Canadian Geoscience Council

Published for the Council
by the Geological Survey of Canada as
Paper 80-6, Part 1

The Geosciences in Canada, 1979

Part 1: Geology and Geophysics in Canadian Universities

E.R.W. Neale and J.E. Armstrong

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

GEOLOGICAL SURVEY
PAPER 80-6, PART 1

THE GEOSCIENCES IN CANADA, 1979

Part 1: Geology and Geophysics in Canadian Universities

E.R.W. NEALE and J.E. ARMSTRONG

Committee on university study

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1981

Available in Canada through

authorized bookstore agents
and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Hull, Québec, Canada K1A 0S9

and from

Geological Survey of Canada
601 Booth Street
Ottawa, Canada K1A 0E8

A deposit copy of this publication is also available
for reference in public libraries across Canada

Cat. No. M44-80/6-1E   Canada: $5.00
ISBN – 0-660-10852-6   Other countries: $6.00

Price subject to change without notice

Preface

As the Canadian Geoscience Council has grown and matured since its founding in 1972, it has tackled progressively more complex and fundamental issues facing the Canadian earth sciences. This, the major section of the seventh Annual Report of the Council, deals with Teaching and Research in Geology and Geophysics in Canadian Universities. The two year study has been spearheaded by E.R. Ward Neale and Jack E. Armstrong to whom the Council is truly indebted for their endless, volunteered hours of investigation, discussion, analysis, and writing blended with frustration, wit, insight and compromise.

The Council is committed to a series of analytical reviews of different sectors of the earth sciences. Earlier studies have included research in petroleum exploration geology, the soil sciences, and the Geological Survey of Canada; studies in progress involve research in marine geosciences and also geoscience research in the mineral industry.

Geoscience studies in Canada, whether undertaken in industry, in federal or provincial institutions, or in universities, require a constant source of new, trained, and talented personnel. Geology and geophysics departments in Canadian Universities are the principal source for this personnel and it is important that they produce enough individuals with suitable basic or specialized backgrounds to satisfy the national need for geoscientists. University departments are largely responsible for ensuring that a fair proportion of the talented high schools students are initially attracted into the discipline, for teaching the most significant aspects of the discipline in stimulating and innovative ways, for ensuring an appropriate background in other basic or related subjects, and for preparing the students to be effective contributors to one or more sectors of the geosciences upon graduation. The present study documents nearly all aspects of teaching and research in the 40 geology and geophysics departments in Canada. All departments were visited and data collected, views sought from faculty and students, from industry and government and from a wide variety of distinguished international specialists.

The authors, after frequent consultation with the Council, have tried to synthesize all the available fact and fiction, tabulating much data as appendices.

The study was funded by grants from the Geological Survey of Canada and the Natural Sciences and Engineering Research Council of Canada together with the Canadian Geoscience Council's own resources. The production and printing of both the English and French editions has been carried out as part of the Geological Survey of Canada's publication program. The study provides a review of the topic in order to help improve the academic systems and to assist geoscientists and others in industry and government to better appreciate the objectives, problems, concerns and constraints of the academic community.

The limits of funding, manpower and time of such reports as this inevitably result in some subjective synthesis, omission of pertinent examples, and perhaps a tendency to be overly critical. The data reported are as factual and up to date as possible; the views of academic, industrial or government scientists and employers do reflect current attitudes, whether they be accurate or distorted.

A major aim of the Council is to effect improved interaction and communication between the various sectors in the geosciences and this report was prepared as yet another step in that direction. The report is too large to extract or advocate key recommendations - these are listed in Chapter 1 - but one quote (Francis Bacon, 1608) is well worth reiterating, "Crafty Men contemne studies; simple Men admire them; and wise Men use them." There is much in the report to be used; if used well, major improvements will accrue to all geoscience sectors with a net benefit to the nation.

Part II of this report describes the many other activities of the Council during the past year. These have been extremely varied and are discussed in the Report of the President.

Finally, this annual volume of the Canadian Geoscience Council is designed to present the results of major studies conducted on behalf of the Council and to include its annual reports and major briefs or statements by its member societies. Council is anxious that it also serve as a forum for informed views of individuals or groups on topics of concern in Canadian geoscience. Contributions are invited for future volumes.

March, 1980

C.R. Barnes
Past-President

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Additional supporting information is presented in the form of appendices and will be found at the end of the report.

