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# Background Study for the Science Council of Canada

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# Earth Sciences Serving the Nation

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# Earth Sciences Serving the Nation

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## Highlights

Solid-earth sciences serve Canada in numerous ways and provide essential services in major growth areas of the Canadian economy.

This study relates to the solid part of the earth and includes geology, geophysics, geochemistry, physical geography, hydrogeology, soil science, and several related disciplines. It embraces research and development, scientific data collection, and scientific information activities related to these disciplines.

Here, for the first time, is a detailed account of solid-earth science activities in the mineral and construction industries, federal and provincial government agencies, and research councils and universities.

The study describes the present patterns, and proposes major improvements for earth science activities during the next decade. The most important findings and conclusions follow.

The importance of earth sciences in our national life extends far beyond the development of mineral resources, although this activity remains the most important for the 6 000 earth science professionals practising in Canada. Earth sciences contribute to other important objectives, including regional and northern development, improved building and engineering construction, urban planning, development of water resources, management of renewable resources such as agricultural soils and forests, multiple land use, and pollution control.

In 1968, the total earth science expenditures in Canada were:

| | |
|---|---|
| Research | $ 30 million |
| Development | 6 million |
| Data interpretation | 30 million |
| Data collection | 217 million |
| Exploratory drilling | 172 million |
| Scientific information | 13 million |
| Total | $ 468 million |

Excluding expenditures by industry on exploratory drilling, the financial participation of the various sectors in these activities is: industry, 80 per cent; federal government, 12 per cent; provincial governments, 6 per cent; and universities, 2 per cent.

Notwithstanding the importance of earth science activities in Canada's development, the great majority of Canadians have scarcely a rudimentary knowledge of the earth on which they live. The fast-growing interest in our physical environment, the mounting pressures concerning landscape preservation and anti-pollution, the need for improved urban planning, and the importance of natural resource development in Canada highlight the relevance of earth sciences for Canadians.

Students in our secondary schools should be given the opportunity to learn the principles of science through discovery of the physical world in which they live–the atmosphere, the lakes and rivers, the oceans, the mountains, the rocks, the minerals–so that science can be seen to be *relevant* and *useful.* We thus submit:

*Provincial departments of education should encourage and promote the teaching of earth science in secondary schools.*

For several years there has been a shortage of earth science professionals in Canada. Of the positions available in 1968 for earth scientists, only 35 per cent were filled by the output of Canadian universities; scientists from abroad filled a large part of the Canadian need. Of graduate students now in geology, geophysics and physical geography, over 40 per cent are non-Canadians. Universities must face the challenge of increasing the number of graduates while simultaneously fostering research training.

In spite of the present major rejuvenating process in geology, comparable to that experienced by physics in the 1890s, and the important contributions of geology and geophysics to Canada's economic and regional development, many earth science departments in Canadian universities are inadequately housed. We conclude:

*Government and university administrators should take steps to improve earth science facilities in the universities.*

Centres for special studies (centres of excellence) in earth sciences should be developed in some universities, with the support of government and industry. These centres should focus on important national scientific problems, with special emphasis on studies of earth features which are uniquely or best developed in Canada. We conclude:

*The following fields are exceptionally suited for special Canadian studies (in alphabetical order): Cordilleran studies, marine sciences, mineral exploration research, northern terrain research, Precambrian studies, and Quaternary studies. Because of earth features best developed in Canada, geomagnetism, geotectonics, glaciology (including snow and ice), meteorite crater studies and mineral deposits geology are well suited for Canadian research.*

Canadian earth scientists are not exempt from "solitudes". A major objective of policy in earth sciences should be better co-ordination of their activities and establishment of better communications among geoscientists in industry, government and universities. Earth science activities should be considered as an area for federal-provincial co-operation and co-ordination and should avoid constraints arising from matters of jurisdiction. In conjunction with several conclusions appearing in this report on the subject of co-ordination, we submit:

*The major advisory functions on the orientation, and to some extent the funding, of earth science research in Canada should be distributed as follows:*

*a) National Advisory Committees* (such as the National Advisory Committee on Mineral Resources Research recommended herein), multidisciplinary in nature, representative of all major sectors and funded by the federal government, to advise governments and industry related to research in major national missions;

*b) Research Committees* formed by scientific and professional societies, to achieve co-ordination among specific earth science disciplines, to provide advice on future research, and to perform related functions; and

*c) Committees of the National Research Council* to provide grants-in-aid for university research.

The mineral industry is by far the largest performer of earth science activities in Canada and the largest employer of earth scientists. The sustained growth of this industry is essential to Canada's economic and social development. To this end, mineral exploration should be vigorously pursued and encouraged. Research into new methods and instrumentation for increasing the efficiency of mineral exploration warrants particular encouragement in industry, government agencies and universities. Thus, we conclude:

*The Canadian Government should adopt measures to encourage the mineral industry to carry out, or support, more "in-Canada" earth science research. Industry should co-operate fully with government agencies and universities in the establishment of the Canadian Geoscience Data Institute, the establishment of central core storage libraries, the conduct of research in mineral exploration and drilling technology, and the provision of research fellowships associated with industrial sabbatical leaves. Universities should, before 1975, double their present level of research in economic geology and triple it in exploration geochemistry and geophysics.*

Earth science research should be actively pursued in areas of major concern related to building and engineering construction, urban planning, multiple land use, management of renewable resources, control of pollution, and geochemical aspects of nutrition and health. Consequently, we submit:

*Geotechnical research and development by the construction industry and the engineering profession should be encouraged through tax incentives. Better co-ordination is needed among the various governments, including municipal authorities, to ensure an adequate earth science input in urban and regional planning.*

*Scientific investigation and mapping of surficial deposits and landforms should be accelerated to meet the rapidly growing needs of better land use and ensure the proper development of renewable resources. Education, training, mapping and research relating to renewable resources should emphasize a multidisciplinary approach to problems.*

There is very little earth science basic research in Canada that anyone would wish to curtail. The level of this research is barely adequate to meet the need for fundamental scientific knowledge relating to national endeavours and research training. By improving the effectiveness of our earth science activities, building on existing strength, and promoting research on typical Canadian problems such as the Precambrian Shield, northern terrains, Quaternary geology and the like, Canada could readily acquire, at relatively minor cost, a greater position of prestige in international science while still nurturing science that is of immediate benefit to the nation. This is why we recommend:

*A comprehensive and multidisciplinary program of research into the origin and evolution of the Canadian Shield should be undertaken in Canada during the next decade.*

Finally, we have developed in this report a basic philosophy on the role of earth sciences and natural resource development in Canada's programs of assistance to developing countries. Several of our conclusions on this subject in Chapter VIII have far-reaching implications, not only for the Canadian International Development Agency but for the Canadian earth science community as well. Thus we conclude:

*National resources development and its necessary input of earth sciences should be an important component of Canada's programs of external aid. A realistic target for earth science activities in these programs is $30 million by the year 1975, involving 200 man-years of professional and 60 man-years of technical manpower. In this connection, the Department of Energy, Mines and Resources should establish an Overseas Branch, funded by CIDA, to provide a permanent cadre for earth science work overseas.*

The Solid-Earth Sciences Study Group

# Conclusions

*In the following list, conclusions appearing in the text are grouped according to the major themes or functions to which they relate, and subgrouped according to the major sector primarily addressed.*

**Communications and Co-ordination**

*Federal and Provincial Governments*
Earth science activities should be clearly designated as an area for federal-provincial co-operation and co-ordination to meet the needs of the country; the planning and conduct of these activities should not be subject to constraints arising from matters of jurisdiction *(II.7, p. 90)*

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 *(VII.3, p. 277)*

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, and particularly among the various provincial and federal agencies involved in this field *(VI.10, p. 266)*

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.1, p. 231)*

*Federal Government*
A National Advisory Committee on Mineral Resources Research should be established by the Department of Energy, Mines and Resources to co-ordinate a national program of mineral resources research *(II.9, p. 95)*

The National Research Council and the Department of Energy, Mines and Resources should review the roles of their Associate and Advisory Committees with a view to clarifying their mission-orientation and transferring increased responsibility for the co-ordination of discipline-oriented research to the appropriate professional societies *(II.10, p. 95)*

Plans for the establishment of a National Scientific and Technical Information Service should recognize the desirability of integrating earth science information into the network. To this end, it is important that earth scientists be represented on the secretariat and board of directors of any bodies that may be formed to direct the operation of the national network, and that the earth sciences be fully included in the journals of research, bibliographies, indices and other information provided by the Service *(II.15, p. 124)*

The Government of Canada should establish a continuing interdepartmental committee on earth sciences, with membership drawn from the user departments and agencies *(II.2, p. 87)*

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.4, p. 282)*

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.5, p. 283)*

The earth science research and services related to regional and northern development should be centralized in the Department of Energy, Mines and Resources *(II.3, p. 88)*

The earth science activities of the Department of Energy, Mines and Resources require closer co-ordination. This can be encouraged by grouping a number of the earth science activities relating to non-renewable resources (presently located under four separate assistant deputy ministers) under the assistant deputy minister for geosciences *(II.4, p. 89)*

To make its results more quickly available, yet at competitive cost, the Geological Survey of Canada should be assigned complete responsibility for its own publications *(II.5, p. 89)*

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 *(V.5, p. 243)*

*Provincial Governments*

Consideration should be given to the formation of provincial earth science co-ordinating committees composed of senior representatives of user departments and agencies, as well as of other groups performing earth science research in the provinces, to provide a forum for discussion and co-ordination of earth science activities at the provincial level, and to appraise and evaluate current work in terms of provincial and national goals *(II.13, p. 108)*

*Industry*

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.14, p. 215)*

*Universities*

Universities should define the basis upon which they would be willing to integrate their research-training policies with the research activities of government agencies, research councils, and industry. Such definition should include the basis (obligations and privileges) for temporary appointments, the sharing of facilities and expenses, and the basis of supervision of graduate students either on campus or in the matching organization. Government and industrial organizations located near university campuses should initiate discussions on means of sharing facilities and personnel in the interests of national effectiveness *(II.8, p. 91)*

The growth of earth science university groups involving geologists, geophysicists, geochemists, geographers and others should be encouraged, and so should the development of soil science groups involving as many of the essential disciplines as possible *(III.8, p. 153)*

*Scientific and Professional Societies*

Scientific societies should play a more active role in bringing earth science into the public eye. Government agencies, industry, universities and museums should co-operate more closely in educating the general public on the Canadian georama and stressing the importance of earth science activities in reaching national goals *(III.4, p. 139)*

A Council of the Canadian Earth Science Societies should be established to provide advice to governments and to perform many of the common functions necessary for the development of the earth science professions in Canada. Leaders of the earth science societies should convene a meeting of senior members to examine areas for co-ordination and co-operation and the formulation of long-range plans *(II.14, p. 120)*

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.6, p. 244)*

**Education and Training**

*Provincial Governments*
Provincial departments of education should encourage and promote the teaching of earth science in secondary schools, so that science can be seen to be relevant to the physical world in which the student lives, and in order that the fundamental principles of science be taught within the frame of reference of man's environment. Universities should help in the training of high school teachers and the development of the audio-visual aids and texts required for this modern course *(III.5, p. 143)*

To avoid excessive dispersion of energies and encourage the development of excellence in earth science research and training, provincial governments and universities should not authorize the establishment of new advanced-degree programs in the earth sciences except where there is a demonstrable demand for earth scientists with a certain type of specialization. These programs should be established only where the ratio of bachelor graduates to faculty has been greater than 2 to 1 during four consecutive years, and on the basis of firm commitments from the local government and university to provide a minimum faculty of 10, as well as adequate teaching and research facilities *(III.10, p. 164)*

*Universities*
Canadian universities are not meeting national manpower needs in most earth science fields, in terms of both output of professionals and the type of graduates produced. In addition to providing better physical facilities for earth science departments, universities are urged to fulfil the nation's earth science manpower needs by encouraging more students to enter the earth science professions, adapting several of their courses to meet these needs, and promoting the widespread introduction of a modern earth science course in secondary schools *(III.6, p. 147)*

Undergraduate training in the earth sciences should be broadly based, with increased emphasis on the unifying concepts in geology, modern theories of global evolution, basic sciences, statistics, and computer technology. Better balance in curriculum content should be achieved by greater consideration of national manpower needs, as well as greater inter- and intra-departmental communications and co-operation. "No-thesis" advanced degrees should be introduced to meet the needs in the expanding sectors of the economy and the interdisciplinary areas in which Canada may, in the future, make rapid strides *(III.7, p. 152)*

Adequate training of professionals in the various aspects of geotechnique should be supported at the postgraduate level on the basis of strong interrelations among university departments of civil engineering, geology, and other disciplines of earth science. Interdepartmental instruction and research in geotechnique should be fostered by the universities and encouraged through research grants *(V.4, p. 239)*

Canadian universities should foster and expand graduate programs in hydrogeology, both through specific training–in an earth science context–in subjects specific to hydrogeology, and by providing a broad base in hydrological sciences, environmental sciences and water resource management *(VI.4, p. 262)*

*Industry*
Industry should provide training opportunities to female as well as male earth science students, and provide more careers for women in the earth sciences *(III.9, p. 153)*

**Economic Development**

*Federal-Provincial Governments*
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 *(IV.13, p. 214)*

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.1, p. 274)*

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 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 *(VII.2, p. 276)*

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.3, p. 236)*

The proposed National Advisory Committee on Mineral Resources Research should assume the responsibility of developing and monitoring a national program for exploration, exploitation, and policy formulation related to the non-renewable resources of Canada's continental shelves *(VII.6, p. 286)*

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 *(VI.8, p. 265)*

*Provincial Governments*
The present level of earth science activity by provincial departments is insufficient to meet regional requirements, and should be increased correspondingly to reflect the present and potential revenues derived from the mineral industry *(II.12, p. 98)*

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 *(VI.6, p. 264)*

*Municipal Governments*
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 *(V.2, p. 235)*

*Industry*

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 *(IV.8, p. 194)*

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 *(IV.7, p. 194)*

## Research

*Federal-Provincial Governments*

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 *(IV.4, p. 189)*

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 *(VI.9, p. 266)*

Continuing increase in the use of the groundwater zone, both as a source of water supply and as 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 *(VI.5, p. 262)*

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 earth sciences *(VI.3, p. 258)*

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 increased Canadian geotechnical competence and manpower capacity in these fields *(V.11, p. 249)*

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.2, p. 258)*

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.1, p. 255)*

*Federal Government*

To meet the urgent need for better information concerning Canadian scientific manpower, the Federal Government should direct one of its agencies to develop a comprehensive manpower register, to be operated on a contract basis by the appropriate professional and scientific societies *(II.1, p. 50)*

It is in the national interest that the Federal Government reassess its current level of expenditure on earth science activities. In the light of a reassessment, involving consultations with provincial governments and industry, the Federal Government should establish realistic goals and levels of expenditure and activity: to meet the needs of national economic development and encourage the growth of the mineral, agricultural and construction industries; to support regional and northern development; to meet the cultural, environmental and recreational needs of Canadians; and to provide the necessary assistance in external aid *(II.6, p. 89)*

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 *(IV.9, p. 203)*

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 *(VI.7, p. 264)*

The Earth Science Grant Selection Committee of the National Research Council should include earth scientists from industry or government; this Committee should be more selective in judging grant request *(II.11, p. 96)*

*Industry*

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 *(V.7, p. 247)*

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 *(IV.10, p. 205)*

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 *(IV.1, p. 188)*

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 *(IV.2, p. 189)*

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 *(IV.6, p. 189)*

*Universities*

Canada should promote centres for special studies (centres of excellence) in the following earth science fields: Cordilleran studies, marine sciences, mining exploration research, northern terrain studies, Precambrian studies, Quaternary studies, and sedimentary geology *(III.11, p. 169)*

The following fields are exceptionally suited for Canadian research (in alphabetical order): geomagnetism, geotectonics, glaciology (including snow and ice), mineral deposits geology, mining exploration geophysics, muskeg studies, permafrost studies, Precambrian research, and Quaternary geology *(III.3, p. 135)*

*Federal Government*

The Dominion Bureau of Statistics should clarify its definitions of scientific activities to confirm that the earth science activities performed in the field to advance scientific knowledge and discover new applications of scientific principles are to be categorized as research. Consideration should also be given to including under research and development the interpretation of geoscientific surveys serving the operational needs of the mineral exploration industry *(I.1, p. 33)*

A comprehensive and multidisciplinary program of research into the origin and evolution of the Canadian Shield should be undertaken during the next decade, with particular reference to geodynamics of proto-continents, and Precambrian sedimentation, volcanism, plutonism, metamorphism, and orogenesis. This program should be under the general direction of the Geological Survey of Canada and should entail the active co-operation of provincial agencies, industry and universities. A major synthesis of this research should be published in 1980 *(III.1, p. 132)*

Fundamental knowledge on the nature and history of the major elements of Canada's geological provinces and their correlation with similar elements in contiguous regions of the world should remain a prime research objective of the government agencies and university departments engaged in earth science activities *(III.2, p. 132)*

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 *(IV.11, p. 211)*

A national program of research should be initiated by the National Research Council to develop better instruments and improved methods of borehole surveying *(IV.12, p. 211)*

The Canadian Government should adopt measures to encourage the mineral industry to carry out or support more earth science research in Canada *(IV.3, p. 189)*

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 *(V.7, p. 247)*

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 *(V.10, p. 249)*

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 *(IV.5, p. 189)*

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 *(V.9, p. 248)*

**Foreign Aid**

A realistic target for the magnitude of the earth science aid to developing countries is $30 million for 1975, involving 200 man-years of professional and 60 man-years of technical manpower allocated annually to earth science activities abroad (excluding manpower of contracting firms) *(VIII.3, p. 303)*

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 five-year period to allow for the orderly training and recruiting of Canadians for Canada's bilateral and multilateral assistance programs *(VIII.2, p. 301)*

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 mid-project reviews and post-project appraisals *(VIII.4, p. 305)*

The Canadian International Development Agency should solicit more actively the co-operation of other government agencies for 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 *(VIII.6, p. 309)*

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 *(VIII.7, p. 310)*

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 or in the UN-sponsored regional earth science institutes, rather than in Canada; c) training in Canada should be specifically and exclusively oriented toward 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 *(VIII.8, p. 315)*

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 *(VIII.9, p. 316)*

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 *(VIII.1, p. 299)*

The Canadian International Development Agency should establish the 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 Conslusion VIII.7). The publishing costs should be be built into the assistance budget *(VIII.5, p. 308)*

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# Chapter I

# The Nature and Organization of the Study

"Crafty Men contemne studies;
simple Men admire them;
and wise Men use them."

Francis Bacon, 1608

## I.1 Prologue

Man is a compulsive discoverer. As this report was being prepared, astronaut Neil Armstrong became the first man to set foot on the moon. This triumph of science and technology illustrates man's appetite for knowledge and his urge to explore and understand the universe.

The sciences dealing with the solid part of the earth, which are the object of this Special Study, cover a wide spectrum of activities related to both the exploration of our planet and our best use of it. As Charles Kingsley remarked almost a century ago, if we do not intend to live on the earth as hermits, we must learn to take full advantage of our physical environment, whether it be for ensuring our technology of affluence or controlling the environment for our comfort and safety.

In this report we indicate the extent to which earth science activities affect important facets of our national life. In the context of an expanding economy and an increased use of earth sciences in the service of the nation, we propose a number of major goals to improve the effectiveness of earth science activities in Canada.

Our land offers unsurpassed opportunities for the study of many features of the solid part of the earth, for example Precambrian sedimentation and volcanism, Quaternary features, etc. From a purely scientific point of view we owe it to ourselves, as well as to international science, to apply our expertise to the study of the earth's phenomena, particularly those well developed in Canada.

Earth sciences fit the Canadian scene more than any other scientific discipline and should be widely taught in our high schools and universities. It is suggested in this report that they become part of our national culture. Indeed, without this knowledge how can we intelligently enjoy the beauties of nature and understand the forces that created them? Would it not be appropriate for Canadians to have a better appreciation of their physical environment?

The mineral industry is a major contributor to our national wealth and foreign trade. The exploitation of mineral resources is also an important factor in regional development, including the development of the North. It provides a means of strengthening our sovereignty in the Arctic and our claims to 1.5 million square miles of continental shelf areas. The sustained growth of this industry depends on a continuous replenishment of mineral reserves, which requires risk capital, improved technology, and the successful application of earth sciences to the search for new sources of minerals in the earth's crust.

The distribution, properties and equilibrium conditions of soils, permanently frozen ground, peat, ground water, and various types of rocks affect engineering structures. Earth sciences thus find important applications in the construction industry, particularly in foundation engineering, transportation, and urban development. Earth science research in such fields as muskeg and permafrost must help reduce northern construction costs to the level of those farther south so that people and industry can afford to move to the North. Our ability to predict time, place and magnitude of earthquakes, landslides, floods and other earth hazards is also very much dependent on our knowledge of the behaviour of the earth and the nature of surficial processes.

Earth sciences find important applications in the field of renewable resources. The materials of the earth's surface, and the geological processes which have produced them, affect such resources as agricultural soils, forests and ground water. Proper management of these resources is increasingly dependent on earth science activities.

In foreign aid, Canada can provide important earth science expertise to help in the natural resource development of emerging nations. As discussed in Chapter VIII, it should be a major objective of Canadian government policy to provide this expertise on a much larger scale.

## I.2 Purpose of the Study

The *general purpose* of this study has been to conduct a comprehensive review of Canadian scientific activities pertaining to the solid earth, appraise their adequacy, and recommend the goals of future activities, including means of ensuring their effective application to Canada's economic and social development.

It should be stressed that this study deals only with the solid earth below the interface with air and water. The study not only covers earth science research and development but also embraces related activities such as scientific data collection, scientific information, and various aspects of training.

More specifically, the *aims* of the study have been:

1. To survey the organization of the solid-earth science activities in Canada and to compare this framework with that of other countries.
2. To survey and evaluate all activities in solid-earth sciences of industry, government agencies, universities and other organizations.
3. To study solid-earth science expenditures, including their sources, distribution and effectiveness.
4. To study the numbers, distribution and qualifications of personnel engaged in solid-earth science activities.
5. To inquire into the training of scientists and technicians in these fields, including the influence of foreign research, and to examine the supply and demand for these people.
6. To review the means and the effectiveness of information exchange through publications, meetings, seminars, refresher courses, professional and scientific societies.
7. To outline major objectives for the various solid-earth science disciplines relative to the country as a whole and to its geological provinces, weighing their importance and indicating the activities required to meet the objectives.
8. To define the Canadian expertise in solid-earth sciences, which may benefit developing countries through training programs, exchange of scientists, and use of Canadian expertise in natural resource development.

## I.3 Scope of Study

This study is very broad in scope and covers matters of organization, manpower, expenditures, information exchange, scientific development, cultural aspects, economic development, regional development, and other practical applications of earth sciences affecting Canada's economic and social well-being. Some 40 scientific disciplines are included (see Appendix 4).

The study embraces the exploration activities of the mining and petroleum industry (mineral output of $4.7 billion in 1968), the geotechnical aspects of the construction industry (an industry of $12.2 billion in 1968), as well as soil and land use in relation to agriculture and forestry. It takes into account the multiple geoscientific activities of federal government agencies, particularly the Department of Energy, Mines and Resources, and of provincial departments of natural resources, provincial research councils, and public utility companies, such as provincial hydroelectric power commissions. The study includes the departments of geological sciences, geophysics, physical geography, soil sciences (excluding fertilities studies), mining engineering (rock mechanics only) and civil engineering (soil and rock mechanics only) in some 35 Canadian universities.

The earth sciences relating to the hydrosphere and the atmosphere have been excluded because these subjects have been dealt with in other special studies of the Science Council, namely, *Upper Atmosphere and Space Programs in Canada* (Study No. 1), *Physics in Canada: Survey and Outlook* (Study No. 2), *Water*

*Resources Research in Canada* (Study No. 5), and *Chemistry and Chemical Engineering: A Survey of Research and Development in Canada* (Study No. 9). *The important field of snow and ice is not included; it warrants a special study in itself.*

The mineral industry is covered in this report only to the stage of mine and oilfield development. The various aspects of mineral exploration are discussed in detail, *including* exploratory drilling and field surveys as well as field and laboratory research in geology, geophysics and geochemistry, but *excluding* costs of staking and land acquisition, and development drilling. *In view of these limitations, we urge the Science Council to sponsor a continuation of the present study to cover other essential aspects of mineral science and technology in Canada.*

## I.4 Definition of Scientific Activities in the Solid-earth Sciences

*Solid-earth sciences* include geology, geophysics, geochemistry, physical geography, geotechnique (application of earth sciences to civil engineering), and disciplines such as soil mechanics, rock mechanics, petroleum geology, groundwater geology, pedology, etc. (see Appendix 4).

This study is not confined to research and development (R & D); it includes data collection and scientific information services as well. It covers field work as well as laboratory studies. Because industry accounts for much of these activities (see Table II.1), and the industrial R & D surveys by the Dominion Bureau of Statistics (DBS) generally exclude the R & D component of mineral exploration and industrial field surveys[1], we have modified some of the DBS definitions of scientific activities. The changes relate principally to our interpretation of scientific development (not to be confused with development of mines or oilfields), and to our recognition that *field surveys may be done for a research purpose,* that is, for the advancement of scientific knowledge. *Earth science research and development is an essential component of mineral exploration activities (see Section IV.3) and a substantial portion of it is carried out in the field (see Table II.16).* For a geoscientist the earth is his subject and the field his natural laboratory.

After studying the definitions commonly used by the Dominion Bureau of Statistics and the Organisation for Economic Co-operation and Development (OECD), and after discussion with research workers in industry, government and universities, we have divided scientific activities into the categories listed in Table I.1 and arrived at the definitions which follow. These have been used throughout the study and are illustrated by specific examples abstracted from questionnaire returns.

**Table I.1 - List of Scientific Activities**

| Type of Activity | Office and Laboratory | Field Component (Exploration) |
|---|---|---|
| A) Basic Research | X | X |
| B) Applied Research | X | X |
| C) Scientific Development | X | X |
| D) Scientific Data Interpretation | X | |
| E) Scientific Data Collection | X | X |
| F) Scientific Information | X | |

These definitions are:

*A) Basic research is undertaken to advance scientific knowledge, without a*

[1]The DBS definition on this point is somewhat ambiguous, namely: "Scientific R & D does NOT include geological and geophysical surveys, mapping, exploration and similar activities not resulting in scientific and technological advance". It is not clear whether these surveys are specifically excluded or only those which do not result in scientific or technological advance. When a survey is undertaken, how can one appraise within a few months whether or not this work will result in a scientific or technological advance? The "research" in physics or chemistry done in a laboratory may not result in scientific advance, yet it is classified as research because of the *intent* to discover new scientific principles. The same interpretation should apply to earth science activities, whether carried out in a laboratory or in the field, and whether done for mineral exploration or another purpose. The reporting of levels of earth science activity should be brought to a standard comparable to that in other fields of physical sciences.

*practical objective. Scientific curiosity and interest in nature guide the investigator. This research develops science and produces results of broad fundamental significance.*

Examples:

1. Computation of the leaking modes of elastic energy caused by a time-varying point source of energy in a layered elastic medium;
2. Study of the origin and geological history of the carbonatite complexes in Canada;
3. Interpretation of the structure of pingos in the Northwest Territories;
4. Separation of the components of the total thermodynamic potential of a soil-water mixture.

*B) Applied research is the search for new knowledge to achieve a practical objective. It aims at serving mankind by applying scientific results to a problem, process or product. The nature of its motivation distinguishes it from basic research.*

Examples:

1. Detailed geological mapping and related laboratory investigations to determine ore controls and discover new principles for mineral exploration;
2. Petrographic studies of Devonian carbonate rocks for the purpose of relating rock characteristics to sedimentary environments of petroleum accumulation;
3. Research into a new technique for filtering the spatial variations of the earth's magnetic intensity for improved geophysical exploration;
4. Study of the relations between soil properties and compaction for the design of earth dams.

*C) Scientific development is the use of scientific knowledge in the experimental production of a new device, product or process. It includes the development of scientific instrument prototypes and the conduct of full-scale field trial of these instruments.*

Examples:

1. Development of a three-component-measuring aerial electromagnetic unit, with associated flight testing;
2. Field experimentation in seismic, aeromagnetic, and gravity surveys, which are carried out before regular data gathering to establish the necessary field parameters and develop new surveys;
3. Geochemical field surveys to establish optimum sampling procedures;
4. Development of a new type of extensometer for *in situ* rock testing.

*D) Scientific data interpretation, as the name implies, is the interpretation of geological, geophysical, geochemical, and drilling data, and related computer costs, for the purpose of meeting the operational needs of industry.*

Examples:

1. Interpretation of isopach, lithofacies, and pressure gradient maps and cross-sections, as an aid to petroleum exploration;
2. Interpretation of a geophysical survey to locate exploratory diamond drill holes;
3. Computer processing of large volumes of earth science data to define the geometry and other physical characteristics of subsurface features which may contain economic mineral deposits.

Where new techniques and models are developed, this activity becomes research. The actual compilation of data, on the other hand, falls under scientific data collection.

*It should be stressed that in this study geoscientific data interpretation has been included under "scientific development".* The essential reasons for this departure from the procedures normally followed by DBS are:

a) The interpretation of geological, geophysical and geochemical surveys relating to mineral exploration is a sophisticated scientific activity involving semi- or non-standard procedures. In general it requires considerable experience and scientific knowledge. In contrast with topographic and bathymetric surveys, the geoscientific surveys deal with natural variables that present numerous discontinuities and involve changes caused by numerous very complex factors. Furthermore, these variables are imperfectly known and are hard to measure accurately. As the discussion in Section IV.3 points out, no two mineral deposits or oil fields are exactly alike. Consequently, in attempting to unravel the hidden features of the earth's crust and reconstitute their historical development, the interpretation of these surveys requires the best scientific knowledge available in order that the probability of occurrence of economic deposits may be appraised as exactly as possible.

b) The interpretation of these surveys constitutes the central activity of mineral exploration companies. Of the $32 million spent by mining and petroleum companies on "scientific development" in 1968, we estimate that $30 million was spent on scientific data interpretation (Table II.2), compared to $7 million on basic and applied research (Table II.2) and $343 million on scientific data collection (Table II.3). With data interpretation included under development, the total earth science research and development of mining and petroleum companies in Canada in 1968 amounted to 10 per cent of their total earth science expenditures. This percentage appears to be a realistic estimate, for the mineral exploration industry is very much dependent on earth science R & D for its progress.

c) Finally, scientific data interpretation leads directly to innovation in the mineral industry, that is, to the discovery of economic deposits via the exploitation of scientific knowledge.

*E) Scientific data collection includes the systematic gathering of topographic, hydrographic, geological, geophysical and geochemical observations, as well as the cost of exploratory drilling and routine laboratory determinations. The collection of data, particularly field data, is vital because its interpretation is the essence of science.*

Examples:

1. Exploratory diamond drilling for discovering and outlining ore-bearing structures;
2. Airborne and ground geophysical surveys to guide mineral exploration;
3. Routine computer processing of earth science data, e.g. seismic data;
4. Routine porosity and permeability tests on soil and rocks.

*F) Scientific information includes all the activities related to the dissemination of solid-earth scientific and technological information, such as the costs of publications, drafting, earth science libraries, displays, purchase of computer programs and well logs, and attendance at scientific meetings.*

This question of definitions of scientific activities is not merely a matter of semantics. "Scientific services", such as geological mapping, geophysical surveying, land use mapping, etc., assume singular importance in natural resource development, as widely acknowledged by the geoscientific community and recognized by the Science Council of Canada.[1] If the wording of some definitions is such that important segments of industrial activity are omitted from the national research and development accounts, the contributions by government and universities appear as unduly inflated and the national R & D picture becomes unrealistic. It is felt that the definitions of R & D should include the field activities which are performed for the purpose of advancing scientific knowledge and discovering new scientific principles, including the principles guiding mineral exploration.

There is a widespread feeling in the Canadian geoscientific community that

[1]"Scientific services" include scientific surveys and data collection, scientific and technical libraries and information services, museums, etc. "Because of Canada's great size, the peculiarities of her geography, and the importance of natural resource development to her economy, these scientific services are more important to Canada than they are to many other nations. The usual definitions of research and development exclude these activities...It would be unwise of Canada to continue this practice and to ignore the importance of these services." Towards a national science policy for Canada, Science Council of Canada, Report No. 4, Ottawa, Queen's Printer, October 1968, pp. 7-8.

the present exclusion of earth science field research is unjustified both in principle and on practical grounds. In our considered opinion, it should not matter whether the R & D is carried out in the field or in the laboratory.

In view of these arguments, and in the light of the findings contained in this report, we submit:

---

*Conclusion I.1*

*The Dominion Bureau of Statistics should clarify its definitions of scientific activities to confirm that the earth science activities performed in the field to advance scientific knowledge and discover new applications of scientific principles are to be categorized as research. Consideration should also be given to including under research and development the interpretation of geoscientific surveys serving the operational needs of the mineral exploration industry.*

---

## I.5 Organization of the Study

This study was initiated in September 1968 after acceptance by the Science Council on June 25, 1968, of a detailed proposal and outline prepared by Professor Blais. He, as Chairman of the Study Group, and C. H. Smith, as Project Officer, were granted 16-month leaves of absence by their employers to devote their full time to this undertaking. The remaining members of the Study Group, who are listed in Appendix 2, participated on a part-time basis in the conduct of the study and the preparation of this report.

In the summer of 1968 the Science Council appointed an Earth Science Committee, with W. H. Gauvin as Chairman, to receive and review the Study Group's report and recommend it for publication. This Committee prepared a separate report[1] containing the Science Council's recommendations for action. Further Council recommendations on the funding of earth science activities will appear in a forthcoming series of overviews related to the primary industries.

**Study Group Meetings**

A total of 16 days was spent on six formal meetings held between September 1968 and November 1969. The complete report was discussed by the Science Council at its meeting on January 15, 1970, and the Study Group held its final meeting on January 29, 1970.

**Meetings of the Science Council Committee on Earth Sciences**

Between September 1968 and May 1969 this committee met three times to hear and discuss progress reports from the Study Group's Chairman and Project Officer. In addition, the committee met four times between November 1969 and January 1970 to prepare its final report to the Science Council.

**Meetings across Canada**

Between October 1968 and April 1969 the Study Group made a survey during which some of its members travelled 19 000 miles across Canada and conducted 128 formal meetings: 53 in 35 universities, 44 with representatives of 46 government agencies, 14 with people from industry, and 17 other meetings, including discussions with representatives of the Treasury Board, the Department of Finance, and the Canadian International Development Agency.

These meetings were attended by 1 509 persons: 364 faculty, 417 undergraduate and graduate university students, 482 government earth scientists, 109 industry personnel, and 137 others.

On the average, each of these 128 meetings was attended by four members of the Study Group. All members of the Advisory Committee attended one or more meetings with at least one of the above groups, thus gaining a better insight on the study and a better appreciation of the feelings of the Canadian geoscientific community. In addition, members of the Advisory Committee were sent copies of all compilations,

[1] Science Council of Canada. Earth sciences serving the nation-recommendations. Report No. 7. Ottawa, Queen's Printer, 1970.

background papers, briefs, etc., and were kept informed of progress at all times.

These meetings have been most beneficial in motivating widespread interest in the study and obtaining important opinions from scientists and engineers in various sectors of activity. Our initiative of meeting with students in geology, geophysics and physical geography in many Canadian universities has also been most profitable.

**Questionnaires**

Questionnaires are the *bête noire* of an inventory study. However, since we knew of no other way to obtain quickly, and from reliable sources, the quantitative and qualitative information indispensable to reaching the aims of the study (see Section I.2), we designed four distinct questionnaires–for the mineral industry (and with minor modifications for geoscience consultants), geotechnical firms, university departments and government agencies. Parallel questions were included in the four questionnaires, with some modifications to suit each sector. Copies of these questionnaires are on file at the Science Council of Canada.

The questionnaire returns from industry and geoscience consultants were coded and compiled in such a manner that no members of the Study Group, except the project officer and his executive assistant, could actually identify the responding companies or individuals. Answers to specific questions were compiled in voluminous data books, providing an important basis for much of this report. These data books, with coded answers, are included in the Earth Science Open File and may be consulted on request to the Science Council of Canada. Table I.2 presents the status of our questionnaire survey.

**Special Background Papers**

Largely through the National Advisory Committee for Research in Geological Sciences, the Associate Committee on Geodesy and Geophysics, the Associate Committee on Quaternary Research, the Associate Committee on Geotechnical Research, and the Geotechnical Division of the Engineering Institute of Canada, and also from a number of devoted scientists from universities, government and industry, we were most fortunate to obtain 40 special background papers covering a wide range of earth science disciplines (see Appendix 4). Most of these papers were written and submitted before the end of 1968. Each was circulated for critical review to some 50 to 110 specialists.

To better appraise the fundamental problems underlying the geology of Canada and to define major goals accordingly, a total of 13 regional and special background papers was also prepared.

In all, these special background papers were sent to a total of 2 560 reviewers besides the members of the Study Group and the Science Council's Committee, who also reviewed them. An effort was made to obtain a well-balanced cross-section of opinions, and an average of 22 reviews per paper was received. It is significant that some were highly critical and most provided valuable advice and supplementary information. To encourage the free expression of opinions, the papers were sent anonymously.

These papers have been published separately by the Geological Survey of Canada under the sponsorship of the National Advisory Committee for Research in Geological Sciences[1], and by the Canadian Institute of Mining and Metallurgy.[2] These two collections of papers provide a valuable contribution to solid-earth sciences in Canada, and the Study Group has used some of them extensively and adapted several of their recommendations in this report.

**Briefs**

In response to invitations sent in October 1968 to Canadian geoscientific so-

[1]Smith, C.H., ed. Background papers on earth sciences in Canada. Geological Survey of Canada, Special Paper 69-56. 1970.

[2]Geological provinces of Canada - Exploration and outlook. CIM Bull. 63 (693): 23-49 and 63 (694): 185-213. 1970.

**Table I.2–Summary of Questionnaire Returns**

| Responding Organizations | Total Mailing | Complete Returns | % Coverage |
|---|---|---|---|
| Mining Companies | 175 | 86 | 70[a] |
| Oil and Gas Companies | 100 | 43 | 70[a] |
| Geoscience Consultants | 310 | 48 | 40[b] |
| Geotechnical Groups | 93 | 37 | 70[b] |
| Federal Agencies | 28 | 28 | 100 |
| Provincial Agencies | 14 | 14 | 100 |
| Provincial Research Councils | 7 | 7 | 100 |
| University Departments: | 78 | 64 | 82 |
| Geology | 31 | 31 | 100 |
| Geophysics (physics)[c] | 7 | 7 | 100 |
| Soil Science | 4[e] | 2 | [f] |
| Geography[d] | 27 | 17 | 70 |
| Civil & Mining Eng. | 9[e] | 7 | [f] |
| **Total** | **805** | **327** | **64** |

[a] Estimate based on percentage of complete returns and blank returns and other available statistics, including the reported value of mineral production ($2.7 billion in 1968) of the responding mining and petroleum companies.
[b] Estimate based on the in-house earth science activities of these firms.
[c] Includes the geophysics divisions of Physics Departments.
[d] Physical geography only.
[e] Incomplete mailings.
[f] Not estimated.

cieties and other groups, we received 27 briefs (see Appendix 3). These briefs[1] have helped us to appreciate the contribution of earth sciences to the nation.

## I.6 Organization of this Report

As seen in the "Table of Contents", this report is basically structured in relation to major national goals. Rather than discussing the solid-earth sciences along disciplinary lines, we have attempted to show how these sciences are serving the nation. Using a general approach, we have indicated how national goals such as economic growth, education and personal development could be better served in the future.

Four major considerations justify this type of treatment: a) documented discussions of individual earth-science disciplines can be found in the background papers referred to above; b) our study relates directly to national needs; c) this type of treatment lends itself to national science policy formulation; d) a discussion of national goals will probably stand the test of time better than a discussion of individual scientific disciplines.

In keeping with this format, we have introduced a number of repetitions and profuse cross-indexing in the various chapters to improve their readibility.

Finally, in addition to the "Highlights" at the beginning of the report, the subject matter is summarized at the beginning of each chapter.

[1]Readers who have special interest in any of these briefs may consult them at the Science Council of Canada or contact the authors directly.

# Chapter II

# General Patterns

"...institutions are constantly tending to gravitate. Like clocks, they must be occasionally cleansed, and wound up, and set to true time."

Henry Ward Beecher in "Life Thoughts"

## II.1 Synopsis

The earth sciences[1] affect our national life far beyond the frequently expressed but limited view of their relation to the mineral industry. This report by its very structure indicates the relation of the earth sciences to the primary resource industries (mining and petroleum, agriculture, etc.), to construction and land planning and, of equal importance, to the scientific, cultural and leisure activities of Canadians. Our survey presents for the first time some indication of the total magnitude of earth science activities over this broad spectrum of our national life.

Chapter I outlined the nature and scope of our survey and warned the reader that our use of the term "research and development" (R & D) differs somewhat from the practice followed in reporting R & D expenditures to the Dominion Bureau of Statistics (DBS). For those who wish to compare our data with the results of other surveys in which field activities are excluded from R & D, this report separates industry data, where possible, into laboratory and field components. As mentioned in Chapter I, this survey encompasses the full range of scientific activities and is not confined to R & D alone. In this regard it differs from previous Science Council studies and current surveys of industry by the Dominion Bureau of Statistics. Scientific data collection is an important and costly activity which cannot be ignored in earth science policy and management. The casual reader must take note that the large earth science data collection expenditures (especially by industry) reported herein should not be compared directly with the R & D expenditures reported in other surveys.

This chapter presents data on the present and proposed levels of earth science expenditure and manpower utilization by the industry, government and university sectors in Canada, as well as information on the organization, or other means of co-ordination, of their activities. The chapter thus forms a basis for the discussion in succeeding chapters of future goals and levels of activity.

## II.2 The National Level of Activity

**Expenditures on Earth Science Activities**
The national expenditure on these activities during 1968 was $468 million (Table II.1), of which 87 per cent represents expenditures by the petroleum, mining and construction industries.[2] The petroleum industry was by far the largest spender, accounting for 64 per cent of the total, and eight petroleum companies alone accounted for 28 per cent.

The national expenditure on earth science *research and development* was $66 million (14 per cent of the total, see Table II.2). Universities, provincial research councils, and geoscience consultants allocated over half of their earth science budgets to R & D, while contractors and consultants in the construction industry allocated less than 3 per cent. Nevertheless, the petroleum industry was by far the largest spender on R & D (50% of national R & D expenditures), due largely to the costs of interpretation of subsurface geological and geophysical data which in this report are included under "development".

The necessity of conducting numerous and costly exploration surveys makes *data collection* (Table II.3) important in earth science. Because of Canada's size

[1]For the sake of simplicity and brevity, the term "earth sciences" will be used throughout this report as synonymous with "solid-earth sciences".

[2]If expenditures related specifically to construction, agriculture, external aid, etc. are excluded, the earth science expenditures specifically related to the mineral industry reach about 9 per cent of the total value of mineral production in 1968.

**Table II.1–Total Expenditures on Solid-Earth Science Activities in Canada by Sector of Performance, 1968**

| Sector of Performance | Total Expenditures on R & D, Scientific Data Collection, and Scientific Information | |
|---|---|---|
| | $ '000 | % of Subtotal |
| *Industry* | | |
| Petroleum | 299 364[a] | 73 |
| Mining | 87 836 | 22 |
| Consulting firms | 4 443 | 1 |
| Construction | 717 | 0 |
| Consulting firms | 17 237 | 4 |
| **Subtotal** | **409 597** | **100** |
| **% of Total** | **(87%)** | |
| *Government* | | |
| Federal | 34 440 | 67 |
| Provincial | 15 389 | 30 |
| Research Councils | 1 769 | 3 |
| **Subtotal** | **51 598** | **100** |
| **% of Total** | **(11%)** | |
| *University* | 7 116 | |
| **% of Total** | **(2%)** | |
| **Total** | **468 311 (100%)** | |

[a] The last three figures are probably not significant. However, this mode of reporting has been adopted throughout the report because of the detailed accounting of the expenditures reported in numerous categories and from many sources. In the text the figures are rounded off.

**Table II.2–Total Expenditures on Solid-Earth Science R & D[a] by Sector of Performance, 1968**

| Sector of Performance | Expenditures on R & D | | | | | | | | R & D as a Function of Total Earth Science Expenditure in each Sector |
|---|---|---|---|---|---|---|---|---|---|
| | Total | | Basic Research | | Applied Research | | Development[a] | | |
| | $'000 | % | $'000 | % | $'000 | % | $'000 | % | % |
| *Industry* | | | | | | | | | |
| Petroleum | 32 165 | 77 | 1 801 | 91 | 3 794 | 59 | 26 570 | 79 | 11 |
| Mining | 7 091 | 17 | 131 | 7 | 1 692 | 26 | 5 268 | 16 | 8 |
| Consulting firms | 2 281 | 5 | 47 | 2 | 540 | 9 | 1 694 | 5 | 51 |
| Construction | – | – | – | – | – | – | – | – | <1 |
| Consulting firms | 459 | 1 | – | – | 400 | 6 | 59 | <0.2 | 3 |
| **Subtotal** | **41 996** | **100** | **1 979** | **100** | **6 426** | **100** | **33 591** | **100** | |
| **% of Subtotal** | **(100%)** | | **(5%)** | | **(15%)** | | **(80%)** | | |
| *Government*[b] | | | | | | | | | |
| Federal | 13 388 | 77 | 3 782 | 89 | 7 317 | 67 | 2 289 | 100 | 39 |
| Provincial | 2 924 | 17 | 134 | 3 | 2 773 | 26 | 17 | <0.1 | 19 |
| Research Councils (Provincial) | 1 156 | 6 | 352 | 8 | 790 | 7 | 14 | <0.1 | 65 |
| **Subtotal** | **17 468** | **100** | **4 268** | **100** | **10 880** | **100** | **2 320** | **100** | |
| **% of Subtotal** | **(100%)** | | **(25%)** | | **(62%)** | | **(13%)** | | |
| *University*[c] | 6 616 | – | 4 565 | – | 1 720 | – | 331 | – | 93 |
| **% of Subtotal** | **(100%)** | | **(69%)** | | **(26%)** | | **(5%)** | | |
| **Total** | **66 080** | **100** | **10 812** | **100** | **19 026** | **100** | **36 242** | **100** | **14** |
| **% of Total** | **(100%)** | | **(16%)** | | **(29%)** | | **(55%)** | | |

[a] See Chapter I for definitions and examples of R & D. For the purposes of this study, the *interpretation* of earth science data and related computer costs is included under *development* although it may be carried out for the purpose of meeting the operational needs of mineral and petroleum exploration.

[b] The earth science activities of government agencies relate to all classes of the industry sector distinguished above, as well as to defence, external aid, etc. Hence it is not valid to equate the level of government expenditures reported in this table with a specific industry.

[c] Based on reported operational costs of earth science departments corrected according to reported percentage (about 50%) of time spent on teaching.

**Table II.3–Total Expenditures on Solid-Earth Science Data Collection[a] by Sector of Performance, 1968**

| Sector of Performance | Expenditures on Scientific Data Collection | | % of Total Earth Science Expenditures |
|---|---|---|---|
| | $'000 | % of Subtotal | % |
| *Industry*[b] | | | |
| Petroleum | 263 266[c] | 73 | 88 |
| Mining | 79 952[d] | 22 | 91 |
| Consulting firms | 1 885 | <0.5 | 43 |
| Construction | 697 | <0.5 | 97 |
| Consulting firms | 16 538 | 5 | 96 |
| **Subtotal** | **362 338** | **100** | |
| **% of Total** | **(93%)** | | |
| *Government* | | | |
| Federal | 15 438 | 58 | 45 |
| Provincial | 10 785 | 40 | 72 |
| Research Councils | 522 | 2 | 30 |
| **Subtotal** | **26 745** | **100** | |
| **% of Total** | **(7%)** | | |
| *University* | – | – | – |
| **Total** | **389 083** | – | **83** |

[a] Data collection includes the systematic and continuous collection of topographic, hydrographic, geological, geophysical and geochemical observations, as well as the cost of exploratory drilling and routine laboratory determinations. Data collection related directly to a research or development project is accounted for separately.
[b] Expenditures relate only to scientific data collection in Canada and adjacent continental shelf areas.
[c] Including $140 million for exploratory drilling.
[d] Including $33 million for exploratory drilling.

