of the professional staff, 25 per cent are based outside Ottawa, principally in Calgary and Vancouver. The 1968-69 intramural budget of the Geological Survey was distributed in terms of scientific activities as follows: basic research, 11 per cent; applied research, 40 per cent; development, 11 per cent; scientific data collection, 18 per cent; scientific information, 20 per cent.

The Geological Survey is a major earth science publishing house. In 1968-69 its staff published 92 memoirs, bulletins and papers in the Survey publication series, and 100 papers in scientific journals. In addition, some 700 aeromagnetic and 40 other geological maps were issued.

#### Surveys and Mapping Branch The Surveys and Mapping Branch seeks to fulfil the national need for surveys and

mapping, including geodetic, topographic, planimetric and legal surveys. It compiles and publishes the National Topographic Series of maps, organizes the national air photo coverage, and produces a national atlas of Canada. The Branch co-operates with other federal agencies in the publication of geological, geophysical, geographical and soil maps of Canada. The maps of the Branch are multipurpose. They form the base for many forms of earth science surveys and compilations. Additionally, they meet the needs of public administration, national security, regulation of boundaries, economic and social measures, education and recreation.

The 1968-69 budget of the Branch was \$11.4 million. We have included \$6.8 million in our tabulations of solid-earth science expenditures of the federal government (Table 5.4), the remainder of the budget being accounted for by nonearth-science expenditures related to legal, aeronautical and general governmental needs. This amount is proportioned among the various scientific activities as follows: basic research, <1 per cent; applied research, 1 per cent; development, 2 per cent; scientific data collection, 69 per cent; scientific information, 28 per cent. The Branch has a total staff of 873 and a professional staff of 83, of which 85 per cent are at the bachelor's level.

Although the major function of the Branch involves scientific data collection and information, a small amount of research is undertaken in photogrammetry, geodesy and automated cartography. Maps are the principal publication format of the Branch, 472 maps at various scales being published in 1968-69. Annual grants totalling \$25 000 are awarded to support research in surveying and photogrammetry in Canadian universities. The Branch is also responsible for Canada's membership in the Pan American Institute of Geography and History, and provides the secretariat for the National Advisory Committee on Control Surveys and Mapping.

#### Observatories Branch

The Observatories Branch applies the discipline of physics to astronomy, the sun and meteors, and the solid earth. The latter responsibility is carried out in three different divisions.

The Division of Seismology collects and analyses seismic data and conducts research into seismicity and earthquake hazards, the detection and identification of underground nuclear explosions, and the physical constitution and properties of the crust, mantle and core of the earth. It is responsible for the Canadian contribution to the international co-operative efforts in earthquake determination and research, and for the maintenance and development of a basic infrastructure of seismological stations to achieve the above aims. It also provides a scientific information service in seismicity, in earthquake engineering, and nuclear test-ban problems. Its research projects include the establishment of a seismic observatory network, operation of the Yellowknife seismic array, earthquake motion studies, wave and mechanism research, heat flow, and crustal seismic studies.

The Division of Geomagnetism is responsible for describing the geomagnetic field in Canada and the neighbouring oceanic areas as a function of position and time. This is accomplished through a network of permanent stations, a program of magnetic surveys including airborne surveys, and the study of paleomagnetism. The results of these studies are applied to the preparation of magnetic charts as aids to navigation and to geophysical exploration, to investigation of the origins of the earth's magnetic field, to study of the electric conductivity of rocks deep within the earth, and to the history of the earth's magnetic field through geologic time. Its research projects relate to the operation of geomagnetic observatories, geomagnetic charts, paleomagnetism, and induction studies.

The main function of the *Gravity Division* is to determine the gravitational field over Canada, applying the results to

problems of geodesy and structural studies of the earth's crust and upper mantle. Its research is related to regional gravity surveys, primary control measurements, instrumental development, study of earth tides, and meteorite crater studies.

The Observatories Branch has a professional staff of 61 engaged in solidearth science activities: 68 per cent of them hold advanced degrees, and 26 per cent received their highest degree outside Canada. The 1968-69 expenditure on solid-earth science activities was \$2.7 million (Table 5.3), which was proportioned among the various scientific activities as follows: basic research, 28 per cent; applied research, 13 per cent; development, 8 per cent; data collection, 47 per cent; scientific information, 4 per cent. On the average, the Branch issues 21 publications annually, and staff members publish 27 papers in outside journals. The Branch also awards grants in aid of research in astronomy and geophysics in Canadian universities. In 1968-69, \$9 000 was awarded for field expenses related to co-operative crustal seismic refraction studies.

#### Polar Continental Shelf Project The Polar Continental Shelf Project (PCSP) undertakes research and field surveys in the Continental Shelf area of Arctic Canada and the adjacent islands and Arctic Ocean, in those subjects of interest to the Department of Energy, Mines and Resources. It works closely with other branches of the Department, providing specialized and co-ordinated field support for their studies and surveys. The principal programs, undertaken in co-operation with other departmental branches, include aeromagnetic, geodetic, topographic and hydrographic surveys; marine and terrestrial geology; seismic, gravity, magnetic and heat flow; and glaciological studies.

The PCSP has a staff of 14 and an annual budget of \$2 million, of which 80 per cent goes toward common or pooled items of use to a number of interbranch and interdisciplinary projects. Field facilities and logistics support are also provided to university groups under certain conditions. Six to twelve university parties make use of this assistance each year.

#### Mines Branch

Solid-earth science activities in the Mines Branch are related to its role of developing mining and metallurgical technology for more effective utilization and conservation of Canada's mineral resources. Mining and metallurgy per se are excluded from the terms of reference of our study, but the conduct of this research in the Mines Branch involves earth science activities in several of its Divisions, and accounts for approximately 10 per cent of Branch expenditures.

The Mineral Sciences Division conducts research into the properties and behaviour of minerals and materials; studies the characteristics of mineral assemblages in ore deposits, and develops methods of analysis of ores, minerals and metals. It has a professional staff of 17, with training in chemistry, geology or physics. The Mining Research Centre, through its Rock Mechanics Laboratories, in Ottawa and Elliott Lake, conducts research on slope stability and the nature of rock failure. The Mineral Processing Division conducts mineralogical studies related to improving the efficiency of processing metallic and non-metallic ores. Approximately 40 professionals are associated with the Mines Branch earth science activities; 13 are engineers (principally mining), 11 physicists, 8 chemists and 8 geologists. Sixty-two per cent hold advanced degrees. The expenditure on the activities in 1968-69 was \$765 000 (Table 5.3).

The Mines Branch also provides the secretariat for the National Advisory Committee on Mining and Metallurgical Research. In 1968-69 it awarded \$100 000 for university research, of which \$38 000 was for research in rock mechanisms.

#### Mineral Resources Branch

The Mineral Resources Branch collects and analyses data on the non-renewable resources of Canada, on Canadian industries directly based on such resources, and on non-renewable resources and related industries of the world where such data have implications for Canadian mineral policy. It conducts mineral policy research and formulates programs of mineral resource utilization and industry development. Its professional staff of 38. including 22 geologists and 13 mining engineers, works principally in the field of mineral economics. Approximately 25 per cent of its annual budget, or \$228 000 (Table 5.3), relates to scientific activities as defined in this Study.

The Mineral Resources Branch provides support to the Department in meeting the needs of Canada's membership in a number of UN and OECD committees; provides liaison betwen EMR and CIDA; advises the Department of National Revenue on administering the Income Tax Act, and the Department of Industry, Trade and Commerce on the administration of IRDIA.

#### **Resources** Administrative Division

The Resources Administration Division, with a professional staff of five, is responsible for the administration and management of the federal interest in mineral resources offshore from Canada's east and west coasts and in the Hudson Bay-Hudson Strait region, as well as the disposition of mineral rights from federally owned lands in the provinces (under PFRA, Soldier Settlement, etc.). It also develops policy recommendations related to offshore areas.

The administration is based on a number of Acts and Regulations (including the Canada Oil and Gas Regulations, Canada Mining Regulations, Public Lands Mining Regulations, etc.) which require the performance of earth science activities and the submission of information to the government. The earth science information which is submitted remains confidential for periods of up to two years and is then available for inspection in Ottawa, Calgary and Dartmouth. The total expenditures on earth science data collection during 1968-69

are difficult to estimate but were of the order of \$100 000. Plans are in preparation to establish a branch office in Dartmouth to handle and process samples and information from offshore drilling, and provide core storage.