October, 1980

Chief Scientific Editor
Geological Survey of Canada

GEOLOGY AND GEOPHYSICS IN CANADIAN UNIVERSITIES

1. SUMMARY AND RECOMMENDATIONS

(prepared by the Canadian Geoscience Council)

Crafty Men contemne studies; simple Men admire them; and wise Men use them
Francis Bacon, 1608

GEOSCIENCE TODAY

The pendulum of public need and public interest is swinging from an almost total concentration on science's most minute particles back to those areas, such as the geosciences, that seek to understand systems as they exit in nature. Change in public attitudes began in the early 1960s with the widespread realization that man's meddling with Nature was beginning to produce some long term, perhaps irreversible deterioration in the environment. Additionally, the technological triumphs of space exploration resulted in photographs of Earth that stirred the thoughtful elements of society to ponder the physical limits of the relatively small, rotating spheroid on which we live. Finally, the recent energy crisis, accurately predicted by a geoscientist a quarter century ago, has brought an even larger segment of the population to appreciate the finite quality of many of Earth's resources.

Suddenly the thin outer rind of the Earth and its covering of soils, the realm of most geoscience, have regained an importance in Canadian consciousness which they held in the last century and which they never should have so completely lost. The search for ever more elusive mineral and hydrocarbon deposits, the estimation of potential resources, the devising of sane conservation practices, all require progressively more sophisticated practice of geoscience. So, too, does a continuing assessment of the ability of Earth's environment to sustain our edifices and to contain our wastes. The knowledge of geoscientists is needed more urgently and in more ways than ever before.

RATIONALE

University departments of geology and geophysics have burgeoned in the last two decades. They presently produce most of the scientists required by our rapidly expanding resource industries and government agencies. They have also become a major research force because of the rapid growth in faculty numbers, due to an emphasis on research by university administrators, and by their (belated) access to federal grants in aid of research in the 1960s. Students no longer go abroad for post-graduate studies and training in research, most enrol in Canadian universities. Professors of geology and geophysics, who chiefly confined themselves to local or provincial affairs in the first half of this century, now appear to be assuming many more national and international leadership roles.

This increased prominence and importance of our academic geologists and geophysicists over the past decade has made their departments logical targets for analysis by the Canadian Geoscience Council. The study seeks to determine their fitness to meet the growing national demands and challenges that are being thrust upon the geosciences.

This study is the fourth in a series that the Council has addressed to institutions and subdisciplines of the geosciences. All build upon and update the single, comprehensive study of the whole spectrum of our geosciences which was undertaken a decade ago by a committee of the Science Council of Canada (Blais et al., 1971). The present report is in some ways the most ambitious of the series. It seeks to provide basic data on faculties, enrolments and facilities of 40 geology and geophysics departments; to describe and evaluate their roles in the dissemination of knowledge and in the creation of new knowledge; to touch on their relationships with other segments of geoscience; and to examine their communications with those beyond the geoscience circle.

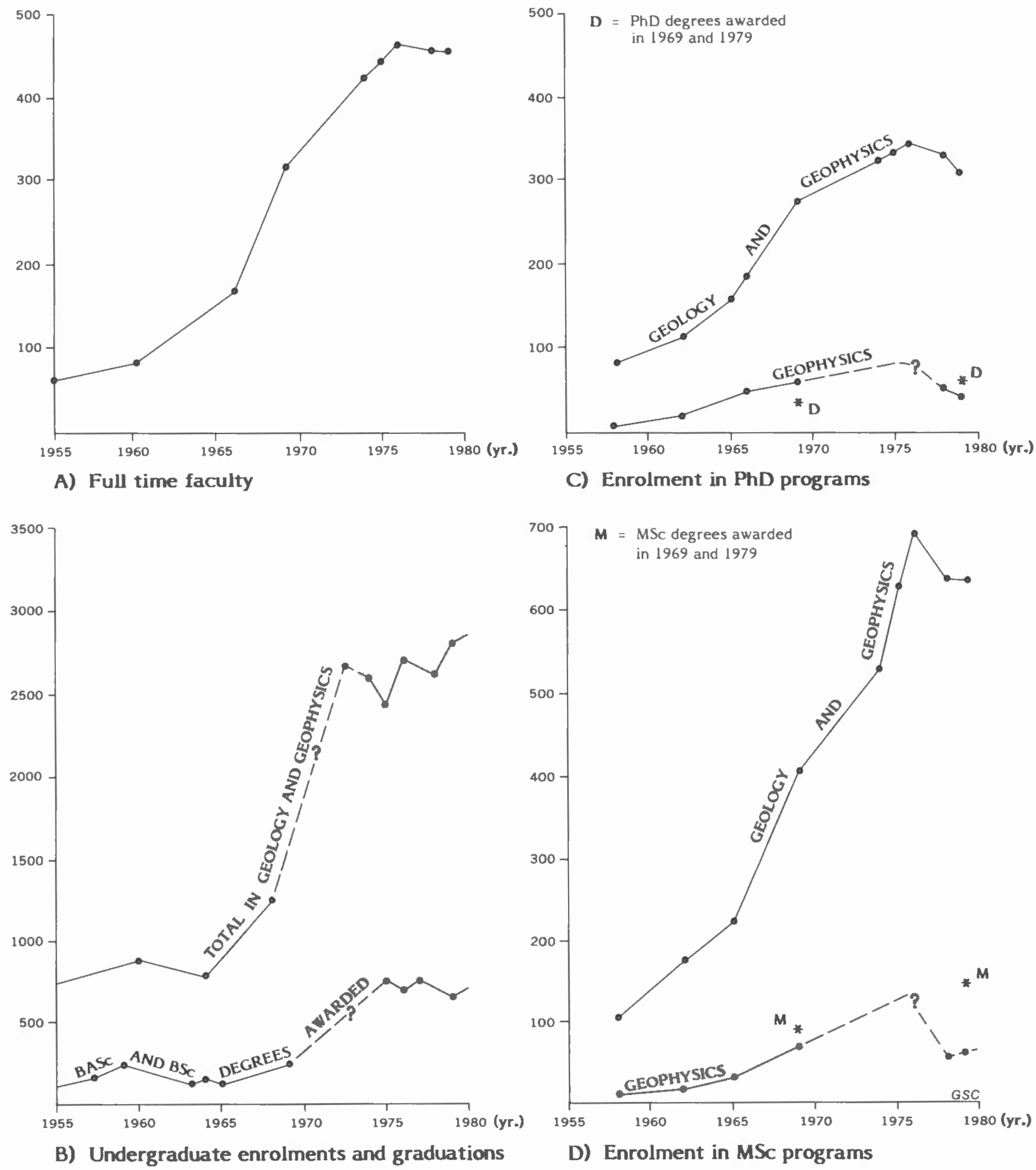
This undertaking has involved visits to almost all departments; discussions with senior university administrators; opinions and comments by officials of mining exploration and petroleum companies, appraisals by scientists of federal and provincial agencies and comprehensive assessments of the whole Canadian geoscience scene by distinguished scientists from abroad.