**Table II.4–Total Expenditures on Solid-Earth Science Information[a] by Sector of Performance, 1968**

| Sector of Performance | Expenditure | | % of Total Earth Science Expenditures |
|---|---|---|---|
| | $'000 | % of Subtotal | % |
| *Industry* | | | |
| Petroleum | 3 933 | 75 | 1 |
| Mining | 793 | 15 | 1 |
| Consulting firms | 277 | 6 | 6 |
| Construction | 20[b] | <0.5 | 3 |
| Consulting firms | 240[b] | 4 | 1 |
| **Subtotal** | **5 263** | **100** | |
| **% of Total** | **(40%)** | | |
| *Government* | | | |
| Federal | 5 614 | 79 | 19 |
| Provincial | 1 680 | 20 | 10 |
| Research Councils | 91[b] | 1 | 5 |
| **Subtotal** | **7 385** | **100** | |
| **% of Total** | **(56%)** | | |
| *University* | 500[b] | – | 7 |
| **% of Total** | **(4%)** | | |
| **Total** | **13 148 (100%)** | – | **3** |

[a] Scientific information includes activities related to the dissemination of scientific and technological information in the earth sciences, such as the costs of publications, drafting, purchase of computer programs, libraries, displays, attendance at scientific meetings.
[b] Estimated.

and many remote areas, extensive use of aircraft, ships and (potentially) satellites is required to collect data for mineral exploration, national physical development, and research. Subsurface exploration by drilling requires large expenditures (about 44% of the data collection costs). Industry allocates nearly 90 per cent of its earth science budget to scientific data collection which, in 1968, amounted to an expenditure of $389 million (83% of the total national expenditure on earth science activities).

Earth science *information* expenditures (Table II.4) were $13 million in 1968 (3% of the total). Government agencies allocated a larger proportion of their budgets (10 to 19%) to this purpose than did industry and universities, principally because of their role in generating maps and related forms of public information.

Figure II.1 illustrates the regional distribution of earth science expenditures in Canada during 1968. Not all expenditures could be subdivided satisfactorily on a regional basis. For instance, the geotechnical expenditures related to construction, soil science expenditures, and certain federal expenditures related to the Agricultural Rehabilitation and Development Act (ARDA) and other regional programs are not included. Nevertheless, the map is fairly indicative of the relative distribution of expenditures both between and within provinces or regions.

The largest total provincial expenditure was in Alberta ($178 million in 1968). Of the provincial totals, mining exploration represents the largest item in New Brunswick, Quebec, Ontario and Manitoba. Petroleum exploration is the largest item in Saskatchewan, Alberta and the North. In Nova Scotia, most expenditures are in university earth science departments. In many instances, university expenditures on earth sciences (research and training) within provinces are equal to or greater than the earth science expenditures of the local department of mines. In Ontario and Quebec, the departments of mines spend less on earth science activities than their counterparts in the geotechnical field.

## Manpower

*Size of Earth Scientist Population*

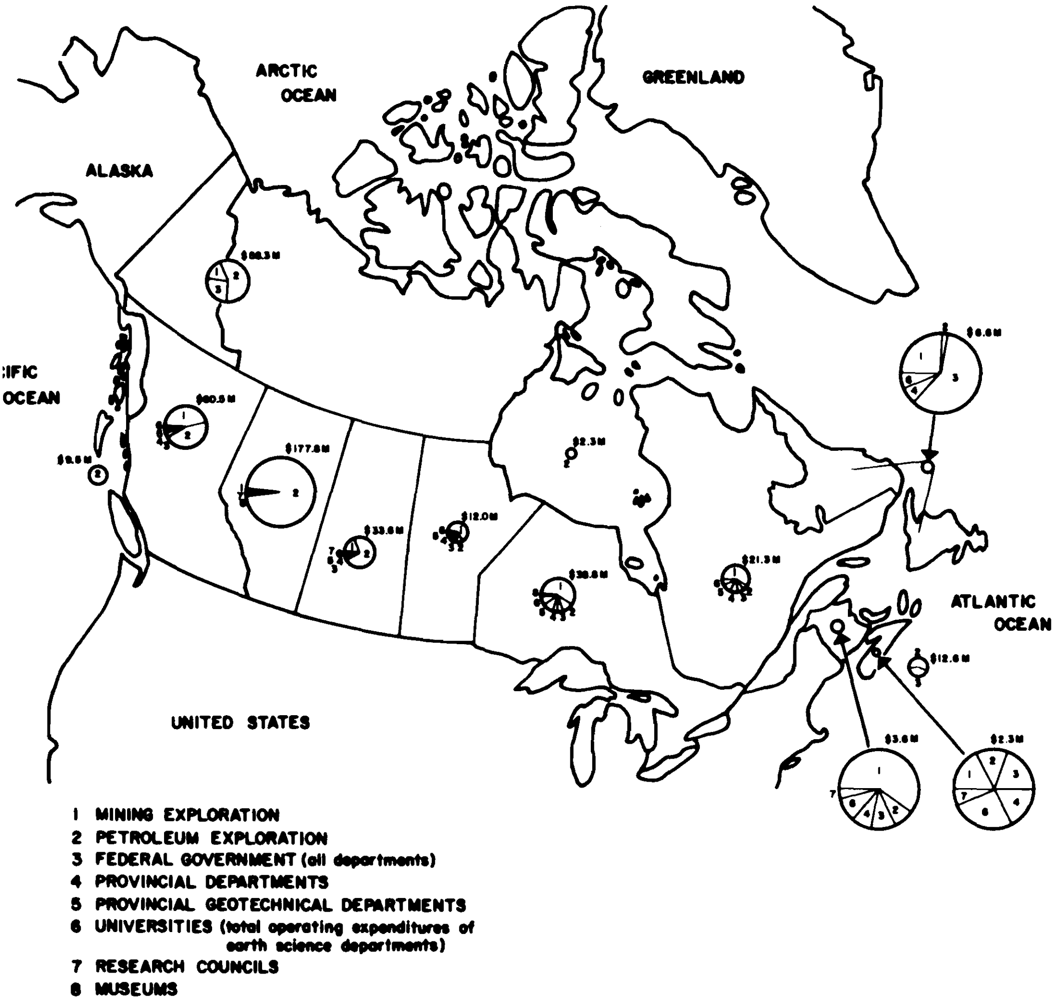
Approximately 6 000 professionals are engaged in earth science activities in Canada (Table II.5), with 72 per cent employed in industry, 11 per cent in the federal government, 10 per cent in the universities, 5 per cent in provincial government departments, 1 per cent in the research councils, and 1 per cent elsewhere. The Canadian earth scientist population is approximately equal to the number of earth scientists employed in federal agencies in the United States (5 636 in 1967[1]).

Fifty-eight per cent of Canadian earth scientists are geologists, 18 per cent are engineers, 14 per cent are geophysicists, and 10 per cent were trained in other physical sciences. This national distribution closely approximates that in the industry sector alone. Provincial agencies differ from the national pattern in having more geologists (Figure II.2). There are only three geophysicists in all of the provincial departments of mines.

In academic training, 21 per cent of Canadian earth scientists have a doctorate (the United States reported approximately the same percentage in 1966), and 41 per cent have a master's or higher degree. As might be expected, universities employ a higher proportion of those with doctorates, industry more with bachelor's degrees (Figure II.3). Because of a lack of detailed information on the number of earth scientists engaged in industrial research, certain assumptions have been made to arrive at an estimate of 935 scientists and engineers (full-time equivalent) engaged in earth science research in Canada (Table II.7). This number represents 16 per cent of the total earth science professional group. The equivalent proportion for the entire Canadian scientific and engineering work force in 1965 was

[1]Solid-earth science. A report of an *ad hoc* Working Group to the U.S. Federal Council of Science and Technology. July 1967.

Figure II.1–Expenditures on Solid-Earth Science Activities by Province or Region, 1968 (Diameters of circles are relative to the magnitude of total expenditures)



Figures II.2–Distribution of Earth Science Professional Manpower by Disciplines, 1968

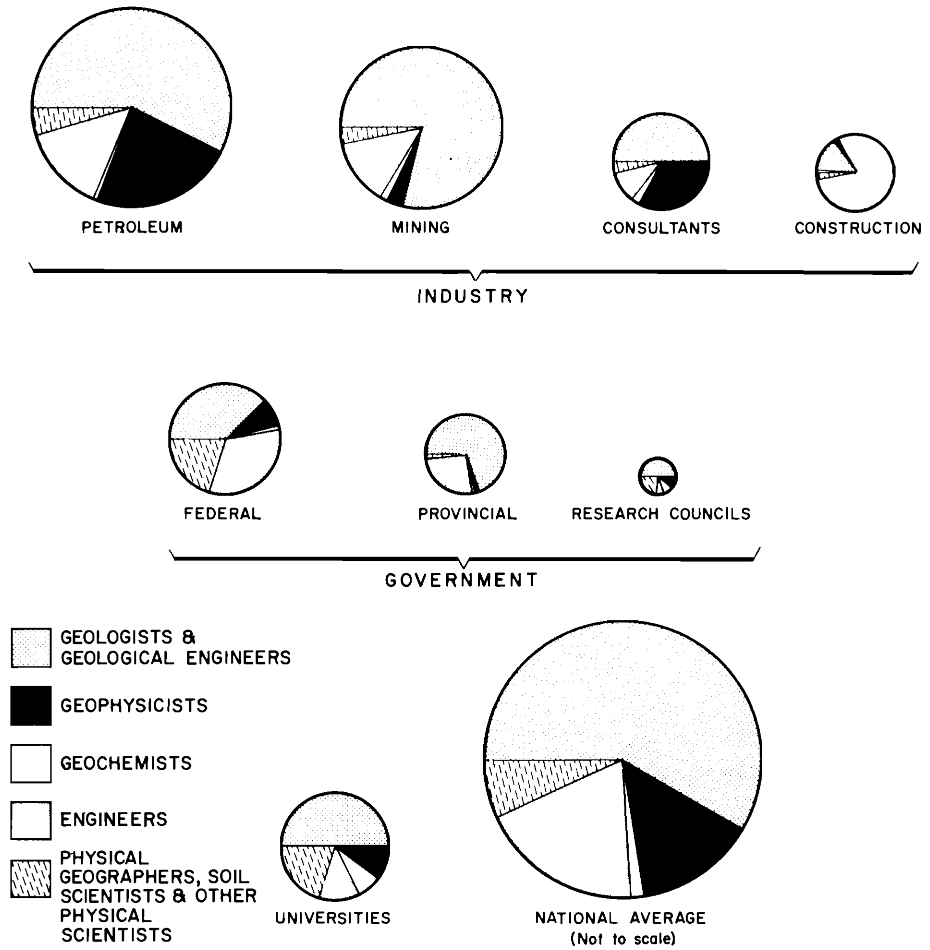


Figure II.3–Distribution of Earth Science Professional Manpower by Highest University Degree, 1968

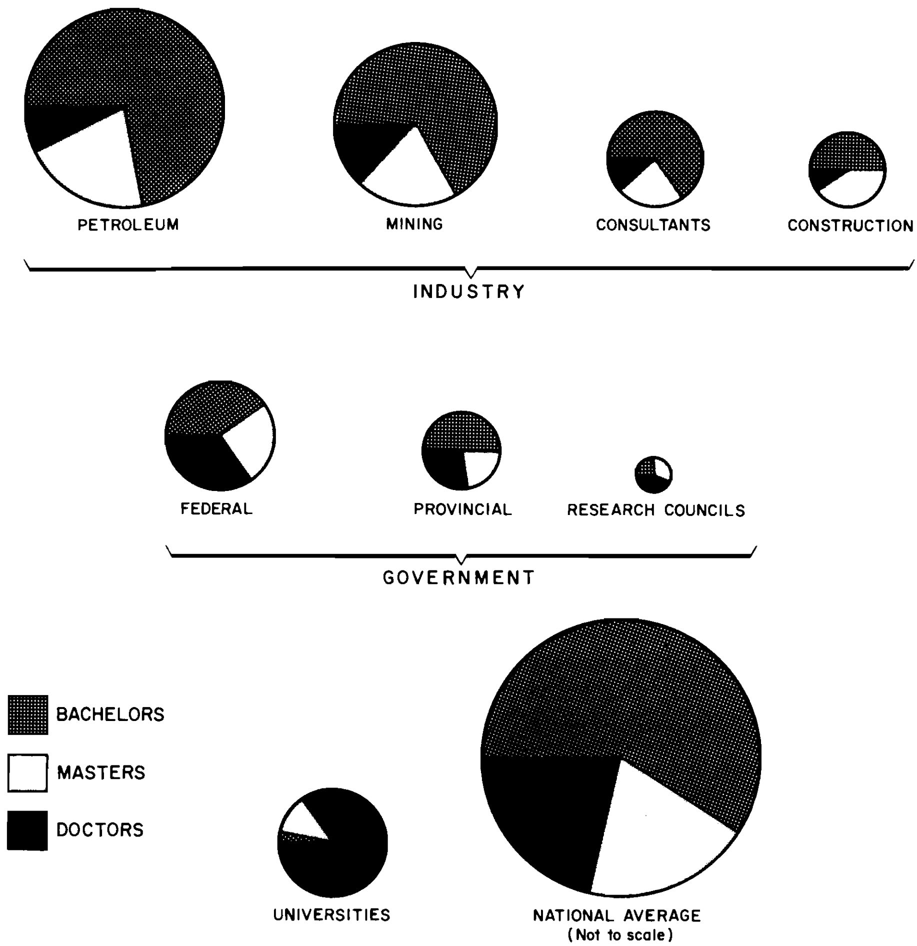


**Table II.5–Solid-Earth Science Professional Staff[a] by Sector and Principal Discipline, 1968**

| Sector | Total: Number | Total: % | Discipline: Geology | Geophysics | Geochemistry | Physical Geography | Soil Science | Engineering | Other Physical Sciences |
|---|---|---|---|---|---|---|---|---|---|
| *Industry* | | | | | | | | | |
| Petroleum[b] | 2 111 | 50 | 1 243 | 491 | 5 | – | – | 296 | 76 |
| Mining[b] | 1 401 | 33 | 1 091 | 52 | 16 | – | – | 191 | 51 |
| Consulting firms[c] | 457 | 11 | 231 | 152 | 11 | – | – | 47 | 16 |
| Construction[d] | 250 | 6 | 34 | 2 | – | 5 | – | 209 | – |
| **Subtotal** | **4 219** | **100** | **2 599** | **697** | **32** | **5** | **–** | **743** | **143** |
| *Government* | | | | | | | | | |
| Federal | 666 | 65 | 251 | 52 | 9 | 30 | 38 | 205 | 81 |
| Provincial[e] | 303 | 29 | 209 | 3 | 1 | 1 | 1 | 84 | 4 |
| Research Councils | 63 | 6 | 33 | 6 | 5 | 1 | 7 | 4 | 7 |
| **Subtotal** | **1 032** | **100** | **493** | **61** | **15** | **32** | **46** | **293** | **92** |
| *University*[f] | 593 | – | 297 | 64 | 40 | 97 | 25[g] | 70 | – |
| **Total** | **5 844** | **–** | **3 389** | **822** | **87** | **134** | **71**[h] | **1 106** | **235** |

[a] Professionals engaged in earth science activities but trained in the disciplines indicated.
[b] Reported values are inflated by a factor of 1.428, based on our estimate of 70% response to industry questionnaire.
[c] Reported values are inflated by a factor of 2.5, based on an estimate of 40% response to the consultant questionnaire.
[d] Relates primarily to the design professions of the construction industry.
[e] Includes departments of mines, departments of highways, and power corporations.
[f] Includes research associates and postdoctorate fellows.
[g] Estimated.
[h] Does not include provincial departments of agriculture and forestry.

**Table II.6–Solid-Earth Science Professional Staff by Sector and Highest Degree, 1968**

| Sector | | Academic Level: Bachelors | Masters | Doctors | Total |
|---|---|---|---|---|---|
| *Industry* | | | | | |
| Petroleum | | 1 556 | 425 | 130 | 2 111 |
| Mining | | 937 | 286 | 178 | 1 401 |
| Consultants | | 297 | 105 | 55 | 457 |
| Construction | | 125 | 100 | 25 | 250 |
| **Subtotal** | | **2 915** | **916** | **388** | **4 219** |
| *Government* | | | | | |
| Federal | | 273 | 157 | 236 | 666 |
| Provincial | | 150 | 64 | 89 | 303 |
| Research Councils | | 16 | 19 | 28 | 63 |
| **Subtotal** | | **439** | **240** | **353** | **1 032** |
| *Universities* | | 23 | 70 | 500 | 593 |
| **Total** | **Number** | **3 377** | **1 226** | **1 241** | **5 844** |
| | **%** | **(59%)** | **(20%)**[a] | **(21%)**[a] | **(100%)** |

[a] In contrast, the proportion of professional personnel engaged in R & D in all Canadian industries, and trained at the Master level or above, was 24.2 per cent in 1965 (J. L. Orr, *Statistical Data on Industrial R & D in Canada*, Department of Industry, Ottawa, March 17, 1967). The 41 per cent reported above refers to earth science personnel engaged in *all* scientific activities, not only R & D, and indicates the need for higher training even for personnel engaged in earth science data collection.

14.3 per cent.[1] On the basis of 1965 statistics, as reported by the Science Council, we estimate that the professional manpower in Canada devoted to earth science research and development is approximately 5 per cent of the total national manpower engaged in R & D. It is estimated (Table II.7) that over 50 per cent of Canadian scientists engaged in earth science R & D are in the fields of economic geology and applied geophysics.

*Sources of Earth Science Manpower*

Before 1967, Canadian universities were the principal source of Canadian professional earth science manpower. At present, however, the largest input is through immigration (Table II.8). The number of geologists immigrating to Canada rose from 58 to 336 between 1962 and 1968. In 1968 there were 146 from European countries (52 from Great Britain) and 98 from the United States. One hundred and twenty-nine immigrant geologists indicated Alberta as their destination and the next largest group (91) moved to Ontario. A similar picture exists in the mining engineer category, where 174 entered Canada in 1968 as landed immigrants, 92 of whom came from Europe (55 from Great Britain) and 42 from the United States.

Canadian universities graduated a combined total of 503 students in the fields of geology, geophysics, physical geography and mining engineering during 1968 (Table II.38). Of these, we estimate that 315 entered the labour force. The output of geologists and mining engineers was considerably less than the number of immigrants in these fields (Table II.8). *We estimate that in 1968 Canadian universities provided only 35 per cent of the geologists and 27 per cent of the mining engineers required by industry, government and universities.*

To obtain a complete picture of changes in the population of earth scientists in Canada, information on deaths and retirements, emigration from Canada, and number of Canadians trained in other countries would be required. This information is generally lacking. The U.S. Institute of International Education reported that in 1967-68 there were 206 Canadians studying earth sciences in the United States at all levels (102 in all aspects of geography, 85 in geology and the rest in geophysics, geochemistry and related earth sciences). It is thus estimated that about 20 Canadians graduate in geology in the United States each year.

*Growth Areas in Earth Science Manpower*

Projections of manpower supply and demand are frequently inaccurate in substance and misleading in application. This is particularly true in the earth sciences where: a) professionals trained in allied disciplines, e.g. physics, chemistry and mathematics, may readily enter the earth science labour force; b) scientists may equally leave the labour force for employment in unrelated managerial or educational posts; c) scientists may practise their profession in a variety of missions related to the mining, petroleum, construction, governmental and academic fields. Similarly, in defining the appropriate level of teaching in the earth sciences, it would be quite improper to consider enrolments solely in relation to the needs of an immediate employer, without having regard to the equally important advantages of cultural courses on the environment in which we all live.

During the period 1964-68, the principal growth in earth science employment took place in the mineral industry and among university staffs. The average annual increase of earth scientists in the mineral industry was 226 (not including replacements owing to retirement, etc.). In the construction industry there was an annual increase of 80 during the same period. *The annual increase in the university sector was 30, which was about equal to the total Canadian Ph.D. output in the earth sciences.* In the federal government, the Department of Energy, Mines and

[1]Jackson, R.W., D.W. Henderson, and B. Leung. Background studies in science policy. Science Council of Canada, Special Study No. 6. Ottawa, Queen's Printer, 1969. p. 47.

**Table II.7–An Estimate of the Professional Man-Years Spent on Solid-Earth Science Research, Related to Sector, 1968**

| Sector | No. of Professionals Engaged in Earth Science Research | Full-Time Equivalent (Man-years) |
|---|---|---|
| *Industry* | | |
| Petroleum | 211[a] | 211 |
| Mining | 140[a] | 140 |
| Consultants | 46[a] | 46 |
| Construction | 23 | 23[b] |
| **Subtotal** | **420** | **420** |
| *Government* | | |
| Federal | 600 | 240[c] |
| Provincial | 270 | 108[d] |
| Research Councils | 60 | 40[e] |
| Museums | 13 | 7 |
| **Subtotal** | **943** | **395** |
| *University*[f] | 300 | 120[g] |
| **Total** | **1 663** | **935** |

[a] Industrial R & D manpower estimated to be 10% of earth science professionals in industry, on the basis of the proportion of R & D funding to total scientific activities (10%) and the proportion of Ph.D.s to total professionals in the mineral industry (9.2%).
[b] This is the actual number reported, not an inflated figure, and relates primarily to the design professions.
[c] Estimated on the basis of 10% of total staff (663) being engaged in administrative duties, and 40% of remainder engaged in R & D (as opposed to other scientific activities).
[d] Estimated as for federal government.
[e] Estimated that two-thirds of professional man-years are involved in R & D. Ratio of R & D expenditures to total expenditures is 65%.
[f] Estimated on the basis of 300 graduate faculty spending a reported 40% of their time on R & D activities.
[g] The Bonneau report (p. 45) of the National Research Council (1969) gives an equivalent estimate of 165 man-years for all earth science departments (including meteorology and oceanography).

**Table II.8–Source of Canadian Geologists and Mining Engineer Manpower, 1968**

| Source | Number | | | |
|---|---|---|---|---|
| | Geologists | | Mining Engineers | |
| 1. Immigration[a] | | 336 | | 174 |
| 2. Canadian universities[b] | | | | |
| Bachelor's level | 121 | | 42 | |
| Master's level | 36 | | 20 | |
| Ph.D. level | 36 | 193 | 3 | 65 |
| 3. U.S. universities (Canadian citizens)[c] | | 20 | | – |
| 4. Other foreign universities (Canadian citizens)[d] | | 10 | | – |
| **Total possible additions to labour force**[e] | | **559** | | **239** |

[a] Immigration statistics published by Department of Manpower and Immigration.
[b] Our survey indicated that over the period 1966-68, 45% of the bachelor graduates, 40% of the master graduates, and 5% of the doctoral graduates continued their education. The total number of graduates during 1968 has been deflated accordingly to arrive at the number entering the labour force. However, no correction has been made for the non-Canadian content of the graduating class, which may lower the M.Sc. and Ph.D. totals by as much as 40%.
[c] Estimated. The U.S. Institute of International Education reported that 85 Canadians were studying geology in the United States, at all levels, in 1967-68.
[d] Estimated.
[e] No reduction is made for the emigration of geologists and mining engineers from Canada.

**Table II.9–Anticipated Annual Requirements of Solid-Earth Science Professionals, 1968-1972**

| Sector | Annual Increase (Professionals) | | |
|---|---|---|---|
| | In Establishment | Replacements[a] | Total |
| *Industry* | | | |
| Petroleum and Mining | 226[b] | 105 | 331 |
| Consultants | 20 | 14 | 34 |
| Construction, inc. Consultants | 20 | 8 | 28 |
| **Subtotal** | **266** | **127** | **393** |
| *Government* | | | |
| Federal | 20 | 20 | 40 |
| Provincial | 20 | 9 | 29 |
| Research Councils | 3 | 2 | 5 |
| **Subtotal** | **43** | **31** | **74** |
| *University* | 30 | 18 | 48 |
| **Total** | **339** | **176** | **515** |

[a] Assuming a 3% replacement of total staff arising from retirements, deaths, other occupations, etc.
[b] Based on employment trends during the period 1964-68.

Resources increased its earth science staff at the rate of 15 a year. This increase took place largely in the Inland Waters, Marine Sciences, and Observatories Branches, while the Geological Survey of Canada had a net increase of only one professional over the five-year period.

*The outlook for future employment varies among sectors but is generally very promising.* Sixty-nine per cent of the 120 mining and petroleum company respondents indicated that their activities would probably increase, while 26 per cent indicated they would probably remain the same. Several companies stated, however, that these expectations were very much dependent upon future government fiscal policies. An indication of the intended growth in university faculty appointments is given in the Bonneau report[1], where a growth of 220 in earth science faculty is forecast over the period 1968-72. This seems optimistic, and a growth of the order of 150 would appear to be more realistic. Provincial departments of mines forecast an increase in staff of 80 geologists over the next five years, principally in the larger departments. The future employment of earth scientists in the federal government is currently limited by a "freeze" in employment, but moderate employment opportunities can be foreseen to fill vacancies arising from staff turnover. Considering all these factors, we estimate that there will be an annual requirement for approximately 515 earth science graduates until 1972 (Table II. 9).

Using a deflating factor[2] of 300 sophomore students resulting in 220 bachelor graduates, we arrive at a forecast of 350 bachelor graduates in geology in 1971, based on the sophomore class of 1969. Of this number, 55 per cent, or 193, may enter the labour market directly (based on employment trends of Canadian earth science graduates in 1966-68). The future number of masters and doctoral graduates is less dependent on the current enrolments than on the entry to Canada of foreign students who form a large part of the graduate population (44%). Using an optimistic estimate, we consider that there will be a maximum of 100 masters and 50 doctoral graduates in geology in 1971.

On the basis of the above considerations, there will continue to be a shortage of Canadian geologist graduates to meet Canadian needs until after 1972 (the end of our forecast period). The an-

[1]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, 1969.

[2]Based on data from the American Geological Institute.

ticipated growth rates after 1972 in the mineral industry alone will require an increasing number of earth scientists (Chapter IV), and we can see no return to a balance of supply and demand without a considerable increase in the number of geology students in Canadian universities. Furthermore, we are not considering here the number of geology graduates required for teaching earth sciences in the secondary schools in Canada (Chapter III), nor those required for increased earth science activities in foreign aid (see Chapter VIII, Section 11). The potential additional personnel requirements arising from future expansion of these two programs are indicated in Table III.2. The picture is much worse in the case of mining engineering, although equivalent manpower data are not available. We believe it is also true in the field of applied geophysics, although in this case physics graduates contribute significantly to meeting the rising demand.

*It is our judgment that the output of Canadian graduates in geology, geophysics and mining engineering should be increased as soon as possible. In a number of universities this could be achieved without a significant increase in facilities.*

*Student Employment*

A large seasonal employment of earth science students by industry, government, and increasingly by universities, is a Canadian practice not commonly followed in other countries. The policy of hiring and assisting in the training of summer students was established by the Geological Survey of Canada before World War I, and has had an extremely beneficial role in the training of Canadian earth science manpower. The Canadian system is beneficial to employers and students alike and could be considerably expanded with the ultimate purpose of encouraging a sense of national identity among young students as they explore the various regions of our country. We estimate that during the summer of 1968 more than 2 570 students were employed in earth science projects in Canada (compared to a total of 1 760 undergraduate and graduate geology students enrolled in Canadian universities in 1968).

The weighted annual increase of summer student requirements during the last five years has been 5.5 per cent, and there is every indication that this growth will continue. Unfortunately, this employment is immediately susceptible to changes in the economy. The period of the late fifties was a time of recession when employment opportunities were reduced. *It is considered that any reduction in the summer employment of students is shortsighted and harmful to student training and morale.* It is extremely important that employers recognize their obligation to aid the training process, and that they provide increased summer work opportunities for students.

*A National Manpower Register*

In the course of our study we were continually reminded of the annoyance caused by the many and varied questionnaires which are circulated to gather information on manpower, expenditures, opinions, conditions, etc. We share this general attitude. We were, nevertheless, equally impressed with the inadequacies existing in the present earth science data collection systems, and we were forced to design and circulate additional questionnaires.

Our coverage was extensive but still only partly successful. Yet we were able to discover many facts and imbalances bearing on earth science policy which were not previously apparent. *It is a matter of concern to us that no mechanism exists to continue an improved version of our manpower survey over the next few years.*

We were impressed with the United States National Register of Scientific and Technical Personnel, a biennial survey which provides statistical information on the supply, utilization and characteristics of the nation's scientists. This register is maintained by contract to the appropriate scientific agencies. The American Geological Institute and the American

Meteorological Society jointly survey manpower in atmospheric, earth, marine and space sciences. The resultant data are invaluable to those engaged in policy formulation, education, recruiting and related matters in the earth sciences. Since the earth science population in Canada is only a small part of the total professional population, and similar problems also exist in the other scientific sectors, we consider that the development of an earth science professional manpower register is contingent on the existence of a National Manpower Register covering all scientific fields in Canada.

Hence we conclude:

*Conclusion II.1*
*To meet the urgent need for better information concerning Canadian scientific manpower, the Federal Government should direct one of its agencies to develop a comprehensive manpower register, to be operated on a contract basis by the appropriate professional and scientific societies.*

## II.3 The Mineral Industry

**Definitions**

The Canadian mineral industry appears to be more heterogeneous in terms of types of activity, variations in the size of individual companies and related factors, than any other Canadian industry. Hence the use and interpretation of industrial statistics or problems related to the mineral industry must be undertaken with full understanding of its internal variability and the recognition that generalizations based on the whole industry may be quite untypical of certain components of it.

One classification of the *mineral industry* used frequently in this report is based on the materials exploited. For example:

*1. The mining industry,* referring not only to those companies active in mining as such but also those engaged in mineral exploration alone. *The Financial Post Survey of Mines (1969)* lists the names of 2 949 mining companies. This number provides a first approximation of the number interested but not necessarily involved in earth science activities. Of this number, 102 companies produce over 95 per cent of Canada's output of metals and industrial minerals. The 86 companies who responded to our questionnaire account for approximately 63 per cent of the national mining output. Also, there are some 150 consultants and contractors engaged in supplying earth science services to the mining industry.

*2. The petroleum and natural gas industry,* again referring not only to those engaged in production, but also to exploration companies and the consultants and contractors supplying earth science services. *The Financial Post Survey of Oils (1969)* lists the names of 756 petroleum and natural gas companies. Of this number, about 100 account for approximately 97 per cent of Canada's oil and natural gas production. The 43 companies who responded to our questionnaire account for approximately 62 per cent of the national production. In addition, there are more than 150 consultants and contractors engaged in supplying earth science services to the petroleum industry.

*3. Companies engaged in the extraction of structural materials* (clay, cement, lime, sand, gravel and stone). The value of mineral production by these companies in 1968 was $444 million. Their actual expenditure in earth science activities was very small and has not been included in this survey.

The significant distinction between (1) and (2) is further indicated by the fact that each has its respective trade association, for example, the Canadian Petroleum Association and Independent Petroleum Association of Canada for the petroleum industry; and the Mining Association of Canada, Prospectors and Developers Association, and several provincial Chambers of Mines for the mining industry. In a sense, the distinction extends to scientific societies (the Alberta Society of Petroleum Geologists on the one hand, and the Geology and Industrial Minerals

Divisions of the Canadian Institute of Mining and Metallurgy on the other), as well as drilling associations (the Canadian Oil Well Drilling Association, and the Canadian Diamond Drillers Association). These distinctions are now beginning to narrow, especially with the entry of petroleum companies into mining exploration.

A second subdivision of the mineral industry relates to the sequence of activity in the industry itself. The sequence is as follows:

1. Exploration
2. Development
3. Production
4. Processing
5. Marketing

Some mining companies are engaged in stage 1 activities only, while others encompass stages 1 to 5. Earth science activities related to the mineral industry are largely confined to stage 1, with the exception of underground geological mapping and reservoir studies related to development and production, and a small amount of mineralogical and petrological studies related to the concentration and recovery of economic minerals. The gross value of metallic, non-metallic and structural material products and fuels (coal, oil and gas) produced in 1968 was $4.7 billion. This is a hybrid number, based on the value after stage 3 for some commodities (e.g. iron ore and oil) and after stage 4 for other commodities (e.g. copper and nickel). In view of the fact that this study reviews only part of the total scientific activity of the mineral industry, and because of the importance of all aspects of the industry to the national economy, we consider that a special study of scientific activities related to the production and processing of mineral resources is warranted.

A third classification of the mineral industry is based on size. Table II.10 illustrates the relationship between the size of companies in the mineral industry (based on gross value of production) and the magnitude of expenditures on earth science activities. *The table shows quite clearly that the financial capability to undertake the whole range of earth science activities (research, development, data collection) is concentrated in a small number of companies;* thus, the statistics and conclusions derived from the expenditures of the larger companies do not necessarily apply equally to the smaller companies. For instance, emphasis on the protection of proprietary information or the development of research laboratories may benefit only the larger company, whereas the provision of scientific data and related research by public organizations (government and university) is the lifeblood of the smaller company.

**The Structure and Growth of the Mineral Industry**

The present size, structure, diversity and growth of the mineral industry have been largely determined by Canada's diverse geological framework, combined with the effects of resource development, marketing progress and government policies since the 1940s. The value of total output increased more than ninefold in the period 1945 to 1968 (Figure II.4); the increase for fuels was more than fourteenfold, for non-metals more than tenfold, and for metals eightfold. In volume terms, output increased almost sixfold, the increases for the fuels, non-metallics and metals being ten-, five- and fourfold respectively. The all-time growth in value of mineral production to 1945 was less than one-eighth, in current dollar terms, of the increase that took place from 1945 to 1968.

The 1968 value of output of $4.7 billion (Figure II.4) was obtained from metals (53%), fuels (28%), industrial minerals and structural minerals (19%). This general relationship has held in recent years although, in the mid-1940s, metals accounted for nearly two-thirds of total output (Figure II.4).

The physical volume of output, as expressed in terms of volume indices, rose four times in the period 1950-68 com-

**Table II.10–Relation Between Earth Science Expenditures[a] and Size of Reporting Company, 1968**

| Type of Company | Average Gross Value of Production | No. of Company Respondents | Total Reported Expenditures | Average Expenditure per Company in terms of Scientific Activities | | | | | Average Expenditure per Company in Earth Science Disciplines and Activities | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Basic Research | Applied Research | Develop-ment | Scientific Data Collection | Scientific Information | Geology | Geophysics | Geo-chemistry | Exploratory Drilling | Other Related Expen-ditures |
| | | | $'000 | $'000 | $'000 | $'000 | $'000 | $'000 | $'000 | $'000 | $'000 | $'000 | $'000 |
| Petroleum | over $50 million | 8 | 127 852 | 202 | 266 | 1 375 | 13 913 | 225 | 782 | 6 170 | 17 | 7 343 | 1 670 |
| | less than $50 million | 30 | 78 571 | 0.2 | 38 | 245 | 2 308 | 29 | 189 | 949 | 7 | 1 215 | 258 |
| | Non-producer | 3 | 3 188 | 0 | 50 | 55 | 931 | 27 | 133 | 205 | 0 | 660 | 65 |
| Mining | over $50 million | 6 | 25 532 | 5 | 80 | 282 | 3 864 | 24 | 838 | 535 | 23 | 1 926 | 1 096 |
| | less than $50 million | 42 | 24 138 | 2 | 14 | 29 | 522 | 7 | 116 | 41 | 28 | 135 | 67 |
| | Non-producer | 31 | 11 870 | 0 | 15 | 25 | 342 | 4 | 129 | 108 | 60 | 182 | 14 |
| **Total Expenditures (all companies)** | | **120** | **271 151** | **1 739** | **4 940** | **22 171** | **239 010** | **3 291** | **25 247** | **86 582** | **3 521** | **120 041** | **35 760** |
| **% of Total Companies' Expenditures** | | | **100** | **<1** | **2** | **8** | **88** | **1** | **10** | **32** | **1** | **44** | **13** |

[a] The expenditure of $271 million reported by 120 mining and petroleum companies is classified in this table in terms of both scientific activities and disciplines.

Figure II.4–Growth of Canadian Mineral Production by Classes, 1945-68

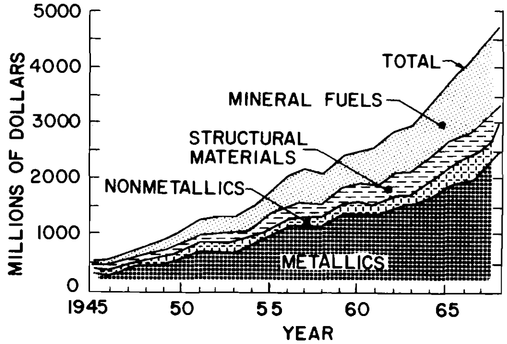


Figure II.5–Growth of the Canadian Mineral Industry compared with Indices of Industrial Production and Manufacturing Production, 1935-68

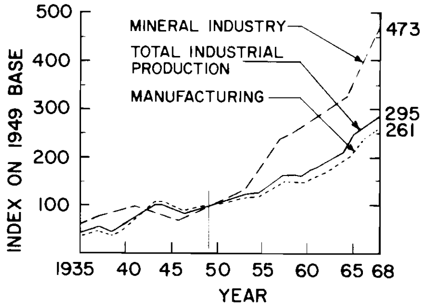


**Table II.11–Value of Mineral Production by Classes, Selected Years, 1930 to 1968**

| Year | Metallics | Non-Metallics | Structural Materials | Mineral Fuels | Total |
|---|---|---|---|---|---|
| | $ million | $ million | $ million | $ million | $ million |
| 1968 | 2 492.6 | 446.9 | 443.3 | 1 342.5 | 4 725.3 |
| 1960 | 1 406.6 | 197.5 | 322.6 | 565.8 | 2 492.5 |
| 1950 | 617.3 | 94.7 | 132.3 | 201.2 | 1 045.5 |
| 1940 | 382.4 | 26.1 | 42.5 | 78.8 | 529.8 |
| 1930 | 142.6 | 15.4 | 53.7 | 68.2 | 279.9 |

pared with less than three times for the industrial economy as a whole (Figure II.5).

A further indicator of growth is the Gross Domestic Product (GDP) at factor cost. The mining sector GDP increased three and a half times from 1950 to 1967 and, in the latter year, was 90 per cent that of agriculture, compared with one-third in the early 1950s. In the same period, mining advanced from less than double the value of the forestry GDP to four times its value. The real domestic product index for the mineral industry grew at an annual average rate of 8.7 per cent in the period 1946-68, compared with 1.7 per cent for agriculture, 2.3 per cent for forestry, and 5.5 per cent for manufacturing.

Although Ontario, Alberta and Quebec account for about two-thirds of the value of Canada's mineral production, there is a good distribution of exploration and other mineral industry activities across the country; in fact, exploration is often most active in regions of lower production such as the North. This widespread activity is indicative of the countrywide character of mineral resource development and the aggressive effort being made to test the mineral potential of Canada's varied geological environments. Canada's economic position would be improved if new sources of some minerals could be discovered at locations more economically accessible to major markets. In a country as large as Canada, transportation can be the main obstacle to profitable production. This was the case with coal in the past, and transportation now stands as one of the principal obstacles in moving crude oil to larger markets in eastern Canada. Successful exploration for oil off the east coast would diversify the geography of petroleum production and permit a greater degree of self-sufficiency. The degree of self-sufficiency and the ability to produce and market greater quantities of minerals will depend considerably on the geographic distribution of mineral discoveries in relation to advances in transportation technology.

The geographical diversity of exploration and production is paralleled by the diversified mineral output (Table II.12). Canada's mineral production includes some 60 minerals and, while only 10 minerals account for about four-fifths of the production value, there are very few minerals–such as manganese and tin–which Canada could not produce in quantities sufficient to meet its own needs.

The active mineral development program in Canada (some 125 new mines brought into production during the period 1955-65) has resulted not only in a broad regional distribution of production facilities across the country but also in extensive processing facilities. The processing structure of the mineral industry in the late 1960s can be described in terms of: copper and nickel-copper smelters in Ontario, Quebec and Manitoba (total capacity of about 9 million tons annually); a nickel refinery in Alberta; lead and zinc smelting and refining facilities in British Columbia, Manitoba, Quebec and New Brunswick; and plans for a major zinc smelter in the Porcupine area of Ontario. The many other facilities designed to process metals in-

**Table II.12–The Ten Leading Commodities in Canadian Mineral Production, 1968**

| | Value of production ($ million) | Per cent of total value |
|---|---|---|
| Petroleum | 937.3 | 19.8 |
| Copper | 607.9 | 12.8 |
| Iron ore | 532.7 | 11.3 |
| Nickel | 528.2 | 11.2 |
| Zinc | 326.9 | 6.9 |
| Natural gas | 225.3 | 4.8 |
| Asbestos | 185.0 | 3.9 |
| Cement | 152.0 | 3.2 |
| Sand and gravel | 129.5 | 2.8 |
| Natural gas by-products | 126.1 | 2.7 |
| All other minerals | 974.4 | 20.6 |
| **Total** | **4 725.3** | **100.0** |

clude capacity to produce about 12 million tons of steel ingots annually. Processing facilities for industrial minerals have been established in many parts of the country and also contribute greatly to regional development.

The country's petroleum refining capacity, while concentrated in Quebec and Ontario, is sufficiently dispersed to meet regional needs and to supply practically all of the country's requirements in petroleum products. Natural gas processing capacity has been rapidly expanding in western Canada, and important by-products such as sulphur and propane more than meet Canada's requirements. The capital investment and the employment associated with processing facilities constitute an important multiplying effect of mineral development.

**Mineral-producing Operations in the Provinces and Territories**

As a further description of the regional structure of mineral-producing operations–which in turn are the bases for processing, transportation and marketing activities–brief reference is made to the principal minerals produced in each of the provinces and territories in terms of 1968 data. Table II.13 gives the production value by provinces for selected years from 1950 to 1968.

Figure II.6 illustrates the value of the leading minerals produced in the provinces and territories. Mineral production in British Columbia has grown and diversified rapidly in recent years, with attention now centring on copper and molybdenum in the central and northwestern parts of the province, and on coal in the

**Table II.13–Value of Mineral Production by Provinces and Territories (in millions of dollars)**

| Province | 1950 | 1955 | 1960 | 1965 | 1968 |
|---|---|---|---|---|---|
| Ontario | 367 | 584 | 983 | 993 | 1 356 |
| Alberta | 136 | 326 | 396 | 794 | 1 092 |
| Quebec | 220 | 357 | 446 | 716 | 729 |
| British Columbia | 139 | 189 | 186 | 280 | 389 |
| Saskatchewan | 36 | 85 | 212 | 328 | 357 |
| Newfoundland | 26 | 68 | 87 | 207 | 310 |
| Manitoba | 32 | 62 | 59 | 183 | 209 |
| Northwest Territories | 8 | 26 | 27 | 77 | 116 |
| New Brunswick | 13 | 16 | 17 | 82 | 88 |
| Nova Scotia | 59 | 67 | 66 | 71 | 57 |
| Yukon | 9 | 15 | 13 | 13 | 21 |
| Prince Edward Island | – | – | 1 | 1 | 1 |
| **Total** | **1 045** | **1 795** | **2 493** | **3 745** | **4 725** |

Figure II.6–Value of Leading Mineral Commodities by Province and Territory, 1968 (Diameters of circles are proportioned to the total provincial expenditure)

southeast. The oil and gas industry dominates the mineral economy of Alberta, which produces two-thirds of the country's crude oil and four-fifths of its natural gas. The chief value of Saskatchewan's mineral output is in crude oil and potash, but uranium, other metals, and structural materials are also produced. The recent rapid development of Saskatchewan's potash resources has provided a mining capacity sufficient to supply over one-third of the world's requirements. The most important metals produced in Manitoba are nickel and copper. The Thompson Mine nickel area, and northwestern Manitoba adjacent to the Saskatchewan border, are favourable areas for base metal prospects.

Ontario produces a diversity of metals and structural materials. Nickel from the Sudbury area continues to be the most important mineral, but the development of a very large zinc-copper-lead-silver deposit near Timmins, a revival of uranium activity at Elliot Lake, and iron ore production in the northwestern parts of the province have served to diversify and increase mineral output. Quebec remains the leading asbestos producer in Canada and the second largest copper producer. These two minerals, and a large output of iron ore, are the leading mineral products of that province. Like Ontario, Quebec produces a large volume of structural materials for the construction industry. New Brunswick is primarily a base metal producing province, with exploration and production centred in the Bathurst area. Coal has long dominated Nova Scotia's mineral economy; there are no significant metal mines but there is an important production of structural materials and non-metallic minerals such as gypsum and salt. Prince Edward Island's production is restricted to relatively small amounts of sand, gravel and stone, and is not shown in Figure II.6. In Newfoundland and Labrador, iron ore is by far the most important mineral product. Areas offshore from the Atlantic Provinces offer favourable prospects for oil and gas, which are undergoing active exploration.

In the North, mineral exploration has been reactivated. New metal mining in the Ross River area is a highlight in the Yukon. In the Northwest Territories, the Pine Point mine on the south shore of Great Slave Lake is the principal producer, but exploration for oil and gas is widespread. As a result of the Prudhoe Bay oil discovery in northern Alaska, petroleum exploration in the Mackenzie Delta area and the Arctic Islands has increased considerably, and new occurrences have been found in the Mackenzie Delta region.

**The Importance of the Mineral Industry in the Canadian Economy**

There are many indicators of the importance of the mineral industry in the Canadian economy. In 1968 the value of mineral production was equivalent to approximately 7 per cent of the Gross National Product, compared with 4.2 per cent in 1945. This is a minimum assessment of the industry's contribution, as it does not take into consideration the value of manufacturing activities dependent on the mineral industry or the multiplying effect in the transportation and service industries. Within the manufacturing group of industries, for instance, there are four components–primary metals, metal fabrication, non-metallic mineral products, and petroleum and coal products–which are directly mineral based. These four industries account for over one-fifth of the value of all manufacturing in Canada.

The primary stage of the mineral industry, including the production of both mines and oil fields, accounts for over one-third of the "value added" in the production process by all primary industries (agriculture, forestry, fishing, mining (including oil and gas), and electric power), and for about one-tenth of all industrial production in the Canadian economy. The growing importance of the mining and oil industries in the primary production sector of the Canadian economy, as indicated by the concept of value added in the production process, is indicated in Table II.14. Trends in the late 1960s suggest that the relative importance of the mining and oil industries will continue to increase.

*Total wages and salaries paid in the mineral industry are almost double those paid in forestry and well over three times the income to labour in agriculture.* Corporation profits, before taxes, of companies engaged in mining and oil production constitute about 11 per cent of the corporation profits of all industries. Business gross fixed capital formation in the mineral industry accounts for 8 per cent of total capital formation by industry in Canada. When amounts expended in mineral-based manufacturing and in pipeline transportation and marketing related to petroleum and natural gas are added to primary sector investment, the percentage of direct mineral industry investment is increased to 15 per cent of total annual investment by industry.

Companies engaged in mining and oil production and in related manufacturing activities, such as smelting and refining, metal fabrication, petroleum refining, and non-metallic mineral processing, pay almost 20 per cent of all federal income taxes. These companies are also major contributors to provincial and municipal treasuries.