#### Marine Sciences Branch

The Marine Sciences Branch carries out hydrographic and oceanographic surveys and studies to meet the national needs for nautical charts and associated publications on Canada's coastal and inland waters, and for oceanographic information, atlases and publications. It carries out surveys of marine resources on the Continental Shelves and adjacent oceans; conducts oceanographic studies of water properties, marine pollution, currents and waves; undertakes research in wave theory, diffusion, circulation patterns and related marine phenomena; and advises on the formulation of Canada's international position and policies concerned with the oceans.

The principal programs involving solid-earth science activities include hydrographic surveys, marine geophysics, and marine geology. "The Marine Sciences Branch has been given prime responsibility for providing information on the physical (including geophysical and geological) properties of the marine environment of concern to Canada."1

Expenditures on these activities form approximately 39 per cent of the Branch's budget. The 1968-69 expenditure on solid-earth science activities (only part of the hydrographic service included) of the Branch was approximately \$5.7 million (Table 5.4), which consisted of basic research, 10 per cent; applied research, 12 per cent; development, 9 per cent; data collection, 54 per cent; scientific information, 15 per cent. Staff members publish principally in outside journals (20 in 1968-69), and earth data are issued in cruise and internal reports. Plans are under way for a Natural Re-

Department of Energy, Mines and Resources. 1970-71 Program Forecast. 1969.

sources Charts series portraying bathymetry, magnetic and gravity data on a scale of 1:250 000.

The Marine Sciences Branch is organized into three operating regions-Atlantic, Central and Pacific-under the general direction of a headquarters unit which establishes requirements, allocates resources, and supplies specialized support services. Each region is heavily involved in hydrographic surveys. Marine geology and geophysics are at present concentrated on the east coast, although expansion to the west coast is planned within the next five years.

The Atlantic Oceanographic Laboratory (AOL), located at Dartmouth, N.S., supports the Marine Geology and Hydrography Sections, and the Marine Geophysics Group (part of the Oceanographic Research Section), as well as supplying the vessels for their programs. Although essentially none of the senior hydrographic staff have formal degrees, 10 are considered to have "professional" status. They are responsible for charting all navigable waters in the Atlantic region, as well as the development of related instrumentation and techniques. The Marine Geology Section has a professional staff of 14, of whom 93 per cent hold advanced degrees. It conducts projects involving physical geology, geochemistry and micropaleontology on the Atlantic Continental Shelf and Slope, in parts of the Arctic Ocean, and the Mid-Atlantic Ridge. The Marine Geophysics Section is concerned with investigation of the properties of the earth beneath the sea to understand the processes of formation of continental margins and ocean basins. Its professional staff of seven conducts gravity, magnetic and electromagnetic studies on the Continental Shelf and Mid-Atlantic Ridge.

#### Inland Waters Branch

The functions of the Inland Waters Branch are to investigate and describe the inland water resources of Canada. It collects, organizes and analyses data on inland waters, conducts research on water quality, and on methods of controlling pollution. The principal programs of the Branch involve an inventory of Canada's water resources; investigation of lake water circulation and sediment transport; pollution studies; investigation of factors governing the behaviour and occurrence of groundwater, ground ice, glaciers and surface water; development of methods, including engineering systems, for effective utilization of water resources; and basic research on water properties.

The principal activities involving solid-earth sciences include groundwater, glaciology and limnogeology. Expenditures on these activities form 6 per cent of the Branch's budget. The 1968-69 expenditures on solid-earth science activities were \$977 000, consisting of an estimated 1 per cent on basic research, 40 per cent applied research, 8 per cent development, 44 per cent data collection, and 7 per cent for scientific information. Staff members publish principally in outside journals (18 in 1968-69), as well as in government reports (11 during the same period).

The Inland Waters Branch is organized into six subactivities, namely, Branch Administration, Water Quality, Engineering, Great Lakes, Hydrologic Sciences, and the Water Survey of Canada. Solid-earth science activities are pursued principally within the Hydrologic Sciences Division (Groundwater and Glaciology Subdivisions) and the Great Lakes Division (Limnogeology Section). The Groundwater Subdivision has a professional staff of 18 (50% with advanced degrees). Its scientific activities relate groundwater to the hydrologic cycle, and include groundwater hydrology, hydrochemistry and climatology, as well as hydrogeology. The Glaciology Subdivision is concerned with the study of ice and its role in the hydrologic cycle. Physical geographers form the larger proportion of its professional staff of 14. The Limnogeology Section, located in the Canada Centre for Inland Waters, at Burlington, Ontario, is involved in sedimentology, organic and inorganic geochemistry, palaeoecology and

clay mineralogy, as they apply to the sediments of the Great Lakes. It was established in 1967 from a nucleus in the Geological Survey and currently has a professional staff of eight.

The Inland Waters Branch also supports the National Advisory Committee for Water Resources Research and, through it, provides grants in aid of university research in water resources (\$201 000 in 1968-69).

#### Policy and Planning Branch

The solid-earth science activities of the Policy and Planning Branch arise from its support of the National Advisory Committees on Geographical Research, including the provision of \$47 000 in grantsin-aid (\$15 000 provided for research in physical geography in 1968-69); and from its support of the National Advisory Committee on Water Resources Research, including the provision of grants in aid of resources research (\$690 000 in 1969-70). It is also responsible for Canada's membership in the International Geographic Union.

National Museum of Natural Sciences Solid-earth science activities are conducted in the Museum of Natural Sciences, one of the National Museums of Canada. Although the basis for a national museum was developed initially by Sir William Logan within the Geological Survey, the first statement of a museum function appeared in the Geological Survey Act of 1890:

"4(b) To maintain a museum of geological and natural history and to collect, classify and arrange for exhibition in the museum...such specimens as are necessary to afford a complete and exact knowledge of the geology, mineralogy... fauna and flora of Canada."

In 1950 the Museum was transferred from the Geological Survey of Canada to the Department of Resources and Development (the predecessor of the current Department of Indian Affairs and North-<sup>336</sup> ern Development). In 1964 it was transferred to the Ministry of the Secretary of State, and in 1969 it became part of the National Museums of Canada Corporation, responsible to the Secretary of State. The purposes of the National Museums are defined by the National Museums Act, 16 Eliz. II, Chapter 21, 21 December 1967, namely to "demonstrate the products of nature and the work of man, with special but not exclusive reference to Canada, so as to promote interest therein throughout Canada and to disseminate knowledge thereof". Under their mandate they may "collect, classify, preserve and display objects relevant to its purposes; undertake or sponsor related research; arrange travelling exhibitions; sell publications and materials to the public; train museum specialists; establish liaison with other museums and universities, and provide technical services to other organizations with similar purposes".

The National Museum of Natural Science has two earth science divisions. the Paleontology Division and the Mineral Sciences Division. The Paleontology Division has a professional staff of two, and functions only in the field of vertebrate paleontology. Its current research includes the description of Pleistocene mammals from the Yukon, and Cretaceous dinosaurs of Alberta and Saskatchewan. The Mineral Sciences Division has a professional staff of one, specializing in mineralogy. Both divisions are responsible for the field collection, cataloguing and display of earth science materials, and the dissemination of information and materials to schools and the public. The 1968 budget of the divisions was \$138 830, or 13 per cent of the total budget of the Museum of Natural Sciences (Table II.23). The professional and technical staff of the two divisions was seven.

# Department of Industry, Trade and Commerce

The Department of Industry, Trade and Commerce administers several incentive

programs for the purpose of expanding scientific R & D in industry and stimulating the exploitation of new technology. The principal programs are the Program for Advancement of Industrial Technology (PAIT) and the Industrial Research and Development Incentives Act (IRDIA). These programs are directed principally toward the support of manufacturing industries (as are the similar industrial incentive programs of NRC and DRB). The definitions of R & D used in the administration of the programs specifically exclude activities related to "prospecting, exploring or drilling for or producing minerals, petroleum or natural gas".

During 1968-69, \$116 000 was committed in support of the development of geophysical instrumentation under PAIT (Table II.23). Payments under the IRDIA program are based on the level of R & D in a company rather than specific projects. Companies classed as "mines, oil wells and gas wells", using DBS phraseology, received \$745 600 under IRDIA in 1968-69. It is not possible to define the projects of application but, in general, they are related to production, processing and geophysical instrument research.

#### Department of Indian Affairs and Northern Development

The solid-earth science activities of the Department of Indian Affairs and Northern Development relate to its administration of the Yukon and Northwest Territories, Indian Reserves in the provinces, and the National and Historic Parks of Canada.