The report is prepared and written with a content and in a style designed mainly to inform those outside universities on the activities and status of our geology and geophysics departments. Is is anticipated, however, that this review and commentary might also prove helpful to the departments themselves. For this reason, many of the recommendations are addressed directly to them.

A DECADE OF GROWTH AND DEVELOPMENT

Departments of geology and, to a lesser extent, geophysics have grown fairly steadily over the past ten years, following a short period of very rapid growth in the 1960s. They have not been subjected to the erratic fluctuations in enrolment that plagued them in the past. The latter part of this growth period has been all the more noticeable because is has taken place at a time of generally declining university enrolments and sharp declines of both undergraduate and graduate students in the other sciences. Departments of geology that were scarcely known at the time of the Science Council study in the late 1960s now rank among our largest and strongest teaching and research schools. The major reason for the high enrolments is the abundant opportunities for employment that have been sustained over several years. Competition for the services of new graduates and restricted opportunities for research careers in Canadian industry have combined, however, to level off graduate school enrolment in the past few years -- a serious concern if we intend to continue to produce our own leaders in geoscience.

Government funds in support of research have dwindled steadily in terms of real dollars over the past decade. Only in the year of this report has the main funding agency



1. Data from Stearn (1968), Blais et al. (1971), Strangway (1978).
2. Recent data from Department Heads in Geology and Geophysics.

FIGURE 1.1. Basic statistics on Geology and Geophysics Departments, 1955-1980

(NSERC)[1] been permitted to restore grants to 1969 levels. Financial support came later to academic geology than to geophysics and to other university sciences. Viable geological research was barely underway in the universities before it was beset with a decade of restraint and with the political antipathy that was directed to all the physical sciences. Geoscience research in the universities remains grossly underfunded in relation to its importance to goals of energy self-sufficiency and environmental protection. Grants-in-aid of all university geoscience research remain slightly below the operating budget of a single federal agency, the Geological Survey of Canada (GSC), and well below the combined operating budgets of the provincial geoscience agencies. Support of university or any other research by industry remains trivial, in part a reflection of our branch plant economy.

Despite this, some individuals and some teams have built up fine reputations for excellence over the past decade. In terms of international prestige they compare very favourably with practitioners in the most vigorous of their sister sciences. Their greatest accomplishments are in regional synthesis, solid earth and exploration geophysics, resource exploration and terrain evaluation: all fields that are particularly suited to Canadian needs. Despite many bright spots, however, academic research is judged as very competent rather than excellent which is not surprising in view of its very short history.

Geology and geophysics have grown in prestige on Canadian campuses and most departments are no longer at the bottom of the pecking order of the sciences as they were 15 years ago. In at least two of the newer and one of the older universities they are obviously the premier science departments. The status of others has improved immensely but university support has been slow to depart from traditional patterns and they do not receive the funding and facilities that their enrolments and research activities warrant. A few, including some very respectable teaching and research groups, still labor in very unsatisfactory circumstances - apparently without the sympathy of senior administrators.