Minerals and metals hold a prominent position in Canada's external trade, currently accounting for about 30 per cent of all merchandise exports compared with 20 per cent in 1950 (Figure II.7). The industry is strongly export oriented; the equivalent of almost two-thirds of its production goes into the export market, largely to the United States. Minerals and mineral products make up one-half of Canada's 20 leading exports. Canada's position as fifth largest world trader is due in no small part to the large and growing exports of the mineral industry. The importance of the primary mineral industry, including oil and gas, in the country's trade is well illustrated in the comparisons for 1964 and 1968 of foreign trade balances (exports less imports) for the key sectors of the economy (Table II.15). The mineral industry exceeded all other sectors in the size and growth rate of its trade balance.

The mineral industry has a major impact on regional development throughout the country. Possibly this is most dramatically illustrated in terms of oil industry activity in western Canada. The oil industry has greatly enhanced the economic position of the Prairie Provinces, and, being a substantial consumer of capital goods produced elsewhere in the country, has thereby made a major contribution to the total economy. Since 1947 some $12 billion has been spent in the development of oil and gas resources in western Canada, and this has had a widespread multiplying effect. Governments in Canada have received an estimated $3 billion of the total funds expended by the industry as direct payment for mineral rights and royalties. The gross value of the petroleum industry's output since

**Table II.14–Percentage Production Contribution by Industry in the Primary Sector, Selected Years, 1951-67**

| | 1951 | 1956 | 1961 | 1966 | 1967 |
|---|---|---|---|---|---|
| | % | % | % | % | % |
| Agriculture | 56.3 | 42.3 | 34.4 | 41.1 | 35.1 |
| Forestry | 15.1 | 16.2 | 12.9 | 8.5 | 8.9 |
| Fishing | 2.5 | 2.6 | 2.6 | 2.7 | 2.4 |
| Mining (including oil and gas) | 17.7 | 26.4 | 33.6 | 33.3 | 37.8 |
| Electric Power | 8.4 | 12.5 | 16.5 | 14.4 | 15.8 |
| **Totals** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** |

Figure II.7–Value of Canadian Merchandise Exports by Commodity Class, 1950-68 (Rise in manufacturing curve arises from exports of motor vehicles and parts

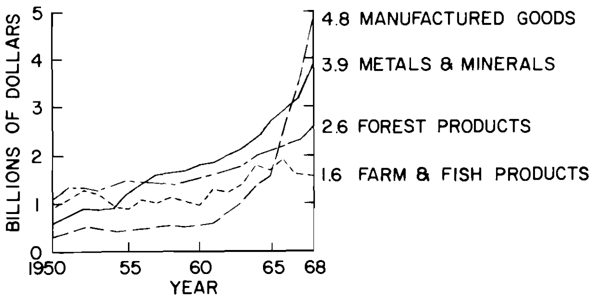


**Table II.15–Trade Balances for Key Sectors of the Economy, 1964 and 1968**

| Sector | 1964 | 1968 |
|---|---|---|
| | $ million | $ million |
| Farming | 646 | 356 |
| Fishing | 11 | 3 |
| Forestry | 24 | 26 |
| Mining | 777 | 1 345 |
| Manufacturing | −858 | −879 |

1957 has aggregated over $10 billion.

The increased resource activity related to the growth of the petroleum industry has provided support for a population one million greater than would have been possible had the industry not developed. The industry provides employment opportunities for many professional and technical workers. Some indication of this impact can be seen in the increase of professional engineers, scientists and technical personnel in western Canada, from 6 700 in 1941 to 19 500 in 1961. Although these people were employed in a number of industries, the petroleum industry and related activities accounted for a very large part of the increase.

Important regional benefits from mineral industry growth can also be noted in relation to many new mining developments of the past 20 years. Each new project serves to push back the frontier and to provide employment in the towns, transportation facilities, and many service industries associated with mine development and operation. The multiplier effect throughout the economy is considerable, inasmuch as one worker's activities in mining and petroleum at the primary production level give rise to employment for as many as five or more workers in other sectors of the economy. A large new coal mining operation in western Canada is estimated to have an employment multiplier of seven.[1] Revenues accruing to various sectors of the economy, resulting from mineral production, exceed revenues generated in the economy by other primary industries and by many secondary and tertiary industries. The impact of mineral industry activity on the economy is correspondingly greater than that resulting from agriculture, forestry, fishing, and many manufacturing and service industries.

Although the mineral industry has achieved a prominent place in the Canadian economy, it is beset by a number of problems. For example, the industry is characterized by a high degree of foreign ownership and control; in the mining and smelting industries, foreign ownership is 62 per cent and foreign control, 59 per cent; comparable figures for the petroleum industry are 64 per cent and 70 per cent. The high degree of foreign participation tends to restrict the amount of earth science research that might otherwise be carried out within Canada. Petroleum companies have tended to concentrate their research efforts in research centres outside the country even for problems that relate directly to Canadian exploration. To the extent that this happens, it prevents Canada from enjoying the benefits of active research programs, such as the building up of a cadre of researchers, the introduction of foreign research results, and the financial returns associated with capital and operating expenditures on research activities.

Another problem facing the mineral industry is the chronic shortage of well-trained earth scientists and technologists, attributable in part to living and working conditions in remote mining and oil

[1]The impact of the coal mining operations of Kaiser Resources Ltd. on the Canadian economy. Report prepared for Kaiser Resources Ltd. by Hedlin-Menzies and Associates Ltd. 1969.

operations. This is an important factor in restricting the ability to compete against the more glamorous "space age" industries for scarce professional manpower. The geography of our mineral resources also constitutes a problem and demands that certain priorities be placed in mineral development. In the competition for foreign markets, the far-inland location of mineral operations sometimes imposes a serious transportation penalty which is gradually being lessened through research on transportation technology.

### Level of Earth Science Activities in the Mineral Industry

*Expenditures*

The expenditure data obtained from our survey of the mineral industry are summarized in Table II.16.[1] The principal check on these results comes from DBS reports, although no absolute comparison is possible because, as explained in Section I.4, the Dominion Bureau of Statistics has used other definitions of scientific activities and other modes of reporting. As a result, the statistical data on the mineral industry included in DBS reports refer essentially to the mining and metallurgical or refining activities of the mineral industry alone.

Data on petroleum exploration expenditures have been collected by the Dominion Bureau of Statistics since 1965, and information on previous years is available from the Canadian Petroleum Association. The DBS reports indicate the net cash expenditures of the oil and gas industry and include: a) geological and geophysical expenditures, and b) exploratory drilling expenditures; however, no attempt has been made to categorize these expenditures in terms of scientific activities (R & D, data collection, etc.). Our estimate of the total geological and geophysical expenditure by the petroleum industry (1968) is $129 million compared with a DBS reported expenditure of $150 million.

Data on the total exploration expenditures of mining and exploration companies have been collected by the Dominion Bureau of Statistics only since 1967, although partial data exist for earlier years. Our estimate of mining exploration expenditures in 1967 is $76 million (Table II.17). This total compares favourably with the DBS estimate of $70 million for all outside exploration ($53 million), plus half the "on-property exploration and development" and half "the related administration and overhead charges".

Part of the basic and applied *research* reported by petroleum companies includes the cost of research conducted in laboratories in the United States or Europe. Field research includes, for example, studies of carbonate reefs to develop models for oil exploration, and regional studies to identify and interpret factors controlling the origin and distribution of ore deposits. The geological research of consultants involves the initiation and conduct of new exploration projects. Geophysical firms are involved in research and development related to instrument development, part of which is funded by industrial R & D programs of: the Department of Industry, Trade and Commerce; the National Research Council; and the Defence Research Board. Most companies consider that the federal government incentive programs for industrial research should be broadened to stimulate more research in Canada (see Section IV.5).

*Scientific development* includes not only the development of geophysical instruments but also the costs of *interpretation* of geochemical, geophysical and geological data. The latter activity represents the synthesis of large amounts of data, with computers and other methods being used to define the geometry of parts of the earth's crust which may contain economic deposits. Where new techniques and models are developed, this becomes re-

[1]Our questionnaire survey included a number of qualitative questions on earth science activities, the replies to which are summarized in Appendix 6.

**Table II.16–Total Solid-Earth Science Expenditures of Mineral[a] Industry Related to Type of Scientific Activity, 1968**

| Type of Scientific Activity | Total Expenditures | | Petroleum Industry[b] | | | | Mining Industry[c] | | | | Consulting Firms[d] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Office (Laboratory) | Field (Exploration) | Total | | Office (Laboratory) | Field (Exploration) | Total | | Office (Laboratory) | Field (Exploration) | Total | |
| | $'000 | % | $'000 | $'000 | $'000 | % | $'000 | $'000 | $'000 | % | $'000 | $'000 | $'000 | % |
| Basic Research | 1 979 | 0.5 | 1 801 | – | 1 801 | 0.6 | 125 | 6 | 131 | 0.1 | 47 | – | 47 | 1.2 |
| Applied Research | 6 026 | 1.5 | 2 709 | 1 085 | 3 794 | 1.3 | 972 | 720 | 1 692 | 1.9 | 406 | 134 | 540 | 12.1 |
| Development | 33 532 | 8.6 | 25 170 | 1 400 | 26 570 | 8.9 | 3 622 | 1 646 | 5 268 | 6.0 | 1 277 | 417 | 1 694 | 38.1 |
| Scientific Data Collection | | | | | | | | | | | | | | |
| A. Surveys & lab. studies | 172 546 | 44.1 | 16 515 | 107 192 | 123 707 | 41.3 | 4 551 | 42 581 | 47 132 | 53.7 | 654 | 1 053 | 1 707 | 38.4 |
| B. Exploration drilling | 172 557 | 44.1 | – | 139 559 | 139 559 | 46.6 | – | 32 820 | 32 820 | 37.4 | – | 178 | 178 | 4.0 |
| Scientific Information | 5 003 | 1.2 | 3 933 | – | 3 933 | 1.3 | 793 | – | 793 | 0.9 | 277 | – | 277 | 6.2 |
| **Totals** **Amount** | **391 643** | **100.0** | **50 128** | **249 236** | **299 364** | **100.0** | **10 063** | **77 773** | **87 836** | **100.0** | **2 661** | **1 782** | **4 443** | **100.0** |
| % | | | **(16.7%)** | **(83.3%)** | **(100.0%)** | | **(11.5%)** | **(88.5%)** | **(100.0%)** | | **(59.9%)** | **(40.1%)** | **(100.0%)** | |

[a] Mineral industry is defined as including the mining and petroleum industries.

[b] On the basis of replies from 41 companies which account for 62% ($0.8 billion) of the annual gross value of petroleum production, we estimate that 70% of the annual expenditure on solid-earth science activities was reported (90% of the research and 69.6% of the remaining scientific activities). Hence the reported expenditures on research have been divided by 90% and the remaining activities by 70%.

[c] On the basis of replies from 79 companies, which represent $1.9 billion (63%) of the 1968 production, we estimate that 70% of the total earth science expenditures were reported (90% of the research and 69.6% of the remaining scientific activities). Hence the reported research expenditures have been divided by 90% and the remaining scientific activities by 70%.

[d] Includes geological and geophysical firms involved in activities related to the petroleum and mining industries. The return on our consultant questionnaire was very low (15%). We empirically estimate that our survey represents 40% of the *in-house* earth science activities and hence the reported expenditures have been divided by that amount.

**Table II.17–Growth in Solid-Earth Science Expenditures of Canadian Mining and Petroleum Companies, 1964-68[a] (in millions of dollars)**

| Scientific Activity | Petroleum Companies | | | | | Mining Companies | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1964 | 1965 | 1966 | 1967 | 1968 | 1964 | 1965 | 1966 | 1967 | 1968 |
| Geology | 11.7 | 14.0 | 14.7 | 15.9 | 17.5 | 11.2 | 15.2 | 18.2 | 17.0 | 18.3 |
| Geophysics | 51.1 | 59.1 | 76.2 | 112.1 | 111.2 | 5.9 | 9.7 | 11.0 | 10.2 | 11.5 |
| Geochemistry | 0.1 | 0.3 | 0.2 | 0.8 | 0.5 | 1.9 | 3.3 | 3.9 | 4.6 | 4.5 |
| Exploratory Drilling | 84.9 | 105.8 | 127.4 | 125.6 | 139.6 | 18.3 | 26.3 | 29.7 | 27.4 | 32.8 |
| Other Related Expenditures | 17.1 | 18.9 | 23.5 | 26.8 | 30.6 | 10.3 | 13.0 | 15.1 | 17.1 | 20.8 |
| **Total** | **164.9** | **198.1** | **242.0** | **281.2** | **299.4** | **47.6** | **67.5** | **77.9** | **76.3** | **87.9** |
| **Ratio[b]** | **0.16** | **0.18** | **0.21** | **0.22** | **0.22** | **0.02** | **0.03** | **0.03** | **0.03** | **0.03** |

[a] Expenditures represent our estimates for the entire mineral industry.
[b] Ratio of exploration expenditure to production value.

search. Where semi-standard procedures are followed, this represents the development stage of scientific activities leading hopefully) toward economic exploitation of the scientific knowledge that has been generated. Scientific development therefore represents a central activity of exploration companies. As defined herein, it represents the major scientific activity conducted in the office and laboratory.

*Scientific data collection* includes the systematic collection of both surface and subsurface data. Canada is so large that this activity is the most expensive. Industry collects data principally in areas of known or suspected economic significance, and uses geological, geophysical and geochemical techniques in attempts to improve the success of exploratory drilling. Drilling is the main expense in industrial data collection, but large sums are also spent on seismic and other regional surveys. Data collection encompasses a multiplicity of projects of varying scope, detail and quality which, because of competition and their proprietary nature, are often duplicative. Information is released to meet the minimum requirements of governmental legislation, while the rest is either destroyed (e.g. drill cores left on the ice or in "scrambled" piles), retained in company files, or in a few cases transmitted to data centres located outside the country. To an outsider, certain aspects of industrial data collection resemble a situation in which every airline has to collect its own weather data.

The levels of earth science expenditure of petroleum and mining industries have grown steadily during the period 1964-68, as shown in Table II.17. The annual expenditures of the petroleum industry are between 3.0 and 3.7 times those of the mining industry, as a result of larger expenditures on geophysics and exploratory drilling. The expenditures of the petroleum industry on exploration have increased at a faster rate than the gross value of petroleum production (Table II.17).

*Manpower*

The professional manpower engaged in earth science activities in the mining and petroleum industries is classified in Table II.18 in terms of specialities and academic degrees. Geologists and geophysicists together compose 82 per cent of this industry personnel. However, the proportion of geologists to geophysicists is 21 to 1 in the mining industry and 2½ to 1 in the petroleum industry. Geochemists represent only 1 per cent or less of the population. Doctoral degrees are more common among earth scientists in the mining industry (12%) than in the petroleum industry (6%).

Table II.19 shows that the professional staff of petroleum companies has grown at a rate similar to that of the staff of mining companies during the period 1964-68. If one allows a 3 per cent replacement rate for attrition (retirement, death, etc.), the average new earth

**Table II.18–Earth Science Manpower in Canadian Mineral Industry, 1968**[a]

| Specialty | Degrees | | | Subtotal |
|---|---|---|---|---|
| | B.Sc. | M.Sc. | Ph.D. | |
| *Geologists & Geological Engineers* | | | | |
| Petroleum | 841 | 291 | 111 | 1 243 |
| Mining | 680 | 253 | 158 | 1 091 |
| Consulting | 158 | 45 | 28 | 231 |
| **Subtotal** | **1 679** | **589** | **297** | **2 565** |
| *Geophysicists* | | | | |
| Petroleum | 386 | 89 | 16 | 491 |
| Mining | 24 | 18 | 10 | 52 |
| Consulting | 80 | 54 | 18 | 152 |
| **Subtotal** | **490** | **161** | **44** | **695** |
| *Geochemists* | | | | |
| Petroleum | 2 | – | 3 | 5 |
| Mining | – | 6 | 10 | 16 |
| Consulting | 5 | 3 | 3 | 11 |
| **Subtotal** | **7** | **9** | **16** | **32** |
| *Mining Engineers* | | | | |
| Petroleum | 32 | 3 | – | 35 |
| Mining | 177 | 7 | – | 184 |
| Consulting | 8 | 1 | – | 9 |
| **Subtotal** | **217** | **11** | **–** | **228** |
| *Other Engineers* | | | | |
| Petroleum | 231 | 30 | – | 261 |
| Mining | 7 | – | – | 7 |
| Consulting | 33 | 2 | 3 | 38 |
| **Subtotal** | **271** | **32** | **3** | **306** |
| *Physicists* | | | | |
| Petroleum | 7 | 4 | – | 11 |
| Mining | 6 | – | – | 6 |
| Consulting | – | – | 3 | 3 |
| **Subtotal** | **13** | **4** | **3** | **20** |
| *Chemists* | | | | |
| Petroleum | – | 2 | – | 2 |
| Mining | 13 | 2 | – | 15 |
| Consulting | 5 | – | – | 5 |
| **Subtotal** | **18** | **4** | **–** | **22** |
| *Mathematicians* | | | | |
| Petroleum | 17 | 4 | – | 21 |
| Mining | 3 | – | – | 3 |
| **Subtotal** | **20** | **4** | **–** | **24** |
| *Other Professionals* | | | | |
| Petroleum | 40 | 2 | – | 42 |
| Mining | 27 | – | – | 27 |
| Consulting | 8 | – | – | 8 |
| **Subtotal** | **75** | **2** | **–** | **77** |
| **Total** | **2 790** | **816** | **363** | **3 969** |

[a] Estimates of total numbers of professionals engaged in earth science activities in the Canadian mineral industry in 1968, based on 120 questionnaire returns which have been inflated by a factor of 1.4 to arrive at an estimate for the total mineral industry.

science employment in the mineral industry has been 369 per annum during the last five years. In view of the lower rate of graduation from Canadian universities, and the decreasing proportion of graduates entering industry (as opposed to teaching, etc.), it is apparent that the immigrant component of this personnel has increased rapidly since 1964. If the mineral industry continues to grow at the same rate as in 1964-68 (Figure II.9), with the same rate of increase in earth science manpower, it may well be that by 1980 more than 6 700 will be engaged in mineral exploration, compared to about 4 000 in 1968 (Table II.19).

## II.4 The Construction Industry

**Definitions**

Construction is an activity not only of those contractors and consultants engaged in the construction industry proper, but also of the labour forces of utilities, manufacturing, mining and logging firms and government departments. Construction statistics reflect the value and level of activity of all these groups, many of whom are not employed in the private sector or primarily engaged in construction as such. The scale of construction activity may range from large dams, highways and bridges to single-family dwellings.

Every structure is in contact with the ground and depends on surface materials for its stability and performance. The term "geotechnique" is used to describe the earth science activities applied in the construction industry. These activities involve application of the principles and techniques of engineering geology, soil and rock mechanics, geomorphology, muskeg, snow and ice studies, hydrogeology, and geophysics. According to R.F. Legget, "it is strange to reflect upon the paradox of the long-standing acceptance in scientific circles of the application of geology to mining ventures, and to the discovery and extraction of petroleum, in contrast with the neglect of the corresponding but much more frequent applications of geology to the works of the civil engineer".[1]

**Present Levels of Activity**

*Expenditures*

Since 1961, the value of construction in Canada has risen rapidly, to exceed $13 billion in 1969 (Figure II.10). It is forecast that the annual volume of construction will rise to $20 billion by the year 1980 (Legget, *op. cit.*). In addition, Canadian contractors, consultants and geotechnical specialists are becoming increasingly involved in construction activities in developing countries through the Canadian International Development Agency and the United Nations Development Program.

The construction industry has been growing faster than the Canadian economy as a whole. This is apparent from an examination of the value added to production in the various resource and secondary industries. Since 1961 the average annual increase in this indicator for the construction industry has been 11.5 per cent, compared with 9.5 per cent for all other industries. Over the period 1935-61 the average annual increase was 10 per cent for construction, compared with 8.5 per cent for all other industries. Thus, the construction industry has helped to increase the rate of economic growth in Canada. Its prominent position as a growth industry and its relative importance in the economy are seen from the fact that in 1935 the value of construction was 2.6 per cent of the Canadian Gross Domestic Product; by 1961 it accounted for 5.5 per cent and currently is close to 6.5 per cent. In the entire group of primary and secondary industries it is second only to manufacturing in its contribution to the Gross Domestic Product.

The total expenditure on geotechnical research and development in Canada

[1]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, 1968. p. 188. 1968.

**Table II.19–Growth in Solid-Earth Science Professional Staff of Canadian Mining and Petroleum Companies, 1964-68**

| Degree | Petroleum Companies | | | | | Mining Companies | | | | | Consultants | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1964 | 1965 | 1966 | 1967 | 1968 | 1964 | 1965 | 1966 | 1967 | 1968 | 1964 | 1965 | 1966 | 1967 | 1968 |
| Bachelors | 1 221 | 1 274 | 1 364 | 1 446 | 1 556 | 599 | 659 | 781 | 853 | 937 | 98 | 125 | 168 | 258 | 297 |
| Masters | 273 | 290 | 323 | 379 | 425 | 156 | 174 | 211 | 246 | 286 | 40 | 63 | 75 | 108 | 105 |
| Doctors | 100 | 110 | 116 | 124 | 130 | 100 | 120 | 140 | 161 | 178 | 25 | 33 | 40 | 45 | 55 |
| **Total** | **1 594** | **1 674** | **1 803** | **1 949** | **2 111** | **855** | **953** | **1 132** | **1 260** | **1 401** | **163** | **221** | **283** | **411** | **457** |

Figure II.8–Growth in Earth Science Expenditures of the Petroleum and Mining Industries, 1964-68

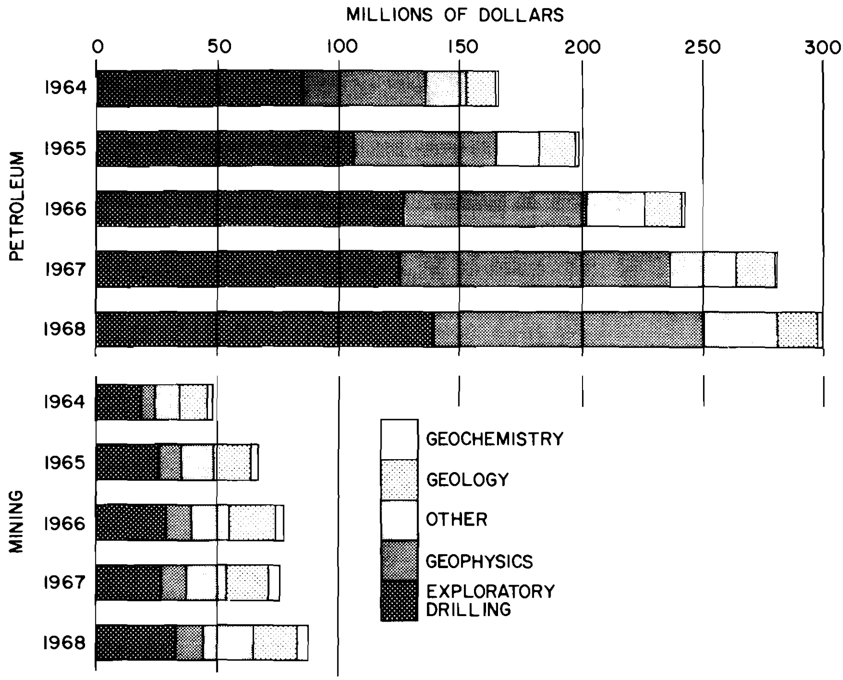


Figure II.9–Growth in Earth Science Manpower in the Mineral Industry, 1964-68

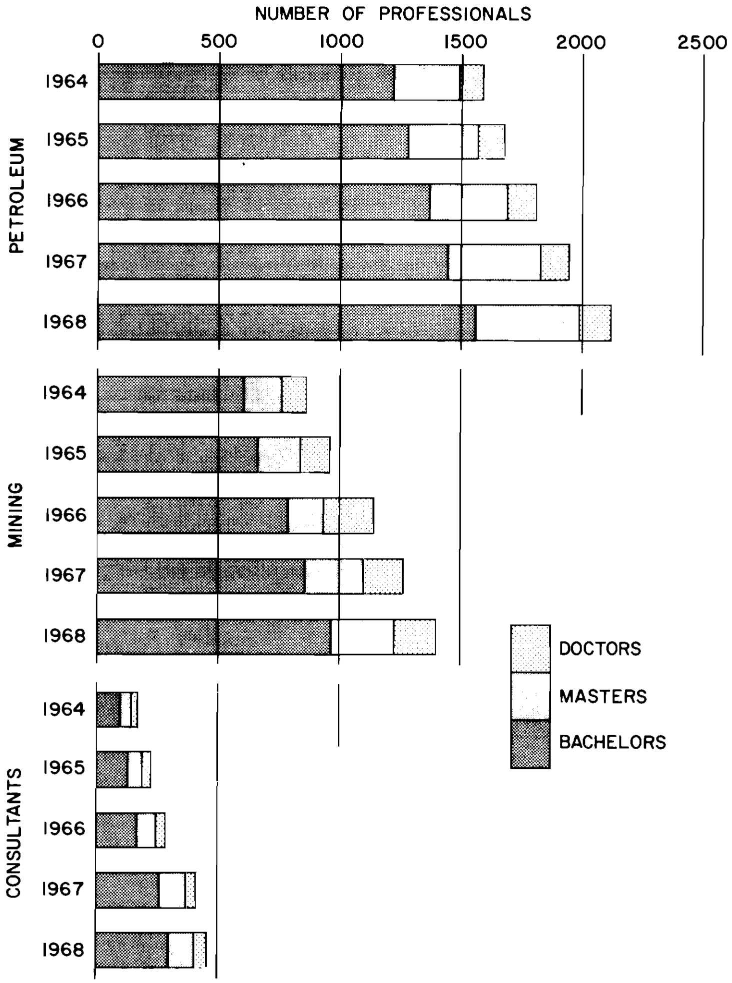
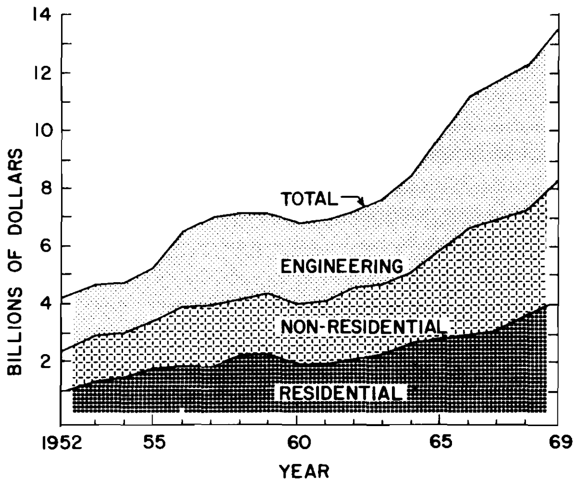


Figure II.10–Growth of Canadian Construction Industry, 1952-69 (Figures include new construction and repair)



during 1968 was approximately $4 million, or 0.03 per cent of the value of non-residential and engineering construction[1] (Table II.20). The corresponding expenditure on all forms of geotechnical activity was $33 million, or 0.3 per cent of the value of construction.

University groups, principally departments of civil engineering and, to a lesser extent, departments of geology, mining and geography, conduct over half the geotechnical R & D in Canada, from funds provided through federal government agencies. However, consulting firms perform over half the total geotechnical activity on behalf of clients in both the private and public sectors. The geotechnical expenditures of provincial agencies, which include the departments of highways, public works, and utilities, are greater than the total earth science expenditures of the provincial departments of mines ($8.6 million versus $6.8 million). Provincial government agencies perform 70 per cent of the geotechnical work of all government agencies, the largest performers being those of Ontario, Quebec and British Columbia. As with industry, much of this activity is undertaken to meet the needs of specific construction projects, and hence is "consumed" on the site. The generation of new public knowledge in geotechnique is a much more restricted activity, being predominantly pursued in the universities and by selected government agencies, e.g. the National Research Council and the Geological Survey of Canada. Little effort is made by government agencies to collect, summarize, interpret and disseminate the vast amount of geotechnical data which is available from major construction projects.

The level of geotechnical activities in the federal government in 1968 is indicated in Table II.21. Eighty-two per cent of the activities are conducted to meet the operating needs of other federal programs - external aid, farm rehabilitation, airport construction, defence construction, and public works - rather than to generate scientific knowledge for public use. Only the Division of Building Research of the National Research Council, and branches of the Department of Energy, Mines and Resources, publish geotechnical information for general use by

[1]Geotechnical activities relate primarily to new construction in the non-residential and engineering categories of construction expenditures, and hence the costs of residential construction have been deleted from these comparisons.

**Table II.20–Total Expenditures on Geotechnical Activities by Sector of Performance, 1968**

| Sector of Performance | Total | R & D[a] | Scientific Data Collection | | | Scientific Information |
|---|---|---|---|---|---|---|
| | | | Laboratory and Office | Drilling and Sampling | Other Field Activities | |
| | $'000 | $'000 | $'000 | $'000 | $'000 | $'000 |
| *Industry*[b] | | | | | | |
| Contractors | 717 | – | 402 | 139 | 156 | 20 |
| Consulting firms | 17 237 | 459 | 4 984 | 8 590 | 2 964 | 240 |
| *Government* | | | | | | |
| Federal | 3 805 | 548 | 1 425 | 1 000 | 685 | 147 |
| Provincial[c] | 8 550 | 450 | 2 430 | 3 250 | 2 310 | 110 |
| *University*[d] | 2 250 | 2 200 | – | – | – | 50 |
| **Total** | **32 559** | **3 657** | **9 241** | **12 979** | **6 115** | **567** |

[a] R & D and data collection expenditures were reported as percentages of total geotechnical costs rather than fixed amounts.
[b] Questionnaire returns from industry were multiplied by 1.56, on the basis of the proportion of reported capital costs of projects to the total new construction in non-residential and engineering categories reported by the Dominion Bureau of Statistics.
[c] Based on partial returns and estimates. The subdivision into scientific activities is based on the proportions indicated by the reporting agencies.
[d] The university expenditure is difficult to estimate because of the distribution of geotechnical activities among various engineering and science departments.

**Table II.21–Total Earth Science Expenditures of the Federal Government on Geotechnical Activities Related to Construction and Transportation, Year 1968-69**

| Department | Total | Basic Research | Applied Research | Development | Scientific Data Collection | Scientific Information |
|---|---|---|---|---|---|---|
| | $'000 | $'000 | $'000 | $'000 | $'000 | $'000 |
| 1. Dept. of Energy, Mines & Resources: Mines and Geosciences Sector | 100[a] | – | – | 20 | 70 | 10 |
| 2. Canadian International Development Agency | 150 | – | – | – | 150 | – |
| 3. National Research Council: Division of Building Research | 572 | 143 | 171 | 86 | 115 | 57 |
| 4. Canada Dept. of Agriculture: Prairie Farm Rehabilitation Administration | 850 | – | 35 | – | 785 | 30 |
| 5. Dept. of Transport: Engineering Design Division | 1 800 | – | 18 | – | 1 732 | 50 |
| 6. Defence Research | 33 | – | 33 | – | – | – |
| 7. Dept. of Public Works: Testing Laboratories | 300 | – | 40 | 2 | 258 | – |
| **Total** | **3 805** | **143** | **297** | **108** | **3 110** | **147** |

[a] Only costs related to engineering geology are indicated here. Of course, the general-purpose topographic, geological and geophysical mapping of the Department also finds widespread application in the construction industry as in the mineral industry.

the industry. On the provincial level, an even smaller proportion of the data from geotechnical activities finds its way into general public use.

*Manpower*

The number of professionals engaged in geotechnical activities in Canada represents approximately 10 per cent of the national earth scientist population (Table II.22). Although the contractors and consultants are grouped, the geotechnical personnel in industry is employed almost exclusively by consultants or the design professions rather than by contractors. In contrast to other areas of earth science activity, engineers form the major speciality group (85%), although the distribution of degrees is not significantly different from that in the national earth scientist population.

Figure II.11 shows the 1963-68 growth in geotechnical manpower, as indicated in returns to the Study Group. The figure clearly illustrates the growing geotechnical expertise in response to the rapid expansion of the construction industry in Canada.

## II.5 The Federal Agencies[1]

### General

Canada supports a wide range of earth science activities at the federal level.

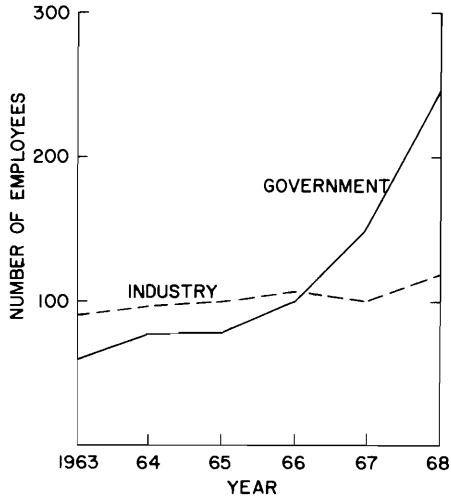
[1]Descriptions of the departments and their functions are given in Appendix 5.

**Table II.22–Geotechnical Manpower in Canada, 1968**

| Sector | Total | Degree | | | Speciality | | |
|---|---|---|---|---|---|---|---|
| | | Bachelor | Master | Doctor | Engineering | Geology | Other |
| *Industry* | 250 | 125 | 100 | 25 | 209 | 34 | 7 |
| *Government* | | | | | | | |
| Federal | 123 | 98 | 18 | 7 | 117 | 1 | 5 |
| Provincial | 105 | 84 | 16 | 5 | 80 | 25 | – |
| *University* | 70[a] | – | 5 | 65 | 60 | 6 | 4 |
| **Total** | **548** | **307** | **139** | **102** | **466** | **66** | **16** |

[a] Exclusive of graduate students.

Figure II.11–Growth in Geotechnical Manpower in Industry and the Federal Government, 1963-68



Their origin dates from the founding of the Geological Survey of Canada in 1842. Now 11 departments or agencies (Figure II.12) spend $53 million annually and employ 663 professionals in earth science activities (Tables II.23 and II.24). Fifty-nine per cent of the expenditures and 71 per cent of the personnel are in the Department of Energy, Mines and Resources (32% of the latter in the Geological Survey of Canada). Some departments, such as Energy, Mines and Resources, are equally funders, performers and co-ordinators of earth science activities. Others, such as the Canadian International Development Agency, are funders alone. Still others, such as the Department of Transport and the Department of Public Works, are principally performers and consumers of earth science activities to meet the internal needs of their departments.

The federal government has many reasons to use the earth sciences in the implementation of its national policies (Table II.25). The Canadian International Development Agency spends 12 per cent of the federal earth science budget as a means of aiding developing countries. The Defence Research Board places emphasis on seismology, geomagnetism and geotechnique, for nuclear detection, submarine detection and terrain analysis in the North. The Department of Agriculture supports soil science studies for agricultural development. The Department of Energy, Mines and Resources accounts for 59 per cent of the federal earth science expenditures: to provide the national basis for economic development through airphoto, topographic, geological and geophysical and hydrographic maps; to support the development of specific regions; to perform research and development in geological, geophysical and geochemical sciences for mineral resource development; and to sustain general physical science research. The Department of Industry, Trade and Commerce, as well as the National Research Council, encourages R & D in geophysical instrumentation as a factor in the growth of secondary industry. The Defence Research Board does likewise, but only to meet defence needs. The National Research Council funds earth science research in Canadian universities as part of its role in promoting scientific research in Canada, and performs earth science research related to the construction industry. The Department of Regional Economic Expansion is a funder of earth science activities for regional needs. Similarly, the Department of Indian Affairs and Northern Development supports earth science activities for northern development. Finally, the National Museum and the National and Historic Parks Branch of the Department of Indian Affairs and Northern Development portray the earth sciences to the public in their cultural and recreational programs.

**The Federal Government as a Funder of Earth Sciences**

The federal government's expenditure on earth science activities in 1968-69 was $53 million (Table II.23), accounting for 11 per cent of the national total (Table II.1). Of the federal government's research and development expenditure of $18 million, 31 per cent supported the conduct of R & D in universities and industry.

Table II.25 illustrates the breakdown of federal funding in terms of the various functions for which earth sciences are employed. Expenditures had to be assigned somewhat arbitrarily, as most earth science expenditures benefit many government functions beyond the immediate responsibilities of individual departments. For instance, the grants-in-aid of university research by the Defence Research Board and by Energy, Mines and Resources might well be classed under "general research" (Table II.25, item 6) rather than under the respective functions of the granting department (defence or economic measures). Activities of the Geological Survey of Canada are divided into: (1) mineral industry support, 50 per cent; (2) regional development, 30 per cent; (3) general purpose mapping, 20 per cent. Nevertheless, the estimates of

Figure II.12–Solid-Earth Science Activities in the Federal Government, 1969 (Circles are proportional to size of expenditure and size of in-house activity (black)

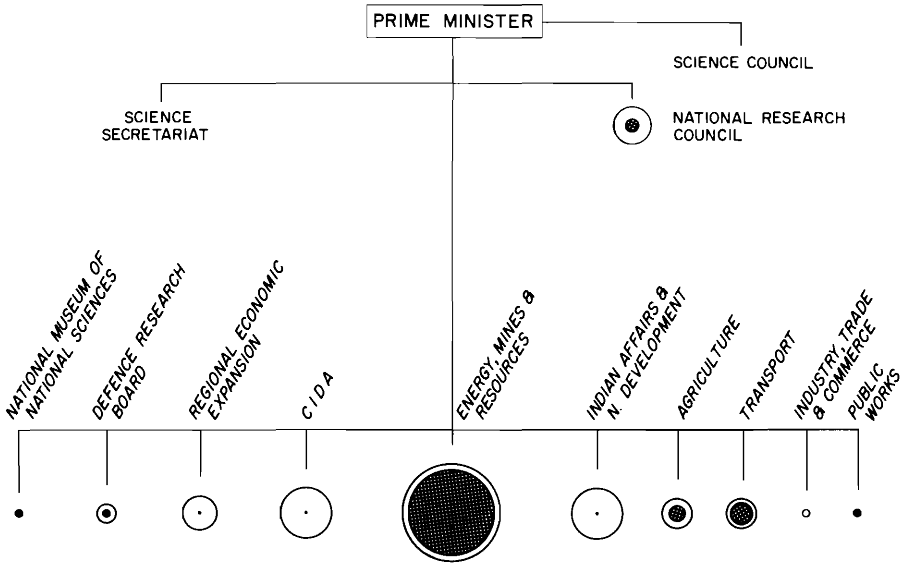


**Table II.23–Total Solid-Earth Science Funding[a] by the Federal Government, Year 1968-69**

| Department and Unit | Total Expenditure | Basic Research | Applied Research | Development | Scientific Data Collection | Scientific Information | Intramural, % of Total Expenditure |
|---|---|---|---|---|---|---|---|
| | $'000 | $'000 | $'000 | $'000 | $'000 | $'000 | % |
| 1. Department of Energy, Mines & Resources[b] | | | | | | | |
| A. Mines & Geosciences Sector (incl. Mineral Development) | 24 152 | 3 162 | 4 931 | 1 601 | 10 091 | 4 367 | 93 |
| B. Water Sector (solid-earth activities only) | 6 727 | 643 | 1 063 | 600 | 3 507 | 914 | 99 |
| **Subtotal** | **30 879** | **3 805** | **5 994** | **2 201** | **13 598** | **5 281** | **94** |
| 2. Canadian International Development Agency | 6 030 | – | – | 630 | 4 640 | 760[c] | 0 |
| 3. Department of Indian Affairs & Northern Development | | | | | | | |
| A. Northern Mineral Development & Assistance Grants | 5 290 | – | – | – | 5 290 | – | 0 |
| 4. National Research Council | | | | | | | |
| A. Division of Building Research | 533 | 143 | 132 | 86 | 115 | 57 | 100 |
| B. Canadian Journal of Earth Sciences | 107 | | | | – | 107 | 100 |
| C. Earth Science grants | 3 171 | 2 146 | 842 | 183 | – | – | 0 |
| D. Associate committees in earth sciences | 33 | – | – | – | – | 33 | 0 |
| E. Industrial Research Assistance Program | 77 | – | 77 | – | – | – | 0 |
| **Subtotal** | **3 921** | **2 289** | **1 051** | **269** | **115** | **197** | **17** |
| 5. Department of Agriculture | | | | | | | |
| A. Soil Research Institute | 1 181 | 207 | 532 | – | 395 | 47 | 100 |
| B. Prairie Farm Rehabilitation Administration | 850 | – | 35 | – | 785 | 30 | 100 |
| C. Departmental grants (soil science research) | 32 | 9 | 23 | – | – | – | 0 |
| **Subtotal** | **2 063** | **216** | **590** | **–** | **1 180** | **77** | **98** |
| 6. Department of Transport | | | | | | | |
| A. Engineering Design Division | 1 800 | – | 18 | – | 1 732 | 50 | 90 |
| 7. Department of Regional Economic Expansion | | | | | | | |
| A. Atlantic Development Board | 35 | – | 35 | – | – | – | 0 |
| B. Canada Land Inventory | 1 250 | – | – | – | – | 1 250 | 0 |
| **Subtotal** | **1 285** | **–** | **35** | **–** | **–** | **1 250** | **0** |
| 8. Defence Research Board | 800 | 138 | 662 | – | – | – | 62 |
| 9. National Museum of Natural Sciences | 139 | 28 | 27 | – | 42 | 42 | 100 |
| 10. Department of Industry, Trade and Commerce | 116 | – | – | 116[d] | – | – | 0 |
| 11. Department of Public Works | | | | | | | |
| A. Testing Laboratories | 300 | – | 40 | 2 | 258 | – | 100 |
| **Total Federal Expenditures** | **52 623** | **6 476** | **8 417** | **3 218** | **26 855** | **7 657** | **67%** |

[a] Eldorado Nuclear Ltd. is classified under the industry sector in this Study.

[a] Eldorado Nuclear Ltd. is classified under the industry sector in this Study.
[b] See Appendix 5, Table 5, for further subdivision.
[c] Expenditures on earth science education and training.
[d] Expenditures under PAIT. Payments made under the IRDIA program are assigned to overall research programs of companies rather than specific projects, and it is not possible to classify them in terms of solid-earth sciences. IRDIA payments to companies classified as "mines, oil wells and gas wells" in 1968-69 were $745 000.

**Table II.24–Federal Government Professional Personnel Engaged in Solid-Earth Science Activities, Year 1968-69**

| Department and Unit | Geology | Geophysics | Geo-chemistry | Geography | Soil Science | Engineering | Other Physical Sciences | Total |
|---|---|---|---|---|---|---|---|---|
| 1. Department of Energy, Mines & Resources | | | | | | | | |
| *A. Mines & Geosciences Sector* | | | | | | | | |
| 1. Geological Survey of Canada | 163 | 11 | 7 | 10 | – | 5 | 15 | 211 |
| 2. Observatories Branch | 9 | 28 | – | – | – | – | 24 | 61 |
| 3. Surveys & Mapping Branch | – | – | – | 2 | – | 47 | – | 49 |
| 4. Mines Branch | 8 | – | – | – | – | 13 | 19 | 40 |
| 5. Polar Continental Shelf Project | 3 | 4 | – | 2 | – | – | 2 | 11 |
| *B. Mineral Development Sector* | | | | | | | | |
| 1. Mineral Resources Branch | 22 | – | – | 1 | – | 13 | – | 36 |
| *C. Water Sector* | | | | | | | | |
| 1. Inland Waters Branch | 19 | 1 | 2 | 7 | – | 3 | 5 | 37 |
| 2. Marine Sciences Branch | 13 | 7 | – | – | – | 1 | 1 | 22 |
| **Subtotal** | **237** | **51** | **9** | **22** | **–** | **82** | **66** | **467 (70%)** |
| 2. Department of Transport | – | – | – | – | – | 82 | – | 82 |
| 3. Department of Agriculture | | | | | | | | |
| A. Soil Research Institute | 4 | – | – | 1 | 37 | – | 8 | 50 |
| B. Prairie Farm Rehabilitation Administration | – | – | – | – | – | 17 | – | 17 |
| 4. National Research Council | | | | | | | | |
| A. Division of Building Research | – | – | – | 2 | 1 | 10 | 2 | 15 |
| 5. Dept. of Indian Affairs & Northern Development | 6 | – | – | – | – | 6 | – | 12 |
| 6. Defence Research Board | 2 | 1 | – | 1 | – | – | 5 | 9 |
| 7. Dept. of Public Works | – | – | – | – | – | 8 | – | 8 |
| 8. National Museum of Natural Sciences | 2 | – | – | – | – | – | 1 | 3 |
| 9. Cdn. International Development Agency | – | – | – | – | – | – | – | – |
| 10. Dept. of Regional Economic Expansion | | | | | | | | |
| A. Canada Land Inventory | – | – | – | – | – | – | – | – |
| **Total** | **251** | **52** | **9** | **26** | **38** | **205** | **82** | **663 (100%)** |

**Table II.25–Total Expenditures on Solid-Earth Science Activities by Federal Departments and Agencies, Year 1968-69, Classified According to Function[a]**

| Governmental Functions | Expenditure | | | |
|---|---|---|---|---|
| | Total Scientific Activities | | R & D | |
| | $'000 | % | $'000 | % |
| 1. Foreign Affairs | | | | |
| a) Contributions to international organizations (EMR, NRC) | 37 | – | – | – |
| b) Assistance to developing countries (CIDA) | 6 030 | – | 630 | – |
| **Subtotal** | **6 067** | **12** | **630** | **3** |
| 2. Defence | | | | |
| a) Defence Research Board | 800 | 2 | 800 | – |
| **Subtotal** | **800** | **2** | **800** | **4** |
| 3. Economic Measures | | | | |
| *A. Primary Industry* | | | | |
| a) Agriculture (CDA) | 1 213 | 2 | 771 | 4 |
| b) Minerals (EMR) | 6 936 | 13 | 3 943 | 22 |
| c) Water resources (EMR) | 4 027 | 8 | 2 306 | 13 |
| **Subtotal** | **12 176** | **23** | **7 020** | **39** |
| *B. Secondary Industry* | | | | |
| a) Industrial Research Assistance (NRC) | 77 | – | 77 | – |
| b) General Incentives for R&D (Dept. of Industry) | 116 | – | 116 | – |
| **Subtotal** | **193** | **<1** | **193** | **1** |
| *C. Transportation* | | | | |
| a) Air transport (DOT) | 1 800 | 3 | 18 | – |
| b) Road transport (DPW) | 300 | 1 | 42 | – |
| c) Marine transport (EMR) | 2 600 | 5 | – | – |
| **Subtotal** | **4 700** | **9** | **60** | **<1** |
| *D. Construction* | | | | |
| a) Building Research Division, NRC | 533 | 1 | 361 | – |
| b) Geological Survey of Canada | 100 | – | 20 | – |
| **Subtotal** | **633** | **1** | **381** | **2** |
| *E. General Research (Physical Sciences)* | | | | |
| a) University grants (NRC, etc.) | 3 177 | 6 | 3 177 | 18 |
| b) Polar Continental Shelf Project | 1 991 | 4 | 966 | 5 |
| c) Observatories Branch, EMR | 2 678 | 5 | 1 328 | 7 |
| **Subtotal** | **7 846** | **15** | **5 471** | **30** |
| *F. Regional Development* | | | | |
| a) Northern Mineral Development (IAND) | 5 290 | 10 | – | – |
| b) Geological Survey of Canada (30% of budget) | 3 500 | 7 | 1 960 | 11 |
| c) Cdn Land Inventory & Atlantic Development Board | 1 285 | 2 | 35 | – |
| d) Prairie Farm Rehabilitation Administration | 850 | 1 | 35 | – |
| **Subtotal** | **10 925** | **20** | **2 030** | **11** |
| *G. Other Economic Measures* (general purpose mapping) | | | | |
| a) Surveys & Mapping Branch (EMR) | 6 704 | 13 | 170 | 1 |
| b) Geological Survey of Canada (20% of budget) | 2 315 | 4 | 1 300 | 7 |
| **Subtotal** | **9 019** | **17** | **1 470** | **8** |
| 4. Culture and Recreation | | | | |
| a) National Museum | 139 | – | 55 | – |
| b) National Parks & Historic Sites | 10 | – | – | – |
| c) Geological Survey of Canada | 25 | – | – | – |
| **Subtotal** | **174** | **<1** | **55** | **<1** |
| **Total** | **52 533** | **100** | **18 110** | **100** |

[a] This is the functional classification of government expenditures adopted by the Treasury Board of the federal government. General Government, Social Measures, and Education classifications are excluded.

expenditures shown in the table are sufficiently accurate to allow analysis, and to indicate the low levels of funding that exist.