The Oil and Mineral Division, with a professional staff of 10, is responsible for the management of oil and gas and mineral lands and rights in the Yukon and Northwest Territories, as well as under the adjacent Continental Shelves (excluding Hudson Bay which is administered by EMR), and on Indian Reservations. The administration of mineral exploration and development is based on some 12 Acts and Regulations, 4 of which (Canada Oil and Gas Land Regulations, Canada Mining Regulations, Yukon Quartz Mining Act, and Yukon Placer Mining Act) include provisions requiring exploration expenditures and the submission of earth science information to the government. The latter may include aerial photographs, geological maps and reports, various types of geophysical and geochemical surveys, and drill hole data. The information remains confidential for varying periods of time, commonly up to three years, and is then available for inspection at offices of the Department in Ottawa, Calgary, Yellowknife and Whitehorse. The Division also administers a Prospectors Assistance Program and a Northern Mineral Exploration Program, to encourage mineral exploration activity. These programs also result in the collection of earth science data. During 1968-69 the Department's expenditures on these programs (excluding road construction) included contributions to the Panarctic oil operations and totalled \$5.3 million (Table II.23).

The Northern Science Research Group of the Department sponsors research on northern subjects. Its grants program supports a number of northern research projects which involve science disciplines. Grants, totalling \$250 000 in 1968-69, are made to the Arctic Institute of North America and a number of institutes, committees and centres at Canadian universities.

The Advisory Committee on Northern Development of the Department, chaired by the Deputy Minister and composed of senior representatives (commonly the Deputy Minister level) of all federal departments and agencies engaged in northern activities, has the responsibility to "advise the Government on questions" of policy relating to civilian and military undertakings in Northern Canada and to provide for the effective co-ordination of all government activities in that area". The Committee provides a mechanism for co-ordination of the earth science R & D and data collection activities of other federal departments with the administrative activities of the Department.

#### National Research Council

The National Research Council Act assigns to the Council a broad responsibility "to undertake, assist or promote scientific and industrial research". In general terms, its role is one of developing a national capability in scientific and industrial research, and of deploying scientific research for the national benefit. To fulfil this role it maintains its own laboratories, monitors the progress of science through its advisory and associate committees, provides university grants and scholarships, supports an Industrial Research Assistance Program (IRAP), maintains international exchange agreements, and publishes scientific journals. The earth science activities of the Council are distributed throughout the programs.

Intramural solid-earth science activities are conducted principally by the Geotechnical Group of the Division of Building Research, whose function is to improve engineering design and construction techniques in which the performance of soil, snow and ice or permafrost is an important consideration. The Group includes 15 professionals, mostly civil engineers. The expenditure on soil mechanics projects and snow and ice studies during fiscal year 1968 was \$533 000 (Table II.28). In addition, the Photogrammetric Research Section of the Division of Applied Physics is engaged in the development of instruments and photogrammetric techniques of application to glaciology and avalanche research.

The Associate Committees of the National Research Council act as a co-ordinating mechanism in Canadian science. Members are drawn from universities, industry and government, and are selected for their competence and interest in the field concerned. They review, co-ordinate and, if necessary, initiate new research. Of the 42 committees, those relating most closely to the solid-earth sciences are:

1. Associate Committee on Geodesy and Geophysics, with subcommittees on geodesy, gravity, seismology, meteorology, hydrology, glaciers, magnetism, aeronomy, isotope studies, exploration geophy-<sup>338</sup> sics and volcanology. The Committee also acts as the National Committee for the International Union of Geodesy and Geophysics, and publishes the Canadian Geophysical Bulletin.

2. Associate Committee on Geotechnical Research, with subcommittees on muskeg, permafrost, snow and ice, and soil mechanics. It also serves as the executive for the Canadian Section of the International Society for Soil Mechanics and Foundation Engineering.

3. Associate Committee on Meteorites.

4. Associate Committee on Quaternary Research.

5. Canadian Committee on Oceanography, composed of members from organizations engaged in, or supplying facilities to, the national oceanographic (including marine geology and geophysics) program. This committee co-ordinates the activities of all Canadian government agencies, as well as advising on Canada's international responsibilities in oceanography.

The international role of the National Research Council in the earth sciences is not only as the adhering body for international unions, such as the International Unions of Crystallography, Geodesy and Geophysics, and the Scientific Committee on Oceanographic Research (SCOR), but is also in maintaining scientific exchange programs with governments of the U.S.S.R., France, Brazil and Czechoslovakia. During the period 1960 to 1968, eleven Canadian earth scientists visited the Soviet Union under the agreement with the Soviet Ácademy of Sciences.

The National Research Council publishes the *Canadian Journal of Earth Sciences* and the *Canadian Journal of Geotechnology*, among its nine journals of research.

The Industrial Research Assistance Program (IRAP) is specifically directed to establish a number of competent research teams in manufacturing companies in non-defence areas. During the year 1968-69, \$77 000 was provided under the program for the development of geophysical instruments. Figure 5.3-Relative Increase in NRC Grants-in-Aid to University Research in the Earth Sciences, in relation to Physical Sciences and Engineering Grants, 1958-69



The University Grants and Scholarships Program of NRC seeks to support the training of research manpower as well as the acquisition of new knowledge. The awards policy is established by standing committees on Negotiated Grants, on Scholarships and Fellowships, and on Annual Grants. The Earth Science Grant Selection Committee, composed of academic representatives from a number of universities and disciplines, is responsible for grants in the solid-earth sciences, which amounted to \$3.1 million in fiscal year 1968 (Table II.27 and Figure 5.3).

#### **Department of Public Works**

The Department of Public Works is responsible for the management and direction of the public works of Canada, which include the construction and maintenance of public buildings, wharves, piers, roads and bridges, and the undertaking of dredging and navigable waters protection work. Its Testing Laboratories provide earth science expertise to meet the Department's needs as well as the needs of other government construction agencies.

Foundation studies, as well as the establishment of design criteria for the foundations of structures, and the selection of building stones, are areas of earth science involvement.

The professional staff of eight are civil engineers specializing in soil and rock mechanics and foundation engineering. Their research activities include the study of strength mechanisms and response of highly sensitive clays to simulated earthquake shock loading, and the design criteria for rock-socketed piles. The results of these research activities, as well as field investigations including test borings, are largely restricted to internal reports. The total expenditure on geotechnical activities during 1968-69 was \$300 000, of which \$41 000 was related to R & D.

#### Comments of the Mineral Industry on Questions Formulated by the Study Group

The mineral industry questionnaire circulated by the Study Group contained a number of questions on the present and future conduct of earth sciences in Canada. Most replies were well and extensively prepared. While the replies cannot be readily quantified and tabulated, they nevertheless form a valid base for expressing the attitudes of industry on these matters. The extent to which the replies represent the opinions of the company respondent (commonly an earth scientist at the middle or upper management level) rather than company policy is a matter for debate. The questions, in their order of presentation in the questionnaire, and a synopsis of replies, follow.

#### 1. Use of Scientific Publications

Question: To what extent do you make use of the earth science publications of federal government agencies? Please give your frank comments concerning their quality and their usefulness, and relate your comments-where possible-to specific organizations.

Answer (104)': There was a general appreciation of the usefulness of federal government publications and a desire for expansion of services. Geological Survey of Canada publications or geological maps drew 83 comments. Of these, 50 indicated the reports were used frequently, were of high quality, or were invaluable; 31 referred to their use only; and 11 criticized slowness in publication. Other agencies receiving fewer (2 to 5), but favourable, comments included the Mines, Mineral Resources, Observatories, Surveys and Mapping, and Marine Sciences Branches of the Department of Energy, Mines and Resources; the Dominion Bureau of Statistics: and the Canada Department of Agriculture. The comments of geological and geophysical consultants (46) indicated a similar attitude.

Question: To what extent do you make use of the earth science publications of provincial government agencies? Please give your frank comments concerning their quality and their usefulness, and relate your comments - where possible to specific organizations.

Answer (91): The number of comments per province varied, reflecting the larger concentration of companies in Ontario, Quebec, Saskatchewan, Alberta and British Columbia. As for the federal agencies, there was a general appreciation of the usefulness of provincial maps and reports; but comments indicated that the quality varied among provinces. The metal mining companies rated maps and reports of the Ontario Department of Mines most highly; those of Quebec, Sas-

'Numbers in brackets refer to the number of replies received to a specific question. katchewan, British Columbia and Manitoba received favourable comment. The Saskatchewan Department of Mineral Resources was consistently complimented by the petroleum companies on the quality of its publication services. The importance of well schedules from all provinces was mentioned, and the services of the Alberta Research Council and Alberta Oil and Gas Conservation Board were commended. There was some comment on the lack of uniformity in scales of mapping and reference systems between provincial and federal agencies.

Question: To what extent do you make use of Canadian scientific journals? Please give your frank comments concerning their quality and their usefulness, and relate your comments-where possible-to specific publications and organizations.

Answer (114): The general tone of the answers was favourable, but some reservations were repeated. The complaint that these journals and bulletins are too "academic" and "wordy" and not enough concerned with practical "economic" or "technical" detail was the basis of these reservations; the dozen or so respondents who were uncomplimentary about Canadian publications gave this "irrelevancy" as their reason. However, many companies subscribed to "all" of them, and used from two to seven periodicals regularly.

Specific mention was made of 12 publications. Of those used by both mining and petroleum companies, the Bulletin of the Canadian Institute of Mining and Metallurgy and the Canadian Journal of Earth Sciences were the most favoured, with 36 favourable comments each. The petroleum companies chose the Canadian Petroleum Geology Bulletin of the Alberta Society of Petroleum Geologists (29). The mining companies selected the Canadian Mining Journal (19) and Mining in Canada (10) as the most useful of the publications directed specifically at them. Other periodicals had five or fewer advocates.

#### 2. Other Forms of Assistance

Question: Please specify and comment on the assistance from *federal government agencies* that you find most useful in carrying out your earth science activities.

Answer (92): As an indication of the extent of industry consultations with personnel of the related federal agencies, the answers to this question are revealing. Of the 92 respondents, 44 made specific reference to consultations with officers of the Geological Survey on a frequent or regular basis; 6 others used this service occasionally. The value of open files, libraries, and other reference materials in the federal agencies accounted for the rest of the replies. Government-organized seminars and symposia were also considered of value. The general impression is that the quality of assistance provided was high.

Other EMR branches receiving favourable comment were: Marine Sciences, in particular the Bedford Institute of Oceanography (7); Observatories (4); and the Surveys and Mapping National Air Photo Library (4). The Department of Indian Affairs and Northern Development was referred to nine times as a good reference source, and three companies mentioned consultations with National Research Council personnel.

Question: Please specify and comment on the assistance from provincial government agencies that you find most useful in carrying out your earth science activities.

Answer (82): Consultation with staffs of provincial agencies earned mention from 34 of the respondents, although almost a third of these were just "occasional" contacts. Respondents also mentioned reference sources such as core storage systems, open files and libraries. Provincial research councils were referred to favourably by 10 companies; their value as consultants was singled out. Specific mention of consultation with provincial resident geologists came from an equal number of companies, all but two based in Ontario and Quebec. Core storage and retrieval facilities of Saskatchewan, Alberta and British Columbia won approval as valuable reference sources from 10 others, all western-based.

In general, the number of favourable comments for each province approximated the amount of industry activity in the region: British Columbia, Alberta, Saskatchewan, Ontario and Quebec ranged from 11 for British Columbia to 14 for Saskatchewan and Alberta. Saskatchewan has a "better oriented and organized earth science program than any in Western Canada", according to one company. The various agencies in the Maritime Provinces cropped up in only six answers.

*Question:* Please specify and comment on the assistance from *Canadian universities* that you find most helpful in carrying out your earth science activities.

Answer (87): University research was of principal interest to the majority of respondents; 22 made reference to research in general or to specific studies, and another 22 particularly mentioned the use of postgraduate theses. However, many of these replies included complaints to the effect that "the emphasis is not directed toward practical or applied research of benefit to the mineral industry". This failing, and the lack of thesis abstracting services, "limited the usefulness of results to industry". Mineral deposits geology and petroleum geology were both signgled out as neglected fields of activity.

Twenty-one companies referred to the value of university libraries, laboratory facilities, and technical assistance in their activities. Consulting with university professors on specific earth science problems earned favourable mention from another 21 respondents. Fourteen respondents mentioned the value of universitysponsored seminars, symposia and lectures in keeping industry personnel up-to-date on developments.

#### 3. Earth Science Research in Industry

Question: Do you consider that there is a need for increased earth science re-

search in industry? If so, what are your views as to how research in industry could be encouraged in Canada through tax incentives or other means?

Answer (95): Seventy-five companies agreed there is a need for increased industry research in the earth sciences. Some (4) felt increased industrial research will develop naturally, given a stable economic climate, which of course was considered to be the responsibility of the government. A problem is that many companies are subsidiaries of foreign firms, in which case research tends to be concentrated outside the country. One company pointed out that "industry must be converted to see the need" for increased research, and that perhaps competitive factors will contribute to this goal. Ten denied a need for industry to conduct research, and eight favoured the status quo.

Among the respondents favouring increased research activity, several suggested co-operation among interested sectors as the ideal solution. This would eliminate the waste that duplication of effort now involves; it would also benefit smaller companies unable to afford their own research personnel and facilities. There were 11 suggestions to the effect that publication of results from such co-operative research would benefit the whole industry. Some type of jointly sponsored national research institute (involving industry, government and universities) was suggested by four respondents; joint programs with existing universities and government research agencies was an alternative proposed by three others.

Many companies (59) favoured tax incentives for industrial research. The majority wanted them increased; several said 150 to 200 per cent of research costs was only fair. It was felt that the present definitions of research activity need to be broadened considerably, so that tax incentives for research would cover the field more realistically. The definitions of R & D used by IRDIA were mentioned as inadequate.

#### 4. Forms of Government-Industry-University Co-operation

Question: What type of assistance or cooperation from government and/or university facilities would be most useful to industry within the next five years?

Answer (93): The majority of respondents referred to areas of activity which really belong in the answer to the next question. Fifty-six referred to the need for the accumulation of more basic earth science data and research, and 50 stressed a very great need for improved data handling and information dissemination; a need for development of improved instrumentation and techniques accounted for 14 more comments. Sixteen complained about university training of earth scientists (see also item 6 below).

Twenty replies said there was a need for increased industry access to government and university laboratory and technical facilities. Several suggested this should be on the basis of fees and rental charges for the independent use of facilities and equipment. Analytical services of various types (particularly of rocks and minerals) were mentioned by 11 respondents.

Industry's use of educational facilities accounted for 14 suggestions. Most stated the need for less costly, more pertinent, and plentiful refresher courses, seminars, symposia and lectures for industry personnel; the main burden for these was placed on the universities. Establishment of liaison officers on university staffs was suggested to keep industry informed of developments.

Better co-ordination of the efforts of all three sectors concerned 14 companies. One suggested a combined organization for research activities; two mentioned the need for some sort of national earth science research centre. In the area of government responsibility there was a plea for the standardization of provincial mining regulations across the country.

Four companies denied any value for themselves in these facilities. Their argu-

ment was that competitive factors precluded their paying the required price of publicizing results.

# 5. Earth Science Activities That Should Be Undertaken

Question: Indicate by disciplines or other categories the types of earth science activities that should be undertaken in Canada to increase the effectiveness of mineral and petroleum exploration.

Answer (86 plus at least 56 commentators from previous question): In a general summary of disciplines, geophysics was mentioned specifically by 41 respondents; geology by 39; and geochemistry by 33. However, most companies categorized their answers under the areas of scientific activity defined elsewhere in this report. Specific disciplines generally occurred as details in this "activities" breakdown, and are thus included in all the following summaries.

The respondents were least interested in *basic* research, which was mentioned only 43 times. Of these, the main pursuits recommended for basic research were: general study of the Arctic and northern areas of Canada (14); origins and genesis of ore deposits (7). Some companies implied that a proper division of responsibility for research activity would leave basic research in the universities and government agencies, and applied research in the hands of industry. The main shortcoming of present activities was considered to be their lack of support for industry-applied research.

Applied research received slightly more mention than basic research, but still accounted for only 51 comments. Industry's part in this facet of research was emphasized and the idea expressed that the specific needs of industry should govern the choice of problems under study. But smaller companies felt that they cannot afford significant research activity. These respondents indicated a lack of research in such areas as petroleum (7), mining exploration (3), testing of ores for new economic uses (3), economic applications in general (5) and environmental problems (4); they gave the government and universities the burden of responsibility.

Several companies suggested that university research activities left something to be desired; in particular, that too much emphasis is placed on theoretical, "pure" research. One respondent felt that grants to universities should involve more practical aspects of investigation. Another felt that the universities should collaborate more with industry, to the extent of having "a consulting section in earth science".