In Chapter VIII we reach the conclusion that the federal expenditure of $6 million on earth sciences in the foreign aid program should be increased to reach a level of $30 million by 1975. We do not have at hand ready yardsticks to assess levels of earth science expenditure related to defence, agriculture and water.

In 1968 the federal expenditure on earth science activities related directly to the mineral industry (Table II.25) was $7 million.[1] Those expenditures related to regional development, including northern development, are not included in this estimate since they are a "charge" on the entire economy, not on the mineral industry specifically. The need for increased federal funding to meet the scientific needs of industry are developed in succeeding chapters. Evidence that the mineral industry is "paying its way" is presented in Figure II.13 and Table II.26, which summarize government revenues from the mineral industry.

The proper level of funding of earth science activities related to regional development is a matter of political decision arising from economic considerations. Twenty per cent of the federal earth science expenditures can be classified for this purpose, three-quarters of which (approximately $8 million) are spent north of the 60th parallel. This sum can be compared with $6 million spent by the Canadian Government on earth science activities in developing countries.

The federal expenditure on general-purpose mapping can be assessed in relation to the present extent of national coverage, and the present rate of progress by federal and provincial agencies in completing the national coverage to acceptable standards. These matters are

[1] If we add to this the expenditures of the Mines Branch of the Department of Energy, Mines and Resources related to mining and metallurgy, the total federal expenditure for scientific activities bearing on the mining industry was approximately $15 million.

**Table II.26–Federal Government Revenues from the Mineral Industry**

| Department | Purpose | Year 1965–66 | Year 1966–67 | Year 1967–68 | Year 1968–69 |
|---|---|---|---|---|---|
| | | $million | $million | $million | $million |
| Indian Affairs and Northern Development | Revenues from mining operations | 1.17 | 1.26 | 0.76 | 0.80 |
| | Revenues from oil operations | 6.27 | 1.77 | 2.00 | 9.60 |
| **Subtotal** | | **7.44** | **3.03** | **2.76** | **10.40** |
| Energy, Mines & Resources | Offshore oil permits | – | 0.11 | 0.10 | 0.64 |
| | Federal leases in provinces | – | 0.30 | 0.28 | 0.31 |
| **Subtotal** | | – | **0.41** | **0.38** | **0.95** |
| | | Year 1965 | Year 1966 | Year 1967 | Year 1968 |
| Finance[a] | Corporation income tax from companies classified by DBS as: | | | | |
| | Gold mines | 2.5 | 2.4 | 1.7 | Not available |
| | Iron mines | 3.7 | 2.8 | 1.1 | |
| | Other metal mines | 25.7 | 20.5 | 29.0 | |
| | Coal mines | 0.3 | 0.2 | 0.1 | |
| | Oil & gas wells | 9.0 | 14.1 | 46.5 | |
| | Nonmetal mining | 14.0 | 16.9 | 11.4 | |
| | Quarries | 1.2 | 3.4 | 2.6 | |
| | Mining services | 6.2 | 2.5 | 2.4 | |
| **Subtotal** | | **62.6** | **62.8** | **94.8** | |

[a] Revenues from companies classified under smelting and refining, iron and steel mills, iron foundries, petroleum refineries, and coal and oil products are not included in this tabulation.

expenditures shown in the table are sufficiently accurate to allow analysis, and to indicate the low levels of funding that exist.

In Chapter VIII we reach the conclusion that the federal expenditure of $6 million on earth sciences in the foreign aid program should be increased to reach a level of $30 million by 1975. We do not have at hand ready yardsticks to assess levels of earth science expenditure related to defence, agriculture and water.

In 1968 the federal expenditure on earth science activities related directly to the mineral industry (Table II.25) was $7 million.[1] Those expenditures related to regional development, including northern development, are not included in this estimate since they are a "charge" on the entire economy, not on the mineral industry specifically. The need for increased federal funding to meet the scientific needs of industry are developed in succeeding chapters. Evidence that the mineral industry is "paying its way" is presented in Figure II.13 and Table II.26, which summarize government revenues from the mineral industry.

The proper level of funding of earth science activities related to regional development is a matter of political decision arising from economic considerations. Twenty per cent of the federal earth science expenditures can be classified for this purpose, three-quarters of which (approximately $8 million) are spent north of the 60th parallel. This sum can be compared with $6 million spent by the Canadian Government on earth science activities in developing countries.

The federal expenditure on general-purpose mapping can be assessed in relation to the present extent of national coverage, and the present rate of progress by federal and provincial agencies in completing the national coverage to acceptable standards. These matters are

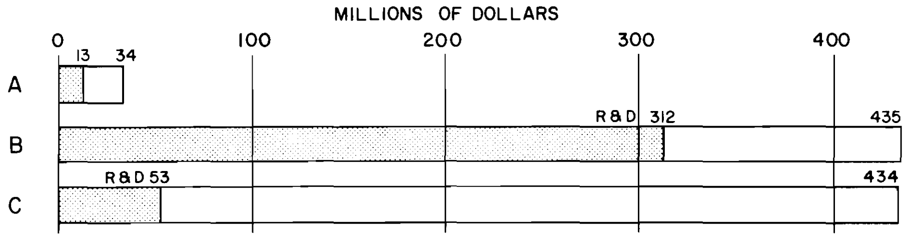
[1]If we add to this the expenditures of the Mines Branch of the Department of Energy, Mines and Resources related to mining and metallurgy, the total federal expenditure for scientific activities bearing on the mining industry was approximately $15 million.

**Table II.26–Federal Government Revenues from the Mineral Industry**

| Department | Purpose | Year | | | |
|---|---|---|---|---|---|
| | | 1965–66 | 1966–67 | 1967–68 | 1968–69 |
| | | $million | $million | $million | $million |
| Indian Affairs and Northern Development | Revenues from mining operations | 1.17 | 1.26 | 0.76 | 0.80 |
| | Revenues from oil operations | 6.27 | 1.77 | 2.00 | 9.60 |
| **Subtotal** | | **7.44** | **3.03** | **2.76** | **10.40** |
| Energy, Mines & Resources | Offshore oil permits | – | 0.11 | 0.10 | 0.64 |
| | Federal leases in provinces | – | 0.30 | 0.28 | 0.31 |
| **Subtotal** | | – | **0.41** | **0.38** | **0.95** |
| | | Year 1965 | Year 1966 | Year 1967 | Year 1968 |
| Finance[a] | Corporation income tax from companies classified by DBS as: | | | | |
| | Gold mines | 2.5 | 2.4 | 1.7 | Not available |
| | Iron mines | 3.7 | 2.8 | 1.1 | |
| | Other metal mines | 25.7 | 20.5 | 29.0 | |
| | Coal mines | 0.3 | 0.2 | 0.1 | |
| | Oil & gas wells | 9.0 | 14.1 | 46.5 | |
| | Nonmetal mining | 14.0 | 16.9 | 11.4 | |
| | Quarries | 1.2 | 3.4 | 2.6 | |
| | Mining services | 6.2 | 2.5 | 2.4 | |
| **Subtotal** | | **62.6** | **62.8** | **94.8** | |

[a] Revenues from companies classified under smelting and refining, iron and steel mills, iron foundries, petroleum refineries, and coal and oil products are not included in this tabulation.

Figure II.13–Federal Expenditures on In-House Solid-Earth Activities (A), compared with Total Federal In-House Expenditures on other Scientific Activities (B), and Solid-Earth Science Expenditures of all other Sectors–Industry, Universities and Provincial Agencies (C), 1968-69



discussed in Chapter VII, where it is indicated that the present rates of completion of the topographic, geological and geophysical mapping of Canada are not adequate for the immediate needs of national development.

The federal level of funding earth science research (excluding contract research) in the universities is summarized in Table II.27. If we include major equipment and travel grants, this amounted to over $4 million, or $6 700 for every earth science professor in the geology, geophysics, geography, engineering and agricultural departments of Canadian universities. The number of grants (594) awarded in 1968 is remarkably close to the number of faculty members plus research associates (593 in total) shown in Table II.5. This situation is not uncommon in the funding of university research in Canada. There are at least 10 different sources of federal funds for university research in the earth sciences, over half being in the Department of Energy, Mines and Resources (Table II.27). Only grants of the National Research Council and the Geological Survey of Canada cover the complete range of earth science specialities. A number of specialities (Quaternary geology, glaciology, seismology, geomagnetism, rock mechanics, soil mechanics, and hydrogeology) can expect to obtain support from three or four agencies, while one (mineral economics) requires support outside the normal granting committees. Despite these multiple sources of research funds, the level of support, as well as the relative levels of support between disciplines, is established primarily by the National Research Council earth science grants. This situation has led the National Advisory Committee on Research in the Geological Sciences to comment[1]:

"The large increase in NRC grants has resulted in the majority of applicants for GSC grants also receiving substantial grants from NRC. In fact, in the last few years, 75 to 80 per cent of the applicants for GSC grants have been awarded grants for the same or similar projects a month or so before the applications for GSC grants are reviewed. As a consequence, 75 to 80 per cent of the GSC applications are, in effect, for supplements to NRC grants. Because NRC awards are on the average less than two-thirds of the amount requested, these supplements are needed and justified. However, it means that in reviewing the GSC applications, after providing for the 20 to 25 per cent not already receiving NRC grants, the Projects Subcommittee has no recourse but to divide the balance equally between the 75 to 80 per cent of the applicants receiving NRC grants whose projects have already been reviewed by NRC. This has led the NAC to consider means whereby the GSC grants may be directed to fields or major projects which the Committee through its subcommittees considers as particularly deserving of support."

The level of earth science funding in Canadian universities and the adequacy of the funding mechanisms are discussed more fully in Chapter III.

Direct federal funding of earth science activities in provincial agencies is remarkably low, although examples exist of projects which were funded and performed co-operatively by both groups. The federal-provincial aeromagnetic program is a good example. A case can be made that the constitutional division of responsibilities for the administration of mineral resources under the British North America Act is a barrier to the flow of federal funds in support of provincial departments of mines. As a result, in a number of provinces, earth science expenditures in the universities (largely supported by federal funds for research) are higher than those in provincial departments of mines. Federal support of earth science activities in provincial research councils has come largely

[1]Eighteenth Annual Report (1967-68) of the National Advisory Committee on Research in the Geological Sciences. 1969. pp. 2-3.

**Table II.27–Grants-in-Aid[a] of University Research in the Solid-Earth Sciences, Year 1968-69**

| Solid-Earth Science Speciality | Funding Departments | | | | | | | | | | | | | | | | | | | | Totals | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | National Research Council[b] | | Defence Research Board | | Dept. of Agriculture | | Department of Energy, Mines and Resources | | | | | | | | | | | | | | | |
| | | | | | | | Geological Survey of Canada | | Mines Branch | | Observa-tories Branch | | NACWRR[c] | | NACGR[d] | | Surveys and Mapping Branch | | Mineral Resources Branch | | | |
| | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 |
| *Geology* | | | | | | | | | | | | | | | | | | | | | | |
| Paleontology & paleobotany | 29 | 223 | – | – | – | – | 12 | 29 | – | – | – | – | – | – | – | – | – | – | – | – | 41 | 252 |
| Mineralogy & crystallography | 26 | 203 | – | – | – | – | 10 | 15 | – | – | – | – | – | – | – | – | – | – | – | – | 36 | 218 |
| Stratigraphy & sedimentology | 30 | 200 | – | – | – | – | 17 | 35 | – | – | – | – | – | – | – | – | – | – | – | – | 47 | 235 |
| Petrology | 30 | 180 | – | – | – | – | 19 | 40 | – | – | – | – | – | – | – | – | – | – | – | – | 49 | 220 |
| Structural geology & tectonophysics | 17 | 148 | 1 | 6 | – | – | 10 | 21 | – | – | – | – | – | – | – | – | – | – | – | – | 28 | 175 |
| Mineral deposits geology | 15 | 119 | – | – | – | – | 7 | 16 | – | – | – | – | – | – | – | – | – | – | – | – | 22 | 135 |
| Quaternary geology & geomorphology | 25 | 139 | 1 | 2 | – | – | 5 | 8 | – | – | – | – | – | – | 13 | 15 | – | – | – | – | 44 | 164 |
| Pedology | 12 | 90 | – | – | 8 | 32 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 20 | 122 |
| Glaciology (incl. snow & ice) | 10 | 74 | 2 | 16 | – | – | – | – | – | – | – | – | 3 | 22 | – | – | – | – | – | – | 15 | 112 |
| Marine geology | 7 | 68 | – | – | – | – | 2 | 4 | – | – | – | – | – | – | – | – | – | – | – | – | 9 | 72 |
| Computer applications | 8 | 45 | – | – | – | – | 5 | 43 | – | – | – | – | – | – | – | – | – | – | – | – | 13 | 88 |
| **Subtotal** | **209** | **1 489** | **4** | **24** | **8** | **32** | **87** | **211** | **–** | **–** | **–** | **–** | **3** | **22** | **13** | **15** | **–** | **–** | **–** | **–** | **324** | **1 793** |
| *Geophysics* | | | | | | | | | | | | | | | | | | | | | | |
| Seismology | 11 | 119 | 7 | 61 | – | – | 3 | 6 | – | – | 5 | 9 | – | – | – | – | – | – | – | – | 26 | 195 |
| Geomagnetism | 10 | 103 | 2 | 18 | – | – | 3 | 4 | – | – | – | – | – | – | – | – | – | – | – | – | 15 | 125 |
| Heat flow | 5 | 61 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 5 | 61 |
| Exploration geophysics | 6 | 42 | – | – | – | – | 1 | 2 | – | – | – | – | – | – | – | – | – | – | – | – | 7 | 44 |
| Marine geophysics | 4 | 29 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 4 | 29 |
| Other geophysical research | 10 | 84 | – | – | – | – | 1 | 2 | – | – | – | – | – | – | – | – | – | – | – | – | 11 | 86 |
| **Subtotal** | **46** | **438** | **9** | **79** | **–** | **–** | **8** | **14** | **–** | **–** | **5** | **9** | **–** | **–** | **–** | **–** | **–** | **–** | **–** | **–** | **68** | **540** |

**Table II.27–Grants-in-Aid[a] of University Research in the Solid-Earth Sciences, Year 1968-69 (Concluded)**

| Solid-Earth Science Speciality | Funding Departments | | | | | | | | | | | | | | | | | | | | Totals | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | National Research Council[b] | | Defence Research Board | | Dept. of Agriculture | | Department of Energy, Mines and Resources | | | | | | | | | | | | | | | |
| | | | | | | | Geological Survey of Canada | | Mines Branch | | Observatories Branch | | NACWRR[c] | | NACGR[d] | | Surveys and Mapping Branch | | Mineral Resources Branch | | | |
| | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 | No. | $'000 |
| *Geochemistry* | | | | | | | | | | | | | | | | | | | | | | |
| Isotope geochemistry | 20 | 200 | – | – | – | – | 6 | 12 | – | – | – | – | – | – | – | – | – | – | – | – | 26 | 212 |
| Inorganic geochemistry | 18 | 184 | – | – | – | – | 9 | 15 | – | – | – | – | – | – | – | – | – | – | – | – | 27 | 199 |
| Mineral synthesis | 7 | 64 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 7 | 64 |
| Organic geochemistry | 4 | 35 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 4 | 35 |
| Exploration geochemistry | 5 | 29 | – | – | – | – | 2 | 3 | – | – | – | – | – | – | – | – | – | – | – | – | 7 | 32 |
| **Subtotal** | **54** | **512** | **–** | **–** | **–** | **–** | **17** | **30** | **–** | **–** | **–** | **–** | **–** | **–** | **–** | **–** | **–** | **–** | **–** | **–** | **71** | **542** |
| *Geotechnique* | | | | | | | | | | | | | | | | | | | | | | |
| Soil mechanics | 44 | 313 | 3 | 7 | – | – | 2 | 4 | – | – | – | – | – | – | – | – | – | – | – | – | 49 | 324 |
| Rock mechanics | 19 | 129 | 2 | 14 | – | – | 1 | 2 | 11 | 38 | – | – | – | – | – | – | – | – | – | – | 33 | 183 |
| Hydrogeology | 29 | 196 | – | – | – | – | 1 | 2 | – | – | – | – | 1 | 3 | – | – | – | – | – | – | 31 | 201 |
| Engineering geology | 9 | 55 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 9 | 55 |
| **Subtotal** | **101** | **693** | **5** | **21** | **–** | **–** | **4** | **8** | **11** | **38** | **–** | **–** | **1** | **3** | **–** | **–** | **–** | **–** | **–** | **–** | **122** | **763** |
| Photogrammetry | 3 | 39 | 2 | 14 | – | – | – | – | – | – | – | – | – | – | – | – | 2 | 2 | – | – | 7 | 55 |
| Geodesy | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 1 | 7 | – | – | 1 | 7 |
| Mineral economics | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 1 | 5 | 1 | 5 |
| **Total Solid-Earth Science Grants** | **413** | **3 171** | **20** | **138** | **8** | **32** | **116** | **263** | **11** | **38** | **5** | **9** | **4** | **25** | **13** | **15** | **3** | **9** | **1** | **5** | **594** | **3 705** |
| **% of Total University Grants** | | **10** | | **5** | | **5** | | **100** | | **38** | | **32** | | **5** | | **47** | | **36** | | **100** | | **10** |

[a] Contracts for university research are not included. The earth science component of Northern Research Grants by the Dept. of Indian Affairs and Northern Development are not included.
[b] Travel grants and major equipment grants are not included.
[c] National Advisory Committee on Water Resources Research grants, awarded jointly by Inland Waters, and Policy and Planning Branch.
[d] National Advisory Committee on Geographical Research grants, awarded by Policy and Planning Branch.

through the Agricultural Rehabilitation and Development Act programs (research in geology, hydrology, geophysics, and for groundwater and soil surveys), as well as through the Atlantic Development Board.

Federal funding of earth science activities in industry is also on a limited scale. In terms of R & D funding, the practically total exclusion of exploration activities from research and development, by definition, effectively limits earth science R & D support to the field of geophysical instrument development. It may be argued, however, that federal depletion and other tax allowances, as well as the Northern Mineral Development grants, compensate for the need to provide support for industrial research and development related to exploration.

## The Federal Government as a Performer of Earth Science Activities

### *General Level of Activity*

Federal government in-house earth science activities amount to 14 per cent of the national expenditure on earth sciences. With respect to R & D, federal in-house expenditures are 20 per cent of the national expenditure. This is in startling contrast to the normal distribution among sectors of R & D effort in all sciences in Canada.[1] *Earth science R & D represents only 4 per cent of the federal government's total R & D in the physical sciences (Figure II.13).*

Much of the federal in-house earth science activity benefits a large part of society and is conducted in support of the broad functions of the federal government (Table II.28). Sixty per cent of the expenditure is allocated to scientific data collection and information. Research and development is performed as a supporting activity for government missions. In 1968, the federal in-house expenditure on R & D ($13 million) was twice the university expenditure ($6 million).

The principal performers of federal activities are also indicated in Table II.28, where they are related to the functions served. The nature of their work is described more fully in Appendix 5. Seventy-one per cent of the earth scientists engaged in these activities are in the Department of Energy, Mines and Resources (Table II.24). Their fields of training are: geology (38%), engineering (31%), other physical sciences (12%), geophysics (8%), soil sciences (6%), geography (4%) and geochemistry (1%). The number of earth scientists in federal agencies (663) is comparable to the size of the earth science faculty in universities (593).

### *Summary of In-House Earth Science Activities*

The earth science activities of the *Department of Agriculture* (Table II.28, item 2Aa) are concerned with the study of soils, including their distribution, mineral composition and alteration, and chemical and physical properties. The in-house expenditure of $2 million represents 3.6 per cent of the department's expenditure on scientific activities.

The earth science activities of the *Defence Research Board* relate principally to nuclear explosion, submarine detection and terrain analysis (Table II.28, item 1a). They represent 0.8 per cent of the total in-house scientific activity of the Department of National Defence.

Earth science activities in the *Department of Energy, Mines and Resources* relate to many functions of government (see Appendix 5 for organization chart and detailed descriptions). The accurate description of Canada's land surface through aerial photography, geodetic and topographic surveys, and the publication

[1]According to Senator A. Grosart in *Challenges to the Canadian Science Community*, Report of the National Science and Engineering Conference, Carleton University, 1969, "the mix was industry 17 per cent, universities 18 per cent, government in-house 62 per cent" in 1968. Our data show that in the earth sciences, industry performs 64 per cent, universities perform 10 per cent, the federal government performs 20 per cent, and provincial agencies perform 6 per cent. In the United States: "...the aggregate of research undertaken by industry, State and local governments and the academic community has been estimated to be less than half the amount conducted by the Federal Government." *Solid-Earth Science*, a report of an *ad hoc* Working Group to the U.S. Federal Council of Science and Technology, July 1967.

**Table II.28–In-House Expenditures on Solid-Earth Science Activities by Federal Departments and Agencies, Classified according to Function, Year 1968-69**

| Governmental Functions | Expenditure | | | |
|---|---|---|---|---|
| | Total Scientific Activities | | R & D | |
| | $'000 | % | $'000 | % |
| 1. Defence | | | | |
| a) Defence Research Board | 500 | – | 500 | – |
| **Subtotal** | **500** | **1** | **500** | **4** |
| 2. Economic Measures | | | | |
| *2A. Primary Industry* | | | | |
| a) Agriculture (CDA) | 2 031 | 6 | 774 | 6 |
| b) Minerals (EMR) | 6 100 | 18 | 3 796 | 28 |
| c) Water resources (EMR) | 3 952 | 11 | 2 231 | 17 |
| **Subtotal** | **12 083** | **35** | **6 801** | **51** |
| *2B. Transportation* | | | | |
| a) Air transport (DOT) | 1 620 | 5 | 18 | – |
| b) Road transport (DPW) | 300 | 1 | 42 | – |
| c) Marine transport (EMR) | 2 700 | 8 | – | – |
| **Subtotal** | **4 620** | **14** | **60** | **–** |
| *2C. Construction* | | | | |
| a) Building Research Division (NRC) | 533 | – | 361 | – |
| b) Geological Survey of Canada | 100 | – | 20 | – |
| **Subtotal** | **633** | **1** | **381** | **3** |
| *2D. General Research (Physical Sciences)* | | | | |
| a) Polar Continental Shelf Project | 1 991 | 6 | 966 | 7 |
| b) Observatories Branch, EMR | 2 669 | 8 | 1 319 | 10 |
| c) NRC Journal of Earth Sciences | 107 | – | – | – |
| **Subtotal** | **4 767** | **14** | **2 285** | **17** |
| *2E. Regional Development* | | | | |
| a) Geological Survey of Canada (30% of budget) | 3 035 | – | 1 901 | – |
| **Subtotal** | **3 035** | **9** | **1 901** | **14** |
| *2F. Other Economic Measures (general purpose mapping)* | | | | |
| a) Surveys & Mapping Branch (EMR) | 6 705 | 19 | 172 | 2 |
| b) Geological Survey of Canada (20% of budget) | 1 923 | 6 | 1 233 | 9 |
| **Subtotal** | **8 628** | **25** | **1 405** | **11** |
| 3. Culture and Recreation | | | | |
| a) National Museum | 139 | – | 55 | – |
| b) National Parks & Historic Sites | 10 | – | – | – |
| c) Geological Survey of Canada | 25 | – | – | – |
| **Subtotal** | **174** | **1** | **55** | **–** |
| **Total** | **34 440** | **100** | **13 388** | **100** |

of the National Topographic Series of maps are the role of the Surveys and Mapping Branch (Table II.28, item 2 Fa).

The *Geological Survey of Canada* provides geological support for several government functions. It meets the need for systematic geological and aeromagnetic mapping and inventory in federal lands (over 50% of the Canadian landmass), for regional correlations and for national compilations (Item 2Fb). It conducts geological, geophysical and geochemical field research for northern development and for provinces to which it is committed under the terms of Confederation (Item 2Ea). Thirty per cent of the field expenditures in the year 1968-69 were for work north of the 60th parallel. The Geological Survey conducts mineral resource research on the origin of ore deposits, on theories and techniques of geochemical and geophysical exploration and related instrument development (Item 2Ab). It conducts geotechnical studies related to power sites (Item 2Cb). In support of all these activities it maintains core storage, geological, mineralogical, paleontological, meteorite and book collections, and data banks. In the year 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 maps were published.

The *Observatories Branch*[1] of the Department of Energy, Mines and Resources applies physics to the study of the solid earth. Although its activities are classified under general research (2Db) in Treasury Board classification, these activities meet national needs related to seismicity and earthquake hazards, nuclear blast detection and the description of the magnetic and gravity fields over Canada. The *Polar Continental Shelf Project* works closely with other Branches of Energy, Mines and Resources to co-ordinate and conduct earth science and other research in the far North (2Da). The *Mines Branch* uses the earth sciences and performs related research to improve the beneficiation of raw materials and develop mining technology (2Ab). The *Mineral Resources Branch* collects and analyses economic data on non-renewable resources (2Ab).

The *Marine Sciences Branch* is responsible for charting the sea floor (2Bc). It also conducts geological and geophysical surveys as part of its marine program. The *Inland Waters Branch* uses groundwater studies, glaciology and limnogeology in its function of investigating the inland water resources of Canada (2Ac).

In total, the Department of Energy, Mines and Resources had a professional staff of 467 engaged in the above activities in 1968-69. The expenditure amounted to $31 million (Appendix 5, Table 5.3), or approximately 40 per cent of the department's expenditure on scientific activities.

The *National Museum of Natural Sciences* spent $139 000 (13% of its budget) on earth science research and display activities (Item 3a). It is the principal federal agency responsible for portraying the earth sciences to the general public, yet it has very little impact except in the immediate Ottawa area. Immediate steps should be taken to improve and enlarge its displays of earth science materials, including the preparation of well-illustrated mobile exhibits portraying geological processes and the newer concepts of a dynamic earth. *The least that can be said is that present staff positions and budgets allocated to this Museum are wholly inadequate and completely below the expectations for a country such as ours, so richly endowed with geological phenomena and mineral resources.*

The *National Research Council* is not only the principal funder of earth science research in the universities, but is also the principal performer of federal geotechnical research related to the construction industry (Item 2Ca). Its expenditure on this function is also extremely low in relation to the value of construction in Canada. *In the year 1968-69, the National Research Council's expenditures of $533 000 on geotechnical activities were*

[1]Renamed the Earth Physics Branch, effective 1 April 1970.

*0.8 per cent of the National Research Council's total in-house expenditures on scientific activities.* The federal earth science expenditures of the *Department of Transport* and the *Department of Public Works* (Item 2Ba, b) represent geotechnical activities required to support the missions of these departments.

*Evaluation of Federal Earth Science Activities*

The decentralized application and funding of earth sciences in federal departments is a recent and natural development. Nevertheless it is accompanied by problems of communication, co-ordination, and effective use of professional staff, and several federal agencies have indicated the desirability of closer co-ordination. W.G. Schneider has indicated that "horizontal integration" in government is weak. He stated[1]:

"While there is good vertical integration within individual departments and agencies, horizontal integration and an overall synthesis of the total research effort tends to be weak...unless a more effective horizontal integration, together with some across-the-board planning, is achieved, our attack on problems is likely to be fragmentary and totally ineffective. I do not believe that the answer is to create more departments and agencies. This will only amplify the problem. Rather we must build on present structures and strengths and evolve some effective means for an overall synthesis and a more co-ordinated attack."

Problems of communication and co-ordination among earth science performers in the federal government could be reduced by the formation of a continuing federal committee on earth sciences, following a pattern proposed for the U.S. Federal Council for Science and Technology[2], and we submit:

[1]Decision making at the National Research Council. Address to National Science and Engineering Conference. Carleton University, July 31-Aug. 1, 1969.

[2]*Op. cit.*

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*Conclusion II.2*
*The Government of Canada should establish a continuing interdepartmental committee on earth sciences, with membership drawn from the user departments and agencies.*

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The functions of the proposed committee could include:

1. to provide for general discussion of the utilization of the earth sciences in the federal government, and for continuity of appraisal and consideration in terms of federal and national goals;
2. to provide a single authoritative information source of the federal government's activity in the earth sciences;
3. to provide a medium for program co-ordination and for discussion of interdepartmental relations;
4. to identify missing program elements and recommend appropriate action;
5. to investigate further opportunities for effective application of earth sciences toward attainment of national goals; and
6. to undertake special studies at the request of the Government of Canada.

Among the early tasks which could be undertaken by the committee, we recommend:

1. the preparation and dissemination of a guide to federal activities in the earth sciences (expanding upon Appendix 5 of our report), and
2. preparation of a statement of the Canadian government's goals in the earth sciences, taking into account the statements of industry, the universities and the scientific associations, as well as the statements of federal earth science departments as expressed in their program forecasts, and the definition of criteria by which to judge the government's program to achieve these goals.

Through questionnaire replies and briefs, industry has indicated that it receives excellent co-operation from the earth science agencies in government. Nevertheless, the widespread distribution of earth science activities through the federal government causes problems of co-ordination and information flow. The Alberta Society of Petroleum Geologists (ASPG) pinpointed a specific problem:

"Members of the Alberta Society of Petroleum Geologists, as representatives of their various companies, have noted that within that portion of government which deals with regulations governing exploration and basic exploration data, some duplication and lack of communication exist among the individual agencies in Government. It should be emphasized very strongly here that co-operation by individual agencies within the Government with members of industry is excellent. But it is also apparent that co-operation and communication between such agencies as the Geological Survey of Canada, the Resources Administration Division, the Department of Indian Affairs and Northern Development, and the Bedford Institute of Oceanography, to name the more prominent, is not in the same category as that between the individual agencies and members of industry. Misunderstandings as to the method of determining the use and dissemination of data obtained by the Department of Indian Affairs and Northern Development and the Resources Administration Division is common within the Geological Survey of Canada and other agencies. It is in the area of collection and dissemination of data that the ASPG is primarily concerned. The Society, in addition to this problem area, cannot see the merit of the present breakdown of areas of responsibilities that are held on the one hand by the Department of Indian Affairs and Northern Development, and on the other hand by the Department of Energy, Mines and Resources in the administration of the mineral wealth of that part of Canada not administered by the provinces. It is clear to the Society that one agency could do the job as well as, or better, than two."

We agree in part with the observation of the Alberta Society of Petroleum Geologists, that there is a loss of economy and efficiency in maintaining the mineral resource administration of federal lands in two separate federal departments. Without precluding the responsibilities of the Department of Indian Affairs and Northern Development for the development of northern lands, we consider that a centralization of the scientific services involved would result in better management, economy, and service.
We submit:

*Conclusion II.3*
*The earth science research and services related to regional and northern development should be centralized in the Department of Energy, Mines and Resources.*

Problems of horizontal integration are equally applicable to the internal organization of the Department of Energy, Mines and Resources, where concern and involvement in program planning in a vertical sense leave little time for horizontal co-ordination. Hence statements of sector, branch and division objectives as proposed in program forecasts lead to overlap of scope, and result in confusion among the scientists charged with their conduct. The following example of offshore earth science activities, appearing in the department's program forecast for 1970-71, illustrates the point:

*Geoscience Sector*
"The *Gravity Division* (Observatories Branch) is charged with the preparation and analysis of gravity maps over the land surface of Canada, its inland lakes and seas, and the adjoining continental shelves."

"The *Geological Survey of Canada Branch* investigates, describes and explains the geology (including geophysics, geochemistry, geomorphology and physical geography) of Canada, including the continental shelves..."

"The *Polar Continental Shelf Project* undertakes research and field surveys in the continental shelf area of Arctic Canada."

*Energy Sector*
"The Resource Administration Division is the federal agency primarily responsible for administering offshore mineral resources."

*Water Sector*
"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."

Given these circumstances, it is little wonder that uncertainty exists in the minds of a government officer when he serves the public. We therefore conclude:

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*Conclusion II.4*
*The earth science activities of the Department of Energy, Mines and Resources require closer co-ordination. This can be encouraged by grouping a number of the earth science activities relating to non-renewable resources (presently located under four separate assistant deputy ministers) under the assistant deputy minister for geosciences.*

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Comments on federal earth science publications were very favourable and indicated that industry is highly dependent upon them in mineral exploration programs. This dependence was evident in praise expressed, but also in the strong criticism of the delays in publication of new data. Publication delay results from a number of events starting with the author himself and his delay in finalizing the manucript of this report, proceeding to delays in editing and cartography, and finally to delays in the preparation of printing contracts and the printing itself. The volume of manuscripts to be handled and the requirements for translation further add to processing difficulties. To avoid the publication delay, many federal scientists and agencies publish mainly in outside scientific journals. The Geological Survey has instituted an open-file system for manuscript materials and has placed increased emphasis on the publication of papers in offset form, and maps in preliminary and uncoloured format, rather than the publication of memoirs and coloured maps. Nevertheless, further improvements can be made. More rigorous attention to schedules based on recognized priorities is necessary. Better lines of responsibility must be established. We consider that final responsibility for the editing of manuscripts should lie entirely within the Geological Survey. As well, the Queen's Printer should assign a printing contractor to deal directly with the Survey management on matters of publication. Hence we conclude:

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*Conclusion II.5*
*To make its results more quickly available, yet at competitive cost, the Geological Survey of Canada should be assigned complete responsibility for its own publications.*

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Our review of the scale and diversity of federal earth science activities, as summarized in Table II.28, indicates that the effort is not sufficient in a number of categories. For example, the annual federal level of expenditure on earth science R & D related to minerals is only $4 million, when the federal revenue from the industry is $193 million and the annual value of mineral resources produced in Canada is $4.7 billion. Similarly the level of federal activity related to the construction industry is below a satisfactory level. We conclude:

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*Conclusion II.6*
*It is in the national interest that the Federal Government reassess its current level of expenditure on earth science activities. In the light of a reassessment, involving consultations with provincial governments and industry, the Federal Government should establish realistic goals and levels of expenditure and activity to meet the needs of national economic development and encourage the growth of the mineral, agricultural and construction industries; to support regional and northern development; to*

*meet the cultural, environmental and recreational needs of Canadians; and to provide the necessary assistance in external aid.*

It is anticipated that progressive decentralization of federal earth science activities will take place in the years ahead.[1] We concur with this philosophy to the extent that the decentralization is conducted in a planned and logical manner and results in more effective use of the earth sciences to the benefit of the region. A pragmatic approach is required toward the differing needs and capabilities of the numerous regions of Canada, rather than a legalistic approach. Hence we conclude:

*Conclusion II.7*
*Earth science activities should be clearly designated as an area for federal-provincial co-operation and co-ordination to meet the needs of the country; the planning and conduct of these activities should not be subject to constraints arising from matters of jurisdiction.*

A second problem in regard to the regionalization of governmental facilities is the absence of ground rules or clear understanding of the relative working relationship and responsibilities of the universities, government(s), research councils and industries who would be involved in the activities of regional earth science centres. The MacDonald report[2] states:

"Geographical proximity can do much to facilitate effective working liaison between government and university laboratories...we have observed that even when intramural laboratories are located on a campus, there is no guarantee of collaboration...The underlying causes of this phenomenon are doubtless varied and complex...We are convinced that some of the key contributing factors lie in such tangible domains as the terms under which laboratories can be used by researchers who are graduate students or who hold university teaching appointments. Looking at the other side of the relationship, the conditions under which government employees are permitted to teach in universities and engage in university research are likewise important."

We recognize that co-operation cannot be legislated or induced. Nevertheless the presence of general guidelines can often provide an "umbrella" of common understanding under which individual scientists may develop effective bonds at the operational level. Already certain agreements for co-operation exist between federal and university organizations outside the field of earth sciences, and between provincial research councils and universities as well. However such arrangements are not common, nor are they well understood. According to J. Ruptash, much of the onus is on the universities. He said:[3]

"I submit the university has to take a much broader view. I think you have to involve all people in the educational process. I think you must realize that competence also lies outside the university. Our right, within the university, is that conferred by the state to grant and govern degrees, but I think we can devise methods to broaden our approach. I know this is not the traditional university point of view, but I think it is one that has to be accepted more and more."

Our view on this situation relates as much to industry and provincial agency co-operation with universities as it does to federal government co-operation. Many Canadian cities already contain not only a university with one or more earth science departments, but also one or more earth science groups employed in the industry or government sectors. Although each group has differing objectives, there is nevertheless sufficient overlap in scientific interest and laboratory

[1] Brief to the Senate Committee on Science Policy by the Department of Energy, Mines and Resources, Ottawa, p. 101.

[2] *Op. cit.*

[3] Collaboration in research. *In* Canadian Research & Development, vol. 6, Nov.-Dec. 1968. pp. 22-23.

facilities to conclude that the potential for further progress lies in defining a basis for closer working relationships, including the sharing of facilities as well as personnel. Because the university is the common denominator in these relationships, we conclude:

*Conclusion II.8*
*Universities should define the basis upon which they would be willing to integrate their research-training policies with the research activities of government agencies, research councils, and industry. Such definition should include the basis (obligations and privileges) for temporary appointments, the sharing of facilities and expenses, and the basis of supervision of graduate students either on campus or in the matching organization. Government and industrial organizations located near university campuses should initiate discussions on means of sharing facilities and personnel in the interests of national effectiveness.*

We believe that the implementation of these measures would provide, "almost overnight", the nuclei for development of centres of excellence in the earth sciences.

## The Federal Government as a Co-ordinator of Earth Science Activities

### *The Problems of the Associate and Advisory Committees*

The federal government assumes a responsibility to develop and co-ordinate national policies and programs in the earth sciences as well as in other matters. There are nine principal national earth science committees, located in either the National Research Council or the Department of Energy, Mines and Resources (Table II.29). The older committees were formed just after World War II, but since 1964, four additional committees have been formed in the Department of Energy, Mines and Resources. Some committees are structured along disciplinary lines, (e.g. Associate Committee on Geodesy and Geophysics and National Advisory Committee on Research in the Geological Sciences) and others according to departmental missions (e.g. National Advisory Committee on Water Resources Research). The disciplinary committees have been successful in promoting the earth science specialities which they represent. This has been especially important in the absence of strong professional societies which in other countries perform this role on behalf of their membership.

Several of the major committees have been limited in their role of co-ordinating research by their non-representative membership (absence of industrial or provincial government representatives and over-representation by universities or federal government). The general restriction of funding to university-performed research has not fostered the development of mission-oriented research. Our Study Group detected a strong expression from the scientific community that too much of the earth science research in Canada was impractical. In many questionnaires it was repeatedly pointed out that not enough applied research was being done by the universities, governments or industries. Many claimed that too much over-specialization was occurring, leading to overemphasis of certain fields of basic research, while more practical fields were being ignored or inadequately handled. We received eight proposals for a mineral exploration institute in one form or another. These submissions underlined the need for more research in mineral exploration, whereas other submissions or background papers stressed the needs of other mission-oriented projects in different fields. We believe that the problem of increasing mission-oriented research in the earth sciences in Canada is closely related to the problems of improving the co-ordination between the various agencies currently carrying out research. *To achieve both objectives, we believe it is necessary to reorganize and amalgamate the various committees that are currently responsible on a national basis for research*

**Table II.29–National Committees Concerned With the Solid-Earth Sciences**

| Name | Sponsoring Department | Objective | Membership | | | |
|---|---|---|---|---|---|---|
| | | | Fed. | Prov. | Ind. | Univ. |
| 1. National Advisory Committee on Research in the Geological Sciences (1949)[a] | EMR (Geological Survey) | a) to co-ordinate geological research in Canada b) to suggest research projects that should receive attention c) to aid, insofar as possible, in having problems undertaken by qualified personnel and in securing finances where needed d) reviews grants in aid of geological research | 4 | 4 | 2 | 11 |
| 2. National Advisory Committee on Geographical Research[b] (1965) | EMR (Policy and Planning Branch) | a) provides continuing advice to the Minister on needs and priorities for geographical research in Canada b) assists in the co-ordination of geographical research in Canada c) promotes the development of geographical research and makes recommendations for grants in aid of such research | 5 | 1 | 3 | 10 |
| 3. National Advisory Committee on Mining and Metallurgy[b] (1968) | EMR (Mines Branch) | Advises the Minister on: a) mining and metallurgical research in Canada; b) co-ordination of federal research programs with others; c) sponsorship of university and other research programs and projects | 4 | 3 | 7 | 4 |
| 4. National Advisory Committee on Water Resources Research[b] (1967) | EMR (Policy and Planning Branch and Inland Waters Branch | a) provides continuing advice to the Minister on needs and priorities for research on water resources in Canada b) assists in the co-ordination of water resources research in Canada c) reviews applications for grants in aid of water research | 12 | 4 | – | 5 |
| 5. National Advisory Committee on Control Surveys and Mapping[b] (1964) | EMR (Surveys & Mapping Branch) | Provides advice to the Director, Surveys and Mapping Branch on a) co-ordination of federal surveying and mapping programs, b) promotion and co-ordination of related research and educational programs, including the sponsorship of worthy research projects | 5 | 3 | 2 | 2 |

**Table II.29–National Committees Concerned With the Solid-Earth Sciences (Concluded)**

| Name | Sponsoring Department | Objective | Membership | | | |
|---|---|---|---|---|---|---|
| | | | Fed. | Prov. | Ind. | Univ. |
| 6. Associate Committee on Geodesy and Geophysics[b] (1945) | NRC | To co-ordinate geophysical research in Canada and serve as the National Committee for Canada of the IUGG | 18 | 1 | 2 | 12 |
| 7. Associate Committee on Quaternary Research (1966) | NRC | a) to stimulate and co-ordinate Quaternary research in Canada<br>b) to serve as the Canadian National Committee for INQUA | 2 | – | – | 13 |
| 8. Associate Committee on Geotechnical Research (1945) | NRC | To co-ordinate and stimulate research on the engineering and physical aspects of the terrain in Canada | 10 | 2 | 6 | 4 |
| 9. Canadian Committee on Oceanography (1959) | NRC | (Successor to the Canadian Joint Committee on Oceanography which was formed in 1946)<br>To co-ordinate the oceanographic activities of all Canadian government agencies; to act, as designated by NRC, as the national committee for the Scientific Committee on Oceanographic Research (SCOR) | | | | |

[a] Year of formation.
[b] Denotes committees which are only concerned in part with solid-earth science activities as defined for this report.

*in the earth sciences.*

The formation of advisory committees to federal ministers responsible for national science-based missions has been endorsed by the Science Council, and has resulted in the establishment of a National Advisory Committee on Water Resources Research.[1] Separate from water resources research, there are four national "missions" which merit advisory committees with a large earth science input. They relate to mineral resources, construction, the physical environment, and university research. The importance of research activities related to these economic and social missions is documented in the succeeding chapters of this report.

*A National Advisory Committee on Mineral Resources Research*

The importance of increased and better co-ordinated research related to mineral resources is documented in Chapter IV. We consider that a National Advisory Committee on Mineral Resources Research (NACMRR) could provide the increased thrust required to achieve significant progress in the next decade. Its activities should relate to the entire sequence of mineral resource management, including exploration, production, marketing and policy formulation. Hence it must include, in its overall membership, persons who are not specialists in the earth sciences alone.

A reasonable structure for this committee could be based on three subcommittees, concerned with (1) mineral exploration, (2) mineral production and processing research, and (3) mineral economics and policy research. These subcommittees can be formed in part from existing committees. The National Advisory Committee on Research in the Geological Sciences (EMR) and the Associate Committee on Geology and Geophysics (NRC) have each been concerned with geological and geophysical research relative to mineral exploration. The National Advisory Committee on Mining and Metallurgical Research (EMR) already exists to promote mining and metallurgical research in Canada. The proposal to develop a subcommittee on mineral economics and policy is new, and of increasing importance to future Canadian resource development. The grouping of these three subcommittees under a single National Committee related to the mineral resource mission should provide for better co-ordination and development for the future. Together they may achieve goals of lowering the risk element in searching for mineral deposits, of increasing the efficiency and effectiveness of mineral exploration, of promoting the application of new technology and efficiency in mining and extractive metallurgy, and of encouraging research into new mineral policies.

The principles established for the co-ordination of water resources research by the Science Council[2] serve as a guide to the structure of this proposed committee. The terms of reference should require it:

1. To provide continuing advice to the Minister of Energy, Mines and Resources on research needs and priorities in mineral resources research in all sectors of the economy, and on the application of science to mineral resources management and use;
2. To assist in the co-ordination of mineral resources research;
3. To review and make recommendations on applications for grants from the Department of Energy, Mines and Resources in aid of mineral resources research.

The membership of the Committee should be established as follows:

1. Members should represent all sectors of the economy, that is, federal and provincial public services, universities and industry. No sector should dominate the Committee;
2. The membership of the Committee should reflect, as far as possible, the wide range of disciplines that contribute to

[1]Science Council of Canada. A major program of water resources research in Canada. Report No. 3. Ottawa, Queen's Printer, 1968.

[2]*Op. cit.*

mineral resources research;

3. The senior representative of the Department of Energy, Mines and Resources on the Committee should be appointed convenor of the Committee;

4. The chairman of the Committee need not be a federal public servant; he should be elected to the position by the members of the Committee;

5. The chairman should be elected for a term of three years, once renewable. Members should also be appointed to the Committee for three-year terms, once renewable;

6. The Department of Energy, Mines and Resources should provide the secretariat and a non-voting secretary.

The Committee should have adequate funds to stimulate increased mineral resources research in universities, industry and government through cost-sharing programs. The essential criteria for allocation of funds should be based on achieving goals and priorities set by the Committee. The funds of concern to the Committee should form a separate and identifiable item within the budget of the Department of Energy, Mines and Resources, and the responsibility for advising the Minister on the distribution of these funds should rest solely with the Committee and its appropriate subcommittees.

We therefore conclude:

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*Conclusion II.9*
*A National Committee on Mineral Resources Research should be established by the Department of Energy, Mines and Resources to co-ordinate a national program of mineral resources research.*

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*The Future Development of Other National Earth Science Committees*

There remains a need to sort out the contrasting national committees who are concerned with the health of specific disciplines, and those concerned with the furtherance of specific missions. *The roles of the former could well be assumed by the scientific societies and it is in the interest of the growth of science in Canada that the federal government should transfer, and the professional societies should undertake, the responsibilities for national co-ordination of discipline-oriented research.*

The Study Group has not been able to develop the above concept to a final conclusion. We would consider that certain roles of the National Advisory Committee on Research in the Geological Sciences and the Associate Committee on Geology and Geophysics (to name only two) could be performed equally well by scientific societies. The Associate Committee on Geotechnical Research of NRC, on the other hand, fills an important role directed toward the construction industry. It could be strengthened through restructuring toward the style of the National Advisory Committee described above, and with assignment to the Committee of funds to promote geotechnical research.

Another "mission" wherein national co-ordination and stimulus are required relates to man's environment–its present state, its quality, and means of maintaining it for the future good of Canadians. The environmental earth sciences, which involve the lithosphere (solid earth), hydrosphere (water) and atmosphere have an important contribution to make in solving problems of the environment. Earth science research related to the physical environment is uncoordinated in Canada. The structures of the National Advisory Committee on Research in the Geological Sciences and the Associate Committee on Geodesy and Geophysics tend to maintain a disciplinary emphasis. Overemphasis of disciplinary priorities tends to mute the potential contributions which can be made to the service of man.