Sixty-nine respondents stated a need for increased activity in the *development* of new methods (36) and instruments (20) for earth science activities. Uses for geophysics and development of geophysical methods should be stepped up, and are thrown firmly into government's lap by the 20 companies mentioning them. Methods (13) and instruments (7) for geophysical exploration were the most important areas stated.

Data collection was the second most important need (92) in the minds of the companies replying. Thirty-three companies felt the lack of adequate or complete mapping, 17 of which refer specifically to "geological" mapping; there was one plea among these for standardization of scales in all maps published. Twentyeight respondents called for more airborne geological and geophysical surveying by the government. More regional and distribution studies in geology and geophysics (10), and regional geochemical surveys (8), were also suggested. Geochemical sampling of streams, stream sediments, bedrock, and drill cores was mentioned several times as an area that would benefit from the activity of government agencies. The consensus seems to be that not enough of this type of work has been done, nor is it progressing quickly enough; NASA was mentioned as an example of the sophisticated use of aerial mapping and surveying that is needed.

By far the most vexing problem to industry seems to be the handling of *scien*- tific information, to which a hundred complaints were directed. Coping with the vast amounts of existing earth science data, plus future accumulations, is the major problem, referred to 52 times. The first step called for is the centralization of available data sources (10); this would be followed up with compilation and cataloguing of data and sources to facilitate retrieval and dissemination (11). Eight respondents mentioned standardization of earth science classifications and codes as a necessary step in any centralizing process. Computer applications were repeatedly (20) pointed out as the best solution. There were 13 complaints about the time lag in the publication of new information; most of these were directed specifically at government agencies. Several respondents felt that better access to university and government libraries was necessary. Three others wanted more abstracting and translating services.

# 6. Canadian Universities and Industrial Manpower Requirements

*Question:* Are Canadian universities meeting the present and anticipated requirements of industry in terms of number, quality, kind and degree of specialization of earth science graduates?

Answer (86): Universities received at least three times as many complaints as any other sector; only 16 respondents indicated complete satisfaction. Although 15 companies felt the quantity of earth science graduates from Canadian universities was "sufficient" or "adequate", 25 others complained of shortages. These shortages applied to mining engineers and mine geologists (11) in particular.

Quality and specialization of graduates drew the strongest complaints; only 16 companies approved of the present situation. The main area of complaint was the lack of a basic "practical" grounding (35). Little orientation toward industry, and the economics of earth science activities, were referred to by 10 respondents; inadequate field experience drew another 10 complaints. Inability in the basic sciences and mathematics, in simple surveying, and in making proper ("concise", "practical") reports accounted for another six complaints.

The conviction that bachelors' graduates are already too narrowly specialized drew 12 complaints. A growing tendency to postgraduate study and theoretical laboratory-based research was considered to be a serious problem by 21 others. The general tone of all the complaints was that Canadian universities were either out of touch with the practical needs of industry or did not care about them. One company summed up several complaints with a comment that industry would be in trouble without a continued influx of earth scientists from other countries.

#### 7. Distribution of Earth Science Activities Among the Industry-University-Government Sectors

*Question:* In your opinion, what changes would be desirable in the present distribution of earth science activities in industry, government and universities?

Answer (58): No major change was recommended in the present distribution of earth science activities. Improved coordination and better communications between all three sectors was indicated as a major need, with responsibility for implementation placed on government agencies by 36 companies.

Research was considered important in all three sectors, with basic research receiving higher priority (over applied) in the universities but the reverse in industry. Government research was assumed to be characterized by an intermediate "mix".

Eleven companies pointed out that the function of the universities in educating scientists must come ahead of the research function. Government agencies must place emphasis on data collection, mapping, airborne surveys, regional studies, and the compilation and dissemination of scientific information.

#### 8. Aid to Developing Countries

*Question:* What Canadian expertise in earth sciences would best benefit developing countries? Where possible, please be specific in terms of expertise and countries.

Answer (70): Most respondents (56) felt that Canada should send qualified earth scientists and technicians to developing countries in advisory, organizational and active roles. General exploration expertise was mentioned 35 times; 10 stated that Canada is the most advanced country in this field and therefore should share her experience. Sixteen companies suggested various types of airborne surveying; 10 emphasized the importance of mapping; and 7 mentioned the application of Canadian diamond drilling techniques. Evaluation and development of discovered resources would, according to 13 respondents, be better accomplished with the aid of Canadian experts on loan. Mining expertise (3) and guidance in the economics of mineral development (2) were emphasized. Six companies suggested that the assistance of Canadian personnel in organizing government departments and drafting laws for the control of earth science activities would be helpful to developing countries.

Canadian educational aid was supported by 13 with emphasis placed on practical exploration activities rather than theoretical research. Seven were of the opinion that this education should be given by Canadian personnel on loan to the country because of the tendency of foreign students, sent to Canada for their education, to refuse to return to their native land. Only three respondents felt that earth science education of foreign students in Canada is effective, and they qualified their answers to cover specialized on-the-job experience.

There were five negative answers to this whole question, of which three were based on a "Canada First" policy.

#### 9. Storage of Drill Cores<sup>1</sup>

*Question:* What is your company's policy regarding the storage and retention of bore hole samples? (For example, storing only telescoped drill core, storing only the mineralized sections, abandoning all core on site when property option is dropped, etc.)

Answer (87): Diamond drill cores from exploratory drilling are logged and kept while they have immediate economic use. Mineralized samples are removed for assay and future reference. At the end of the season, if the area is remote, the cores are usually left on the property and in boxes; however, if boxes are scarce or expensive, cores are dumped on the ground. If the property is optioned, cores are turned over to the owner. Several companies felt that at this point the government should provide the means to ensure that information is not lost, stressing the waste of time and expense involved in possible duplication later.

Cores at operating mines are retained for longer periods provided the volume of material, the work of collection and maintenance in a central location, and the cost of core boxes and storage do not become overpowering. An alternative is to photograph the core, commonly in colour, or to retain only representative sections, such as several inches for every 10 feet of core or change of lithology.

Many companies indicated, however, that they have no common policy, and that their core handling varied considerably according to the circumstances.

*Question:* Do you consider that the maintaining of a central core storage library would improve the conduct of future earth science research activities and mineral exploration? Please comment.

Answer (107): The overwhelming opinion in answer to this question was favourable (82). However, there were several reservations and alternatives offered. Seventeen respondents specified that representative, "condensed", "telescoped" core should be stored, on the basis that a total core library would be unwieldy. Eight companies feared the cost of complete core storage would be prohibitive. Other alternatives included storage of drill records and logs (7); core storage libraries on a regional basis (8); and maintenance of photographic records of all core (4). Seven respondents recommended legislation to force disclosure of logs, records and core samples by all companies.

'This question was asked of mining companies only.

Example	of	Computer-Oriented	Well-Data	Files	of	Imperial	Oil
Limited							

Categories	Size and Content	Uses
General Well Data	56 000 wells. All wells dril- led. Well name, location spud and rig-release date, depths, casing, field, pool and zone. Status History (whether on production, abandoned, etc., logs run).	Statistical print-outs, mon- itor of unique identifiers for other categories and other systems (Control category).
Interval Evaluation	30 000 of the 60 000 wells- all wells tested. Basic data on D.S.T.s. Interval tested and result-quantities of for- mation fluids and (or) gases recovered, includes gravities, contaminations, and does not include pressures.	Used to search for wells which had significant test re- sults. Eliminates wells that do not meet certain criteria.
Cored Interval	25 000 of the 60 000 wells. All wells cored. Gives the intervals cored, recovery in feet, type of core, type of coring fluid.	An aid to explorationists in determining what wells were cored over certain intervals. Print-outs can eliminate all unwanted wells.
Formation Markers	55 000 wells. All wells on which logs have been run-to allow the geologist to deter- mine the formation depths.	Used in conjunction with other categories, Internal Evaluation and Cored Inter- vals to select wells cored or tested in selected forma- tions. For plotting and con- touring structures and iso- pach maps as an exploration aid in area evaluations.
Industry Production	20 000 producing and (or) injecting wells-all wells that have been or are producing. Production by month from 1962 to 1968 for all wells in Alta., from inception for all Alta. wells W5th and 6th M. and through B.C. Oil, gas and water prod., oil, gas and water inject. Cumulative production by type of prod- uct.	Listings of producers by pool or zone. Calculations of gas/oil ra- tios. Plots of daily well pro- duction, monthly produc- tion, cumulative production by well. Pool production calculations. Reservoir stud- ies which evaluate produc- tion before and after work- overs, or form part of evalu- ation hearings with govern- ment respecting field allow- ables.

Gas Analysis (Hydrocarbon-Fluid Analysis)	9 500 analyses-for probably 7 000 wells. All analyses that have been run by service labs. Volume percentage of each component of analysis such as methane, ethane, propane, butane, pentane, hydrogen, oxygen, helium, carbon dioxide.	Used by research explora- tionists mainly to search for wells based on certain vol- umes of components. Used in conjunction with forma- tion markers to establish gas components within forma- tions.
Water Analysis	23 000 analyses for probably 17 000 wells. All analyses have been made by service companies. Milligrams per litre of such components as chlorine, hydroxide, calci- um, magnesium, sodium, carbonates, sulphates, rare ions, iron, sulphides. Specif- ic gravity, resistivity and pH factor.	Used by research explora- tionists mainly to search for wells based on certain vol- umes of components. Used in conjunction with forma- tion markers to establish gas components within forma- tions.
Cuttings-Gas Analysis	350 wells. All wells for which company has run chromato- graph counts on cuttings samples. Components: methane, ethane, propane and butanes.	Digitizing of component ele- ments for plotting on behalf of research explorationists.
Source-Rock and Gasoline-Range Analysis	Around 150 wells-all wells for which 10L Laboratory has run chromatograph counts on source-rock sam- ples. Components: $C_1$ to $C_7$ incl. plus 24 isomers.	Digitized data used to cal- culate reports on behalf of research explorationists.
Lithology	Around 1 000 wells in N.W. Alta. and N.E. B.C. A pilot project of digitized lithologic descriptions of the forma- tion.	By Division and Regional explorationists to study for- mation characteristics rela- tive to exploration play areas.
Core Analysis	Around 5 000 wells in 40 project areas or fields across the Western Basin. Contains sample interval, recovery, porosity, permeability, K Max, K 90 and K Vert.	Reservoir characteristics studies through print-outs and plots for engineers and geologists. Used in conjunc- tion with digitized formation markers and digitized logs for correlation studies.
D.S.T. Charts Digitizing	Around 1 000 wells in Sask. Pilot Project. Contains pressures and times through digitizing D.S.T. charts.	By explorationists for extra- polating reservoir character- istics through pressure changes. Not operative, must reprogram.

in.

Area-Country	Type of Project	Amount \$ Can.	Date
Caribbean			
Antique	Groundwater study	$250,000,(G)^2$	1967
Antigua	Aerial manning project	<u></u> <u>50 000 (G)</u>	1969
Guiana	1 Topographic and airborne survey	800 000 (L) <sup>3</sup>	1968
	2 Topographic and airborne survey	1 800 000 (L)	1966-68
Inmaica	Water development (hydrogeol & civil	1 000 000 (E)	1700-00
Jamaica	eng.)	1 000 000 + (L)	1968+
Leeward and Windward Isl.	Groundwater study and well drilling	200 000 (G)	1969 ?
Montserrat	Groundwater and well drilling	75 000 (G)	1968+
St. Lucia	Groundwater development	350 000 (G)	1965+
St. Vincent	Groundwater development	75 000 (G)	1968+
Anglophone Africa			
Ghana	Irrigation and land reclamation	500 000 (L)	1968+
Kenya	1. Aerial mapping project	500 000 (L)	1968+
	2. Land use and resource development	1 000 000 (L?)	1968+
	3. Mineral exploration equipment	60 000 (G?)	1964 ?
Nigeria	1. Western region mapping project	1 850 000 (G)	1961-64
	2. Mapping and aerial surveys	1 580 000 (G)	1965-68
Tanzania	1. Aerial mapping project	1 000 000 (L)	1968+
	2. Aerial mapping project	1 346 000 (G)	1964-67
Uganda	Geological equipment	50 000 (G)	1962-63
Francophone Africa			
Algeria	Natural resources development	?	1969 ?
Cameroun	Airborne geophysical survey	1 500 000 (L?)	1968+
Ivory Coast	Preliminary surveys	200 000 (L ?)	1969 ?
Niger	Airborne geophysical survey	1 000 000 (L)	Under
			negotiation
Asia			1055 57
Burma	Photogrammetric equipment (Survey Dept.)	<u> </u>	1955-57
Ceylon	Natural resources inventory	<u>2 492 000 (?)</u>	1955-57
India	1. Geological survey, and equipment	<u>9 000 000 (L)</u>	1968+
	2. Petroleum exploration equipment	-1200000 (G)	196/+
	3. Geological survey	(?)	1964-65
	4. Airborne magnetometer survey	<u>207 200 (?)</u>	1955-56
Malaysia	1. Natural resources and fand use survey	<u>1 300 000 (G)</u>	1900-09+
	hydroelectric project	900 000 (G)	1965-68
	3. Aeromagnetic survey	201 000 (G)	1956-58
Mekong	Ground surveys, aerial photography and topographic mapping	1 300 000 (?)	1958-62
West Pakistan	Geological, landform, soil and land use surveys	3 353 708 (?)	1951-61
	33 Projects Total	35 276 919	

<sup>3</sup> Loan.

#### Table 8.2-Canadian Advisers in Geoscience Technical and Educational Fields. Period 1953-1969

Class of Advisers	Duration of Each Project	No. of Advisers
Advisers:		
a) Air Survey	1-2 months	3
b) Geology	1-2 months	4
c) Geology, gold	2 months	1
d) Gold mining	1 year	1
e) Mining legislation	1 year	1
f) Mining, oil & gas	1 year	1
Aerial photography	8 years	1
Air photo-interpretation (soil)	2 months	1
Cartography	2 years	2
Drilling	1 at 2 months; 3 at $1\frac{1}{2}-2\frac{1}{2}$ years	4
Engineering:		
a) Mining	3 at 2 months; 1 at 1 month; 1 at 2 years	5
b) Topographic	1 year	1
Geochemistry	2 1/2 years	1
Geology:		
a) General	7 at 1-4 months; 12 at 1-4 years; 5 at 4-6 yrs	24
b) Economic	3 <sup>1</sup> / <sub>2</sub> years	1
c) Groundwater	2 months	2
Geophysics	1 at 3 months; other at 8 months	2
Land use	2 years	1
Map production	3 years	1
Photogrammetry	1 year	1
Photography	2 years	1
Professors:		
a) Geology	1 at 1 year; 3 at 2 years	4
b) Geography	2 years	2
c) Mining	1 year	1
Soil Science	1 at 1 month; other at 2 months	2
Surveying:		
a) Topography	3 at 1 month; 11 at 1-3 years	14
b) Instructors	2 months	2
c) Soil Surveys	1 at 2 months; 7 at 1 <sup>1</sup> / <sub>4</sub> -3 <sup>1</sup> / <sub>2</sub> years	8
Total-prior to 1965	32 man-years at \$20 000 p.a. = \$640 000	27
from 1953 to 1969	134 man-years at \$20 000 p.a. = \$2 680 000	92
<ul> <li>Data from CIDA files.</li> </ul>		

#### Table 8.3-CIDA-Sponsored Geoscience Trainees in Canada as of September 30, 1968<sup>1</sup>

Type of Study	Duration of Training	No. of Trainees
Drilling	3 months	1
Engineering, Mining	4 at 2 years; 7 at 3-5 years; 2 at 7-8 years	13
Geodesy	1 and 2 years	2
Geography	6 at 1-2 years; 18 at 3-5 years	24
Geology, General	11 at 1-2 years; 20 at 3-5 years	31
Geophysics	1 ½ years	2
Land Use	6 months	1
Mining	3 at 3 <sup>1</sup> / <sub>2</sub> months; 1 at 1 year	4
Petroleum	3 years	2
Photogrammetry	2 and 3 years	2
Soil Mechanics	2, 3 and 4 years	3
Soil Science	5 at 2 years; 8 at 3-5 years	13
Spectroscopy	5 years	1
Surveying	12 at 1-2 years; 27 at 3-5 years	39
Technology, Mining	3 at 2 years; 3 at 3-5 years	6
Total	<b>435 man-years at \$4 500 p.a.</b> = <b>\$1 957 500</b> (Estimated number of geoscience trainees from 1965 to 1967 is 290)	
## Table 8.4-Number of Persons Trained in Canada in 1968 through Technical Co-operation Service according to Agency for which Training was Arranged<sup>1</sup>

	Mining and Surveys	All other Fields <sup>2</sup>	_
Colombo Plan	6	308	
Commonwealth Caribbean Assistance Program	10	135	
Special Commonwealth Africa Assistance Prog.	13	129	
Other Countries and Territories	_	13	
Canadian Commonwealth Scholarship and Fellowship Plan	2	96	
French Speaking African States	7	149	
Latin American Plan	2	8	
UNTAA	7	29	
UNESCO	3	9	
Other Agencies	_	18	
Total	50	894	

<sup>1</sup> Data from CIDA. <sup>2</sup> Other fields include health and sanitation, social welfare, education, agriculture, forestry, fisheries, power and utilities, manufacturing, civil engineering and construction, administration and planning, and transportation.