As a result of the views presented above, the Study Group is of the opinion that:

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*Conclusion II.10*
*The National Research Council and the Department of Energy, Mines and Resources should review the roles of their Associate and Advisory Committees with a view to clarifying their mission orientation and*

*transferring increased responsibility for the co-ordination of discipline-oriented research to the appropriate professional societies.*

Underlying the health of the earth sciences, as well as other sciences, in Canada is the state of funding provided by the National Research Council to maintain strong, first-class educational institutions that can provide highly trained manpower and stimulate the creation of new knowledge. The principal support for earth science research toward this "mission" is provided by the Earth Science Grant Selection Committee of NRC (Table II.27). This support should continue to be provided by the National Research Council. We are of the opinion that the present level of support is reasonably adequate in terms of the size of faculty and number of *Canadian* graduate students. Nevertheless, the federal government must increase the proportion of research support channelled through other mission-oriented departments, and the effectiveness of the Earth Science Grant Selection Committee should be improved. The Committee has been too generous in recent years toward the less able and less productive applicants. It has been composed entirely of university professors, and greater objectivity, as well as assistance with the difficult task, could probably be provided by inviting one or two scientists from government or industry to participate. Hence, we conclude:

*Conclusion II.11*
*The Earth Science Grant Selection Committee of the National Research Council should include earth scientists from industry or government; this Committee should be more selective in judging grant requests.*

## II.6 The Provincial Agencies

**General Statement**

The first provincial geologist was Sir William Logan, who was assigned the task of ascertaining the mineral resources of the Province of Canada in 1842, for "a sum not exceeding one thousand, five hundred pounds". Logan and his staff were located with the federal government at the time of Confederation, reporting to the Governor General. At the same time, the ownership of mineral resources was vested with the provincial governments. As succeeding provinces joined in confederation–Manitoba, Prince Edward Island, British Columbia and Newfoundland–the responsibility to "assume and defray the costs of the geological survey" was allocated to the federal government, along with defence, customs and other matters of common national interest.

Earth science capabilities within provincial governments developed slowly. In 1902, W. G. Miller became the first provincial geologist in the Bureau of Mines of Ontario. At present, the combined professional staffs of the provincial departments of mines totals approximately 200, the largest departments being those of Ontario, Quebec and Saskatchewan. Provincial research councils also undertake earth science research. The first was formed in Alberta in 1921. At present, there are five provincial research councils, employing 63 professionals in earth science research. In some provinces, earth science activities are also performed in departments of highways, of agriculture or forestry, and by provincial utilities. When one considers the earth science capabilities in universities and local mineral or construction industries, the potential for co-ordinated regional earth science in some parts of Canada is considerable.

The growth of earth science expertise at the provincial level has been a necessary and important development, which allows greater attention to be given to the local or regional differences which characterize Canada. This section of the report documents only briefly the nature of existing provincial earth science agencies and considers some means whereby their effectiveness can be further increased.

## Provincial Departments of Mines and Resources

The typical provincial department of mines, represented by the British Columbia Department of Mines and Petroleum Resources, the Saskatchewan Department of Mineral Resources and the Nova Scotia Department of Mines, is shown in Figure II.16A. It consists of a minister responsible to cabinet solely for the mineral sector, a deputy minister, and separate branches for mines (one or more), petroleum and natural gas (one) and geology (one). The geology function in Alberta is conducted by the Alberta Research Council rather than the Department of Mines and Minerals. In Ontario, responsibility for petroleum is allocated to the Department of Energy and Resources Management rather than the Department of Mines, and hence there are two spokesmen for the mineral industry in the provincial cabinet.

In the remaining provinces the mineral resource function is combined with other resource activities in a single department, usually referred to as a Department of Natural Resources because of its hybrid nature. In Quebec, for instance, the typical structure referred to above exists largely in the Mines Branch (the petroleum function is minor); the Waters Branch and the New Quebec Branch form the other major components (Figure II.16B). In New Brunswick and Manitoba, the Mines Division and Mines Branch respectively perform the mineral resource function, and the Deputy Minister of Natural Resources is also responsible for resource functions related to fish and wildlife, and lands and forests. In Newfoundland, responsibility for agriculture is also included in the Department of Mines, Agriculture and Resources.

Hence the organization for mineral resource functions (and earth science activity within this function) in provincial governments is derived from a basic structure (Figure II.16A) and modified to meet specific provincial needs. There is an overall correlation between the importance attached to the mineral resource function (as indicated by the appointment of one or more cabinet ministers responsible for mineral resources alone) and the revenue derived from mining, although exceptions are present.

The expenditures of provincial governments on services to the mineral industry are generally low, on average being less than 1 per cent of the revenue derived from the mineral industry (Table II.30). The relationship between provincial revenues and expenditures for all provinces is illustrated in Figure II.14. Although revenues from the mineral industry increase annually, the expenditures of provincial mines departments have not increased sufficiently to remain ahead of rising costs of operation. Alberta receives by far the largest revenue from the mineral industry. Only Nova Scotia and New Brunswick spend an amount equivalent to their revenue on mines and minerals (Figure II.15).

The total provincial expenditures on solid-earth science activities amounted to $7 million in 1968 (Table II.31), approximately equivalent to 60 per cent of the budget of the Geological Survey of Canada. Their total professional staff was approximately 200 (Table II.32), or generally equivalent to the staff of the Geological Survey.

The average number of earth science reports issued annually by provincial departments of mines, and by research councils, is tabulated in Table II.32A. Members of industry indicated, in response to questionnaires, their appreciation of the usefulness of these reports and the accompanying maps. Among the metal mining companies, maps and reports of the Ontario Department of Mines rated most highly, and those of Quebec, Saskatchewan, British Columbia and Manitoba received recognition. The petroleum companies commended the Saskatchewan Department of Mineral Resources most frequently on the quality of its publication services.

The activities of provincial mines departments are discussed further in succeeding chapters of this report. In

**Table II.30–Importance of the Mineral Industry in the Provincial Economy, 1968**

| Province | Value of Mineral Production 1968 | Direct Provincial Income from Minerals | Provincial Expenditure on Minerals |
|---|---|---|---|
| | $ million | $ million | $ million |
| British Columbia | 391 | 50 (13%)[a] | 5 (1%)[a] |
| Alberta | 1 080 | 223 (22%) | 6 (1%) |
| Saskatchewan | 371 | 35 (9%) | 3 (1%) |
| Manitoba | 208 | 3 (1%) | 1 (<1%) |
| Ontario | 1 340 | 19 (1%) | 4 (<1%) |
| Quebec | 731 | 20 (3%) | 4 (<1%) |
| New Brunswick | 87 | 0.3 (<1%) | 0.3 (<1%) |
| Nova Scotia | 58 | 1 (1%) | 1 (1%) |
| Newfoundland | 324 | 3 (1%) | 1 (<1%) |
| | **4 590** | **354 (7%)** | **25 (<1%)** |

[a] Percentages are expressed in relation to total value of provincial mineral production.

Chapter IV we indicate the importance of core storage libraries and the current practices of provincial agencies in establishing such facilities. We also indicate their important role in establishing and maintaining a nationwide system of earth science data storage and retrieval. In Chapters V and VI it is indicated that to some extent, provincial departments play a traditional role of supporting the needs of the mineral industry, while giving insufficient attention to the equally important role of environmental earth sciences in provincial and municipal affairs. We consider this weakness should be overcome. In Chapter VII we describe the current rates of progress in systematic earth science mapping in Canada and indicate that current rates of progress are insufficient to meet national needs. In this context, it is important that provincial and federal agencies plan together, to develop common standards, to define future provincial and national needs, and to develop co-ordinated programs to meet these needs. Hence, we conclude:

*Conclusion II.12*
*The present level of earth science activity by provincial departments is insufficient to meet regional requirements, and should be increased correspondingly to reflect the present and potential revenues derived from the mineral industry.*

**Provincial Research Councils and Foundations**

The provincial research councils and foundations play an important role in the scientific activities of their respective provinces. Such organizations are unique to Canada, and date from 1921 when the Alberta Research Council was established. They are administered by councils or boards which vary in government representation, from the Alberta Research Council, with a number of provincial cabinet ministers on its Council, to the Ontario Research Foundation, with none. All have university and industrial members.

The various councils and boards are established as bodies corporate to assist in the expansion of the economy of the province in which they are located, by undertaking research and development for industry and government. Each receives a provincial government grant. The British Columbia Research Council is the least dependent on provincial government funds. The New Brunswick Research and Productivity Council receives over 80 per cent of its funds from a provincial grant. The Ontario Research Foundation receives a provincial grant which matches their research contract revenue.

The Organisation for Economic Cooperation and Development, in its review of national science policy, has found it

**Table II.31–Solid-Earth Science Expenditures of Provincial Mines Departments, Related to Type of Activity, 1968**

| Province | Department or Agency | Total Dept'l. Budget | Total Solid-Earth Science Expenditure | Basic Research | Applied Research | Development | Scientific Data Collection | Scientific Information |
|---|---|---|---|---|---|---|---|---|
| | | $'000 | $'000 | $'000 | $'000 | $'000 | $'000 | $'000 |
| Alberta | Mines and Minerals[a] | 1 930 | – | – | – | – | – | – |
| | Oil and Gas Conservation Board | 2 592 | 100 | – | – | – | – | – |
| British Columbia | Mines and Petroleum Resources | 5 192 | 397 | – | 77 | – | 310 | 10 |
| Manitoba | Mines and Natural Resources | 6 979 | 662 | – | 103 | 18 | 519 | 22 |
| New Brunswick | Natural Resources | 10 314 | 300 | – | 133 | – | 132 | 35 |
| Newfoundland | Mines, Agriculture, and Resources | 6 978 | 308 | – | 15 | – | 291 | 2 |
| Nova Scotia | Mines | 953 | 438 | – | 87 | – | 311 | 40 |
| Ontario | Mines | 3 838 | 1 700 | 34 | 765 | – | 316 | 585 |
| | Energy and Resources Management | 18 702 | 181 | – | 18 | – | 27 | 136 |
| Prince Edwards Is. | Industry and Natural Resources | 345 | – | – | – | – | – | – |
| Quebec | Natural Resources | 14 669 | 1 983 | 100 | 954 | – | 614 | 315 |
| Saskatchewan | Mineral Resources | 2 849 | 770 | – | 170 | – | 275 | 325 |
| **Total** | **Amount** | **75 341** | **6 839** | **134** | **2 322** | **18** | **2 795** | **1 470** |
| | **%** | | **100** | **5** | **35** | **<1** | **38** | **22** |

[a] The Alberta Research Council conducts earth science activities in Alberta on behalf of the province.

Figure II.14–Total Direct Revenues and Expenditures of Provincial Governments on the Mineral Industry, 1959-68

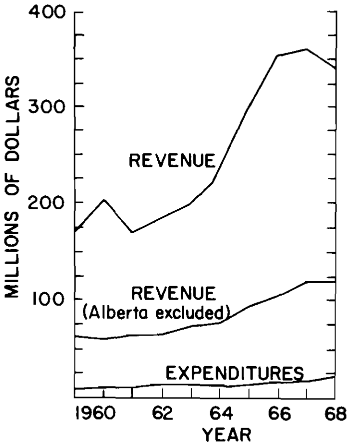

Figure II.15–Revenues from the Mineral Industry related to Expenditures on Solid-Earth Science Activities, by Province, 1968

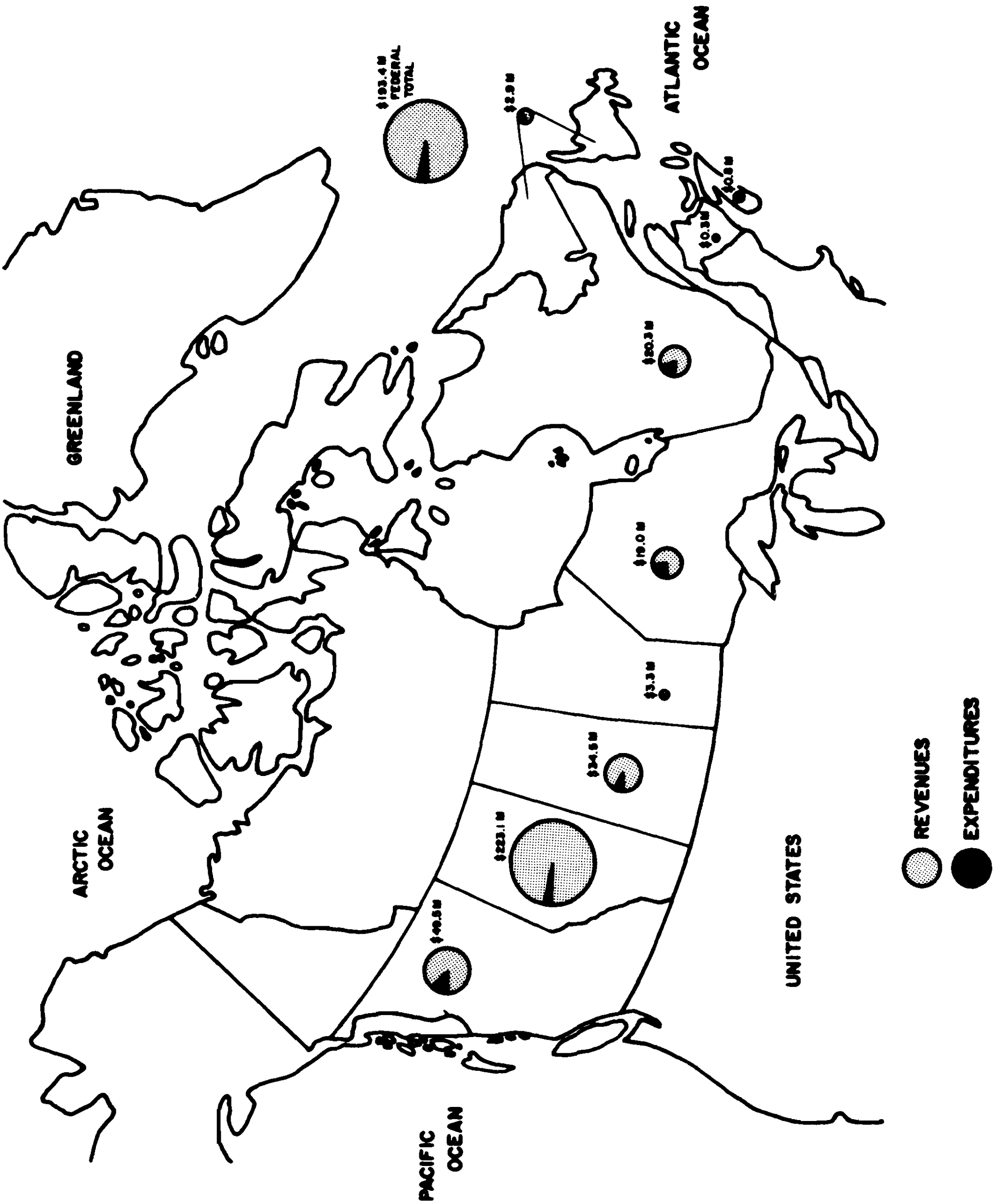

Figure II.16A–Typical Organizational Structure of a Provincial Department of Mines, as in British Columbia, Saskatchewan, and Nova Scotia

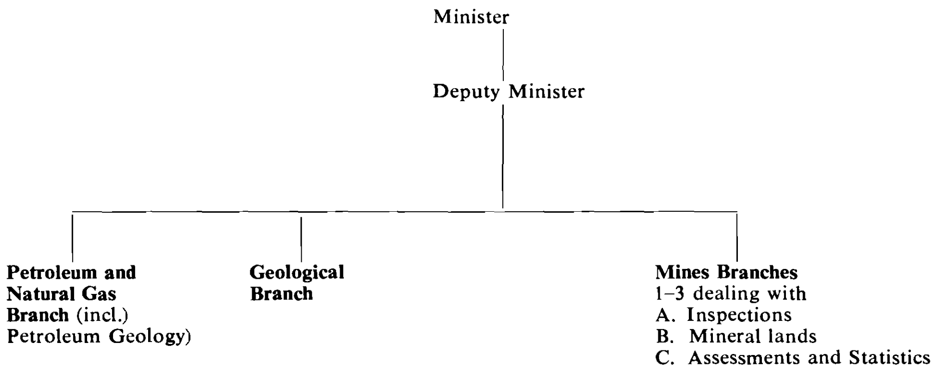

Figure II.16B–Typical Organizational Structure of a Provincial Department of Natural Resources, as in New Brunswick and Manitoba and, in a Modified Form, in Quebec and Newfoundland

Minister

Deputy Minister

**Mines Branch**
(responsible for mines, petroleum and geology functions)

**Resource Branches**
(separate branches responsible for fisheries, forestry, wildlife, land use, water)

**Regional Branches**
(responsible for technical services in specific regions)

**Table II.32–Earth Science Staff of Provincial Departments of Mines, 1969**

| Category | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Scientists & Engineers:* | | | | | | | | | | | |
| Bachelors | 2 | 2 | 1 | 14 | 5 | 5 | 6 | 14 | 11 | 4 | 64 |
| Masters | 4 | 4 | 5 | 4 | 18 | – | 4 | 7 | 1 | 3 | 50 |
| Doctors | 1 | 3 | 2 | 18 | 14 | – | 6 | 14 | – | 15 | 73 |
| (Vacant) | 2 | – | 1 | – | 7 | 1 | – | – | – | – | 11 |
| **Subtotal** | **9** | **9** | **9** | **36** | **44** | **6** | **16** | **35** | **12** | **22** | **198** |
| *Supporting Personnel:* | | | | | | | | | | | |
| Technicians | 1 | 5 | 4 | 31 | 48 | 9 | 2 | 7 | – | 5 | 112 |
| University Students (in man-years) | 9 | 3 | 5 | 35 | 30 | 2 | 10 | 24 | – | 2 | 120 |
| **Subtotal** | **10** | **8** | **9** | **66** | **78** | **11** | **12** | **31** | – | **7** | **232** |
| **Total** | **19** | **17** | **18** | **102** | **122** | **17** | **28** | **66** | **12** | **29** | **430** |

(1) Newfoundland Department of Mines, Agriculture and Resources.
(2) Nova Scotia Department of Mines.
(3) New Brunswick Department of Natural Resources.
(4) Ministère des Richesses Naturelles du Québec.
(5) Ontario Department of Mines.
(6) Ontario Department of Energy and Resources Management.
(7) Manitoba Department of Mines and Natural Resources.
(8) Saskatchewan Department of Mineral Resources.
(9) Alberta Oil and Gas Conservation Board.
(10) British Columbia Department of Mines and Petroleum Resources.

**Table II.32A–Earth Science Reports of Provincial Government Agencies (exclusive of publications of staff members in professional journals)**

| Agency | Title | Average No. Issued per Year over Period 1963 | | | |
|---|---|---|---|---|---|
| | | Geology | Geophysics | Geochemistry | Other |
| 1. B.C. Dept. of Mines | Annual Report | 1 | – | – | – |
| | Bulletin | 1.5 | – | – | – |
| 2. Alberta Research Council | Bulletins | 3 | – | – | – |
| | Reports | 4 | – | – | – |
| 4. Saskatchewan Dept. of Mineral Resources | Reports | 5 | 1 | – | 2 |
| 4. Saskatchewan Research Council | Reports | ——10—— | | | |
| 5. Manitoba Dept. of Mines & Natural Resources | Publications | 5 | – | – | – |
| 6. Ontario Dept. of Mines | Geological Reports | 10 | – | – | – |
| | Industrial Mineral Reports | 3 | – | – | – |
| | Mineral Resources Circular | – | – | – | 1 |
| | Miscellaneous Papers | 7 | – | – | – |
| 7. Quebec Dept. of Natural Resources | Preliminary Geological Reports | 11 | – | – | – |
| | Final Geological Reports | 7 | – | – | – |
| | Special Studies | 2 | – | – | 1 |
| 8. New Brunswick Dept. of Natural Resources | Mineral Resources Reports | 0.5 | – | – | – |
| | Reports of Investigations | 1.5 | – | – | – |
| | Information Circular | 1 | – | 1 | – |
| 9. New Brunswick Research & Productivity Council | Research Notes | 3 | – | – | – |
| 10. Nova Scotia Dept. of Mines | Annual Report | 1 | – | – | 1 |
| 11. Nova Scotia Research Foundation | Reports | —1— | | – | – |
| 12. Newfoundland Dept. of Mines, Agriculture & Resources | Bulletins, reports, information circulars | 1.5 | – | – | – |

convenient to group these bodies as government agencies and independent establishments. Although this grouping is not exactly correct, it does indicate the amount of provincial government research in which each is engaged. For example, the Alberta Research Council is very heavily committed to provincial government research programs.

The British Columbia Research Council, the Ontario Research Foundation, the New Brunswick Research and Productivity Council and the Nova Scotia Research Foundation have each moved into new laboratories within the last two years, and the Alberta Research Council has recently enlarged its facilities.

Each council or foundation has been active in the earth sciences. Their solid-earth science expenditure in 1968 totalled $1.8 million (Table II.33) and they employed 63 professionals on these activities (Table II.34). The amount of provincial support available has determined whether these activities originate as in-house or as responsive programs. The Alberta and Saskatchewan Research Councils have programs in surficial geology. The Nova Scotia Research Foundation is active in geophysical exploration. The New Brunswick Research and Productivity Council is committed to mineralogical investigations. The British Columbia Research Council has a research program in mineral microbiology. All of them have excellent facilities in analytical chemistry which are particularly useful to earth sciences. They have engineering and applied physics divisions which can work on instrument development related to the solid earth. For example, the Ontario Research Foundation is growing crystals for use in activation analysis; it could expand this work to include the development of special instruments for whole-rock analysis by using the same technique. A number of research councils have specialized research apparatus, such as the electron probe and mass spectrometer. All have X-ray diffraction equipment. Some have a variety of sophisticated geophysical exploration equipment. The Saskatchewan Research Council had the first carbon-14 dating laboratory in Canada.

These organizations are well suited to investigate regional problems related to the practical applications of earth sciences, and given sufficient incentives, could readily increase their activities in this field. *One method would be for the federal government to provide earth science research and development contracts related to the regions where these organizations are located.*

### Co-ordination of Provincial Earth Science Activities

The multiple responsibilities of provincial governments for mineral resources, for education, and for municipal governments and urban development require that they play a key role in the development and implementation of science policies. Earth science activities in provincial governments are performed principally in the departments of mines, or of natural resources, but in some provinces they are pursued as well in departments of highways, agriculture or forestry, or by provincial utilities. When one includes the earth science capabilities in provincial research councils, in universities, and in local mineral or construction industries, the potential for effective regional earth science programs is considerable. The problems of planning and communication described as existing between federal government departments exist equally at the provincial level. Hence the formation of provincial earth science committees, similar to the interdepartmental committee proposed for the federal government, could serve a useful function. Provincial earth science committees could have terms of reference similar to those of the proposed federal committee, but should include within their framework the related university, research council, and possibly industrial groups and representatives from regional laboratories funded by the federal government. Since the departments of mines have the greatest concentration of earth science

**Table II.33–Solid-Earth Science Expenditures of Provincial Research Councils, Related to Type of Activity, 1968**

| Council | | Total Expendi-ture | Basic Research | Applied Research | Develop-ment | Scientific Data Collection | Scientific Information |
|---|---|---|---|---|---|---|---|
| | | $'000 | $'000 | $'000 | $'000 | $'000 | $'000 |
| Alberta Research Council | | 976 | 146 | 473 | 4 | 279 | 73 |
| British Columbia Research Council | | 46 | – | 39 | – | 7 | – |
| New Brunswick Research and Productivity Council | | 86 | 43 | 26 | – | 9 | 9 |
| Nova Scotia Research Foundation | | 116 | 5 | 38 | 2 | 66 | 5 |
| Saskatchewan Research Council | | 545 | 158 | 214 | 8 | 161 | 4 |
| **Total** | **Amount** | **1 769** | **352** | **790** | **14** | **522** | **91** |
| | **%** | **100** | **20** | **45** | **1** | **29** | **5** |

**Table II.34–Earth Science Staff of Provincial Research Councils, 1968**

| Category | (1) | (2) | (3) | (4) | (5) | Total |
|---|---|---|---|---|---|---|
| *Scientists and Engineers:* | | | | | | |
| Bachelors | 2 | 2 | 4 | 5 | 3 | 16 |
| Masters | 1 | – | 2 | 15 | 1 | 19 |
| Doctors | 3 | 3 | 8 | 14 | – | 28 |
| **Subtotal** | **6** | **5** | **14** | **34** | **4** | **63** |
| *Supporting Personnel:* | | | | | | |
| Technicians | 4 | 4 | 15 | 25 | 1 | 49 |
| University Students (man-years) | 3 | 1 | 1 | 12 | 1 | 18 |
| **Subtotal** | **7** | **5** | **16** | **37** | **2** | **67** |
| **Total** | **13** | **10** | **30** | **71** | **6** | **130** |

(1) Nova Scotia Research Foundation.
(2) New Brunswick Research and Productivity Council.
(3) Saskatchewan Research Council.
(4) Alberta Research Council.
(5) British Columbia Research Council.

activity and expertise in most provinces, the provincial ministers appear to be the logical initiators of provincial action in this regard.

*Conclusion II.13*
*Consideration should be given to the formation of provincial earth science co-ordinating committees composed of senior representatives of user departments and agencies as well as of other groups performing earth science research in the provinces, to provide a forum for discussion and co-ordination of earth science activities at the provincial level, and to appraise and evaluate current work in terms of provincial and national goals.*

## II.7 The Universities

### General

The first Canadian geology department was founded at the University of Toronto in 1853, and by the end of the 19th century there were six departments in Canada.[1] The most impressive growth has occurred since 1949, during which period the number of departments has increased from 15 to 30, with 23 providing graduate instruction. Although geography was taught in a few Canadian universities before the 1930s, commonly in close association with geology departments, a rapid increase in geography departments came after World War II.[2] By 1950 there were 8 geography (or joint) departments, with 6 providing graduate studies; by 1969 the number had risen to 35 (those offering graduate work to 25), and the faculty totalled 300[3] (as compared with 278 in geology departments).

The earth sciences in Canadian universities are dispersed through approximately 62 departments of geology, geophysics (physics) and geography in 33 universities, not to mention the university departments of mining engineering (rock mechanics), civil engineering (geotechnique), chemistry (geochemistry), and soil science (pedology). The study of the earth is, therefore, a more widespread activity on the university campus than tabulations of the geoscience departments themselves would suggest. We enter a note of apology at this point. Although we had extensive contact and response from the geology, geophysics, and the geography departments specializing in physical geography, our coverage of the non-specialized geography departments, the soil science departments and the civil engineering departments is poor. On a number of occasions the Study Group noted that even on the same campus several earth science faculty members were unacquainted with one another or with the courses and research projects under way in separate departments. This absence of co-ordination undoubtedly affects the training programs of students as well as the potential development of local centres of excellence in the earth sciences. Furthermore, with the increasing interest in earth sciences, whether at the college or secondary school level, and the frequent focus on man and his environment, increased co-operation becomes imperative. It is essential to student training as well as to university administration that co-ordinated training and research programs be developed between the earth science departments within universities and among the departments of neighbouring universities.

### The Students

The entry of students into earth science courses at university is largely unplanned and accidental. A survey conducted by

[1]An excellent account of Canadian geology departments may be found in *Geological education in Canada,* by C. W. Stearn. *In* The earth sciences in Canada. Edited by E. W. R. Neale. Royal. Soc. Canada. Spec. Publ. No. 11. 1968. pp. 52-74.

[2]Robinson, J. L. Geography in universities. The Canadian Geographer, 11: 216-229. 1967.

[3]It should be stressed that the faculty engaged in teaching physical geography are only about 25 to 30 per cent of the total number in geography departments. Since physical geography is frequently taught as a first-year course, and the subject matter usually includes subjects not covered by this study (e.g. climatology), the actual number of faculty actively engaged in physical geography as defined in this study is probably only 87.

the American Geological Institute[1] indicated that the majority of undergraduate geology students in the United States and Canada became interested in geology as a result of the introductory course at the college level. Students enrolled in geology or geophysics in Canada can readily obtain summer employment in the field activities of industry or government, and most universities encourage them to do so.

The undergraduate enrolment (Table II.36) and graduation patterns in the earth sciences have been cyclic in nature (Table II.37 and Figure II.17). The number of bachelors graduates in geology has reached a level of 250 in 10-year intervals (1949, 1959, 1969). Such fluctuations have occurred nearly contemporaneously in the United States and Canada, and in the past were largely responsive to, though somewhat out of phase with, industrial manpower demands. The 1949 peak represents the veteran graduates after World War II.

In the United States at least, the dependence on industry demands has decreased considerably because of the generation of other employment opportunities (secondary school teaching, urban and environmental geology, and oceanography), as well as increased opportunity for graduate study. In Canada too, fewer than one-third of the geology and geophysics graduates in 1966-68 entered the mineral industry, even though the industry is the largest potential employer. Almost 50 per cent of the bachelors and masters graduates continued their education. Almost 50 per cent of the Ph.D. graduates entered the teaching profession (Table II.37). Because of a broader employment base, it is unlikely that such fluctuations in the enrolment pattern will occur as extensively in the future. It is disturbing, nevertheless, that despite a considerable increase in the number and size of geology departments, the number of bachelors graduates in 1969 (247) was less than the number graduated in 1949 (252).

The enrolment of masters students in geology and geophysics has increased steadily in the period 1958-68, from 95 to 332 in geology and from 11 to 72 in geophysics. This growth has been in response to an increasing student population, an increasing number of departments, and increasing non-Canadian student enrolment (about 44% in 1968-69). However, the number of masters graduates in geology and geophysics has shown little increase (Figure II.17) when considered in relation to the growth in number and size of departments. This indicates an increasing failure rate or delay in graduation, during the past 10-year period.

The enrolment of doctoral students in geology has increased from 75 to 217 (Table II.36) during the period 1958-68 (geophysicists from 8 to 63) for reasons similar to those affecting the masters enrolment. However, the number of graduates has not kept pace with the rise in enrolment, apparently for the same reasons. In 1969 the 15 doctoral degree-granting departments of geology graduated 28 students, a number equal to their annual new staff requirements for the years 1969-70 and 1970-71. The doctoral situation in geophysics and physical geography is equally poor. There were only four Ph.D. graduates in physical geography from Canadian universities during 1968. The situation led Stearn[2] to conclude that:

"...the recent increase in the number of universities offering graduate work in geology has not been accompanied by an increase in the number of students seeking this training...It is difficult to justify the establishment of additional Ph.D. programs in Canada until the national demand justifies it."

The output of Canadian earth science graduates in 1968, and the estimated number entering the labour force, are summarized in Table II.38. This may be

[1]Snyder, J. L. Why major in geology? Students answer. Geotimes, pp. 13-14, April 1969.

[2]Stearn, *op. cit.*

Figure II.17–Graduates in Geology and Geophysics from Canadian Universities, 1948-69 (M.Sc. graduates in geophysics (not plotted) increased from 6 to 18, and Ph. D. graduates from 1 to 10 during the 1948-68 period)

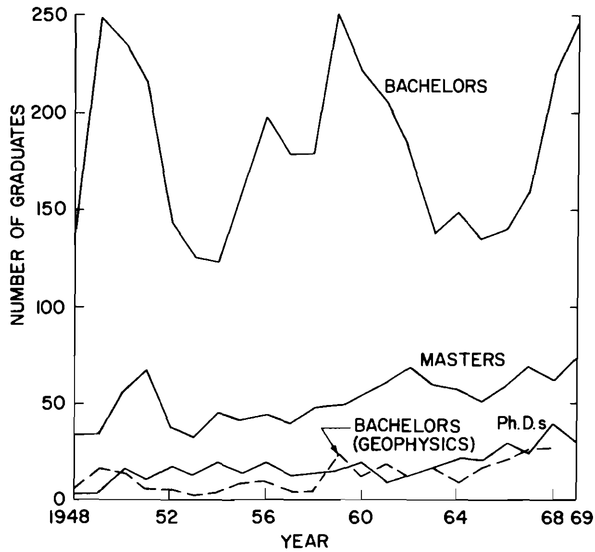

**Table II.35–Summary of Earth Science Departments in Canadian Universities, 1968[a]**

| Type of Departments | No. of Departments | Faculty | Students | | Expenditures[c] |
|---|---|---|---|---|---|
| | | | Undergrad. | Grad. | |
| | | | | | $'000 |
| Geology | 30 | 278 | 1 195[b] | 561 | 8 737 |
| Geophysics (Physics) | 7 | 41 | 47[d] | 123 | 1 203 |
| Physical Geography[e] | 25 | 87 | 145[d] | 128 | 1 850 |
| **Total** | **62** | **406** | **1 387** | **812** | **11 790** |

[a] Our data on mining and civil engineering, and soil science departments are not complete.
[b] Excluding first-year students.
[c] Including operating and equipment expenditures (80% of total), building renovations and new buildings.
[d] Excluding first- and second-year students.
[e] These estimates include also the departments that did not respond to our questionnaire survey.

**Table II.36–Enrolments in Geology and Geophysics in Canadian Universities, 1959-68[a]**

| Type of Department | Years | Non-Majors | Bachelor (year) | | | Master | Ph.D. |
|---|---|---|---|---|---|---|---|
| | | | 1 & 2 | 3 | 4 | | |
| Geology[b] | 1968-69 | 6 804 | 902 | 398 | 251 | 332 | 217 |
| | 1965-66 | 6 579 | – | 250 | 189 | 189 | 157 |
| | 1962-63 | 5 482 | – | 242 | 211 | 156 | 95 |
| | 1958-59 | – | – | 291 | 231 | 95 | 75 |
| Geophysics | 1968-69 | 120 | 19 | 41 | 33 | 72 | 63 |
| | 1965-66 | 123 | – | 20 | 15 | 33 | 33 |
| | 1962-63 | 53 | – | 34 | 22 | 20 | 21 |
| | 1958-59 | – | – | 28 | 10 | 11 | 8 |

[a] Data for years prior to 1968 obtained from surveys of the American Geological Institute.
[b] Includes geological engineering.

**Table II.37–Employment Patterns of Canadian Geology and Geophysics Graduates, 1966-68**

| Field of Employment on Graduation | Level of Graduation | | | | | |
|---|---|---|---|---|---|---|
| | Geology | | | Geophysics | | |
| | B.Sc. | M.Sc. | Ph.D. | B.Sc. | M.Sc. | Ph.D. |
| | % | % | % | % | % | % |
| Mining or Petroleum Industry | 36 | 37 | 23 | 20 | 14 | 5 |
| Government | 3 | 9 | 23 | 6 | 8 | 27 |
| Secondary School & College Teaching | 11 | 8 | – | 15 | 6 | – |
| University Teaching or Research | – | – | 45 | 4 | 6 | 59 |
| Continued Education | 45 | 39 | 2 | 53 | 62 | 9 |
| Other Occupations | 5 | 7 | 7 | 2 | 4 | – |
| | 100 | 100 | 100 | 100 | 100 | 100 |
| No. of Graduates Accounted for | 408 | 161 | 77 | 47 | 49 | 22 |

**Table II.38–Solid-Earth Science Graduates from Canadian Universities, 1968**

| Discipline | Total | | | Estimated Nos. entering Labour Force[a] | | |
|---|---|---|---|---|---|---|
| | B.Sc. | M.Sc. | Ph.D. | B.Sc. | M.Sc. | Ph.D. |
| Geology | 220 | 62 | 38 | 121 | 36 | 36 |
| Geophysics | 27 | 18 | 10 | 10 | 6 | 9 |
| Physical Geography | 41 | 18 | 4 | 18 | 10 | 4 |
| Mining Engineering | 42 | 20 | 3 | 42 | 20 | 3 |
| **Total**[b] | **330** | **118** | **55** | **191** | **72** | **52** |

[a] These numbers include non-Canadian graduates, many of whom returned to their homeland.
[b] Our survey of the soil science and civil engineering departments is too inadequate to provide meaningful data for this table.

compared with the number of departments and faculty members listed in Table II.35. For instance, a total of 278 geology professors resulted in the graduation of 320 geology students (at all levels), of whom about 193 entered the labour force. It is apparent that although the Canadian geology departments have increased in both size and number there has not been a comparable increase in the graduate output.

## The Faculty

*Departments of Geology*
In 1968, the size of faculty in individual geology departments varied between 2 and 19, with over half of the departments having a faculty of more than 10 members (exclusive of research assistants and postdoctorate research fellows). The total faculty was 278, with 191 teaching at the graduate level and associated with 35 postdoctorate research fellows and 25 research assistants (Table II.39).

A comparison with the total population in each province shows that the provincial distribution of geology faculty is essentially the same as that of the general Canadian population, with the exception of Quebec which is on the low side (20% of the national faculty in geology, compared to 29% of the population).

Of the 30 departments, 11 are situated in Ontario. However, the number of geology professors in Ontario is only 1.6 per cent of the total "full-time equivalent" faculty in that province, compared to 1.8 per cent on a national basis (278 professors in geology, compared to 16 529 full-time faculty in all fields). The total number of undergraduate geology students in Ontario represents 0.5 per cent of the total university enrolment in that province, whereas the graduate student enrolment is 2.0 per cent of the total graduate student enrolment in physical sciences in that province. Both percentages for Ontario are very close to the national average. Thus, the only apparent anomaly in Ontario is the relatively large number of geology departments, but it may logically be argued that such a pattern reflects the proliferation of Ontario universities and the strong tendency to regionalization of higher education.

Of the 30 departments listed in Table II.39,[1] the following 10 departments had no graduate program in 1968: Brandon, Brock, Lakehead, Laurentian, Loyola College, Mount Allison, St. Francis Xavier, St. Mary's, Sir George Williams and Windsor. These had an average student/faculty ratio of 3.5 compared to 4.4 for the others (in the latter case the ratio becomes 7.0 if graduate students are included).

The eight largest departments (Alberta, British Columbia, Calgary, Manitoba, McGill, McMaster, Queen's and Toronto) had in 1968 an average of 15 members in faculty, 80 undergraduate students and 45 graduate students. Each received an average of $185 000 from the National Research Council as operating

[1] A new department of geology and geography has since been established at the Université du Québec, Montreal Campus, with an initial faculty of six members.

**Table II.39–Distribution of Geology Departments by Province, Year 1968-69 (numbers in brackets are percentages of the national total)**

| Province | Universities | Faculty | PDF[a] | RA[b] | Tech[c] | Students B.SC. | Students P-G[d] | Oper. Exp.[e] $'000 | Research Exp.[f] $'000 | Research Equip.[g] $'000 | % Equip. Funding[h] NRC | DRB | Univ. | Ind. | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Newfoundland | Memorial | 10 (4) | – | – | 4 (3) | 30 (3) | 24 (4) | 279 (4) | 59 (2) | 50 (1) | 70 | – | 28 | 2 | – |
| Nova Scotia | Acadia, Dalhousie, St. Francis Xavier, St. Mary's | 18 (6) | – | – | 5 (4) | 94 (8) | 25 (4) | 313 (5) | 87 (4) | 285 (5) | 66 | 7 | 24 | – | 3 |
| New Brunswick | Mount Allison, New Brunswick | 16 (6) | – | – | 7 (5) | 47 (4) | 17 (3) | 325 (5) | 74 (3) | 120 (2) | 37 | – | 13 | 14 | 36 |
| Quebec | Ecole Polytechnique, Laval, Loyola, McGill, Montreal, Sir George Williams | 56 (20) | 5 (15) | 6 (24) | 27 (20) | 193 (16) | 109 (19) | 1 126 (17) | 326 (14) | 1 209 (19) | 65 | – | 32 | 1 | 2 |
| Ontario | Brock, Carleton, Lakehead, Laurentian, Ottawa, Queen's, McMaster, Toronto, Waterloo, Western Ontario, Windsor | 101 (36) | 19 (56) | 16 (64) | 62 (45) | 362 (30) | 206 (37) | 2 708 (42) | 1 195 (50) | 2 561 (41) | 47 | – | 44 | 1 | 8 |
| Manitoba | Brandon, Manitoba | 16 (6) | 3 (8) | 2 (8) | 5 (4) | 65 (5) | 36 (6) | 431 (7) | 104 (4) | 418 (7) | 77 | – | 22 | 1 | – |
| Saskatchewan | Saskatchewan | 16 (6) | 1 (3) | – | 5 (4) | 71 (6) | 27 (5) | 297 (5) | 109 (4) | 520 (8) | 65 | 3 | 3 | 28 | 1 |
| Alberta | Alberta, Calgary | 26 (9) | 3 (9) | 1 (4) | 14 (10) | 153 (13) | 79 (14) | 643 (10) | 273 (12) | 807 (13) | 33 | – | 59 | 3 | 5 |
| British Columbia | British Columbia | 19 (7) | 3 (9) | – | 7 (5) | 180 (15) | 38 (7) | 360 (5) | 167 (7) | 250 (4) | 22 | – | 50 | 10 | 18 |
| **Total** | **30 Departments** | **278** | **34** | **25** | **136** | **1 195**[i] | **561** | **6 482** | **2 394** | **6 220** | | | | | |

*Legend:*
[a] Postdoctorate research fellows.
[b] Research assistants.
[c] Technicians.
[d] Postdoctorate students.
[e] Operating expenditures of departments.
[f] Research operating grants.
[g] Undepreciated dollar value of research equipment within the geology departments.
[h] Source of funding of research equipment.
[i] This column of bachelor student enrolment does not include first-year students.
*Note:* Figures in brackets are percentage of the national total.

research grants. It is of interest to note that the University of British Columbia and Queen's University alone had about one-quarter of all geology students enrolled in Canadian universities, whereas McGill, McMaster, Ottawa and Western had an undergraduate/graduate student ratio of less than 1.

The average professor of geology is 38 years old and received his Ph.D. in 1957. Although most geology professors are Canadian by birth, 67 per cent received their highest degree outside Canada (one-third in the United States and one-fifth in the United Kingdom). About 40 per cent have worked for one or more years in industry, and 36 per cent in government.

*Departments of Geophysics*
Seven institutions in Canada grant degrees in geophysics: Alberta, Dalhousie, Memorial, Toronto, British Columbia, Western Ontario, and McGill universities. The first four have geophysics located in physics departments; the last one has geophysics associated with mining engineering. Thus, only two (British Columbia and Western Ontario) have separate geophysics departments. In most of these institutions, the prevailing research preoccupations and activities are in physics of the earth rather than applied geophysics, with the result that very few geophysics graduates enter industry (only 20 to 25 a year, not even enough to compensate for "replacements" of practising geophysicists).

In 1968, the total geophysics faculty in these departments totalled 41, with whom were associated 17 postdoctorate research fellows and 6 research associates (Table II.40). In addition, there were another 14 professors of geophysics in 8 geology departments but none in the geology departments of 15 universities, in spite of the fact that these had a total of 88 professors of geology. In our opinion this situation is anomalous; even though a geology department is small, it should have at least one geophysicist on staff to provide balance in earth science curriculum content.

Of these seven departments, only that of the University of British Columbia had a substantial undergraduate student enrolment in geophysics (Table II.40). Most draw a substantial number of their graduate students from physics, engineering physics and such fields, besides geology and geophysics proper. The proportion of non-Canadian graduate students is about 45 per cent, about equal to the national average for all graduate students in physical sciences and engineering.[1]

The average professor of geophysics is 36 years of age and received his Ph.D. in 1959. Of the 41 professors indicated in Table II.40, 34 per cent have worked for one or more years in industry and 24 per cent in government (in geology the equivalent percentages were 40% and 36% respectively). Only 49 per cent received their highest degree outside Canada (one-third in the United States), compared to 67 per cent in geology and 77 per cent in physical geography.

*Departments of Geography (Physical Geography)*
As an earth science discipline, physical geography is taught mainly in departments of geography. In many universities it constitutes a very minor component of the broad range of geography interests. According to our estimates (Table II.41), physical geography is taught in approximately 25 universities, although there are only four major departments specializing in this field.

Total faculty in physical geography is estimated at approximately 87, who are assisted by only 3 postdoctorate research fellows and 7 research assistants. Based on our limited statistics, the average physical geography professor is 35 years of age and received his Ph.D. in 1961. The same statistics indicate that 77 per cent of these professors obtained their highest degree outside Canada (mostly in the United States, the United Kingdom, and New Zealand).

[1]National Research Council, *op. cit.*, p. 52.

**Table II.40—Distribution of Geophysics (Physics) Departments by Province, Year 1968-69 (numbers in brackets are percentages of the national total)**

| Province | Universities | Faculty | PDF | RA | Tech | Students | | Oper. Exp. | Research Exp. | Research Equip. | % Equip. Funding | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | B.Sc. | P-G | | | | NRC | DRB | Univ. | Ind. | Others |
| | | | | | | | | $'000 | $'000 | $'000 | | | | | |
| Newfoundland | Memorial | 2 (5) | 2 (12) | – | 1 (4) | – | 6 (5) | 67 (5) | 45 (6) | 75 (3) | 33 | – | 65 | – | 2 |
| Nova Scotia | Dalhousie | 5 (12) | 1 (6) | 1 | 1 (4) | – | 9 (7) | 112 (11) | 44 (6) | 250 (11) | 60 | 30 | 5 | 5 | – |
| Quebec | McGill | 3 (7) | 2 (12) | – | 2 (7) | 1 (3) | 12 (11) | 90[a] (9) | 103 (13) | 465 (21) | 83 | – | 15 | – | 2 |
| Ontario | Toronto, Western Ont. | 16 (39) | 8 (46) | 1 | 12 (43) | 13 (27) | 39 (32) | 425 (41) | 368 (45) | 450 (20) | 43 | 6 | 42 | 3 | 6 |
| Alberta | Alberta | 8 (20) | 3 (18) | 1 | 8 (29) | 3 (6) | 25 (20) | 219 (21) | 147 (18) | 550[a] (25) | 50 | – | 42 | 2 | 6 |
| British Columbia | British Columbia | 7 (17) | 1 (6) | 3 (50) | 4 (14) | 30 (64) | 32 (26) | 127 (12) | 100 (12) | 450 (20) | 60 | 5 | 5 | – | 30 |
| **Total** | **7 Departments** | **41**[b] | **17** | **6** | **28** | **47**[c] | **123** | **1 040** | **807** | **2 240** | | | | | |

*Legend:* Same as in Table II.39.
[a] Estimates.
[b] Does not include about 14 professors of geophysics in geology departments.
[c] Third- and fourth-year students only.

**Table II.41–Distribution of Physical Geography in Universities, by Province, Year 1968-69**

| Province | Universities | Faculty | PDF | RA | Tech | Students B.Sc.[b] | Students P-G[c] | Oper. Exp. | Research Exp. | Research Equip. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | $'000 | $'000 | $'000 |
| Newfoundland | Memorial | 1 | – | – | – | – | – | 12[e] | – | 10[e] |
| Quebec | McGill | 12 | 1 | 3 | 4 | 17 | 24 | 363 | 82 | 70 |
| Ontario | Guelph, Ottawa Toronto, Waterloo, Western, York | 22 | – | – | 7 | 86 | 35 | 408 | 40 | 220 |
| Manitoba | Manitoba, Winnipeg | 3 | – | – | 2 | 49 | 5 | 53 | 10[e] | 15[e] |
| Sask. | Sask. | 3 | – | – | – | 6 | 3 | 40 | 10[e] | 10[e] |
| Alberta | Alberta, Calgary | 8 | 1 | 1 | 2 | 14 | 10 | 105 | 19 | 150 |
| British Columbia | Simon Fraser, U.B.C., Victoria | 12 | – | 1 | 5 | 26 | 10 | 171 | 25 | 65 |
| **Total** | **16 Depts.** | **61** | **2** | **5** | **20** | **198** | **87** | **1 152** | **186** | **540** |
| **Est. Total[a]** | **25 Depts.** | **87** | **3** | **7** | **29** | **293** | **128** | **1 646** | **204** | **1 850** |

*Legend:* same as in Table II.39.
[a] Includes the Study Group's estimates for the following departments of geography who did not complete a questionnaire: Brandon, Brock, Carleton, Laval, McMaster, Montréal, Queen's, Sir George Williams, and Windsor.
[b] Includes only third- and fourth-year students in physical geography.
[c] Includes only graduate students in physical geography.