## 🛱 Appendix 9

Table 9.1-List of UNDP C	Geoscientific Pr	rojects involving Canadian Personnel <sup>1</sup> Period 19	59-1969			
Recipient Country	Project No.	Type of Program	Canadian Personnel	Date		\$ U.S. Expenditure
Afganistan	AFG 4	Groundwater investigation	Hydrogeologist (2 yrs)	Jan 63-Dec	68	1 389 700
Argentina	ARG 12	Mineral survey in Andean Cordillera	Geologist mgr (20 mos); photogeologist (3 yrs); deputy mgr (3 yrs); 4 drillers (2½ yrs); 2 fellowships econ. geol. (1 yr); lab. techn. (1 yr); geophysical- survey-McPhar (8 mos, \$43 211)	Jan 63-Dec	66	1 166 900
Argentina	ARG 23	Porphyry copper investigation in Mendoza, Neuquén & San Juan provinces	Geophysical survey (\$101 157); 2 drillers (15 mos)	June 66-June	68	1 158 400
Bolivia	BOL 6	Pilot mineral survey	Chief field geologist (1 yr)	May 61-Dec	66	922 000
Bolivia	BOL 10	Centre for petroleum development	Project manager (2 yrs)	June 65-June	68	819 900
British Solomon Islands	UK 36	Aerial geophysical survey	Geochemist-spectroscopist (21 mos); geoph. oper. service (5 mos); airborne geophysical survey- Seigel (5 mos, \$20 427)	Jan 64-June	67	984 800
Brazil	BRA 6	Survey of rock salt deposits	Drilling consultant (13 mos); geological consultants and drillers (5 mos)	Jan 62-Marc	h 67	102 847
Burma	BUR 1	Survey of Pb-Zn mining & smelting	Mining engineer (15 mos); driller (18 mos)	May 61-May	64	590 400
Burundi	BDI 5	Mineral survey	? ? ?	May 68-??	?	138 500
Chile	CHI 16	Mineral resource survey	Geologist (1 yr); geoph. survey (4 mos); air photo survey (\$14 257)	Jan 63-Aug	66	507 100
Chile	CHI 28	Detailed mineral investigation of zones in Atacama & Coquimbo provinces	Project manager (2 yrs)	June 66-Dec	68	1 161 000
Congo Brazzaville	CONB 6	Mineral exploration in the southwest	Drillers (2 yrs)	Jan 66-Jan	69	775 900
Cyprus	CYP 2	Survey of groundwater & min. resources	Survey man (15 days)	May 62-May	67	1 340 000
Ecuador	ECU 15	Mineral resources survey	Drillers (3 yrs)	Jan 64-June	67	819 600
El Savador	ELS 3	Assessment of mineral deposits in the north	? ? ?	June 65-June	68	597 500
El Savador	ELS 4	Survey of geothermal resources	Consultant (1 yr)	June 65-June	68	998 000
Ethiopia	ETH 17	Mineral resources survey	Exploration geologist (1 yr); driller; geoph. consultant; airborne geophysical survey (Survair); mineral analysis (Technical Services Lab.)	June 67-Jan	71	1 347 200

<u> </u>	CUV 9	Town (normal development)		Lan	66 100	60	975 500
Guyana	GUY 8	Topo. survey (power development)	Contour maps (Snawinigan Engineering)	Jan	oo-Jan	68	8/5 300
Guyana	GUY 11	Aerial geophysical survey (Phase II)	Aerial geophysics (1 month, \$142 221); fellowship mineral exploration (2 mos); 2 drillers (2½ yrs); drilling supervisor (2 yrs)	June	66-June	69	1 036 200
India	IND 22	Inst. for petroleum exploration (Phase II)	? ? ?	Мау	61-Aug	66	790 300
India	IND 64	Mineral development in Madras State	Photogeologist (1 yr)	Jan	67-Jan	70	1 020 600
India	IND 98	Groundwater investigation (Phase II)	Project manager (2 <sup>1</sup> / <sub>2</sub> yrs)	June	68-Dec	70	707 900
Iran	IRA 1	Geological Survey Institute	Fellowship geology (2 mos); drilling and mineral exploration (1 ½ yrs)	Dec	60-June	68	1 566 300
Ivory Coast	IVC 4	Mineral survey in the southwest	2 drillers (15 mos)	June	64-June	67	1 040 900
Kenya	KEN 4	Mineral resources survey	Economic geologist (1 yr); fellowship geology (2 yrs)	Jan	64-June	67	605 300
Madagascar	MAG 3	Mineral and groundwater survey	Driller (6 mos)	Jan	63-Sept	66	1 246 300
Mexico	MEX 4	Survey of metallic mineral deposits	Project mgr (3½ yrs); 2 data compilers (21 mos); consulting geologist (1 month); fellowship geology (1 yr); geoph. operator (2 yrs)	Jan	62-Sept	67	896 600
Nicaragua	NIC 3	Mineral survey	Geophysicists (27 mos); consulting geologist (1 month); fellowship spectrography (1 yr); 2 drillers (3 yrs- 1½ yrs); airborne geophysics and photogeology (2 yrs-\$110 782)	Jan	63-Dec	67	738 500
Nigeria	NIR 19	Aeromagnetic mineral survey in the NW	Airborne geophysical survey-Can. Aero Service (4 mos, \$260 000)	June	64-May	67	556 500
Pakistan	PAK 15	Geodetic survey of Pakistan	Fellowship geodetic surveys (1 yr)	Jan	64-Jan	68	687 500
Panama	PAN 4	Mineral survey of Azuero area	Photogeologist (1 yr); driller; airborne geophysics (2 mos-Lockwood)	Jan	65-Jan	68	829 600
Philippines	PHI 9	Institute of Applied Geology	Project mgr (1 yr); fellowship mineral economics & administration (1 yr)	Jan	62-June	68	704 000
Philippines	PHI 13	Survey of coal resources	2 drillers (1 <sup>1</sup> / <sub>2</sub> yrs)	Jan	69-Jan	72	523 500
Poland	POL 4	Subsurface exploration for K salts	Fellowship mineral exploration (9 mos)	Jan	66-Jan	68	971 300
Senegal	SEN 4	Mineral resources survey	Fellowship applied geology (8 mos); driller (20 mos)	Jan	63-Dec	66	924 600
Somalia	SOM 14	Mineral and groundwater survey (Phase II)	? ? ?	Jan	68-Jan	70	776 600
Sudan	SUD 28	Mineral survey in three areas	Consulting geophysicist (4 mos); aerial geophysical survey	June	67-Sept	71	1 257 700

Recipient Country	Projec No.	ct	Type of Program	Canadian Personnel	Date		\$ U.S. Expenditur
Swaziland	UK	40	Aerial geophysical survey	Geophysicist (12 mos); airborne magnetic and radio- metric survey-Can. Aero Service (1 month, \$103 293); EM Survey-Lockwood (1½ mos, \$94 744)	June 65-June	69	462 900
Tanzania	TAN	5	Mineral exploration in Lake Victoria goldfield	Cons. geologist (1 month); fellowships in geology and geophysics (1 yr)	June 64-May	68	625 50
Togo	TOG	4	Survey of groundwater & mineral resources	Sr exploration geologist (14 mos); fellowship mining geology (6 mos); airborne geophysics-Spartan (\$115 950)	Jan 62-Jan	65	1 273 500
Trinidad & Tobago	TRI	6	Marine seismic survey between Trinidad and Tobago	Project manager geophysics (6 mos)	Jan 68-Jan	69	617 100
Tunisia	TUN	10	Mineral investigation of Foussana basin	Ground geophysical survey-Seigel (1 yr, \$47 708)	Jan 64-Apr	68	922 500
United Arab Republic	UAR	56	Assessment of mineral potential of the Aswan region	Aeromagnetic survey–Lockwood (\$252 000)	June 65-Apr	70	1 795 800
Upper Volta	UPV	4	Mineral and groundwater survey	4 drillers (2-1 yr; 2-8 mos); consultant copper (3 mos); groundwater geophysics-Huntec (1 <sup>1</sup> / <sub>2</sub> yrs, \$79 998)	June 63-Sept	68	1 050 000
Total			44 projects (out of 117 UNDP projects)	For summary of Canadian personnel, see Table 9.2	Period 1959-19	69:	39 322 747

<b>Table 9.2-Canadian Earth Scientists and</b>	Technicians on UNDP Geoscientifi	Projects-	Period	1959-1969
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1   s 3   onths 2   onths; 15 at 1-3 years 19   1 1   1 1
1   s 3   onths 2   onths; 15 at 1-3 years 19   1 1   1 1
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onths     2       onths; 15 at 1-3 years     19       1     1       1     1
onths; 15 at 1-3 years     19       1     1       1     1       1     1
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### Appendix 10

# Canadian Mining Companies Active in Mineral Exploration and Development in Developing Countries<sup>1</sup>

Company	Country and Territory
Alcan Aluminium Ltd.	India (one smelter; 2nd smelter slated for production in 1971, at a cost of \$9M) Guiana (bauxite mining) Guinea (27% or \$19M interest in Boke bauxite deposits to be brought into production in 1972) India (bauxite mining; new smelter operating in 1969)
	Jamaica (very extensive bauxite mining)
Allan Explorations Ltd.	Chile (copper prospect)
Atlas Explorations Ltd.	Chile (copper prospect)
Belra Explorations Ltd.	Chile (copper prospect)
Canadian Javelin Ltd.	El Salvador (preparing for gold and silver production the former producer Montecristo Mine, at 100 t.p.d.)
Cominco Ltd.	Greenland (2/3 int. in 3 125 sq. mi. base metal concession) Guiana India S.W. (40% int. in zinc smelter and sulphuric acid plant) Jamaica (copper prospect) Mexico (base metal exploration)
Cultus Explorations Ltd.	New Guinea (exploration for base and precious metals and asbestos)
Denison Mines Ltd.	Guiana (9 150 sq. mi. concession for uranium and gold) Jamaica (four prospecting licences, copper prospect)
Consolidated Halliwell	Haiti (copper mine 500 t.p.d.)
Falconbridge Nickel Mines Ltd.	New Caledonia (50% of exploration funds; several million dollars spent already) East Congo Dominican Republic (\$180M mining and processing complex scheduled for initial production in late 1971) Nicaragua (La Luz gold mine; Rosita copper mine) Uganda (72.8% int. in Kilembe copper mine, 3000 t.p.d.)

Fundy Exploration Ltd.	Costa Rica (30 sq. mi. exploration concession
	for copper)
International Nickel	British Solomon Islands
Company of	Costa Rica
Canada Ltd.	Guatemala (\$180M mining and processing complex
	pending)
	Indonesia-Sulawesi Isl. (25 000 sq. mi. Ni expl.
	concession)
	New Caledonia (40 % equity in COFIMPAC; responsible
	for $60\%$ financing up to \$200M)
	New Guinea-Papua (exploration for nickel)
	Panama
Lytton Minerals Ltd.	Mexico (copper prospect optioned, \$0.3M spent)
Noranda Mines Ltd.	Chile (exploration for copper)
	Columbia
	Costa Rica
	Dominican Republic
	Honduras
	Mexico (49% interest in world's largest fluorspar mine)
	Nicaragua (61 % direct interest in 300 t.p.d. gold mine)
	Santa Domingo
	Venezuela
North Bordulac Mines	Costa Rica (30 sq. mi. sulphur concession under
Ltd.	application)
Pascar Oils Ltd.	Costa Rica (25 sq. mi. sulphur concession)
Patino Mining Co. Ltd.	New Caledonia (several million dollars spent on
C	exploration)
Placer Development Ltd.	New Guinea (mineral exploration)
L.	Philippines (40% int. in Marcopper Mining Co. and
	15 000 t.p.d. concentrator)
Prado Explorations Ltd.	Saudi Arabia (mineral prospect)
Pure Silver Mines Ltd.	Mexico (30% int. in three silver properties; exploration
	for tungsten and copper)
Sherritt Gordon Mines	Indonesia (10% int. in P.T. Pacific Nickel Indonesia)
Ltd.	, , , , , , , , , , , , , , , , , , ,
Thermochem Industries	Costa Rica (exploration for sulphur)
Ltd.	
<sup>1</sup> Most of this information obt	ained from an article by R. J. Roberts entitled "Foreign Exploration

Boom" and published in the Northern Miner, April 10, 1969.

#### Appendix 11

#### Earth Science Aid Programs of Some Industrialized Countries

#### 1. United States

Several U.S. agencies carry out earthscience-based external assistance programs, notably the Agency for International Development (AID) and the Peace Corps. Scientists of the U.S. Geological Survey (U.S.G.S.) contribute extensively to American aid programs, mostly through AID. Of the international activities with which U.S.G.S. staff are associated, "technical assistance to developing countries involves the largest and most continuous commitments of Geological Survey personnel".' During the past 25 years, about 900 major assignments in more than 70 countries have been completed by the U.S.G.S. staff. In 1967, there were 144 U.S.G.S. personnel working in developing countries, exclusive of Topographic Survey staff. An interesting facet of American policy relating to earth science activities in developing countries reads: "Although technical assistance has been generally concerned with geologic mapping and appraisal of mineral and water resources, or with applied geologic and hydrologic studies, the long-range objectives have been to strengthen counterpart institutions and to develop counterpart scientific personnel".1

Peace Corps volunteers provide numerous junior- and middle-level staff in earth science-based programs, in a manner somewhat similar to CUSO.

#### 2. Great Britain

British technical assistance to developing countries is under the management of the Ministry of Overseas Development, which implements the programs and has direct responsibility for certain aid organizations, including the Directorate of Overseas Surveys. It also finances other specialized agencies, such as the Overseas Division of the Institute of Geological Sciences (formerly the Overseas Geological Survey). The work of the Overseas Division is related chiefly to projects arranged as direct aid to countries abroad, and to support for geological and geophysical surveys overseas as part of UNDP projects. In 1967-68, officers of the Division worked in Bahrain, Guyana, Hong Kong, Laos, Libya, Mauritius, Morocco, Peru, Swaziland, Tanzania, Thailand and Uganda.<sup>2</sup> In 1969, Great Britain had 134 geoscientists engaged in foreign aid, at a total cost (including laboratory support) of £ 670 000.<sup>3</sup>

#### 3. France

The "Bureau de Recherches Géologiques et Minières" (BRGM) is the most important agency of the French government in the field of earth science activities and mineral resource development. In addition to activities in France and former French colonies, the BRGM conducts external assistance programs and acts as a contractor for foreign governments or private commercial concerns, in both mineral exploration and exploitation; in addition, the BRGM conducts commercial operations in developing countries for its own account. Some of the BRGM programs are funded by UNDP, others by the European Development Fund (FDE), while others are directly financed by the French government through its Aid and Co-operation Fund (FAC) channelled to francophone Africa and Madagascar. Other projects are funded by the "Association pour l'Organisation des Missions à l'Etranger" (ASMIC). In 1967, the BRGM augmented its foreign work budget by several million dollars and its activities included 25 developing countries: Cambodge, Cameroun, Congo Brazzaville, Congo Kinshasa, Dahomey, Gabon, India, Indonesia, Iran, Iraq, Ivory Coast, Laos, Lybia, Madagascar, Mali, Mauritania, Niger, Pakistan, Saudi Arabia, Senegal, Tchad, Togo, Turquey, Upper Volta and Zambia.<sup>4</sup>

#### 4. Japan

In 1962 Japan centralized the management and responsibility for its aid programs in its Overseas Technical Co-operation Agency. One major Japanese activity is in development surveys, including feasibility and preinvestment studies on hydroelectric resources, dams, etc., as well as actual resource studies such as those carried out in Laos and Venezuela. Japanese earth science advisers have also worked recently in Thailand and Malaysia. It is of interest to note that Japan, a major importer of primary products, attaches considerable importance in its aid program to the development of mineral resources, specifically in Southeast Asia.

<sup>&</sup>lt;sup>1</sup>U.S.G.S. Geological survey research. Professional Paper 600-A. Washington, D.C., 1968.

<sup>&</sup>lt;sup>2</sup>Natural Environment Research Council. Report for the Year 1 April 1967-31 March 1968. Her Majesty's Stationery Office, London, July 1968.

<sup>&</sup>lt;sup>3</sup>K. C. Dunham, personal communication. <sup>4</sup>BRGM. Rapport Annual, Année 1967. Paris, 1968.

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