The absence of a department of geography serving the seven universities in New Brunswick and Nova Scotia is noteworthy, particularly since these two provinces combined have six university departments of geology. Four of these departments are small, with limited growth potential both in terms of student enrolment and research possibilities. Consequently, we urge these universities to give proper consideration to transforming their geology departments into earth science departments and adding geophysics, oceanography, physical geography and soil science to the curriculum. We recommend that these departments concentrate on providing broad undergraduate education in the earth sciences, and specialize in the training of high school science teachers (see Section III.7).

Although our survey of the geography departments is far from being complete, it is of interest to note that for the 16 departments shown in Table II.41, the larger part of the research equipment in physical geography has been funded directly by the universities. In contrast, the major funder of research equipment in geology and geophysics has been the National Research Council (Tables II.39 and II.40).

Lastly, it should be noted that the size of faculty shown in Table II.41 should not be judged only in terms of the numbers of students indicated. As in geology and geophysics, instruction in the earth sciences is given in these departments to very large numbers of non-majors.

*Other Departments*

Unfortunately, our data for the earth science component of other university departments (soil sciences, geotechnique, etc.) are too incomplete to yield meaningful statistics. Our failure to achieve good coverage there is in part due to the scope of this study and our difficulties of extracting unequivocally the earth science component of their education and research activities. Some professors have commented for instance on their own difficulties in identifying the earth science aspects of their research in soil mechanics and rock mechanics. To some extent, somewhat similar difficulties were encountered in our coverage of physical geography in geography departments.

In the absence of meaningful statistics, we can note however the relative isolation of most soil science departments from geology departments and, to a smaller extent, geography departments. Likewise, there is relative isolation of rock mechanics and soil mechanics from geology in our universities, the former being located generally in mining or civil engineering departments.

## II.8 The Earth Science Societies and Associations

### The Societies

Scientific societies play a vital role in the scientific activities of a nation. They provide the major forum for communication among scientists and are the basic media for maintaining communications among industry, government and universities at the "grass roots" level.

There are 17 large earth science groups in Canada, although 9 of these are incorporated in larger societies supporting other disciplines or objectives (Table II.42). Most of these groups are growing at a rapid rate; for example, the Geology Division of the Canadian Institute of Mining and Metallurgy grew from 1 100 to 1 800 members over the period 1962-68. There are probably another 35 local earth science societies or groups, small and intermittent in nature, that gather to exchange information and ideas of specialized or regional interest. These include geological discussion groups, geophysical and geotechnical societies, and branches of the Canadian Institute of Mining and Metallurgy in many cities and mining towns.

Many of the larger scientific societies are the Canadian analog of United States societies, for example:

- Canadian Institute of Mining and Metallurgy *and* the American Institute of Mining, Metallurgical and Petroleum Engineers;
- Alberta Society of Petroleum Geologists *and* the American Association of Petroleum Geologists;
- Geological Association of Canada *and* the Geological Society of America;
- Mineralogical Association of Canada *and* the Mineralogical Society of America;
- Canadian Society of Exploration Geophysicists *and* the Society of Exploration Geophysicists.

Canadian scientists commonly hold membership or official office and publish in the organs of both societies, and in one instance the Canadian society is formally affiliated with its U.S. counterpart. It is estimated that half the results of research in the earth sciences obtained by Canadians are published as scientific papers outside Canada.[1] In general, however, a certain sense of nationalism has tended to prevent a formal organic linkage of the Canadian societies with their larger counterparts in the United States.

The principal role of the societies has been to encourage the growth of the sciences related to their area of interest through support of publications and annual meetings. Earth scientists publish regularly in the publication series of 13 Canadian societies.

The objectives of the societies are overlapping, uncoordinated and in some cases in need of redefinition (Table II.42). Their limited financial resources have prevented them from developing into a major force in the formation of earth science policy; perhaps their response in this area might be described as one of reaction to change rather than forward planning and action. Minor interest has been shown in the matter of professional or public standards as defined in the objectives of professional engineering, agri-

[1]Harrison, J. M., D. C. Rose, and R. J. Uffen. The nature and organization of earth sciences in Canada. *In* The earth sciences in Canada. Edited by E. W. R. Neale. Roy. Soc. Canada, Spec. Publ. No. 11. 1968. pp. 3-12.

**Table II.42–Major Canadian Earth Science Societies and Associations**

| Name | Year of Formation[a] | Membership[b] | Principal Objectives |
|---|---|---|---|
| *A. Geology* | | | |
| 1. Geology Division of the Canadian Institute of Mining and Metallurgy | 1945 | 1 805 | To provide a meeting ground for professional geologists in Canada |
| 2. Alberta Society of Petroleum Geologists | 1928 | 1 473<br>102[c] | To promote the science of geology, particularly as it relates to petroleum geology in Western Canada |
| 3. Geological Association of Canada | 1947 | 1 300 | To advance the science of geology and to promote a better understanding thereof throughout Canada |
| 4. Mineralogical Association of Canada | 1955 | 865<br>435[c] | To advance knowledge in crystallography, geochemistry, mineralogy, petrology and allied sciences |
| 5. Canadian Society of Soil Science | 1954 | 300 | To foster all branches of soil science |
| 6. Earth Sciences Division of the Royal Society of Canada | 1882 | 95 | To recognize high distinction and stimulate achievement in the earth sciences; to improve communication; to sponsor surveys of the state of earth sciences and suggest improvements |
| 7. Geotechnical Division of the Engineering Institute of Canada | 1962 | 175 | To provide a forum for discussion of engineering problems |
| 8. Geology Section, l'Association Canadienne Française pour l'Avancement des Sciences (ACFAS) | 1931 | – | To promote geology among geologists of the French language in Canada through the organization of annual meetings |
| *B. Geophysics* | | | |
| 1. Canadian Society of Exploration Geophysicists | 1949 | 800 | To promote the science of geophysics, especially as it relates to petroleum exploration |
| 2. Canadian Well Logging Society | 1955 | 200 | To encourage research related to the interpretation of well logs in oil and other mineral-bearing rock formations |
| 3. Earth Physics Division of Canadian Association of Physicists | 1962 | 112 | To promote and encourage the application of physics to problems related to the interior, the surface and the atmosphere of the earth |
| 4. Canadian Exploration Geophysical Society | 1953 | 135 | To promote the science of geophysics, especially as it applies to the exploration of minerals other than oil; to foster the common scientific interests of geophysicists |

**Table II.42–Major Canadian Earth Science Societies and Associations (Concluded)**

| Name | Year of Formation[a] | Membership[b] | Principal Objectives |
|---|---|---|---|
| *C. Geography* | | | |
| 1. Royal Canadian Geographical Society | 1929 | 269 fellows, 13 713 general members | Advancement of geographical knowledge and in particular the general diffusion of information on Canadian geography |
| 2. Canadian Association of Geographers | 1951 | 600 | Development of geography and promotion of communication among geographers in Canada |
| 3. Association des Géographes de l'Amérique française | 1962 | 40 | Promotion of scientific communication between geographers of the French language |
| *D. Topography* | | | |
| 1. Canadian Institute of Surveying | 1882 | 1 192 | To further the professional knowledge of members; promote professional interest in surveying and mapping; enhance usefulness of profession to public |
| *E. Interdisciplinary* | | | |
| 1. Arctic Institute of North America | 1945 | 250 fellows, 1 700 associates | To encourage and support scientific research pertaining to the polar regions |
| *F. Mining and Petroleum Associations* | | | |
| 1. Canadian Petroleum Association | 1952 | 99[c] | To foster better understanding between petroleum and natural gas industry and the public; encourage co-operation with governments; provide forum for discussion of matters affecting welfare of members |
| 2. Independent Petroleum Association of Canada | 1961 | 185[c] | To create an environment conducive to growth and prosperity of oil companies operating in Canada |
| 3. Mining Association of Canada | 1935 | 102[c] | To project the news of the Canadian mining industry on a national scale and present its views to government in regard to policies affecting exploration, mining and processing, and the development of exports |
| 4. Prospectors and Developers Association of Canada | 1932 | 1 400<br>175[c] | To co-ordinate and project the views of the membership through annual scientific and business meetings and liaison with provincial and federal governments |

[a] Where the earth science division is only a part of the Association, the year of commencement of the division is given.
[b] Corporate membership indicated separately, c.
[c] Corporate membership.
[d] Attempts are being made to establish a Canadian Geotechnical Society, which will replace this Division but will become a "Constituent Society" within the Engineering Institute of Canada.

cultural and other associations. Nevertheless, significant examples of active public service include the recommendations of the Geology Division of the CIM in 1947, which resulted in the formation of the National Advisory Committee on Research in the Geological Sciences, as well as the support of this study through the submission of briefs (see Appendix 3).

Formal liaison between the existing earth science societies is practically nonexistent, and the co-ordination that does exist is due principally to a small number of individuals who serve on more than one executive. The societies lack permanent secretariats and depend entirely upon the part-time services of their elected officers, except in those instances where partial secretariat services are provided by societies that support other disciplines, such as the Engineering Institute of Canada, the Canadian Association of Physicists, the Chemical Institute of Canada, the Canadian Institute of Mining and Metallurgy, and the Royal Society of Canada. The latter situation has been very beneficial to the support of earth sciences in Canada and has helped to foster fruitful interdisciplinary contacts. Nevertheless, they have tended to delay the generation of a "critical mass" to deal adequately with problems specifically related to the earth science profession in a national and professional sense.

*Earth science societies have a unique role to play in providing a parliament for the views of the individual earth scientist where he may speak for himself rather than depend on his institution to speak for him.* Matters of professional standards and salaries are immediate and down-to-earth concerns. Explaining earth sciences to the public, especially where they integrate with social problems, is a responsibility and interest of the individual earth scientist. Criticism of national programs in earth sciences should be fostered in open discussion rather than left smouldering in isolated "coffee-break discussions". The stimulus for encouraging the teaching of earth sciences in secondary schools must come from the societies who are less confined by the British North America Act or other restraints than other groups. Hence we conclude:

*Conclusion II.14*
*A Council of the Canadian Earth Science Societies should be established to provide advice to governments and to perform many of the common functions necessary for the development of the earth science professions in Canada. Leaders of the earth science societies should convene a meeting of senior members to examine areas for co-ordination and co-operation and the formulation of long-range plans.*

The Council could establish a central secretariat modelled somewhat after that of the American Geological Institute and, to a lesser extent, after the secretariats of the Canadian Association of Physicists and the Chemical Institute of Canada. Funds for the secretariat would be provided by the member societies, grants and contracts from government, donations from industry, and advertising. The responsibility for initial action in this regard would appear to rest with the Geological Association of Canada and the Alberta Society of Petroleum Geologists. The new organization itself might well evolve from that being established for the 1972 International Geological Congress in Canada. The Council would perform the following functions on behalf of its member societies and the profession:

1. Advise governments (federal, provincial, municipal) on matters of scientific problems or priorities involving the earth sciences and national economic and social goals;
2. Advise governments, industry and universities on the development of the various disciplines and the fostering of research in the various fields of earth sciences;
3. Advise and co-operate with the Canadian International Development Agency on matters relating to Canadian earth science technical assistance to developing countries;
4. Advise the public on the social and

cultural as well as the economic value and implications of the earth sciences, especially in matters of pollution, natural hazards, recreation, and quality of the environment;

5. Sponsor activities in earth science education, especially the development of earth science curricula and teaching aids in secondary schools, and the training of teachers;

6. Provide information services for the earth science profession, industry and governments, such as a register of scientific and technical personnel, information on manpower and salaries, career pamphlets, student counselling;

7. Provide services for the member societies, such as billing, membership list maintenance, addressing and mailing of ballots, assistance with publications, assistance with annual meetings;

8. Maintain communication among earth scientists in Canada through distribution of a monthly newsletter (modelled after *Geotimes)*;

9. Maintain communication with the scientific, engineering and technological community in Canada through active participation in SCITEC[1];

10. Maintain liaison with the American Geological Institute and other international professional societies that conduct similar earth science functions in their respective countries.

**The Associations**

Separate from the scientific societies, with their emphasis on individual membership, are the associations representing mining or petroleum companies (Table II.42). They maintain permanent secretariats with the financial support received from their corporate membership. They are concerned primarily with intra-industry, industry-government, and industry-public relationships rather than with science as such. Nevertheless, the Mining Association of Canada maintains an internal committee on mining and metallurgical research, and the Canadian Petroleum Association has a committee on geology, geophysics, core storage, etc. They exchange scientific information which while not reaching the public domain through meetings or publications, is periodically reflected in association statements on policy matters (e.g. the brief of the Mining Association of Canada to the Special Senate Committee on Science Policy, May 1969).

## II.9 Earth Science Libraries

**General**

Most Canadian earth science libraries have developed in response to the needs of local groups, and many still fill that role alone. In places, however, networks are developing for the exchange of library documents in response to the publication explosion and rising acquisition, storage and handling costs. At the same time, the role of libraries is slowly changing from that of a passive custodian of knowledge to that of a dispenser of information. The change calls for radical shifts in the attitude of librarians as well as in their methods of library organization. New developments in computer technology, reproduction techniques and interlibrary communications now provide a basis for the development of more cohesive library networks. Such changes are imminent or are in the process of implementation in Ontario and elsewhere. It is essential that earth scientists and earth science libraries participate in their implementation and development to ensure that there is an increased flow of information to the earth science community.

Science Council Report No. 7[2], as well as the related documents prepared by

[1]SCITEC is an acronym for The Association of the Scientific, Engineering and Technological Community of Canada, an organization founded in January 1970 which is expected to group more than 60 scientific and engineering national societies and speak for more than 100 000 members of these societies and others. SCITEC's objective is "to marshall the scientific, engineering and technological community to provide leadership and to communicate, co-operate and work within itself, with government and the public in the national interest in those areas in which it can make a competent contribution."

[2]Science Council of Canada. A policy for scientific and technical information dissemination. Report No. 7. Ottawa Queen's Printer, 1969.

J.P.I. Tyas *et al.*[1] for the Science Council, provide useful guidelines for the implementation of an information network. A purpose of this section, which draws heavily on these studies, is to indicate special features of earth science libraries which must be considered in the broader context of library networks in Canada.

**Present Situation**

The library of the Geological Survey of Canada, consisting of about 100 000 volumes, is probably the most comprehensive collection of geological publications in Canada. This library has been developed to meet the needs of the Geological Survey and consequently reflects the changing interests of that department. It is particularly rich in complete runs of geological journals and publications issued by government geology departments and geological societies throughout the world. It should be thought of as supplementing the National Science Library.[2]

The Ontario Department of Mines Library is the largest of those operated by provincial departments. Its holdings include 32 500 volumes, 13 000 miscellaneous reports and pamphlets, and 9 500 geological and geophysical maps.[3]

Among university libraries, Queen's geology holdings are probably the second best in Canada. Its library holds 34 000 volumes, with extensive coverage of geological survey reports, geological maps, and periodical and society publications.

Industrial libraries are smaller in size, reflecting the narrower interests of the company concerned. Most companies retain a minimum library of government and company reports which form the basis for planning exploration activities. Larger companies retain sizable collections of textbooks. The Imperial Oil Regional Information Centre in Calgary, for instance, contains 1 000 textbooks on geology and 500 on geophysics, and the Gulf Oil Company library contains 2 500 books.

It is fair to state that most Canadian earth science libraries operate to meet the needs of local user groups but participate infrequently and reluctantly in interlibrary exchanges. The trend to link university library services in Ontario and the Atlantic Provinces is encouraging. The library most active in encouraging "outside" use of its facilities is that of the Geological Survey of Canada, which distributes its monthly accession lists to 500 persons in industry, universities and governments. Regional libraries are also maintained in Calgary, Vancouver, Yellowknife and Whitehorse.

**Future Trends**

The Science Council of Canada has indicated that a major component of information policy is "the optimum utilization of existing information services and systems and the development of new ones". The widespread geographic distribution and activity of earth science users across Canada, especially in the mining industry, demand an effective information network. All sectors of the economy have a role to play. Hence, the initiatives of individuals, institutions and organizations are important. Well-maintained catalogues and bibliographies are necessary. Regional sub-networks linked by an efficient communications system are required to overcome the effects of distance. Because of the substantial costs involved, every region–let alone every library–cannot hope to assemble complete earth science collections. Hence the importance of a network to inform and transmit information to the user.

The federal role in this field has been described in Science Council Report No. 7. This role is essentially that of a catalyst. The National Research Council Act empowers that institution to "establish, operate and maintain a national science

[1]Tyas, J.P.I., *et al.* Scientific and technical information in Canada. Science Council of Canada, Special Study No. 8, Parts I and II. Ottawa, Queen's Printer, 1969.

[2]Lamb, W. K. and I. E. Brown. Federal government libraries in Ottawa. *In* Report of the National Librarian. 1968.

[3]Downs, R. B. Resources of Canadian academic and research libraries. Report of the Association of Universities and Colleges of Canada. Ottawa, 1967.

**Table II.43–Canadian Earth Science Libraries and Holdings, 1969**

| Province | Library | Holdings | Totals |
|---|---|---|---|
| Alberta | University of Alberta | 22 100 | |
| | University of Calgary | 6 250 | |
| | Alberta Research Council | 31 450 | |
| | Geological Survey of Canada (Calgary) | 40 000 | 99 800 |
| British Columbia | University of British Columbia | 8 400 | |
| | Department of Mines & Petroleum Resources | 4 100 | |
| | British Columbia Research Council | 50 | 12 550 |
| Manitoba | University of Manitoba | 11 000 | |
| | Department of Mines and Natural Resources | 4 000 | 15 000 |
| New Brunswick | Mount Allison University | 5 000 | |
| | University New Brunswick | 4 000 | |
| | Department of Natural Resources | 500 | |
| | Research and Productivity Council | 350 | 9 850 |
| Newfoundland | Memorial University | 4 700 | |
| | Department of Mines, Agriculture and Resources | 2 500 | 7 200 |
| Nova Scotia | Acadia University | 2 500 | |
| | Dalhousie University | 8 000 | |
| | St. Francis Xavier University | 500 | |
| | St. Mary's University | 500 | |
| | Department of Mines | 1 210 | |
| | Nova Scotia Research Foundation | 700 | 13 410 |
| Ontario | Brock University | 5 000 | |
| | Carleton University | 6 300 | |
| | University of Guelph | 500 | |
| | Lakehead University | 1 600 | |
| | Laurentian University | 4 000 | |
| | McMaster University | 10 000 | |
| | University of Ottawa | 2 700 | |
| | Queen's University | 34 000 | |
| | University of Toronto | 12 000 | |
| | University of Waterloo | 20 000 | |
| | University of Western Ontario | 10 500 | |
| | Department of Mines | 50 000 | |
| | Ontario Research Foundation | 150 | |
| | Royal Ontario Museum | 6 000 | |
| | Department of Energy, Mines and Resources: | | |
| | Geological Survey of Canada, Ottawa | 100 000 | |
| | Mines Branch | 1 500 | |
| | Observatories Branch | 13 700 | |
| | Water Sector | 3 500 | |
| | National Science Library | 4 500 | 285 950 |
| Quebec | Ecole Polytechnique | 15 000 | |
| | Université Laval | 1 950 | |
| | Loyola College | 750 | |
| | McGill University | 12 510 | |
| | Université de Montréal | 15 000 | |
| | Sir George Williams University | 1 000 | |
| | Department of Natural Resources | 8 300 | |
| | Arctic Institute of North America | 3 000 | 57 510 |
| Saskatchewan | University of Saskatchewan: Saskatoon | 14 000 | |
| | Regina | 300 | |
| | Department of Mineral Resources | 520 | |
| | Saskatchewan Research Council | 7 500 | 22 320 |

*Source:* SES questionnaires.

library". The National Science Library states that it is "responsible for ensuring that Canadian scientists, engineers and industrialists have direct and immediate access to publications and information required in their day-to-day work". The Science Council has recommended that "the promotion of federal participation in the development of a national network of scientific and technical information services, and the implementation of the federal components of a national policy" be the rèsponsibility of the National Research Council. It is a matter of concern to this Study Group that the principal national earth science library, which is at the Geological Survey of Canada and hence outside the National Science Library administration, may not maintain a level of interchangeability comparable to that existing among the sciences encompassed in the National Science Library system. As indicated by Lamb and Brown[1], the Geological Survey library includes substantial collections which are not duplicated in the National Science Library, and "there should be no need to duplicate in the national libraries items from these specialized collections, provided the material can be made readily available either on interlibrary loan or through photocopies. They should be considered, therefore, as forming part of the national library resources of the country." Hence we conclude it is of vital importance that:

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*Conclusion II.15*
*Plans for the establishment of a National Scientific and Technical Information Service should recognize the desirability of integrating earth science information into the network. To this end, it is important that earth scientists be represented on the secretariat and board of directors of any bodies that may be formed to direct the operation of the national network, and that the earth sciences be fully included in the journals of research, bibliographies, indices and other information provided by the Service.*

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The provincial role in this field requires a close liaison among university, departments of mines, and research council groups in the region. The universities, as the major regional custodians of books on all aspects of earth science, have a major role to play. In Ontario the linking of university libraries by a common computerized system provides a common basis for cataloguing, preparation of awareness lists, etc. It would appear most economical if this capability were made available to industry and government groups as well. Maximum effectiveness in communication would require compatibility among the different library facilities concerned. In the Halifax-Dartmouth area a plan to develop a compatible system among different user agencies has been proposed.[2] The provincial departments of mines, having the major responsibility for the dissemination of earth science information in their region, must play a leading role in these developments. They might well show leadership by reviewing and publicizing the earth science library services and opportunities available to the public in their respective regions. The Ontario Department of Mines, following the recommendations of a Select Committee on Mining of the Legislative Assembly, has already moved toward centralizing its library facilities and integrating them with a data centre in its Information and Education Section.

[1]Lamb and Brown, *op. cit.*, p. 28.
[2]Tyas, *op. cit.*, Part II, Chapter 6, pp. 41-49.

# Chapter III

# Scientific and Cultural Development

"and some rin up hill and down dale, knapping the chucky stanes to pieces wi' hammers, like sae mony road-makers run daft–they say it is to see how the warld was made!"

Sir Walter Scott in "St. Ronans' Well", 1824

## III.1 Synopsis

The mosaic of earth science activities presented in Chapter II naturally elicits the question of a science policy that not only supports fully the application of science and technology in the service of the nation (see following chapters), but also lays sufficient stress on the development of the science itself. The purpose of this chapter is to discuss the important role that research must continue to play in the development of Canadian earth sciences, the particular responsibilities of academic institutions in this regard, and the opportunities in earth sciences for personal development.

Science must satisfy man's appetite for knowledge. Scientists have a particular responsibility towards disseminating their knowledge of the earth so that the layman may better enjoy the beauties of nature, and better understand the forces that have created, and are modifying, our physical environment. If we do not want to live on the earth as hermits, our culture should at least include elementary notions of the world underneath and above us.

Perhaps the most important conclusion in this whole report is the need to introduce a modern course in earth science in all secondary schools across Canada. Besides improving the scientific attitudes of young students, this course will provide tangible evidence that science is, indeed, relevant to man and his environment.

We have in Canada a "georama" which, in several respects, is unique in the world. Many of the earth's crustal features, several of them extremely ancient, are excellently displayed. Opportunities in Canada to search into the mechanisms that have created these features and to unravel the complex history of the earth appear almost unlimited. More than any other science, the earth sciences fit the Canadian scene. By building on existing strength, encouraging further study of our georama, and promoting the practical applications of earth sciences to Canada's economic and social development and technical assistance to developing countries, Canada could readily acquire a position of prestige in international science.

Our universities bear a fundamental responsibility towards the flourishing of earth sciences. Their present role in this respect is not completely satisfactory. Not enough graduates of the type needed by industry are being produced, too many professors work in isolation from industry and government agencies, not enough research is done on important national problems, and too many idiosyncracies pervade the university research effort. Furthermore, many earth science departments are either located in some of the oldest and most run-down buildings on campus, or are critically short of space. Together with the departments concerned, the higher university administration is in good part responsible for this deterioration.

Universities are more than repositories of knowledge; they exist to serve society. They may well provide the unifying force for bringing together the various branches of earth sciences. For evolving a dynamic science, the university departments of earth sciences must attract a greater number of high calibre students than in the past, a challenge that can in part be met through the widespread introduction of earth science in secondary schools.

Basic research in earth sciences must be vigorously pursued in our universities. Our country is so large, our resource-based industries are so vital to the economy, and the need for new principles is so important to improved mineral exploration technology, to safer and more economical construction, and to better land use, that such research must not be allowed to fall behind in either quantity or quality. Nevertheless, it is felt that mission-oriented basic research, particularly that relating to field problems, should receive preferential encouragement. In addition, more funds and better research facilities should be made available to the universities to specifically and preferentially increase their research into the practical applications of earth sciences, thereby promoting better training of students to meet the particular needs of industry.

One of the objectives of Canadian science policy should be to encourage centres for special studies in earth science in selected Canadian universities, involving close collaboration of universities, government agencies and industry. We propose in this chapter a series of principles to guide the establishment of such "centres of excellence".

## III.2 Are Earth Sciences Different from other Physical Sciences?

This question not only calls for a definition of the intrinsic features of earth sciences but invokes their relationship with other physical sciences. The following section, which is intended primarily for the reader unfamiliar with earth sciences, answers this question in general terms.

The intrinsic features of earth sciences can be summarized as follows:

*1. Knowledge of time.* For an earth scientist, the dawn of human history is a mere few seconds at the end of the long day during which the earth was formed, oceans and continents were created, and primeval life appeared. If all the events affecting the earth during *one century* could be summarized in one page, the history of our globe would fill a library of more than 100 000 thick volumes.

We have in Canada an assemblage of rock formations spanning almost the entire geological time scale, many of them older than 2 500 000 000 years. The absolute ages of these formations are known from the so-called "radioactive clocks", namely the measurement of quantities of certain elements which decay with time at a rigorously fixed and measurable rate. The relative ages, on the other hand, are known from fossil assemblages and various relations between rock formations.

The knowledge of vagaries of nature, and the historical reconstitution of the earth's crust and prehistoric life for various eras and periods of the geological time scale, provide challenging opportunities for earth science research in Canada.

*2. Knowledge of prehistoric life.* Life appeared on our planet more than 2 000 million years ago. It had most humble beginnings, as witnessed by the fossil remains found in rocks. At one time it developed into gigantic forms as dinosaurs. Paleontology teaches us that man is the product of an extremely long evolution, and we learn from paleo-ecology that man appeared when the habitat recently became hospitable. The question remains, however, as to how many centuries will elapse before this earth becomes inhospitable again and what will then happen to man.

*3. Knowledge of forces of nature.* A small earthquake may release more surface energy than several atomic bombs put together.[1] A single lava flow may bury an entire city. An oceanic tidal wave may erase from the map an entire beach settlement. A flood may carry bridges and houses as if they were matches. These examples and other earth hazards in the "scare" category are vivid illustrations of the forces of nature. Yet there are many more but much less obvious examples illustrating these forces, for example the formation of a mountain chain, the formation of an ice sheet over

[1]The volcanic explosion of Krakatoa in the Pacific Ocean released energy estimated as the equivalent of 150 megatons of TNT, compared to the bomb of 20 megatons of TNT-equivalent dropped on Hiroshima; yet, the Krakatoa explosion engendered only a very mild tremor.

half a continent, the drifting of continental blocks in the geological past, and the present apparent spreading of ocean floors. These are less obvious because their understanding rests on the reconstitution of the present and past earth's features. An earth scientist must have a good appreciation of these forces in order to interpret intelligently the various records found in rocks of certain ages.

*4. Knowledge of scale.* Intimately related to the knowledge of forces is the proper notion of scale necessary in the understanding of physical phenomena. Earth scientists study phenomena ranging in scale from an atom to a mountain belt 10 000 miles in length. The observer may be a mineralogist studying atomic dislocations in a crystal or a geophysicist measuring magnetotelluric currents of the earth's interior. The size of phenomena is manifest in many ways other than the mere physical size of the earth. For example, the quantity of heat, its mode of transfer from the interior to the surface, the bulk physical and chemical behaviour of materials under pressures and temperatures unattainable in the laboratory are some of the more challenging manifestations.

The laws of physics and chemistry have evolved from laboratory investigations of "closed systems". Geological phenomena generally belong to "open systems" and obey these laws "more or less". The main problem for the earth scientist is to reach in the laboratory the "geological order of magnitude" in terms of high to very high temperatures and pressures, the time necessary for reactions to take place, and the large number of chemical variables affecting the natural systems. His main problem is that he has no empirical laws to help him predict the behaviour of materials at depths greater than a few tens of kilometres, and what the effect of "very long time" might be on sluggish reactions. Furthermore, certain materials may behave as perfectly elastic bodies under certain conditions, but in the long term they may flow like syrup. *Time* is admittedly a most important variable affecting geological phenomena.

Curiosity is the begetter of great adventures and the common quality of all adventures. The discoveries of pure science stem from man's curiosity. In most physical sciences, these discoveries are a mental adventure. In the earth sciences, however, the activities are both a mental and a physical adventure, for it is in the field that the earth scientist has his laboratory, where he observes phenomena and where he measures certain things. To Charles Darwin the mountains of South America were as exciting in the 19th century as Neil Armstrong found the landscape of the moon in 1969.

The American missions on the moon and the familiar television image of astronauts picking rocks convey to the general public the impression that much of the activity in earth sciences resides in the *collection* of scientific data. Yet, as emphasized throughout this report, data collection–important as it is–is only one of several scientific activities essential in earth sciences.

The links between earth sciences and other physical sciences are most evident in the interdisciplinary fields of geophysics and geochemistry, both of which have experienced spectacular growth in the last few decades as a result of advances in the "mother sciences" of physics and chemistry. The links between geophysics and physics are illustrated best by the spectacular advances in geophysical instrumentation of recent years, in electronic circuitry in particular. They are also apparent in the distribution of geophysicists in Canadian universities, most of whom are attached to departments of physics rather than geology.

The most exciting scientific advance of this century is probably the quantum theory. The birth of this theory occurred at the beginning of the century, yet the problems which created the necessity for it had been known for half a century. Likewise, the full impact of this theory did not become significant to geochemistry until 1940. The first stage of geochemistry was the chemical analysis of rocks by "wet methods". With the understanding of atomic and molecular spectra provided by the quantum theory, and the development of optical and X-ray spectographs, it became possible to analyse trace elements in rocks on a routine basis. With the subsequent development of X-ray fluorescence, flame photometry, atomic absorption and neutron activation, the scope of instrumental analysis of rocks and minerals has greatly expanded. With the invention of the microprobe by the French physicist Castaing, it is now possible to obtain an accurate chemical analysis on a volume of mineral of $10^{-15}$ cubic centimetre, and thus obtain new insight on physical matter.

The history of science contains numerous examples of major scientific developments which actually started from the study of minerals or rocks. The theory of evolution was developed from a study of the fossil record. As we enter the space age and gain new knowledge on the nature of the universe, there are signs that the earth sciences–along with the infant planetary sciences–are moving together and converging in many ways. If so, an important synthesis of the earth sciences might be approaching. An indication that this scientific revolution is already in the offing is the scientific observation in the 1960s that large segments of the surface layers of the earth are spreading apart at the rate of a few centimetres per year, with "new crust" being formed along the lines of disjuncture. As explained by Wilson[1], what distinguishes this hypothesis of *sea-floor spreading* from previous hypotheses of earth mechanics is its startling precision, as shown by the fact that three different features of the earth all change in exactly the same ratios: a) the direction of magnetic polarity in lava flows (measured in millions of years); b) the widths of successive strips of magnetic anomalies over ocean basins (measured in hundreds of kilometres); and c) the directions of the feeble magnetization of samples (a few centimetres apart) taken at intervals along a deep-sea core, which are systematically reversely magnetized at intervals which are in a constant ratio for all cores. "This revolutionary theory has been developed through the contributions of *geologists* from all parts of the world, especially those who have recently studied the petrology of ocean floors and islands, *geochemists* who have provided chemical guides to the probable nature of the earth's interior, *geophysicists* who have devised instruments for studying the sea floor and the earth's interior and measuring the age and history of rocks. In large measure, the revolution can be said to have come about because of defence spending, which provided–for the first time–abundant knowledge of hidden places on the ocean floors, of the moon and Mars, and of the earth's interior (through new seismic arrays built to detect atomic bomb explosions)".[2]

A century ago, geology was the leading science in Canada, with such prominent scientists as Sir William Logan, Sir William Dawson, Hunt, Tyrrell, and several others. Geologists played a very major role in the establishment of the Royal Society of Canada. They were "naturalists" of broad scientific knowledge and high culture. Geology is far from having declined in Canada in this century, but it has been eclipsed–perhaps temporarily –by the faster rise of the "glamour" fields of atomic physics, molecular biology, electronics, cybernetics, and a few others. However, as some of these fields lose their freshness and appeal to students, and as earth sciences gain new momentum owing to major scientific discoveries and their increased use in the service of the nation, and because of the interest created by the Apollo space missions, it may be that earth sciences will again acquire a position of pre-eminence. This has been emphasized by Sir Edward Bullard, a distinguished geophysicist at Cambridge University, in these terms: "We are in the middle of a rejuvenating process in Geology comparable to the

[1]Wilson, J. Tuzo. A revolution in earth science. CIM Bull. 61(670): 185-192. 1968.

[2]Wilson, *op. cit.*

one that Physics experienced in the 1890s and to the one that is now in progress in Molecular Biology".[1] As stated at the beginning of this chapter, these sciences fit the Canadian scene very well, which is now the subject we wish to discuss.

## III.3 The Canadian Georama

The term "georama" is our word for the geological riches of this country and our heritage from nature. If we want to be more than hermits on this vast land of ours, we must first of all possess knowledge about it, not only to learn where to find economic minerals to sustain our economy or use the surface to our best advantage, but also to enjoy the landscape and the reconstitution of its extremely long history. The accumulated and organized knowledge of "man and his world" should, in our opinion, become part of our culture.

Canada has been richly endowed from a natural resource standpoint. In land area it is the second largest country in the world, but in continental shelf area and length of coastline it ranks first. Less than 1 per cent of Canadians have a real notion of its size or have crossed it from coast to coast and south to north. Canadian earth scientists know the Canadian territory because of their mineral exploration activities in "civilization" as well as in the most remote and forbidding places. When speaking of regional development, they know what it means because many of them still live in remote mining communities or have worked in the North or the Far North for extended periods. When we advocate financial inducements for people working in the Far North (see Conclusion IV.15), we express our concern for a *just society* extending to the barren lands where people live and work for the benefit of all Canadians.

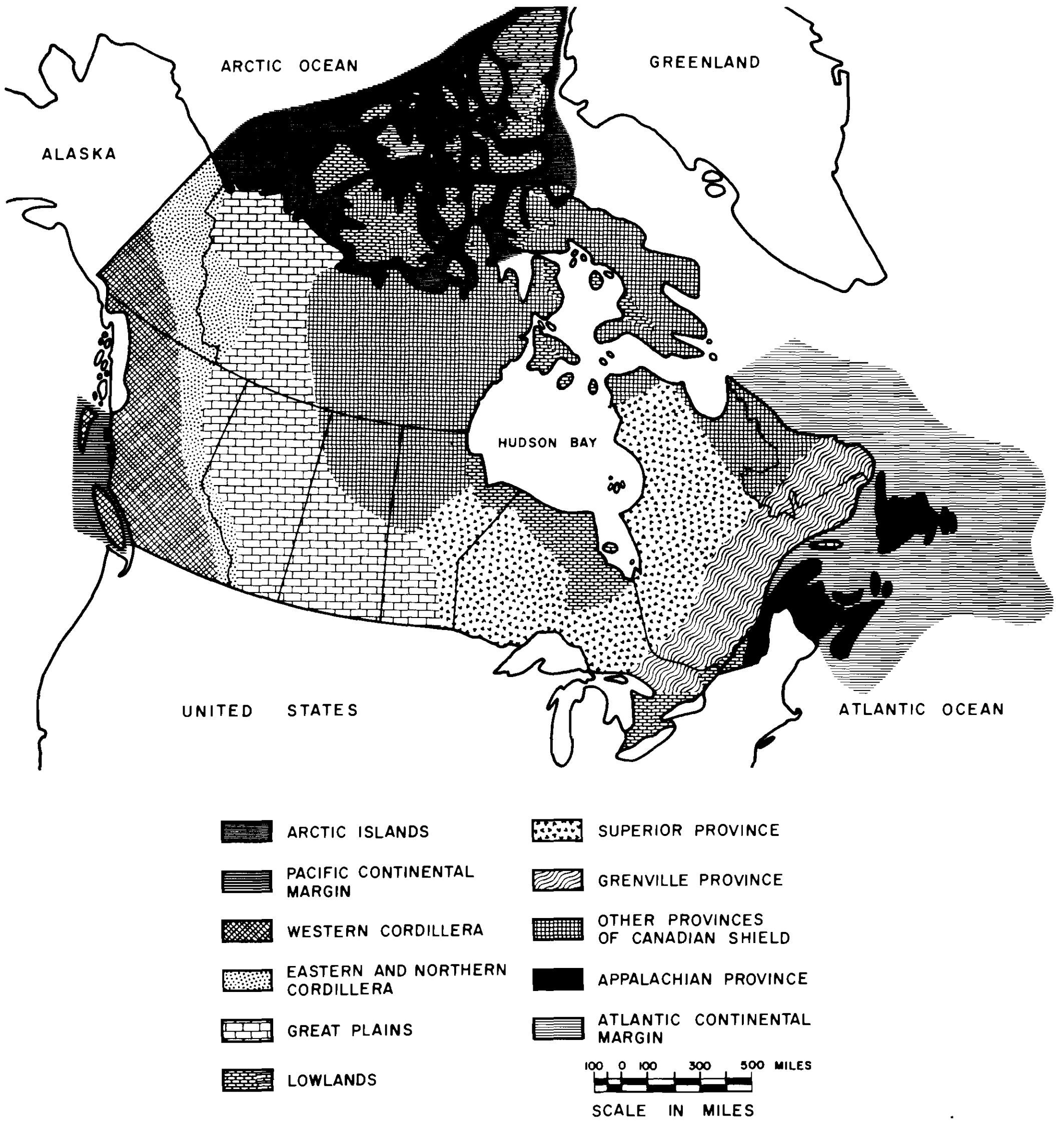
Still on the question of geography, our continental shelf areas (1.5 million sq. miles approximately) offer promise of discoveries of large petroleum resources, and perhaps economic concentrations of certain minerals such as gold and tin. However, as explained in the following chapter, extensive application of earth sciences and large expenditures are prerequisites for making these discoveries.

From a purely geological standpoint, Canada has much to offer. It has the largest continuous Precambrian Shield in the world. Its excellent and innumerable exposures make it the ideal field laboratory to learn about ancient volcanism, igneous intrusions, metamorphism, sedimentation and tectonics, not to mention primeval forms of life. Interest in the Precambrian is paramount because it is such a rich repository of hidden mineral deposits, especially nickel, copper, zinc, iron, and gold. However, from a purely scientific point of view, the Shield is an extraordinary resource for developing basic knowledge of what happened to the earth during the last 3 billion years. Its outcrops having been swept clean by recent glaciation, and being unadulterated by weathering, such as occurs in tropical countries, the opportunities to decipher in Canada the early history of the earth are almost unlimited. Because of its large size (see Figure III.1) and complex history, the Shield is a good place to analyse in detail broad variations in tectonic style and develop new approaches to global tectonics.

Each geological province within the Canadian Shield offers special opportunities for earth science research. For example, the Grenville province contains 90 per cent of the world's known anorthosites and shows an extraordinary development of rocks of the granulite facies; it is an easily accessible natural laboratory for the study of typical Canadian problems and for fundamental research in orogenesis and metamorphic petrology. The Superior province, in the central part of the Shield, is the largest and best exposed single block of the most ancient rocks on earth; concentrated study of the Archean in Canada could produce

[1]Bullard, E. The origin of oceans. Scientific American, September, 1969.

Figure III.1-Geological Provinces of Canada



major advances in the knowledge of proto-continents and yield new concepts for finding new mineral resources. Special opportunities may also be found in the other provinces of the Shield, and this leads us to conclude:

*Conclusion III.1*
*A comprehensive and multidisciplinary program of research into the origin and evolution of the Canadian Shield should be undertaken during the next decade, with particular reference to geodynamics of proto-continents, and Precambrian sedimentation, volcanism, plutonism, metamorphism, and orogenesis. This program should be under the general direction of the Geological Survey of Canada, and entail the active co-operation of provincial agencies, industry and universities. A major synthesis of this research should be published in 1980.*

The other geological provinces forming the Canadian georama include the Appalachian region, the Lowlands, the Great Plains, the Cordillera, the Arctic Islands, the Atlantic and Pacific continental margins, all of which are shown in Figure III.1. The development of each of these regions is very much dependent on earth science activities, not only for mineral exploration, but also to evaluate terrain for engineering projects, transportation routes, agricultural land, forest land, land reclamation projects, waste disposal and–not to be forgotten–the selection of recreation and wilderness areas.[1] Furthermore, research on the geology of these regions is needed to develop new major principles in earth sciences, ranging in scope from crustal-plate tectonics to trace element distribution in a particular rock formation. Henceforth we conclude:

*Conclusion III.2*
*Fundamental knowledge on the nature and history of the major elements of Canada's geological provinces and their correlation with similar elements in contiguous regions of the world should remain a prime research objective of the government agencies and university departments engaged in earth science activities.*

## III.4 Historical Development of Earth Sciences in Canada

As may be expected, the first geological observations in Canada were made by "voyageurs" and mainly by military officers and naturalists staffing various expeditions, such as the Frobisher expedition in the 1570s and the Franklins expedition in the 1820s. However, geology was seeded in Canada in 1816 when the famous French mineralogist Abbé Haüy donated 429 prized mineral specimens to the Séminaire de Québec to help establish its Musée de Minéralogie et de Géologie. The first regular lectures in mineralogy, given at the Séminaire by Abbé Jean Holmes, started in 1822.

Toronto saw the birth of the first university department of geology in Canada in 1853, as well as the first geophysical laboratory (founded by Henry Lefroy in 1840). University research in geophysics started in 1928 when, at the request of the Geological Survey of Canada, the Departments of Physics at McGill University and the University of Toronto began investigations in geophysical prospecting methods.

Apart from lectures given in the early 19th century as part of courses in natural philosophy or natural science, Canadian geology was really born with the founding of the Geological Survey of Canada and the appointment of William Logan as its first Director in 1842. It is interesting to note that apart from a meteorological observatory established earlier by the British Army, *the founding of the Geological Survey of Canada in 1842 marks the beginning of organized scientific research of any kind in this country.*

Logan was the first Canadian scientist to receive, in 1851, the highest award from the Royal Society of London. In

[1] These and other aspects of the geological provinces in Canada are discussed in the 10 background papers published in the CIM Bulletin of January and February, 1970.

1856 he was knighted for his contributions as a scientist. Sir William Logan played an important role in bringing Canadian geology to world attention. In 1863 he published a splendid monograph of 933 pages on the geology of Canada.

The history of the Geological Survey contains several illustrious names, including Tyrrell, Dawson, McConnell, McIntosh, Faribault, Low, and several others, whose works are still used as references today. T. Sterry Hunt, one of the original workers of the Geological Survey, is credited with the first Canadian observations in oil geology and is considered responsible for first proposing in 1858 the anticlinal theory of oil and gas accumulation.

The Geological Survey has been in continuous operation since 1842 and is still considered one of the best geological surveys in the world. Our study shows that this opinion is widely held in Canada, especially in the mineral industry. Interestingly enough, in its 128 years of existence the Geological Survey has cost only an *average* of $750 000 a year ($100 million in total), a small sum compared to the mineral industry investments (see Chapter IV) and the signal services rendered in the form of basic and applied earth science services (see Appendix 5).

The founding of the Dominion Observatory in Ottawa in 1905 was an important development in Canadian geophysics. Canadian geodesists have pioneered in the establishment of accurate control for mapping over large areas, by using shoran and other techniques. The Canadian seismological network is one of the finest in the world in terms of standards, uniformity, and areal extent. The Observatory has pioneered in the use of aeroplanes for transporting gravity meters and has, consequently, surveyed extensively the gravitational field over large parts of Canada, in a great variety of conditions. In conjunction with university researchers, geophysicists of the Observatory have also produced important new knowledge in geomagnetism and heat flow.

An essential trait of the historical development of Canadian earth sciences is the key role played by the provincial departments of mines. In addition to detailed geological mapping of very large areas, these agencies have contributed much new knowledge on the geology of mining districts, particularly in Ontario and Quebec (see Section II.6). They have been instrumental in promoting Canada's mineral resource development since the beginning of this century.

The evolution of geotechnique in Canada was sparked by the establishment in 1947 of the Division of Building Research within the National Research Council. This organization has produced invaluable research in the application of geology to public works, including important studies in soil mechanics, permafrost and muskeg, snow and ice, avalanche protection, and the effects on buildings of vibrations, caused by blasting and earthquakes. With the Associate Committee on Geotechnical Research this organization has played an important role in fostering Canadian research in these important fields, especially in universities.

The advancement of physical geography in Canada can in large measure be credited to the research activities of the Division of Quaternary Research and Geomorphology of the Geological Survey of Canada, which incorporates parts of the former Geographical Branch of the Department of Energy, Mines and Resources. A few Canadian universities have contributed significantly to this field, even though most academic research is in the other fields of geography and the majority of faculty in physical geography has been trained abroad.

The development of rock mechanics in Canada is closely associated with the research activities of the Mining Research Centre of the Mines Branch (EMR), which was established in the 1960s. In the last few years, however, a growing number of universities and mining companies have been expanding their research in rock mechanics.

The development of mine geology was

initiated by Douglas Wright, who worked at Porcupine in 1912. Before that all geological work in mines was done by mining engineers, because it seemed to the mine managers of the time that geologists were too academically oriented. Geologists have long since demonstrated the usefulness of their work in mining operations.

Before World War II, most mining exploration was carried out by prospectors, although these men relied heavily on government geological maps and reports in their work. Prospecting for hidden deposits began in the 1920s but became dominant only after World War II. The services of geologists, geophysicists and geochemists are now used extensively in mining exploration, following the well-established pattern in petroleum exploration (see Chapter IV).

The historical development of the various disciplines in earth sciences is discussed at some length in the background papers referred to in Appendix 4, and in Special Publication No. 11 (1968) of the Royal Society of Canada.

## III.5 General Appraisal of Current Level of Canadian Activity in Earth Sciences

**Research versus Data Collection**

Canada is such a vast country that in two-thirds of the principal fields of earth sciences the current activity still consists predominantly of scientific data collection, and it is anticipated that many fields will remain in this stage for several years to come. Some other fields like mineral deposits geology, tectonophysics, petrology and others are on the threshold of the stage of analysis, interpretation and synthesis of vast quantities of available data. These latter fields will require a tremendous increase in data handling, whereas the former will likewise need to be marshalled to conform to modern methods of data storage and retrieval. Indeed, the need for the development of standards and data storage and retrieval systems is stressed in almost all of the briefs and background papers submitted to this Study Group.

Approximately one-third of the fields listed in Appendix 4 might be described as being in the stage of major synthesis and interpretation, because either they are fields in which Canadian science is eminent or they are fields of international scope in which Canadian scientists have made valuable but still relatively modest contributions. We could cite these fields, but every specialist of other disciplines would probably feel outraged at being left out and would get the wrong impression that data gathering is unimportant.

The concentration on scientific data collection has been necessary because of Canada's special situation as a vast, sparsely populated, northern country. This concentration accounts for Canada's image abroad of a country strong in mine-finding but weak in broad syntheses of international significance. Although theoretical research and broad syntheses in several fields of earth sciences should now be particularly fostered, the costly and time-consuming data collection must still be carried on.

**Level of Activity in Various Fields of Earth Sciences**

On a national and international basis, the level of activity in the various fields of earth sciences in Canada may be *subjectively* described in terms of the following levels:

1. *High Level:* exploration geophysics, geochronology (isotope geochemistry), geomagnetism, geophysical instrumentation, mineral deposits geology, soil mechanics, and stratigraphy.

2. *Intermediate Level:* crystallography, electronic data storage and retrieval, geodesy, geotectonics, gravity, meteorite crater studies, mineralogy, mining geology, paleontology, pedology, petroleum geology, petrology, structural geology, tectonophysics, and volcanology.

3. *Low Level:* biogeochemistry, coal geology, engineering geology, environmental geology, exploration geochemistry, geomorphology, glaciology, heat

flow, hydrogeology, inorganic geochemistry, magnetotelluric studies, marine geology, marine geophysics, mathematical geology, muskeg studies, organic geochemistry, paleobotany, palynology, permafrost studies, photogeology, physical geochemistry, physical geography, Quaternary studies, remote sensing, rock mechanics, and sedimentology.

Canada obviously cannot excel in all earth science fields, but it is somewhat disturbing to note the low level of activity in so many fields and, more particularly, to find in the third category several disciplines which are directly relevant to Canadian terrain conditions and have important practical applications. It should be emphasized, however, that a low level of activity in a particular discipline does not necessarily signify low quality of research.

**Earth Science Fields Especially Adapted to Canada**

Certain features such as the north magnetic pole are unique to Canada, while others such as the Precambrian Shield, the erosion and deposition features of the Ice Ages, and the fold belts found in Canada are shared with other nations, although they are particularly well or best developed or exposed in this country. For example, the southwestern part of the Northwest Territories is seismically one of the most quiet areas in the world, which makes it an ideal region for studying the energy spectra of earthquakes and atomic explosions from anywhere. Canada is not only fortunate to have these features available for research but, as the sovereign power, it bears the responsibility for seeing that they are adequately studied from a theoretical and practical point of view.

A total of 45 principal earth science fields were investigated in an effort to discover the special relevance of these fields to typical Canadian problems and their opportunities for reaching international scientific pre-eminence. The criteria used in this "suitability study" include the large size of Canada, the cold climate of the country, the fresh and abundant rock exposures, the nature of Canada's geological history and the peculiarities of its georama, the nature of its natural resources compared to other countries, as well as the history of Canadian excellence and leadership in these fields.

The principal fields which satisfied several of this kind of criteria were classed as *exceptionally suitable* for Canadian research. Fields which are suitable primarily because of the vast area of Canada were classed as *very suitable.* The remaining fields, which are also important (petroleum geology employs more geologists than any other fields) but not peculiar to Canada, can be expected to produce useful Canadian contributions. However, these contributions are not likely to be as important as those of several other countries where larger population, heavy industrialization, and availability of resources for "big" science are more important factors. Table III.1, in which this classification is given, provides an indication of those fields which are, or could be, preferentially developed in Canada on account of natural advantages. The table does not, however, give ratings according to specific national needs.

According to this study, 10 earth science fields can be classed as exceptionally suitable for developing excellence in Canada, while 13 other fields are very suitable mainly on account of Canada's vast size, and 22 other fields are important but not specifically characteristic of the Canadian scene. We thus submit:

*Conclusion III.3*
*The following fields are exceptionally suited for Canadian research (in alphabetical order): geomagnetism, geotectonics, glaciology (including snow and ice), mineral deposits geology, mining exploration geophysics, muskeg studies, permafrost studies, Precambrian research, and Quaternary geology.*

In most scientific disciplines Canada can only contribute to their growth in re-

**Table III.1–Environmental Suitability of Solid-earth Science Fields to Canada[a]**

| Exceptionally Suitable | Very Suitable | Important but not Peculiar to Canada |
|---|---|---|
| Geomagnetism | Computer storage and retrieval of E.S. data | Basic geochemistry |
| Geotectonics | Geochronology | Biogeochemistry |
| Glaciology | Geodesy | Crystallography |
| Mineral deposits geology | Geomorphology[c] | Engineering geology |
| Mining geophysics | Gravity | Environmental geology |
| Muskeg studies | Heat flow | Exploration geochemistry |
| Permafrost studies | Marine geology | Hydrogeology |
| Precambrian research | Marine geophysics | Magnetotelluric studies |
| Quaternary geology[b] | Meteorite crater studies | Mineralogy |
| | Mining geology | Paleobotany |
| | Paleontology | Palynology |
| | Rock mechanics | Petroleum geology |
| | Soil mechanics | Petroleum geophysics |
| | Volcanology | Petrology |
| | | Photogeology |
| | | Physical geochemistry |
| | | Remote sensing |
| | | Sedimentology |
| | | Seismology |
| | | Stratigraphy |
| | | Structural geology |
| | | Tectonophysics |

[a] Fields listed alphabetically in each column.
[b] Includes palynology of the Quaternary.
[c] Includes physical geography.

lation to their nourishment of the economy and in terms of its limited financial resources and relatively small population. However, in fields which are exceptionally suited for Canadian research, such as those enumerated above, the policy should be to encourage *preferential growth* in order to achieve pre-eminence as soon as possible.

## Important Canadian Contributions in Earth Sciences[1]

Canadian scientists are making outstanding contributions in five major fields of earth sciences, namely, in alphabetical order:

1. Continental drift, global tectonics, and tectonophysics.
2. Geochronology on a regional basis, especially that of the Precambrian.
3. Mineral deposits geology.
4. Mining exploration, including mining exploration geophysics and geophysical instrument development.
5. The Precambrian.

Of the 44 (out of 55 canvassed) departments who answered this question, the above fields appeared in more than half of the answers. They also clearly stand out in questionnaire returns from industry and government agencies, and are mentioned repeatedly in briefs and background papers submitted to this Study Group.

A *second group* of important contributions includes the subjects mentioned in 25-50 per cent of the lists. This group includes the following fields, again listed alphabetically:

1. Carbonate reefs.
2. Cordilleran studies.
3. Glacial processes and ice mechanics.
4. Marine geophysics.
5. Permafrost studies.
6. Quaternary and Pleistocene studies,

[1]This judgment is based essentially on questionnaire returns from university departments of geology, geophysics, and geography. Had several departments of civil engineering been included (see Table I.2), the relative position of contributions from geotechnique would probably be somewhat different.

and geomorphology.

7. Regional geophysical surveys, aeromagnetic surveys in particular.

8. Seismology.

9. Stable isotope studies, sulphur in particular.

10. Soil mechanics.

A *third group* includes the fields mentioned in 10-25 per cent of the cases:

1. Astroblemes.
2. Crust of the earth.
3. Exploration geochemistry.
4. Geological field methods.

The background papers (see Appendix 4) indicated several fields which are greatly underdeveloped or lagging in Canada, especially the following:

1. Biogeochemistry.
2. Magnetotellurics.
3. Physical geochemistry.
4. Permafrost.
5. Remote sensing.
6. Sedimentology.

**International Activities of Canadian Earth Scientists**

The general image of Canadian earth scientists abroad is that of good minefinders, and of experts in field methods. However, in the last decade or so their international scientific stature has been growing rapidly as a result of major contributions of both theoretical and practical significance.

International recognition is indicated by the fact that Canada will host the XXIV International Congress in Montreal in August 1972, where more than 6 000 delegates from 100 different countries are expected. Canada will also host the XXII International Geographical Congress in Montreal in August 1972, for which an important program of physical geography is being prepared.

The Sixth International Conference on Soil Mechanics and Foundation Engineering, grouping 1 500 delegates, was held in Montreal in 1965. The International Union of Geodesy and Geophysics met in Canada in 1957. In addition, Canadians have been presidents of international unions in the earth sciences as well as of large American associations in most of the earth science fields. It is significant that the first president of the International Union of Geological Sciences was a Canadian geologist and that another Canadian was president of the International Union of Geodesy and Geophysics during the International Geophysical Year of 1957.

## III.6 Earth Science in the Public Eye

Earth scientists and people in the mineral industry are prone to ask why, as a nation, we have not been more sensitive to our physical environment and the sciences relating directly to it, and why earth science is generally not taught in our secondary schools. Likewise, we may ask why so many well-educated Canadians know so little of the Canadian georama, and why so many earth science departments are housed in the oldest or most uninviting buildings on university campuses. These questions naturally elicit the problem of bringing earth science into the public eye.

The Science Council of Canada[1] has recognized that one of the goals in setting Canadian science policy should be the "enhancement of opportunities for personal development". We wholeheartedly support this concept because cultural development of the individual should be one of the principal objectives of any nation.

Scientists tend to isolate themselves from "the rest of the world" and forget that the general public, who financially supports the research, needs to be educated on the aims of science and its role in modern society. Earth scientists in this country are no exception, as very little has been done to date to inform the general public on the nature of earth sciences and their contribution to the development of Canada. The image of earth scientists is too frequently associated with

[1]Science Council of Canada. Towards a national science policy for Canada. Report No. 4. Ottawa, Queen's Printer. 1968. p. 13.

the occasional swindle in mining or petroleum business, and the public fails to realize that earth science activities in this country are not uniquely tied to the mineral industry.

In recent months science policy has caught public imagination through news released from the Science Council of Canada and the Senate Committee on Science Policy. "This interest in science and science policy should have the effect of making the scientist more socially conscious of his role and more articulate in his public expression of responsibility".[1] The most recent expression of this growing awareness on the part of scientists and engineers is the creation of SCITEC (see Section II.8).

In this regard, we wish to develop here the thesis that *earth science is potentially the most inspiring science for the layman.* Scientists ought to satisfy man's natural curiosity about his physical environment, the mountains and valleys, the lakes and rivers, the rocks and minerals, the fossils, the sea, the climate: in short, the world around him. Earth science is a dynamic science, full of challenges and opportunities. How truly inspiring is the notion that our physical environment is continually changing under the forces of nature, that continents are not fixed forever, that the ocean floors are spreading, that the crust is sinking in places and rising in others, that rocks contain documents billions of years old, that human life is the culmination of an extremely long and arduous evolution in a world that has, at times, been most hostile.

Anyone who has watched a crowd of visitors in a public museum of minerals and fossils can certify that people of all ages are attracted by the beauties and curiosities of nature. But even more inspiring is the notion of continuous change on the earth, and the general concepts of the processes that have affected the earth's crust through very long periods of time.

As we enter the so-called post-industrial revolution, man will have increasingly more leisure time on his hands. Would it not be appropriate for Canadians to derive greater enjoyment from their travels and holidays through some basic understanding of the immense wealth of natural phenomena exposed under their very eyes? Would it not be reasonable to expect that the layman possessing elementary knowledge of the earth would better appreciate the value of his heritage from nature? Is it not desirable that people cultivate interests by collecting minerals, rocks, fossils? Could we not adopt a national vocation in the earth sciences, both in scientific and cultural development? Surely, for a country as richly endowed in natural phenomena as Canada, with such a diverse georama (see Section III.3) and such mineral resources (see Chapter IV), there is merit in recognizing this particular vocation in cultural development.

There are undoubtedly many ways to bring science to the layman and we cannot possibly cover them all in this report. However, the following suggestions illustrate what could be done to bring the physical environment into proper perspective in the eyes of the layman.

1. Televised lectures by prominent earth scientists on the new revolutionary aspects of earth science, such as sea-floor spreading, continental drift, mountain building, the origin of life.
2. Museum displays that not only illustrate collections of fossils, minerals and rocks but also show schematically the earth processes, and represent graphically the many still unresolved problems in earth science.
3. Colour films illustrating geological phenomena, and their importance to man.
4. Guidebooks describing the earth features that can be observed in national parks and along highways.
5. Road maps giving locations of interest to "rockhounds" and fossil collectors.
6. Road plaques giving popularized explanations on the geological features observable at particular locations.

[1]Wynne-Edwards, H. R. Science, the moon and the mission. Science Forum, Dec. 1969.

7. Press releases discussing geological phenomena or natural catastrophes that have occurred in some part of the world.

8. Publication of popular books on geology and other earth sciences.

9. Above all, as discussed in the next section, the introduction of a modern earth science curriculum in secondary schools.

The responsibility for bringing earth science into the public eye obviously falls on the entire earth science community.

Industry, government agencies and universities all have a major role to play. We therefore suggest:

*Conclusion III.4*
*Scientific societies should play a more active role in bringing earth science into the public eye. Government agencies, industry, universities and museums should co-operate more closely in educating the general public on the Canadian georama and stressing the importance of earth science activities in reaching national goals.*

## III.7 The Teaching of Earth Science in Canadian Secondary Schools

The introduction of a modern earth science curriculum at the Grade 8 or 9 level, followed by a more advanced course at Grade 12 or 13 is, we believe, most desirable.

**Rationale for Introducing Earth Science in Secondary School Education**

1. The earth sciences, by their very nature, furnish aspects of scientific culture that physics, chemistry, mathematics and biology do not provide (see Section III.2).

2. The teaching of earth science in secondary schools can be very beneficial in providing the student with a proper understanding of the fundamental principles of general science, because earth science (including meteorology) is highly relevant to the student's environment. The teaching of science in the general framework of man's environment affords a unifying purpose and provides a continuum which relates all science subjects to a prolific common denominator - the study of the physical environment.[1]

*a)* The *unifying purpose* is provided by a perspective of matter, space, time, and energy (see Section III.2) in relation to man's focal point of interest - his environment on this planet. This framework brings together and enlightens all areas of science. For example, biology, physics, chemistry and mathematics are involved in the discussion of the materials and processes which shape our environment. Astronomy, geology, geophysics, geochemistry, oceanography, geography and meteorology bring into sharp focus the major scientific aspects of the earth. The following examples illustrate how various science topics can be taught in the frame of reference of man's environment:

- Linking the *behaviour of gases* and principles of thermodynamics to the study of the atmosphere, water transport, and climates. The story of how evaporation, condensation and pressure-temperature relationships are involved in forming clouds, causing rain and winds, and how these processes are driven by solar energy affords a meaningful interplay of ideas and concepts which relate to the *real world.* The principles of gas behaviour are treated. The treatment is made interesting by relating the principles to familiar experiences which are then viewed from a different perspective.
- The *structure of solids* is beautifully documented by earth materials. All students are fascinated by the way mica separates into thin sheets, the superb qualities of diamond, and in strong contrast to diamond, the very low hardness and dullness of graphite - another compound of carbon. A youngster discovering for himself the constancy of the interfacial angles in crystals, whatever the provenance, age and the size of these crystals, is naturally inspired by finding this high degree of

[1] *See* R. E. Bisque. Why teach earth science in our secondary schools. ESCP Newsletter, No. 12, pp. 1-2. July 1966.

order in solids, an experience that predisposes him to learn more about atomic structure and the properties of matter. Besides delivering the message that "things act according to the way they are put together", this confrontation introduces the student to materials which comprise the bulk of the earth's crust, to the minerals which ensure our technology of affluence, to the soils which nourish the vegetation. This in turn adds meaning to subsequent discussions of other environmental aspects, the landforms, the features of erosion and deposition, which involve the earth materials through interplay with the weather.

–*Radioactivity* can be introduced and discussed not only from the point of view of atomic explosions but also, and importantly, its use in obtaining the absolute ages of earth materials. Like many scientific principles, this topic can be treated without involving the geological application - in a formal and more or less "dry" manner. But how truly inspiring can it be to the youngster to discover that certain minerals contain minuscule geologic clocks which enable scientists to date phenomena that are billions of years old. This story provides the factual basis for the student's appreciation of geologic time and the introduction for his reasoning of what nature can accomplish during hundreds of millions of years.

Each of these three topics - behaviour of gases, structure of solids, and radioactivity - may in a modern earth science course be treated just as they might be in a general science course, except for one thing: the relevance of these topics to the student's environment. Thus, as a science-teaching medium, earth science affords a strong unifying theme - the environment.

*b*) The *continuum* is the universe, the earth, the moon, the quasars. For the young student, the earth is the focal subject. However, this same subject brings with it the *atom-to-universe involvement* and a comprehension of *scale* in both *space* and *time* - an inspiring frame of reference! With the recent missions to the moon, this framework assumes singular significance especially when the student learns, for example, that one of the minerals found in moon rocks is *bytownite*, a feldspar named after our national capital city ("Bytown" in the early days) by T. Thomson in 1836!

3. Another important aspect of the teaching of earth science in secondary schools is the opportunity it offers for interesting laboratory investigations, for the student to discover things through his own efforts in the classroom as well as outdoors. With the "personal discovery" approach by the student, the teacher can easily initiate discussion and introduce further enquiry. The emphasis becomes "how we learn" rather than "what we know". The methodology thus becomes investigative and experienced-centred. An earth science course is really no less amenable to an investigative approach than any other science course. In fact, it is more amenable than most, in view of the added potential of field trips and the ready availability of earth materials and natural processes.

4. The earth science framework in high schools leads easily to appreciation of timely problems, such as water and air pollution, weather modification, space missions, desalinization of sea water, water supply for our continually expanding cities, scars on the landscape, geologic hazards, navigation of foreign oil carriers in our Arctic waters, selection of recreation and wilderness areas, and a host of topics which will ultimately confront the electorate represented by the younger generation.

5. The introduction of earth science in high schools will be beneficial to both the college- or university-bound student and the terminal student. It provides important elements of basic science in its most relevant aspects. It conveys the message of science in the service of man. It teaches the student that scientific enquiry can be very enjoyable and rewarding. For example, the student can "discover" that light and dark objects absorb radiant energy differently (with a light, two ther-

mometers, and two cans, one black, the other shiny); he may observe that the resultant differences in air density cause motion which can be seen by releasing chalk dust or smoke in the vicinity; a discussion of winds caused by unequal heating of the land and water masses by the sun is a natural follow-up.

6. Through notions of paleontology, earth science provides a basic understanding of the evolution of life on this planet, an important element of culture.

7. If properly taught, earth science can distinctly improve the scientific attitudes of high school students towards science. In particular, the course can help them to sharpen their power of scientific observation and improve their inductive reasoning.

8. The introduction of earth science into the high school curriculum also assists the student in his future career orientation. This particular aspect is of great significance in Canada, where there has been a chronic shortage of earth science professionals and scientists, and a now critical shortage of professional manpower in the mineral industry (see Section II.2). *We consider that the major reason for the low student enrolment in geoscience in Canadian universities is that earth sciences are virtually unknown to students until they reach university, and it is then often too late for them to decide to enter these important fields.*

9. Finally, we consider that the introduction of earth science in high schools would encourage a greater proportion of bright students to enter this important field of science. In view of the great opportunities in Canada for earth science activities, both in the pursuit of pure knowledge and its application to the nation's welfare, earth science should get its fair share of the "bright young lads and lasses".

**The Earth Science Curriculum Program (ESCP) in the United States**

This multimillion-dollar program of the American Geological Institute, which was established in May 1963, took more than four years to develop fully. The teaching material was prepared with the help of a prestigious panel of specialists who wrote units of the preliminary text during summer sessions. The material was tested in selected high schools across the United States, after which the high school teachers commented and criticized. The teaching text was then rewritten and published in preliminary volumes for wider distribution, followed by teacher evaluation of its contents. In 1967, Houghton Mifflin Company published the new material in four volumes - student text, student laboratory manual, and two teacher's guidebooks - under the general title *Investigating the Earth.*

The contents of ESCP, which are intended for Grade 9 students, are presented using every available technique to make the subject matter stimulating, meaningful, and relevant. The text is up-to-date with such subjects as continental drift discussion. The student is given some "unsolved problems" to develop his perception, imagination, and deductive reasoning.

The student's text is an attractive, very well illustrated, modern textbook of science. The subject matter includes units on:

- *the changing earth* (its materials, shape, motions, forces and energy)
- *the earth cycles* (atmospheric, oceanic, surficial, and in depth)
- *the earth's biography* (the historical records in rocks, the present and past life, the development of continents, the evolution of landscapes)
- *earth's environment in space.*

The approach, illustrated by laboratory assignments, is scientific and utilizes the principles and methods of geology, astronomy, physics, chemistry, biology, and mathematics. In short, it is a splendid text.

The ESCP in the United States is financed by the National Science Foundation, and is one of its most recent curriculum reform projects. In 1963, this Foundation spent about $320 million, of which *more than $40 million* were designed for "Institutes", programs primarily intended to improve teaching in primary and secondary schools. In 1969, the National Science Foundation sponsored 41 summer institutes in ESCP and earth sciences.

**Impact of the Earth Science Curriculum Project in the United States**

The impact of ESCP in the United States is measurable in terms of student performance and course appeal. According to the American Geological Institute, the results of the Test of Science Knowledge (TOSK) on college students with and without the Earth Science Curriculum Program suggest that students who had followed the ESCP course were already close in science ability to college students ahead of them and having had high school chemistry, physics and biology. *The results indicate that ESCP is a very effective program for improving the scientific attitudes and abilities of students.*

On the other hand, ESCP has experienced a tremendous expansion since it was inaugurated, starting from an educational "curiosity" and now being a standard part of the junior high school curriculum in the United States. For example, in the State of Oklahoma, earth science was taught in 18 schools in 1962-63; in 1968-69 the number had increased to 162. The State of Ohio had 60 earth science teachers in 1963-64; in early 1969 this number had increased to more than 600.[1] *From 1968 to 1969 the earth science student enrolment (Grade 9 alone) in American high schools increased by almost 100 000 to reach 841 422 in 1969.[2] The current enrolment is approaching the objective set in 1963 of 33 per cent of all ninth graders. Significantly, it is estimated that about 18 000 teachers were engaged in 1969 in the teaching of earth science in American high schools, compared to 2 500 in 1963.*

Use of the ESCP materials *(Investigating the Earth)* is increasing rapidly in the United States. It is estimated that more than 350 000 American students are now using these materials.[3]

**A New Course on Time, Space, and Matter**

The course *Time, Space, and Matter,* although not exclusively or even primarily an earth science course, uses a kindred approach to that of ESCP for the teaching of science at the secondary school level. Another American science education project of the National Science Foundation, this course was developed at Princeton University and completed at Rutgers University.

This science course emphasizes *doing science* rather than recounting its achievements. The course consists of nine interrelated investigations which enable to student to learn about the nature and history of the physical world through direct observation and inference.[4] Several themes are integrated into a sequential format ("the story line"), which provides continuity from one investigation to the next. These nine investigations are:

1. Encountering the Physical World... motion and substance
2. Exploring A Slice of the Earth...a first look at the earth
3. From Microcosm to Macrocosm... extending the senses
4. Levels of Approximation...observation and the need for precision
5. Dimensions and Motions of the Earth...measuring time, space, and matter
6. The Surface of the Earth...a record of ceaseless change
7. The Grand Canyon of the Colorado...a closer study of earth change
8. The Surface of the Moon...records of the past
9. World in Space...dimensions on a vast scale.

Since the course combines several disciplines, some of which may be unfamiliar, the course content is described in Teacher "Folios", one for each investiga-

[1] *Reference:* ESCP Newsletter. No. 19. May 1969.
[2] *Reference:* ESCP Newsletter. No. 20. September 1969. p. 12.
[3] *Reference:* ESCP Teacher Information Bulletin. Nov. 1969.
[4] Time, space, and matter...investigating the physical world, a conspectus. Princeton University, 1968.

tion. As the student proceeds through each investigation, he records his observations and interpretations in a Record Book. While pursuing each investigation, he uses his Investigation Books. These books, which consist almost entirely of photographs, have been developed to provide the student with an opportunity to observe and interpret phenomena which would otherwise not be accessible to him. The selection, sequence, and juxtaposition of pictures serve to advance the "argument" of a particular investigation.

"The course seeks to establish an environment within which the student can learn basic principles of science as he works to answer questions and solve problems that are of intrinsic interest. The student is thus in a position to acquire not only specific and general knowledge about science but, in addition, to develop techniques for solving problems and acquiring knowledge of his own".[1]

**Current Level of Earth Science Teaching in Canadian Secondary Schools**

In contrast to the 18 000 teachers in the United States, we estimate that less than 100 are teaching geology or earth science in high schools in the whole of Canada.[2] Only two provinces seem to have a course that includes earth science or geology even in its title. In most Canadian secondary schools, "bits and pieces" of earth science are taught as a part of courses in science or geography, mostly by teachers who either know very little of modern earth science or show little interest in it. The teaching of earth science by "arts-trained or arts-minded geographers" is clearly unsatisfactory because these teachers do not have adequate training in science and mathematics, not to mention practical or field experience in various earth science activities. Furthermore, adding to our disenchantment is the fact that where earth science is adequately taught in the high schools, the universities in the province will generally not accept the course by allowing it university entrance credits. Surely, this is not a healthy situation for a country like ours, which depends on earth science in so many national and regional undertakings.

In view of this situation, the foregoing arguments, and the documentation assembled in this report, we submit what is perhaps our most important conclusion:

*Conclusion III.5*
*Provincial departments of education should encourage and promote the teaching of earth science in secondary schools, so that science can be seen to be relevant to the physical world in which the student lives and in order that the fundamental principles of science be taught within the frame of reference of man's environment. Universities should help in the training of high school teachers and the development of the audio-visual aids and texts required for this modern course.*

**Proposal for an Earth Science Program in Canadian Secondary Schools**

The widespread introduction of earth science in secondary schools obviously cannot be accomplished in one year. But if we are to develop adequately our next generation of scholars, and provide basic science education to the electorate of the post-industrial era, we must begin *now* to rejuvenate the teaching of science in secondary schools. We must initiate a new approach in teaching methodology focussed on man's environment and on actual problems. We must break down the barriers that artificially separate physics,

[1]Pallrand, G. Time, space, and matter. ESCP Newsletter, No. 19, May 1969. pp. 11-12.

[2]In a survey of high school science teachers in Canada in 1965-66, Dean A. B. Van Cleave of the University of Saskatchewan reported *(Chemistry in Canada*, October, 1967) 2 327 teachers of science, of whom only 81 were teaching geology and 10 of these had no university training! According to Dean Van Cleave, if the equivalent of at least four university courses in a teaching topic would be required of these teachers, less than half of Canadian high school science teachers would be qualified.

chemistry, and mathematics from the real world in which the young student lives. The introduction of earth science to achieve this reform of high school curriculum may be planned and realized as follows:

1. Earth science educator groups (ESEG) should be formed immediately in each province to:

a) survey the effectiveness of science courses at the junior high school level;

b) provide a forum for university and high school teachers interested in the teaching of earth science at the secondary level;

c) obtain the opinions of industry and natural resource government departments as to the desirability of introducing more earth science in secondary schools;

d) make the necessary representations to their respective departments or ministries of education, including the approval *in principle* of Conclusion III.5 above.

2. Once recognized by the departments of education, each ESEG could provide these departments with valuable advice on:

a) programs for training teachers in earth science, including summer institutes modelled after those of the American Earth Science Curriculum Project;

b) the best student texts and teachers manuals available;

c) the most appropriate equipment and supplies for laboratory exercises;

d) the most useful earth science films and other audio-visual aids available.

3. *It is recommended that the Council of Ministers of Education of Canada sponsor a National Earth Science Conference in 1971 for the purpose of obtaining:*

a) a detailed account of the status of earth science teaching in the high schools of each province;

b) an analysis of how earth science could best be integrated into the teaching of general science at the junior high school level;

c) a full perspective of the Earth Science Curriculum Project in the United States and a measure of its effectiveness in improving the scientific attitudes of students;

d) a study on the desirability of making available an advanced earth science course at the senior high school level for students wishing to enter university;

e) an appraisal of the needs for more technological institutes or technical schools oriented towards the needs of the mineral industry;

f) suggestions and recommendations regarding the further implementation of a program of earth science teaching in secondary schools (including the views of scientific societies engaged in earth sciences activities).

4. *It is further recommended that the Federal Government and the provincial departments of education co-operatively develop a national program specifically aimed at improving the quality of science teaching in Canadian secondary schools.* In addition to adequate financial support for teacher training, this program should include an accelerated production of Canadian science textbooks, films and other audio-visual aids.

5. To introduce earth science in secondary schools as soon as possible, it is suggested that the American manual *Investigating the Earth* be used *as is* until 1975 or so.

6. Canadian earth science societies should investigate immediately the desirability of sponsoring the preparation of a Canadian text on earth science, for use in high school teaching. This new textbook could be essentially Canadian in inspiration and content.

7. Canadian earth science societies should initiate immediately the preparation of an earth science laboratory manual, with major emphasis on Canadian geological features. The funds for preparing this manual could perhaps be provided by the Canadian Geological Foundation jointly with the Canadian Institute of Mining and Metallurgy.

# III.8 Role of Universities in Earth Science Education and Training

Universities fulfil a major role in modern society. Their *modus vivendi* can be said to be twofold: *transfer of knowledge,* through education and training, and *production of new knowledge,* through research. In this section, we discuss the first of these two essential functions, with particular emphasis on manpower training to satisfy national needs.

**Universities as a Source of Earth Science Manpower**

The full acceptance by university administrators of the "education and training" function imposes upon them the responsibility of being attuned to the present and future manpower requirements of the nation. These needs can be expressed in terms of numbers of professional graduates and scientists required but also, and importantly, in relation to the type and quality of graduates. Since the mineral industry is by far the largest employer of earth science manpower in Canada (see Table II.5), faculty must be particularly well aware of the manpower needs of this very important industry. Faculty must also co-operate closely with government agencies in their essential missions of promoting Canada's economic and social development. An "ivory tower" attitude on the part of faculty is detrimental to the attainment of this manpower goal which, unfortunately, is very hard to define in realistic quantitative terms.

*According to our survey, it appears that Canadian universities are not producing sufficient numbers of professionals in most earth science fields to meet national needs.* During the last five years, there has been a noticeable shortage of these professionals, particularly in the mineral exploration sector of industry. Industry, government agencies and universities have had to recruit abroad to satisfy their manpower requirements. The shortage is particularly evident in geology and geophysics. The manpower situation can be seen in terms of the following statistics.

*Geology*

1. More geologists immigrated to Canada in 1968 (Table II.8) than the total output of geology graduates (all levels) from all Canadian universities combined (Table II.38), that is, from 30 departments.

2. Whereas the number of geologists in the Canadian mineral industry increased by 215 annually during 1964-68, the average number of geology graduates, who entered *all fields* of employment during 1966-68, was only 162 per year, namely 93 bachelors, 39 masters, and 30 doctors. Of these 162, an average of 95 entered the mineral industry annually, representing 59 per cent of those who entered the labour force, and 44 per cent of the new earth science professionals hired by the mineral industry.

3. The total number of geologists in Canada being currently in the order of 3 400 (Table II.5), a replacement rate of 3 per cent (for retirements, deaths, etc.) signifies that a minimum of 100 new graduates in geology are needed each year for replacements. This number represents more than half of the geology graduates entering the labour force each year!

4. The larger provincial departments of mines, in Quebec and Ontario especially, have reported to us on their difficulties in finding suitable candidates for meeting their geological staff requirements.

5. It is estimated that in 1966-68 the size of faculty in geology departments in Canada increased at an average rate of about 30 per year, this number being equivalent to the total number of Ph.D. degrees granted in geology in Canada.

6. Geologists are also needed in geotechnical activities, soil sciences, high school teaching[1], foreign aid, etc. Unfor-

[1]In the United States, the estimated number of high school earth science teachers added *each year* to the 2 500 in 1963 has increased from 1 000 in 1964 to 3 000 in 1968, whereas the number of graduating seniors in geology rose from 1 800 in 1964 to 2 400 in 1968. *In* ESCP Newsletter, No. 19, May 1969, p. 2.

tunately, our coverage of these other needs is very incomplete, but we may surmise that the aggregate demand in these other fields is at present in excess of 100 geologists per year.

7. Figure II.17 illustrates the cyclic nature of the geology graduation patterns in Canadian universities, which is in large part related to the cyclic demand for geologists in the mineral exploration industry (see Section IV.6). A significant feature of the bachelors graduation pattern is that it is always out-of-phase with industrial manpower demand, with the consequence that geology graduates are in short supply when they are most needed, and in ample supply when the industrial demand has sagged considerably.

8. *According to our statistics for the 1948-69 period, we estimate that the addition of 1 member to faculty in geology has resulted in the addition of 1.4 professional graduates per year.*

On the basis of figures obtained from the Jackson report[1] and the Macdonald report[2], and using a +2 years lag factor for the number of bachelors in relation to present size of faculty, we estimate that the current "bachelor graduate productivity" in physical sciences and engineering departments in Canada is 1.9 bachelor graduates per faculty member, compared to 1.1 in geology (excluding the graduates at the master's and Ph.D. levels). The difference in ratio is in part due to the fact that geology instruction is also given to a large number of non-majors (in 1968 a geology faculty of 278 taught courses to 6 804 non-majors), whereas engineering professors teach generally only to professional students. Another reason for this difference is the fact that several departments of geology in Canada have developed into "graduate schools", in part at the expense of a low productivity of bachelor graduates.

9. Finally, still on the subject of geology graduation pattern, it should be noted that our departments of geology draw a large proportion of their graduate students from other countries. *In 1968 the proportion of non-Canadian graduate students in all geology departments was 44 per cent,* which is also the proportion of graduate students in all fields of physical sciences and engineering who, in 1968, were neither Canadians nor landed immigrants.[3] Although there is some obligation to repay the "cultural debt" to other industrialized countries and there are, indeed, important advantages in having graduate students of various nationalities in our geology departments, *we believe that the proportion of non-Canadian graduate geology students is presently too high.* We suggest that 25 per cent would be a better proportion (it is 18% in the United States) and *we urge the geology departments to increase their output of bachelor graduates so as to increase the Canadian content of graduate student enrolment.*

*Geophysics*

1. The supply situation in geophysics is even worse than in geology. For a country that ranks first in the world in mining exploration geophysics (see Chapter IV), and has in Calgary the second largest concentration of geophysicists in the Western World after Houston, Texas, the national output of geophysicists in 1968 (by no means an exceptional year) was 27 bachelors, 18 masters, and 10 doctorates from seven departments (several of which are oriented towards crustal and deep-interior physics of the earth rather than exploration geophysics).

2. According to our survey, the labour force in the mineral industry increased by 55 geophysicists annually during the period 1964-68 (equivalent to the total geophysics graduation in 1968). This represents an 8 per cent annual increase

[1]Jackson, R. W., D. W. Henderson, and B. Leung. Background studies in science policy: projections of R & D manpower and expenditures. Science Council of Canada, Special Study No. 6. Ottawa, Queen's Printer, 1969, p. 9.

[2]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, p. 52.

[3]National Research Council of Canada. Projections of manpower resources and research funds 1968-72. A report of the Forecasting Committee (Chairman: L. P. Bonneau). Ottawa, 1969, p. 52.

with respect to a population of about 700 geophysicists (Table II. 5), compared to a 6 per cent annual increase for the number of geologists in the mineral industry. In contrast, less than 12 geophysics graduates entered the mineral industry annually during 1966-68, or hardly enough to provide only for replacements. In spite of this, $123 million were spent on geophysical exploration in Canada in 1968, an increase of $66 million over the annual expenditure in 1964 (Table II.17). *It is clear, therefore, that Canadian universities are not producing enough professional geophysicists to meet national needs.*

3. Figure II.17 shows that the number of bachelor graduates in geophysics has remained at a very low level during the past 20 years. On the other hand, during the same 1948-68 period, the geophysics M.Sc. graduates increased from 6 to 18 annually, while the number of Ph.D. graduates rose from 1 to 10. *In other words, the geophysics graduation pattern bears very little relation to the importance of geophysics in this country,* both in mineral exploration and in the investigations of the physics of the earth, not to mention the importance of geophysics in Canada's programs of external assistance to emerging nations.

4. In Canada, much of the teaching and academic research in geophysics is done in university departments of physics (see Section II.7). This situation, which is peculiar to Canada, has been beneficial not only in developing the science itself but also in attracting to geophysics an appreciable number of B.Sc. graduates from physics and certain fields of engineering. Geophysicists in geology departments also play an essential role in training geophysicists for industry. In this respect, the unique location of geophysics in the Mining Engineering Department at McGill University should be critically reviewed. *We believe that it would be in the best interests of McGill University and the mineral industry to integrate geophysics into McGill's Department of Geological Sciences.*

*Physical Geography*

The manpower situation in physical geography is somewhat better than that in geophysics and geology, owing to limited employment opportunities. However, the output of graduates in physical geography does not seem to exceed the demand. For example, in late 1969 Canadian universities had outstanding requests for more than 10 Ph.D. graduates in physical geography, whereas all Canadian universities combined produced only 4 doctorates in this field in 1968. The insufficient output in physical geography in recent years is also indicated by the fact that the larger proportion of faculty in this field has been trained abroad, in spite of all the natural advantages that Canada offers in physiography.

*Other Fields of Earth Sciences*

We do not have reliable statistics for these other fields, but we strongly suspect that the education and training being given in Canadian universities in *hydrogeology, rock mechanics, soil physics and chemistry, and biogeochemistry* is not sufficient to meet national needs, let alone the needs for these specialities in Canada's external assistance programs (see Chapter VIII). In contrast, the universities have developed a strong competence and appear to be producing enough graduates in *soil mechanics,* in part because this speciality is located in departments of civil engineering rather than earth science departments (the latter having experienced difficulties in attracting sufficient numbers of students). Finally, because of low demand from industry and government agencies, and insufficient awareness of university administrators, the education and training in Canadian universities in the expanding fields of *urban geology, engineering geology, northern terrain studies, and multiple land use* are at a minimum level.

In view of these facts we submit:

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*Conclusion III.6*

*Canadian universities are not meeting national manpower needs in most earth* *science fields, in terms of both output of professionals and the type of graduates produced. In addition to providing better physical facilities for earth science departments, universities are urged to fulfil the nation's earth science manpower needs by encouraging more students to enter the earth science professions, adapting several of their courses to meet these needs, and promoting the widespread introduction of a modern earth science course in secondary schools.*

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### Estimated Requirements in Earth Science Manpower

In Table II.9 we indicated that a total of 515 new earth science professionals may be required annually to satisfy national needs until 1972, based on employment patterns during the period 1964-68. If, in addition, we consider the potential demand for graduates for earth science teaching in secondary and technical schools (see Section III.7), increased geoscience assistance to developing countries (see Section VIII.3), urban geology and various fields of geotechnique (see Chapters V and VI), the total requirements may reach 835 annually during 1972-75 (see Table III.2). Although the latter estimate is optimistic, the distribution of potential requirements shown in Table III.2 may be of some help to universities in planning their development.

### Student Views on Education and Training

A university is essentially an association of students and professors. In our desire to associate the student community with this study, and obtain a unique input from students, we have met with 20 groups totalling 417 undergraduate and graduate students of geology, geophysics, geochemistry, physical geography, including a few in soil mechanics. This represents about one-quarter of all earth science students in Canada. Some student groups also submitted briefs (see Appendix 3). The purpose of this section is to report on the major views held by students which, succinctly stated, follow.

1. *Earth sciences are virtually unknown on campuses,* except within earth science departments. Several students remarked that geologists are regarded as "a bunch of guys who dress queerly and live in tents...fellows who go out and look at rocks". All students groups interviewed were unanimous in relating this widespread ignorance or lack of awareness to the fact that modern earth science is not taught in Canadian secondary schools (in strong contrast to the United States, see Section III.7). Students have commented that the little earth science taught is given mostly by teachers who are either ignorant of the fundamental scientific principles applying to the study of the earth or are indifferent and adopt the attitude "I have to teach this course - who could lend me some rocks?". When taught, the course is usually given as a "filler", creating the impression that it is of little significance.

The lack of earth science teaching in the high schools is the single most important factor for the low enrolment of earth science students in our universities. Only 24 per cent of the students polled planned careers in the earth sciences when entering university. The rest "discovered" earth sciences when happening by chance to follow a university course in this subject.[1] Students acquiring a general education seldom elect an earth science course because of lack of exposure to this subject in high school.

2. *Earth sciences project a poor image because geology departments are often housed in the poorest and oldest buildings on campus.* Many students have commented about the shortage of space in several earth science departments. It is quite ironic to find, for example, a department of geology having the largest

[1]In a survey conducted in 1968-69 in 400 geology departments in the United States and Canada, the American Geological Institute learned from 1 200 questionnaire returns that in 29.2 per cent of the cases the introductory geology course in college or the influence of the college teacher were the dominant factors in career orientation. Another 12.6 per cent chose geology because of previous hobbies, and 10.4 per cent were influenced by an earth science course in secondary school. The other factors rated individually less than 6 per cent.

**Table III.2–Estimate of Earth Science Graduates Required Annually to Meet National Needs, 1972-75 (replacements included)**

| Major Sector | Total Earth Scientists, 1968 | Anticipated Annual Requirements, 1972-75 Geology | Geo-physics | Geo-chemistry | Physical Geog-raphy | Geo-technique[b] |
|---|---|---|---|---|---|---|
| Mineral Industry[a] | 3 969 | 255 | 55 | 25 | 2 | 28 |
| Construction Industry[a] | 250 | 10 | 2 | – | 3 | 40 |
| Renewable Resource Industries | 150 | 5 | 2 | 5 | 10 | 5 |
| Federal Government | 666 | 20 | 6 | 5 | 5 | 15 |
| Provincial Governments[c] | 366 | 20 | 5 | 5 | 5 | 20 |
| Municipal Governments | 50 | 3 | – | – | 8 | 10 |
| Universities | 593 | 20 | 10 | 10 | 10 | 10 |
| Technological Institutes | 50 | 7 | 5 | – | 2 | 5 |
| High Schools[d] | 100 | 60 | 25 | 5 | 35 | – |
| Foreign Aid[e] | 16 | 20 | 10 | 5 | 5 | 17 |
| **Total** | **6 210** | **420** | **120** | **60** | **85** | **150** |
| Annual Requirements according to Academic Degrees[f] | Bachelors | 200 | 50 | 15 | 45 | 75 |
| | Masters | 120 | 40 | 25 | 20 | 30 |
| | Doctors | 100 | 30 | 20 | 20 | 45 |
| Average No. Entering Labour Force Each Year During 1966-68[g] | Bachelors | 90 | 12 | 3 | 15 | ? |
| | Masters | 30 | 9 | 9 | 8 | ? |
| | Doctors | 25 | 9 | 5 | 4 | ? |

[a] Including manpower for consulting firms, and assuming no radical change in manpower requirements compared to the period 1964-68.
[b] Including, for sake of convenience, rock mechanics, soil mechanics, and hydrogeology, which are grouped with the fields of geotechnique.
[c] Including the provincial research councils.
[d] Applying only to requirements for earth science teaching in the high schools.
[e] Assuming that the program of earth science foreign aid proposed in Table VIII.3 will be accepted by the Canadian International Development Agency.
[f] Distribution based essentially on the proportions of bachelors, masters and doctors in the total Canadian earth scientist population of 1968.
[g] See employment patterns during 1966-68, Table II.37.

geology student enrolment in Canada housed in temporary quarters and scattered in 10 different buildings on campus, when this department has played a major role in the mineral development of the province in which it is situated, as well as elsewhere (its graduates over the years having contributed directly to the finding of more than $29 billion worth of economic minerals!). It would appear that mining companies are donating fairly generously to university fund-raising campaigns, but somehow this money rarely finds its way towards improving the facilities in mining engineering or earth science departments.

3. *The university should not become a technical school.* Students are aware of the agitation from outside as well as within the university for more technical training and the introduction of terminal graduate courses. The University of Toronto graduate students in geology summed up their attitude in acknowledging the need for skilled geologists who are proficient with current techniques. As young men who may reach their peak 20-25 years hence, they maintain that a broad theoretical training is necessary to adapt to future advances. In their words, "if knowledge is to be imparted at university, it must be continually created there" and Canada must not fall prey to excessive concentration on the pursuit of application of knowledge to the detriment of advances in pure knowledge.

4. *Earth sciences should not be divorced from field problems.* Some thoughtful students have expressed concern about the classroom environment: "Geology is a prodigal son in the University. It must be taught as a lab subject, yet in geology the field is the lab. Most of the classroom laboratories are rather mindless and we do not learn much from them, because the classroom is not the proper environ-

ment for teaching earth sciences. The exercises in the classroom should not be divorced from field problems and practical applications."

*5. The problem-solving approach should be stressed.* Several students have remarked that "knowledge itself can be found in any book, and the role of a university professor is to teach the student how to approach a problem and how to solve it".

*6. Earth sciences provide exciting challenges.* When asked what fields of earth sciences are particularly interesting, most students rallied in favour of the following: dynamics of the earth's crust and processes of mountain building, new methods of mineral exploration, oceanography and exploration of the continental shelves, groundwater studies, research on pollution, ore and land conservation studies, ice and snow research, properties of the earth's interior, origin of petroleum, computer technology and applications of statistics to earth sciences, earth science activities in developing countries. In several discussions, this Study Group obtained the distinct impression that students are generally interested in social and environmental problems, in noticeable contrast with former generations of earth science students.

*7. There are inadequate communications between students and industry.* For example, mining companies are often accused by students of using "old hat" techniques and of being "stingy" about releasing technical information. Although this applies to several companies, students do not seem to have enough appreciation of the effectiveness and low cost of many well-tested and long-used techniques; they are not sufficiently aware of the significance of competitive information and the advantages–as well as the disadvantages–of a free enterprise system.

Many students had acrimonious comments about their summer work for mining and petroleum companies, and complained they have been assigned to routine jobs with too few opportunities to learn; however, they do not seem to realize that if these same jobs were given to technicians or high school students, summer employment opportunities for them would be greatly reduced. Understandably, students want responsible, challenging assignments. They are generally not afraid of hard work and most of them do not mind living in tents and far from civilization during summer work.

The cyclic nature of employment opportunities in industry is often deplored, but most large companies are now recognizing that pronounced fluctuations in manpower requirements are in the long term detrimental for them and they are, accordingly, trying to adopt better recruiting policies. It would appear that company training programs are often oversold, with the result that students become rapidly disillusioned in their summer work.

From the point of view of earth science graduate students, industry fails to recognize the value of their research training and their potential contributions to industry's development. Research opportunities in industry have been described by graduate students as being extremely rare. However, many graduate students are ignorant of industry's goals and methods.

*8. Field work is important in the earth sciences.* Students like field work. They feel generally that it is an essential component of earth science education and training. They have high praise for the Canadian system which procures many summer employment opportunities (see Section II.2). More than 80 per cent of the students interviewed had field experience, and about two-thirds indicated that they expect to be still doing some field work 10 years after graduation "because field work has to be done".

There is, however, a marked tendency for graduate students to choose university work in the summer rather than industry or government field jobs, because it may well save them a year or more in graduate school. Many graduate students now have research fellowships or assistantships, and many have working wives, so that field work as a source of income is not as critical as it was a few years ago. Government has made summer stipends available in all university departments, and university administrators are not likely to treat earth sciences differently. Summer research stipends generally apply only to laboratory work, but they should also be made widely available for *field research* for students participating in meaningful, well-directed and co-ordinated field programs. Government agencies and industry should take note of these new patterns and provide salaries and scientific opportunities to attract bright graduate students in undertaking field research during the summer.

*9. Discrimination against women in earth sciences should cease.* Female students in earth sciences are generally frustrated because of the very few field training and career opportunities in their chosen field. *At present, women represent less than 1 per cent of Canadian earth science professionals,* in strong contrast with most socialist countries where female geologists and geophysicists are not only working in the field but also in underground mines. In Canada the situation is so bad that many mining companies will not even allow a female geologist to visit underground workings!

However, women may soon make an important breakthrough. Modern transportation has outmoded the month-long canoe trips in wilderness areas and the pack trips in the mountains. Working hours in the field may be much longer than in other professions, but they are often compensated by periodic leaves and higher remuneration. We have now reached the stage where women could handle many of the field jobs. Many women have a superior ability to pick important details, and their patience generally exceeds that of men. Being often more meticulous than men, they could excel in detailed core logging, detailed field surveys, scientific data interpretation, laboratory investigations, report editing, translation, and the like. Society now accepts men and women working together. *There is no longer any reason to perpetuate an ascetic approach to field work, which ought to become attractive to men and women.* Companies do not send employees to other cities for months on end without their families, and they commonly fly their salesmen home for weekends. Why should they expect earth science employees to "vegetate" in isolation and difficult field conditions for prolonged periods? Costs of improving conditions would add to the existing high costs of field work, but these extra costs are really very small in comparison to the total investment in field activities.

The expected new direction of earth science into environmental and urban studies should open up suitable careers for female as well as male earth scientists. The widespread introduction of earth sciences into Canadian secondary schools would in itself provide a major field of employment for women. *Thus, it is important that women be given the fullest opportunity to acquire training and field experience in earth sciences.*

### Role of Faculty in Education and Training

Too few people criticizing university faculty have first-hand knowledge of what modern academic life really is. The professor is expected to carry an appreciable load of teaching and student research supervision, besides pursuing his research interests and coping with the profusion of new scientific literature. Not only must he strive toward excellence in research, but he must also excel in motivating students to learn his science. As an adviser, he must help the student in developing his natural talents and abilities; above all, he must show him how to solve problems. As an educator, he must awaken the student to his future professional and social responsibilities. Also, he must spend about one-fifth of his time on committees, paper work, and administrative duties.

Having visited most university earth science departments, this Study Group is convinced that we have there many excellent educators and research scientists, and relatively little mediocrity. However, too many professors appear to live in "solitude" and to be unconcerned about what is happening outside their immediate environment. Industry has frequently voiced criticism about the general orientation of university research in earth sciences, which has been described as esoteric and not sufficiently relevant to the practical needs of the country. We often heard the criticism that our graduate schools are not producing enough of the types of graduates needed in Canada. Universities would do well to pay more attention to these demands and reorganize several courses to achieve better balance in curriculum content.

By and large, the mineral industry (by far the largest employer of geoscientists in Canada) considers that students are receiving good undergraduate training in our universities. However, many (including students) have remarked that professors active in research are often drifting away from undergraduate students in favour of their personal and somewhat narrow research interests. The unifying concepts in geology and the modern theories of global evolution do not appear to be sufficiently stressed in the curriculum.

In our opinion, there is now a need to strengthen the geology and physical geography programs through the introduction of advanced statistical analysis and computer technology courses, and to make the "basic science" courses as relevant as possible to the academic and professional training.

The compartmentalization that divides geology from geophysics on the one hand, and from physical geography on the other hand, is deplorable. It is desirable that individuals should specialize, but for whole departments to be narrow and neglect important related fields impedes scientific development and retards the practical applications of new knowledge. In the past, when geophysical methods were less developed and there was less concern for geodynamics and global evolution, this division was understandable. Likewise, when physical geography was often a literary discourse, geologists understandably felt some reluctance to work with geographers. But now, with the need for major syntheses of crustal evolution and conceptual models for earth processes, and the increasing concern for environmental studies and the developing social dimension of earth sciences, this dichotomy should cease.

Several earth science departments are becoming concerned about internal and external pressures to curtail their expansion. With their low student enrolment, they must counter these pressures by attracting more students toward earth sciences and become as viable as other science departments. However, earth science departments in Canada have been particularly delinquent in not building a strong training program for high school teachers in view of an eventual earth science course in secondary schools, and for not campaigning for such a course to be introduced. Consequently, the numbers entering geology and geophysics will still be markedly influenced by the fluctuating manpower demand in mineral exploration in the years to come. It is nevertheless evident that the "survival" of many university departments of earth sciences is tied directly to their success in training high school teachers.

In view of the foregoing, we submit:

*Conclusion III.7*
*Undergraduate training in the earth sciences should be broadly based, with increased emphasis on the unifying concepts in geology, modern theories of global evolution, basic sciences, statistics, and computer technology. Better balance in curriculum content should be achieved by greater consideration of national manpower needs, as well as greater inter- and intra-departmental communications and co-operation. "No-thesis" advanced degrees should be introduced to meet the needs in the expanding sectors of the economy and the interdisciplinary areas in which Canada may, in the future, make rapid strides.*

*Conclusion III.8*
*The growth of earth science university groups involving geologists, geophysicists, geochemists, geographers and others should be encouraged, and so should the development of soil science groups involving as many of the essential disciplines as possible.*

*Conclusion III.9*
*Industry should provide training opportunities to female as well as male earth science students, and provide more careers for women in the earth sciences.*

## III.9 Role of Universities in Earth Science Research

### General Statement

Universities have a fundamental role to play in the advancement of knowledge and it is widely admitted that their primary responsibility in this regard is basic research (for definitions, see Section I.4). Basic research is frequently classified as either curiosity-motivated or mission-oriented. Traditionally, the curiosity-motivated research and the training associated with it have characterized institutions of higher learning.[1] On the other hand, as the name implies, mission-oriented research is fundamental research, generally involving team work, which is conducted in relation to specific missions of government departments or agencies. Examples of "missions" in the earth sciences include the regional characteristics of the earth's magnetic field, the distribution and properties of Canada's orogenic belts, the geomorphology of the Arctic Islands, the features of Precambrian sedimentary rocks, etc. Most of this research is carried out by government agencies, with a small amount by universities. By way of contrast, most of the applied research in earth sciences is undertaken by industry (see Sections IV.3 and V.7) and government agencies (Table II.2), and a smaller amount by universities (Table II.2).

There is probably little basic research in the earth sciences in Canada that anyone – including scientists in industry – would wish to see curtailed or stopped, because so much needs to be done (see Section III.3). Basic research in this field provides an important base for mineral exploration technology (Section IV.3), improvements in geotechnique (Chapter V), and natural resource development (Chapter VI). In addition, Canada has a fundamental responsibility in furthering the knowledge of the Canadian georama (see Section III.5). *However, as resources of the nation are limited, the future growth and support of basic research in earth sciences in Canada should be consistent with recognized national goals.* If national prosperity is seen as the first goal for science in the service of the nation[2], then basic research in the earth sciences would appear to be an essential ingredient for a country which is so dependent on the mineral industry for its economic well-being as is Canada (Section IV.2). "If science is a decisive factor in economic growth, and a tangible social force, it must acquire purpose and direction. As it has become a major item of national expenditure, it must compete with other objectives of national importance. The argument must be to select among the possibilities, and to channel the effort toward a number of stated and central targets."[3]

### Funding of University Research

Historically and traditionally, curiosity-motivated basic research has been viewed in most countries as the prerequisite, or the prerogative, of universities. However, as the costs of universities to the Canadian taxpayer have soared in

[1] Blackett, P. M. S., *In* Proceedings of the Special Committee on Science Policy. The Senate, p. 89, Ottawa, 1968; and Solandt, O. M., National science and engineering critique. Trans. Roy. Soc. Can., Vol. VI, Series IV, p. 38, June 1968.

[2] Science Council of Canada. Towards a national science policy for Canada. Report No. 4. Ottawa, Queen's Printer, 1968, pp. 13-14.

[3] Wynne-Edwards, *op. cit.*

recent years, and the costs of graduate training and academic research have increased almost exponentially during the last decade (Figure 5.3, Appendix 5), universities are becoming increasingly aware that academic research should play a greater role in the solution of economic, political and social problems, a viewpoint that receives strong support from industry and government.

What has caused the change in university attitude? In the earth sciences, one of the principal factors appears to have been the very rapid increase in research funding during the past decade. To illustrate: the total earth science grants awarded by the National Research Council and the Geological Survey of Canada increased 30-fold in 1958-69 (from $120 000 to $3.6 million), whereas there was only a 4-fold increase in faculty. About 10 or 15 years ago so little funding was available for earth science academic research that the concept of a public "investment" in university research did not really arise. Until 1958, less than $100 000 was allocated annually to earth science research in the universities, and the Geological Survey of Canada was the major funder of this research. Since 1958, however, the situation has improved radically and the National Research Council is now the major funder, together with the provincial governments. The Geological Survey is currently providing less than 10 per cent of the total grants-in-aid to university research in the earth sciences (Table II.27).

The year 1964-65 showed a significant upturn in earth science activity in Canada:

1. It marked the beginning of an unprecedented level of mineral exploration activity (Figure IV.1);
2. It coincided with a rapid increase in geology faculty (about 65 professors added during 1950-65, versus a net increase of 155 since 1965);
3. Finally, it corresponded to a rapid increase in the National Research Council's grants to university research (Figure 5.3).

The growth rate of the National Research Council's funding of earth science university research during the past decade is approximately parallel to that of the physical sciences and engineering (Figure 5.3). The proportion of grants allocated to earth sciences is now approximately 10 per cent of the grants allocated to all fields of physical sciences and engineering.

The rapid growth of earth science research capabilities and activities in Canadian universities is illustrated by the continual decline in the ratio of sums granted to sums requested. The ratio for operating grants has dropped from 77 per cent in 1963 to 55 per cent in 1969, and that for equipment grants ($5 000 to $50 000) from 42 per cent in 1963 to 23 per cent in 1969.

In spite of the foregoing, we are of the opinion that the present level of academic research support provided by the National Research Council is reasonably adequate in terms of size of faculty and number of Canadian graduate students in these departments. It seems adequate for this particular type of support, which is directed essentially at the individual scientist. However, there is a pressing need for support of university research involving a large and costly field component. We feel strongly that support for the latter type of research should be provided by the Department of Energy, Mines and Resources, where such research is in the national interest and falls within the major missions of that department. The present scheme of funding, whereby this department currently allocates a good part of its university research funding in geological sciences on the basis of *individual merit* (and, indirectly, for the support of graduate students) is not satisfactory because it duplicates the role of the National Research Council. Inasmuch as there is a great need for supporting *multidisciplinary* and *mission-orientated* projects, especially those having a large field component, we have advocated in Section II.5 that the funds normally allocated to the National Advisory Committee for Research in Geological Sciences be turned over entirely to mission-oriented national advisory committees, such as that proposed herein for mineral resources research (Section II.5).

As a matter of principle, the National Research Council should remain the main source of funds for scientific research in the universities, but each mission-oriented department in the federal government should provide substantial amounts of research money in fields specifically related to its major missions. The Defence Research Board, for example, would naturally continue to support extramural research related to national defence.

Many university research programs have a large field component. The recent decision of the National Research Council to introduce three-year term grants, starting in 1970, is particularly commendable because it will permit earth scientists to plan their field research activities well ahead of time, thus enhancing the quality of their work. This new procedure may also help to counter the "publish or perish" syndrome pervading academic institutions, and it may preferentially encourage the publication of major syntheses rather than papers of small significance.

**Earth Science Grant Selection Committee of the National Research Council**

The Study Group believes that this committee has done a good job in appraising equitably the hundreds of applications submitted annually. The initiative of this committee, in publishing in 1969 a report[1] on its activities and findings, is commendable. We urge the National Research Council to encourage this practice, so as to keep the university community informed of the progress achieved and the difficulties encountered.

As everyone knows, the Earth Science Grant Selection Committee has the difficult task of appraising the scientific excellence of applicants. We believe that university professors, good and unbiased as they may be, should not alone have the prerogative of serving on grant selection committees. Surely there are scientists in industry and government who can also appraise scientific excellence, including that in basic research. We are of the opinion that one or two scientists from industry and government should be invited to serve on this committee for the specific purpose of judging the scientific merits of the applicants. This should in no way be construed as an attempt to encourage applied research preferentially, unless this becomes the policy of the National Research Council.

The question is frequently raised whether the Grant Selection Committee should assume a more active role in directing the growth of earth sciences in Canada by recommending the full amount requested for the best proposals submitted by the best and most productive applicants, and also by assigning priorities to certain fields or research projects considered to be of greater national importance than others.

We are of the opinion that this Grant Selection Committee has generally been too generous in recent years towards many applicants, and not generous enough for the best and most productive applicants. As stressed in Conclusion II.11, we urge this Committee to be more selective in the future. Many applicants express pious wishes and consider the National Research Council grants as the main vehicle for supporting graduate students. This vehicle concept is right only if the research training of students makes them better equipped to discover new avenues for the science and new applications for the well-being of the nation. *This concept must rest on a graduate productivity base, there being little point in continually increasing research funding if the universities are not proportionately producing more scientists to meet national needs.*

We also believe that a larger proportion of university research should relate

[1]Blais, R. A., *et al.* Report of the Earth Science Grant Selection Committee of NRC. National Research Council. July 25, 1969. 11 p. mimeo.

to national earth science objectives, for example to better knowledge of the Precambrian Shield (Section III.3). This would not infringe on academic freedom nor on the possibilities of conducting pure research, because the research worker would still have full liberty of conducting research in the fields that he likes best.

**Research Training Patterns**

By and large, the earth science faculty in Canadian universities is a teaching faculty. The average geology professor's time allocated to teaching is 45 per cent, compared to 29 per cent in geophysics, and 48 per cent in physical geography. As shown in Table III.3, geophysics alone is competitive with the other physical sciences in the amount of faculty time spent on graduate supervision and research. In geology, soil mechanics, soil sciences, and physical geography, faculty spends more time on undergraduate teaching than do most other science departments.

**Table III.3–Faculty Time Allocated to Graduate Supervision and Research**

| Department | Proportion of Time |
|---|---|
| | % |
| Aerospace | 67 |
| Astronomy | 56 |
| *Geophysics* | 51 |
| Chemistry | 47 |
| Physics | 44 |
| Biological Sciences | 44 |
| Engineering | 35 |
| *Geology* | 34 |
| Mathematics | 33 |
| *Geography* | 30 |

*Source:* Estimates for geophysics, geology and physical geography derived from our questionnaires; others obtained from the Bonneau report, *op. cit.*, p. 46.

The average graduate school geology professor graduates one M.Sc. student every three years (or one Canadian every five years), and one Ph.D. student every five years (or one Canadian every nine years). He may expect to receive $8 500 annually from the federal government in support of his research (exclusive of equipment grants).

In comparison, the average graduate school geophysics professor graduates one M.Sc. student every two years, and one Ph.D. student every four years. He receives from $10 000 to $15 000 annually from the federal government for his research.

In physical geography, the average professor in graduate school graduates one master's student every 5 years, and one Ph.D. student every 10-20 years.

**The University Research Spectrum in Earth Sciences**

A study was made of the publication record of Canadian geology professors during 1963-67, based on the number of titles per earth science speciality. The results indicate that the average geology professor published two papers every three years, with stratigraphers, paleontologists and mineralogists being the more prolific, and economic geologists and petrologists among the least (Table III.4).

The range of earth science research in universities is documented by Table III.5, where faculty members in geology, geophysics, physical geography, and some engineering departments are classified according to their principal field of research. This composite picture gives in effect the distribution of academic research as it has developed through the multiple decisions of university administrators and earth science departments, and the personal preferences of faculty. The distribution determines the "mix" of speciality interests of earth science graduates from Canadian universities.

The largest grouping in Table III.5 relates to soil mechanics, which is mainly taught in departments of civil engineering. The National Research Council's listing of graduate students at Canadian universities[1] shows 145 graduate theses in preparation in soil mechanics and related fields of geotechnical engineering.

[1]Graduate students at Canadian universities in science and engineering, 1968-69. National Research Council. Ottawa, July 1969.

The second major grouping relates to physical geography and geomorphology, largely resulting from the rapid growth of geography departments in Canadian universities. This growth has resulted in hiring of a relatively large number of geographers from the United Kingdom, Australia and New Zealand, where physical geography tends to be taught to a greater extent than in the United States. As a result, physical geography receives more emphasis at the graduate level in Canadian geography departments than in the United States. This trend, as well as the attractiveness of Canada for research in physical geography, has combined to give an enrolment of 100 or more at the graduate level. It should be noted, however, that many of this group are working on problems of the hydrosphere and atmosphere as well as geomorphology. However, on a speciality basis, a large number of university earth science staff and students engaged in problems of the earth's surface are located in departments of geography rather than geology. Probably the largest number of these graduates enter high school or university teaching.

The number of staff engaged in research in stratigraphy, petrology, paleontology, economic geology, mineralogy and structural geology and the various fields of geochemistry reflects an "equilibrium situation", as the 30 departments attempt to develop a capability in the basic fields of a geology department. The trend of some larger departments to diversify into surficial geology (Quaternary geology, geomorphology and physical geography) encounters either conflict or support from the geography departments; this is clearly an area for greater co-operation in the future. Understandably and desirably, there is considerable overlap in geophysics between geology and geophysics departments, the field of magnetotellurics being the only geophysical speciality not represented in a geology department. This overlap is a healthy one in bringing the knowledge and application of geophysics to the geology student and vice versa. It is of interest to note that geophysics associated with geology departments tends to be more applied in nature (exploration geophysics, remote sensing, marine geophysics, etc.), compared with the more fundamental physics of the earth generally taught in physics departments.

The number of faculty members engaged in geophysical research (and teaching) is quite low in comparison to geology and physical geography, and markedly so in comparison to the large expenditures of industry on geophysical data. *Under these circumstances one can question whether the present concentration of effort on physics of the earth, as opposed to exploration geophysics, is warranted.*

The range of academic research is further illustrated by Table II.27, which summarizes the federal government's grants-in-aid of university research according to major earth science specialities. This tabulation supports the following conclusions:

1. As indicated also by the principal fields of research (Table III.5), the dominant research activity is in soil mechanics (9% of total). Next are paleontology, stratigraphy and sedimentology, petrology, followed by mineralogy and crystallography (these four fields accounting for 25% of total).

2. Isotope geochemistry and inorganic geochemistry are also dominant (11% of total).

3. Seismology and geomagnetism dominate the academic research in geophysics (9% of total).

4. In contrast, the combined fields of economic geology, exploration geophysics and exploration geochemistry account for only 6 per cent of the total grants-in-aid. This is somewhat startling because:

a) the mineral industry spent $391 million on exploration in 1968, representing 83 per cent of all earth science expenditures in Canada (Table II.1),

b) the mineral industry employs 68 per cent of all earth science professionals in Canada (Table II.5), and

c) the mineral industry is expected to provide 71 per cent of the new earth

**Table III.4–Publications of Academic Staff in Canadian Geology Departments, 1963-67**

| Speciality | No. of Titles[a] | Average No. of Titles per Year |
|---|---|---|
| 1. Stratigraphy and sedimentology | 145 | 36 |
| 2. Paleontology | 103 | 26 |
| 3. Mineralogy and crystallography | 84 | 21 |
| 4. General geology | 64 | 16 |
| 5. Structural geology | 63 | 16 |
| 6. Petrography and petrology | 53 | 13 |
| 7. Inorganic geochemistry | 45 | 11 |
| 8. Economic geology | 40 | 10 |
| 9. Mineral synthesis and stability relations | 36 | 9 |
| 10. Quaternary geology | 31 | 8 |
| 11. Other fields of geology | 30 | 8 |
| 12. Isotope geology and geochronology | 28 | 7 |
| 13. Historical geology | 15 | 4 |
| 14. Exploration geochemistry | 15 | 4 |
| 15. Marine geology | 11 | 3 |
| 16. Computer applications to earth sciences | 11 | 3 |
| 17. Geomorphology | 10 | 3 |
| 18. Mathematical geology | 9 | 2 |
| 19. Hydrogeology | 8 | 2 |
| 20. Palynology | 7 | 2 |
| 21. Heat flow | 6 | 2 |
| 22. Physical properties of rocks and minerals | 6 | 2 |
| 23. Volcanology | 5 | 1 |
| 24. Seismology | 5 | 1 |
| 25. Biogeochemistry | 5 | 1 |
| 26. Other geochemistry | 5 | 1 |
| 27. Rock mechanics | 2 | <1 |
| 28. Exploration geophysics | 2 | |
| 29. Geomagnetism | 2 | |
| 30. Gravity | 2 | |
| 31. Organic geochemistry | 2 | |
| 32. Engineering geology | 1 | |
| 33. Environmental geology | 1 | |
| 34. Paleobotany | 1 | |
| 35. Petroleum geology | 1 | |
| 36. Photogeology | 1 | |
| **Total** | **855** | **212** |

[a] Titles are published papers. They may vary in magnitude from a book (10 books are included in this compilation) to articles in guidebooks. Abstracts are excluded. Coding of title according to principal speciality was provided by the author. Of course overlap in specialities will occur in many articles. In cases of multiple authorship the count was divided by the number of authors. Since each staff member provided a list of his publications, this caused no reduction due to multiple authorship among staff members. However, when authorship was divided with a graduate student or an industry or government scientists, only partial credit is included in this table.

**Table III.5–Principal Fields of Research of Academic Staff in Canadian Earth Science Departments, Year 1968-69**

| Speciality | Equivalent No. of Staff according to Departments[a] | | | | |
|---|---|---|---|---|---|
| | Total | Geology | Geophysics | Physical Geography | Engineering[b] |
| 1. Soil mechanics | 55.9 | 0.3 | – | 0.6 | 55.0 |
| 2. Physical geography & geomorphology | 38.9 | 2.5 | – | 36.1 | 0.3 |
| 3. Stratigraphy & sedimentology | 35.7 | 33.5 | – | 2.2 | – |
| 4. Petrography & petrology incl. volcanology | 31.6 | 31.6 | – | – | – |
| 5. Economic geology | 24.5 | 22.0 | – | – | 2.5 |
| 6. Paleontology, incl. palynology & paleobotany | 24.1 | 23.6 | – | 0.5 | – |
| 7. Structural geology & tectonophysics | 23.6 | 21.1 | 2.5 | – | – |
| 8. Mineralogy & crystallography | 21.8 | 21.5 | – | 0.3 | – |
| 9. Isotope geochemistry & geochronology | 15.8 | 10.3 | 5.5 | – | – |
| 10. Quaternary geology | 13.5 | 11.0 | – | 2.5 | – |
| 11. Inorganic geochemistry | 10.5 | 10.5 | – | – | – |
| 12. Seismology | 10.4 | 3.2 | 7.2 | – | – |
| 13. Computer applications to earth sciences | 9.3 | 4.5 | 2.8 | 0.7 | 1.3 |
| 14. Mineral synthesis & stability relations | 9.2 | 9.2 | – | – | – |
| 15. Exploration geophysics | 8.3 | 6.7 | 1.3 | – | 0.3 |
| 16. Rock mechanics | 8.1 | 3.5 | – | – | 4.6 |
| 17. Geomagnetism | 8.0 | 1.7 | 6.3 | – | – |
| 18. Exploration geochemistry | 6.3 | 6.3 | – | – | – |
| 19. Other geological fields | 6.2 | 5.0 | – | 1.2 | – |
| 20. Engineering geology | 6.0 | 4.2 | – | – | 1.8 |
| 21. Other geochemical fields | 4.8 | 4.8 | – | – | – |
| 22. Physical properties of rocks | 4.8 | 1.7 | 2.2 | 0.6 | 0.3 |
| 23. Marine geology | 4.7 | 4.0 | 0.5 | 0.2 | – |
| 24. Heat flow | 4.1 | 1.0 | 1.8 | – | 1.3 |
| 25. Pedology | 4.0 | – | – | 4.0 | – |
| 26. Photogeology | 3.9 | 2.3 | – | 1.3 | 0.3 |
| 27. Miscellaneous geophysical fields | 3.5 | – | 2.5 | 1.0 | – |
| 28. Magnetotelluric studies | 3.4 | – | 3.4 | – | – |
| 29. Petroleum geology | 2.8 | 2.8 | – | – | – |
| 30. Hydrogeology | 2.6 | 2.6 | – | – | – |
| 31. Historical geology | 2.6 | 2.6 | – | – | – |
| 32. General and field geology | 2.5 | 2.5 | – | – | – |
| 33. Biogeochemistry | 2.3 | 1.3 | 1.0 | – | – |
| 34. Marine geophysics | 2.3 | 1.0 | – | 1.0 | 0.3 |
| 35. Remote sensing | 1.9 | 1.0 | – | 0.9 | – |
| 36. Geophysical instrumentation | 1.7 | – | 1.7 | – | – |
| 37. Gravity | 1.2 | 1.2 | – | – | – |
| 38. Environmental geology | 0.7 | 0.7 | – | – | – |
| 39. Coal geology | – | – | – | – | – |
| 40. Geodesy | – | – | – | – | – |
| **Total** | **421.5** | **261.7** | **38.7** | **53.1** | **68.0** |

[a] Faculty members were asked to identify their principal field of research according to the list of 49 earth science specialities supplied with our questionnaire. Where a member indicated more than one field of research, he was divided proportionally among his several interests. The equivalent numbers should be multiplied by 0.30 (geography), 0.35 (geology) or 0.50 (geophysics) to obtain equivalent man-years of research and graduate supervision.
[b] Engineering data are not complete.

science employment opportunities in Canada (Table II.9).

## III.10 The Future Orientation of University Research and Graduate Training

The level of research activity, education and training, and major research objectives in the various earth science disciplines, are discussed in detail in the background papers listed in Appendix 4. Thus, the discussion that follows is of a general nature only.

In Section III.8, we recommended that undergraduate education in earth sciences be broadly based, irrespective of the student's future orientation. At the graduate level, however, we recognize that specialization is not only desirable but necessary for scientific research. The training of first-rate research scientists requires a major investment in a few graduate schools, with a concentration of specialists in chosen fields of special studies (see Section III.12), adequate research facilities, and sufficient time for the staff to engage in their own research projects as well as to carry out their teaching and supervisory duties.

The general orientation of university research and graduate training (two inseparable functions) should be guided, in part at least, by the following considerations:

1. It should be critically examined periodically by national advisory research committees. Representing the national interest, these committees should convey to universities the major opinions of industry and government agencies regarding earth science education and training.

2. Within provinces or groups of provinces there should be good liaison between chairmen of earth science university departments to:

a) discuss common problems;

b) avoid unnecessary duplication of expensive research facilities, and ensure the fullest use of the existing facilities;

c) co-ordinate the areas of future expansion and the development of fields of specialization in specific departments;

d) develop joint teaching programs at the graduate-school level;

e) speak with a common voice when soliciting the co-operation of government agencies and industry in regard to graduate student training;

f) provide liaison with the local associations of high school earth science teachers;

g) make the necessary representations to government and industry toward a rational development of earth sciences in their universities.

3. To achieve better communications with the "outside world" (reduce the "credibility" gap) and to promote interior liaison, it is suggested that each university appoint a small visiting committee to:

a) annually review the progress in all earth science departments of university;

b) obtain first-hand knowledge of current problems by talking to students, faculty, and higher university administration;

c) submit the necessary recommendations to the university.

4. Research training in the universities may be judged in terms of:

a) the quality of the research (is it good? is it relevant?);

b) the nature and degree of specialization acquired by the student (are we producing the type of scientist needed?);

c) the numbers graduates (are we producing enough?).

Most earth scientists outside the universities think that the earth science research training in our academic institutions has swung too far toward esoteric research and laboratory investigations. The opinion is widespread that the universities are not meeting adequately the nation's needs for specialists in several fields of earth sciences (e.g. exploration geophysicists, economic geologists, mineral economists, hydrogeologists, northern terrain specialists, environmental engineers, etc.), and are producing too many Ph.D. graduates in other fields (e.g. isotope geochemistry, mineral synthesis).

That the universities should be free to undertake basic research of their own choice is sound in principle, but it has resulted in concentrating research and producing most Ph.D. graduates in fields chosen by professors. In addition to the development of science for its own sake, universities should be encouraged to direct a greater part of their research activities toward fields in which the employment opportunities are geatest.

5. Several fields of earth sciences have undergone major changes during the last decade. The largely conceptual and descriptive approach is rapidly being quantified with greater emphasis on mathematics, electronic data processing, physics and chemistry. These healthy changes must be supported by a sufficient amount of theoretical research to gain a better fundamental understanding of our planet and pave the way to increased practical applications of new knowledge.

6. Research on field problems must continue to be important in our earth science graduate schools. We have been told by people in industry that some geology departments now refuse to accept field problems for Ph.D. thesis requirements. As far as we know these reports are unfounded. The misconception has probably arisen from the fact that most departments will not accept thesis subjects which are essentially descriptive in nature, a decision to which we subscribe.

7. Notwithstanding what is said above about research specialization, every effort should be made to bring together related disciplines, in order to present integrated view of earth problems. Geophysics and geology together provide an outstanding example of related disciplines. As another case in point, a person wishing to become proficient in geotechnique must possess not only a good knowledge of civil engineering practice and soil mechanics, but of geology as well (see Chapter V). Universities should find ways of promoting multidisciplinary research on problems of national interest, rather than allowing too much "irrelevant" research by isolated research workers.

8. A larger proportion of the basic research in earth sciences carried out by universities should be mission-oriented and better co-ordinated with the research carried out by government agencies.

9. Many earth science professors lack practical experience and have little contact with government and industry scientists. Universities should encourage these people to acquire diversified experience. The hiring practice of universities should be flexible enough to allow the hiring of senior earth scientists.

10. Too many graduate students view the object of their research as an end in itself and aspire in professional life to do exactly the same kind of work as they did for their thesis. Faculty should encourage students to apply their expertise to other fields and discover new practical applications of their knowledge.

11. Universities should press government and industry to institute sabbatical leave systems so that non-university research people can join university research groups for extended periods. The resulting "mix" of talent should be most beneficial toward reaching research excellence in universities. It is a sad fact that we do not have in Canada a university centre of high standing that deals with the whole fabric of the petroleum and natural gas industry, nor do we have a centre of mining exploration research that even remotely approaches in reputation some American or British schools. We are not much better equipped in the field of Arctic and sub-Arctic studies.

12. In conjunction with their research and graduate training functions, universities should remain responsive to industry requests for refresher courses. It is somewhat strange, however, that in contrast with the petroleum industry the mining industry has initiated very few such requests in the earth sciences. Yet, we frequently hear the complaint from senior professionals that the young student nowadays speaks a much different scientific language than the one they learned in their school days.

## III.11 Basic Research in Industry and Government Agencies

The broad patterns of research expenditures in earth sciences in Canada are given in Tables II.2 and II.10. Three main conclusions can be drawn from these tables. First, basic research expenditures in the petroleum industry far exceed those of the mining industry. Second, the largest companies carry on most of the basic research, out of proportion to their absolute size. Third, expenditures on basic and applied research, combined, are dwarfed by those spent on instrument development and scientific data collection and interpretation.

On the other hand, university expenditures on basic research and graduate training in the earth sciences are estimated to total $4.5 million (Tables II.39 to II.41). The federal grants-in-aid of earth science research amount to $4 million (Table II.27). Thus, the universities are the largest performers of basic earth science research in Canada, compared to $4 million of in-house basic research in federal government agencies, $2 million in industry, and $0.5 million in provincial departments and research councils.

The reaction of the mineral industry and the construction industry has been, in general, very favourable to the type and amount of earth science research carried out by the federal government agencies. Provincial government agencies were mentioned in questionnaires only in passing, probably because they perform very little basic research themselves, except for one provincial research council.

## III.12 The Development of Centres for Special Earth Science Studies

**Rationale**

Science performance in Canada has fallen short of general expectations. Canadian scientists working in this country have never won a Nobel prize in natural science. Yet with our population of scientists and the large expenditure on scientific research, it might have been expected that at least one Canadian would have received this international recognition. It is true that Nobel prizes are not an absolute measurement of scientific achievement and that Nobel prizewinners and other geniuses cannot be made. They can, however, be nurtured, given the proper environment.

We have some reason to be uneasy about our performance in the various fields of science. *It is time that we tried to redesign our activities and institutions to produce greater excellence in scientific research.* This does not necessarily call for grandiose schemes nor a much larger share of the Gross National Product. Excellence can be reached by reinforcing the programs that have the highest scientific, social and economic advantage.

The essential criterion of excellence must especially apply to our institutions of higher learning and, in turn, characterize faculty and graduate students. Do we have in earth science university departments many of the best men in the country? Is the research conducted by faculty avidly sought by earth scientists in industry and government? Are our Ph.D. students endowed with exceptional originality, flair and intellectual ability? Is the earth science research in our universities world-acclaimed, or at least well recognized?

We believe that we have in Canada the essential ingredients for making the earth sciences a great science, both from the point of view of fundamental knowledge about the earth and the practical applications to economic and social development. The question we want to answer, in part at least, is how we can develop excellence to a higher degree in the future.

Although we have not attempted a study of foreign institutions which may be readily regarded as centres of excellence in earth science research, we are nevertheless aware of some outstanding differences between several of these institutions and our own. Two major traits emerge from these preliminary comparisons, namely, the aspects of "concentration of talent" and "intensity of efforts".

**Concentration**

As a specific example, Charles University, in Prague, has a Division of Geology and Geography comprising 65 staff members with ranks equivalent to Canadian professors, associate professors, and assistant professors. This number does not include the earth science faculty in the Department of Economic and Regional Geography.

Czechoslovakia has only two-thirds of the population of Canada, yet none of our universities has anything to compare with the concentration of talent at Charles University. Our largest group is only one-third the size of the earth science faculty at Charles University, which has as many members in an earth science speciality as Canada usually has in a whole university department.

Greater concentration can reasonably be expected to be proportionately more productive in Canada. Yet, the country being so large, this concentration must be regionalized. No one can question, for example, the necessity of having a strong earth science university group in Vancouver, Calgary, Edmonton, Winnipeg, Saskatoon, Toronto and Montreal, and one in each of the Atlantic Provinces. However, one wonders if we are not dissipating our energies unnecessarily by having too many earth science departments in a given city or province. Montreal is a case in point, with its *six departments of geology* (Ecole Polytechnique, Université de Montréal, Université du Québec, McGill, Loyola College, and Sir George Williams) and *four departments of geography*[1] (Université de Montréal, Université du Québec, McGill, and Sir George Williams). It has, in addition, *two departments of mining engineering* (one at McGill, which includes mining geophysics, and one at Ecole Polytechnique). This proliferation is in part due to the necessity of establishing separate departments in the francophone universities. Even though Ecole Polytechnique and Université de Montréal have joint teaching arrangements, there is some duplication of effort and research facilities in these two departments.

*In Ontario there are 11 departments of geology, 10 departments of geography, and 2 departments of geophysics.* New Brunswick and Nova Scotia combined have four departments of geology, one "department" of geophysics (in the Physics Department at Dalhousie), but no department of geography.

There are admittedly good reasons for the existence of earth science departments in so many universities. One wonders, nevertheless, if this proliferation is conducive to excellence. The principles we wish to stress are:

1. Additional first-degree programs in the earth sciences should be established wherever there is a regional and fairly long-term demand for earth science graduates. *The suggested minimum graduation for an earth science department is five bachelors per year,* which entails an earth science student enrolment in the order of 50 (including first-year students). The present "bachelor degree" departments that are not viable should join with others. For example, some geology departments in the Atlantic Provinces and some in Ontario, which have produced an average of less than five bachelor graduates per year during the last five years, should seriously consider teaming up with geography departments. The smaller geology departments in the Maritime Provinces should perhaps establish a joint geology-geography program, with a concentration on high school science teacher training. These departments and others cannot reasonably hope to develop advanced-degree programs in the near future and, because of their particular environment, cannot expect to build strong undergraduate departments. Therefore, they may as well reach excellence in providing good, well-rounded, basic training in the various aspects of

[1]Only McGill and Montréal have, however, a graduate program in physical geography.

earth sciences. To achieve this, they require faculty input not only in geology but also in geophysics and physical geography, not to mention soil sciences.

2. The advanced-degree programs, which should be established in relation to excellence in certain fields of earth science research, should be encouraged only where there is a demonstrable demand for earth scientists with advanced degrees. New programs of this kind should only be established in consideration of what is offered by the other universities in the province or the region. Duplication in major research endeavours should be avoided wherever possible. Thus we submit:

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*Conclusion III.10*
*To avoid excessive dispersion of energies and encourage the development of excellence in earth science research and training, provincial governments and universities should not authorize the establishment of new advanced-degree programs in the earth sciences except where there is a demonstrable demand for earth scientists with a certain type of specialization. These programs should be established only where the ratio of bachelor graduates to faculty has been greater than 2 to 1 during four consecutive years, and on the basis of firm commitments from the local government and university to provide a minimum faculty of 10, as well as adequate teaching and research facilities.*

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**Application**
One important characteristic of foreign centres of excellence is their pursuit of a particular field of research. In most cases this intense application has been sustained for a number of years, resulting in the production of a large number of specialists for the country and the world. A typical feature of these centres is that they have attracted top scientists, have produced much research, and have engendered a substantial amount of innovation. One good example is the School of Geochemistry of the Royal School of Mines in England. Another is the Centre de Morphologie Mathématique, at Fontainebleau in France, which comprises some 25 experts in geomathematics, statistics and computer technology.

Canada has lost many of its best scientists because of their emigration to other countries. The attraction of large foreign research centres, well-equipped and well-staffed with scientists and technicians, has undoubtedly been a major factor in their emigration. It seems apparent that we could counter this attraction if, by some reorganization and more intense application, comparable institutions were established in Canada.

Canada is falling behind even in its traditional fields of excellence. We have prided ourselves on the excellence of our mineral exploration techniques, but the current situation is that Canada does not even have in one place a laboratory with staff and research facilities that compares with that of the Geologic Research Division of Kennecott Copper Corporation in Salt Lake City, Utah. New techniques are developed there that are beyond our present capability.

**The Canadian Scene**
Earth science departments in Canadian universities are numerous but staffs are small (Tables II.39 to II.41). They are traditionally divided among many specialities in their attempt to cover the broad range of pure and applied earth science research. The effort is usually spread too thin to produce the organization that can engage in multidisciplinary synthesis and analysis of data. A tendency is now developing to channel the research of some graduate schools into a limited number of specialities, in an effort to avoid excessive duplication. Centres of excellence are thus beginning to emerge, but few earth science departments are approaching the critical size of 20 members used as a yardstick of minimum size for earth science research schools in the United States.

Provincial government geological groups tend to be small and strongly oriented toward the production of data for the mineral industry. A research component has recently been introduced into most of these groups to benefit from in-house research and enable these agencies to retain high quality staff.

Federal government institutions have recently been criticized for excessive centralization in Ottawa, and because too much of their basic research is remote from the training of new scientists. The earth science research carried out by these agencies is generally considered to be of high quality. The output, however, is largely in terms of publications rather than production of an adequate supply of research personnel for the country. We recognize that their primary role is to look after national needs; the Geological Survey of Canada, for example, cannot reasonably be expected to devote much attention to the training of scientists without diminishing its research productivity. *However, at the risk of over-simplification, we would like to see more decentralization of federal government agencies engaged in earth science activities, as well as greater co-operation with universities across the country, so that our human resources may be employed in the most effective manner, not only in research but in the training of earth scientists.*

In all fairness to federal government agencies, it must be admitted that the universities in Vancouver and Calgary have not taken full advantage of the presence of Geological Survey groups of scientists in these cities. Co-operation must be a two-way street, and universities should solicit the support of government agencies in their research programs, though not to the detriment of the services these agencies render industry.

Canadian industry, the mineral industry in particular, has produced many important advances in earth sciences. Our competitive economy system has given us a mineral production which is the envy of the world. However, competition in mineral exploration implies that important applied research and field survey data must remain confidential for a time. The implications of a competitive mineral industry lessen the likelihood of direct and full-fledged co-operation between industry and other research sectors. Indeed, the mineral industry supports few research programs in the universities, and its funding of earth science research equipment in universities is small (see Tables II.39 to II.41). Because of these and other factors, industry's main role may be one of advice and financial support. Every attempt should be made however to explore avenues of industry-university co-operation, such as the establishment of industrial fellowships whereby a researcher from industry could pursue some of his research in a university for a certain time. The role of industry in national co-operation is discussed more fully in Section IV.6.

A few research centres, such as the Bedford Institute at Dartmouth, the Great Lakes Institute at Burlington, the Institute of Sedimentary and Petroleum Geology at Calgary, and the Cordilleran Section of the Geological Survey of Canada at Vancouver, have been established with direct financing by the federal government. These centres, which are now well established, produce work of high quality; it is important that they remain fertile environments for brilliant scientists.

*In conclusion, we believe that the earth science research effort in Canada is too widely dispersed and poorly co-ordinated to produce research excellence commensurate with the efforts and expenditures made.* Better co-ordination and development of centres appropriate to the Canadian scene may produce the excellence and innovation for which we have been striving but have not yet attained.

**Parameters for Centres of Special Earth Science Studies**

1. The centres should direct work on future programs rather than be modelled on yesteryear's institutions. We need innovation in the design of institutions, as much as anywhere else in research.

2. The centres should be appropriate to Canada. They should provide a na-

tional focus on important scientific problems, preferably those that have important practical implications. In the earth sciences we should take full advantage of the earth features uniquely or best developed in Canada, and avoid duplication or competition in areas of research which are already well established in other industrialized countries, except in areas which are particularly relevant to Canadian conditions (see Section III.8) and the Canadian economy (see Chapters IV, V and VI). *The ideal program would be based on national needs and the scientific opportunities of the Canadian scene.*

3. The centres should be based upon existing strength and a record of past performance.

4. When possible, the centres should be located where university and government research facilities can combine to produce greater strength. Government research and data-gathering facilities should be combined with the training of new scientists. The university campus appears to be the best site for the typical centre, being close to faculty, graduate students, and the university facilities such as research equipment, specialized libraries, technical services and computer facilities.

5. Industry should enter the decision-making at some centres, either directly or in the capacity of a "technical audit". Where possible, industry should take part in the research program through the use of industrial fellowships, contract research, or other means. The results of the research should be of use to industry, which should be encouraged to use the results. The output of trained people from these centres should be of primary interest to industry.

6. Most centres should contain components of pure research, applied research, development, innovation, data gathering, and scientific information. They should beware of over-specialization, and most should use a multidisciplinary approach to the solution of problems. Some centres should specialize in solving problems which are of direct interest to industry.

7. The area of research should be selected to provide a long-term, or self-renewing, challenge so that the centre will not tend toward a rigid structure with resulting attempts to redesign the institution or concentrate on repair activities whenever a particular program is satisfactorily completed.

8. The best scientists should be encouraged to remain in research and student training instead of being removed from the research scene and burdened with administrative duties. *Canada's greatest brain drain of eminent scientists is to fields of administration rather than to foreign countries,* and this is disastrous for achieving excellence. The administration of these centres of excellence could well follow the administration mode of large hospitals.

9. Geography and communications should be considered when choosing locations for these centres, because most of them are likely to be field oriented.

10. The centres should provide a variety of choices and alternative projects, so that the individual may be free, within limits, to choose his research. Complete freedom of choice is not possible because of financial and physical limits to the research, and the particular orientation of a given centre.

11. Each centre should seek to promote communications between researchers in universities, government and industry, and achieve good co-operation in research in its major sector of activity.

**Organization of Centres**

Two major and contrasting types of organization have been suggested in the various briefs to this Study Group (see Appendix 3). One involves the creation of an entirely new research institute with a university campus as the suggested site. The institute would be an "entirely autonomous, privately incorporated, non-profit organization, financed by industry and government, with majority control in the hands of directors appointed by industry". The institute would be closely associated with a university having comprehensive technical libraries and research facilities, and would have formal working arrangements with industrial organizations. The institute would have its own physical plant and its staff would conduct independent, largely industry-sponsored research.

The other contrasting scheme envisaged would result from the co-ordination and co-operation of existing groups of university, government and (possibly) industry scientists, and the development of a shared centre on a university campus. Each group would maintain a certain degree of autonomy in order to discharge its own statutory responsibilities. Co-ordination would be achieved by physical proximity of scientists working together in a given subject area, by joint research projects, joint supervision of graduate students, and joint colloquium programs.

**Support for the Concept of Centres of Excellence**

The concept of special centres to develop excellence has received widespread support in the background papers, in general submissions from industry, universities and individuals, and in particular briefs recommending the establishment of particular centres.

Industry supports the concept of the "co-ordinated approach". In its brief, the Canadian Institute of Mining and Metallurgy says: "There is some doubt as to whether the resources now available are being used as effectively as they might be. At present, grants are being given in aid of individual research or research projects of limited scope. It would seem reasonable that, with increasing complexity in earth science research subjects, perhaps emphasis should be placed on the larger project approach. That is, we might encourage more co-operative research efforts on different phases of large projects by different agencies and/or individuals...When considering the larger project aspect, joint projects between university and industry and government agencies, in certain fields, should be encouraged."

The brief from the Exploration Department of Imperial Oil Limited makes several recommendations: "Industry should help foster industrial research institutes at selected universities...Government should help universities set up areas of excellence and support long-range research projects in these institutions, as a financial incentive and an attraction to outstanding personnel...Universities should favour areas of excellence...they should use people in government and industry."

The consensus is clear that centres of excellence should be established to increase the effectiveness of earth science research and development. We endorse the general concept of such centres, based on the parameters indicated above and the cautions and requirements given below.

**Cautions in Development of Centres of Excellence**

Many arguments favour the establishment of research centres. However, these should not supplant other sectors of scientific activity but rather strengthen them. There is some danger that staff members not in centres may lose morale, and that universities and colleges with no centre could not attract good staff and students. Certain centres or institutes might undercut some of our fast-developing research industries, particularly in the area of exploration geophysics. Care should be taken that the research would support rather than interfere with industry of this type. Regarding the mineral exploration sector, we feel that the proposed Institutes of Mining Exploration Research (see Section IV.5) would fulfil the role of centres of excellence and be most helpful to the mineral industry. The tendency to over-specialize with resulting loss of balance in training should be avoided, and undergraduate students should not become involved in the activities of the centres at too early a stage.

We should also be aware of the experience of present institutes and centres. The Stanford Research Institute, which is an independent contract institute organized somewhat like the first alternative institute scheme proposed above (Section III.11), was forced to abandon its earth science section because of lack of contracts and support from the mineral industry. Contract research is risky because this type of research is the easiest thing to turn off when money is tight; this affects the sponsoring group very little but has serious consequences for the centre itself. Unfortunately, sponsoring groups take advantage of this cushion to protect departmental budgets. This can cause the disbanding of a good research team that has been built up laboriously, and the abandoning of important research because of a short-term outlook. Under these conditions, institutes or centres of excellence cannot attract high-quality personnel.

Centres require centralization, preferably in one building. Groups working in separate parts of the same city, such as those involved in Project Pioneer in Winnipeg, have found that communications break down and co-operation is difficult with a separation of only a few miles.

**Example of What a University Should Provide**

It is relatively easy to suggest centres of excellence but difficult to ensure their logical development and obtain firm commitments from the organizations that should support them. Government, industry and universities must guarantee long-term support to the centres falling in their major fields of interest, and each sector must meet a list of requirements. As an illustration, we give here the requirements for the university sector in the case of mission-oriented research:

1. The university must have demonstrated reasonable interest and proficiency in the specific area of research proposed for the centre.
2. The geographic location of the university should be suitable for the proposed research.
3. The provincial government should have demonstrated an interest in that field of research.
4. The university should have available large capital equipment for shared research.
5. The university must have an administrative procedure for involving government officers and industry personnel in research and graduate student training.
6. The university must make available a suitable campus site for a government or industry institute if a physical plant is required and the university facilities are inadequate.
7. The university must provide the other sponsoring organizations with the assurance that it intends to emphasize the specific area of research as a subject for graduate training and research.
8. The university should strengthen its staff in the specific area and should choose individuals who would give more than lip service to the proposed co-operative research. This is important to ensure that a flourishing group exists in the university with which the incoming scientists can interact. If the university group is too small, it would simply be absorbed.

It goes without saying that the responsibility of the respective sponsoring organizations must be clearly defined before establishing a centre. The initiative, it is suggested, should come from the university and be addressed first to the federal government, but with evidence of good support from the local provincial government and local industry.

**Suggested Centres for Special Earth Science Studies**

We have received suggestions and proposals for no less than 18 different centres of excellence. These proposals have been carefully analysed, particularly in the context of what is said above. Priority, scale and best location should be established according to the parameters and requirements suggested in this chapter. Accordingly, we recommend the following fields for preferential earth science development, in alphabetical order:

1. Cordilleran studies
2. Marine sciences (east and west divisions)

3. Mining exploration research
4. Northern terrain studies
5. Precambrian studies
6. Quaternary studies
7. Sedimentary geology.

An eastern marine sciences centre and a sedimentary geology centre are already established. Mining exploration research (see Section IV.5) and northern terrain research should receive very high priority. Quaternary research should receive high priority because of all the potential applications of this field to renewable resources, optimum land use and urban planning. Precambrian studies should receive a relatively high priority, in line with the program recommended in Section III.3. Thus, we submit:

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*Conclusion III.11*
*Canada should promote centres for special studies (centres of excellence) in the following earth science fields: Cordilleran studies, marine sciences, mining exploration research, northern terrain studies, Precambrian studies, Quaternary studies, and sedimentary geology.*

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