The relationships of geology and geophysics departments to each other have improved immensely in the paste decade. Joint courses, joint appointments and shared research are much more common than ten years ago. Several geology departments now offer specialization in geophysics at both undergraduate and graduate levels. Nevertheless, there is room for improvement; many geologists still graduate without exposure to geophysics and many geophysics graduates have inadequate backgrounds in geology. Relationships with other departments are generally disappointing. There are a few good examples of cross appointments and joint research with geography and biology departments, teaching exchanges with engineering and with physics departments (particularly when geophysics is within that department) but remarkably little interaction with chemistry departments considering the many opportunities for joint endeavours.

Canadian geoscience has become well integrated in the last decade, following recommendations of a Science Council report (Blais et al., 1971). Academic geoscientists have played a large part in the organizational process. There are still shortcomings in communication between the various segments of the science, due chiefly to the unusual development of its associations which proceeded from the specialized to the general. Nevertheless, some splendid co-operative projects have been achieved, for example in secondary school education and in international geology and geophysics.

Communication beyond the geoscience circle has remained inadequate. Only a few geoscientists are well known to those in other disciplines and to the general public. Academic geoscientists generally shun the limelight and refrain from public comment and debate and from writing popular articles and books on the pressing problems of our time which require objective input from those who know the Earth. Until they do this, they will probably continue to receive less support than merited by their importance both on campus and on the national scene.

SOME FACTS AND OPINIONS

Teaching and research in geology and geophysics are carried out in 40 separate departments or other units devoted to one or both of these subjects. Twenty-six offer degrees only in geology, eight in both geology and geophysics, and seven only in geophysics. The 40 departments are located in 34 of Canada's 53 universities.

Housing and facilities

- There have been improvements in the physical environments of geology and geophysics departments over the past decade. Most are now classed as adequate, six as good to outstanding, but five are overcrowded and unsatisfactory in many ways.

Faculty members

- Between 10 and 15 per cent are classified as "deadwood" by their colleagues and students; this is a modest percentage and is probably better than that found in government and industrial science. The best managed departments had little or no "deadwood", they seemed to have found useful employment for those who were weak teachers and poor researchers.

- There were 457 academics with the rank of assistant professor or higher teaching geology and geophysics in 1979-80. This represents a 42 per cent increase since 1968 (Fig. 1.1).

- Only eight women are listed among the full-time faculty members.

- Average age of faculty members is 43.4 compared to 40.7 in 1974 and 37.5 in 1968. Only one department (Waterloo), average age 37.8, shows a decrease over the past five years.

- Faculty members have commendable industrial and governmental experience; the highest is at Ecole Polytechnique where it represents 32 per cent of total experience, but there are universities where it is about 20 per cent.

- Ten years ago, 67 per cent of geology faculty members had received their highest degree outside of the country, today that figure has increased to 73 per cent. In contrast, only 39 per cent of our academic geophysicists received their doctorates abroad.

[1] Natural Sciences and Engineering Research Council.

Undergraduate students

- 2818 honours, majors and engineering students were enrolled in geology and geophysics in 1979-80, an increase of 212 students over the previous year and an all-time record (Fig. 1.1).

- Women accounted for about 20 per cent of total enrolment, less in engineering programs. Queen's, with 40 per cent in Science and 24 per cent in Engineering, has the highest enrolment of women.

- Total of new graduates in 1979 was 647. This included 485 B.Sc. degrees in geology and 36 in geophysics; 112 B.A.Sc. in geology and 14 in geophysics. Theses data were obtained by individual approaches to department heads and double checked where errors seemed likely.

- Most of the graduates in geophysics are produced by the geology departments that offer geophysics options.

- Data on enrolments and graduations in geology and geophysics compiled by professional societies and government agencies vary widely and invariably err on the high side. The only reliable data presently available are from the Council of Chairmen of Earth Science Departments of Canada.

- Over half of the geology departments have no course requirements in geophysics.

- Most students still enter geology and geophysics programs as a result of chance contacts made after their arrival at university.

- The national ratio of student majors to geology professors is 5. There are wide fluctuations, the ratio of 8 seems the maximum tolerable if professors are to carry out other duties such as service teaching and research. Three schools have much higher ratios, namely 14.8, 13.4 and 12.7. Geophysics teaching units generally have low ratios, far below the national average for geology.

- Some professors noted improvements in the quality of students entering geoscience. Most felt that average quality had remained the same but that the increased numbers had brought in more very bright pupils. Measured by the award of NSERC scholarships to graduates, quality remains lower than in many other sciences.

- The most common single complaint of mineral and petroleum exploration companies and provincial agencies concerns the inability of new graduates in written and oral expression. Second most common was the lack of adequate field training during undergraduate years.

- Mineral and petroleum exploration companies stressed the need for more pragmatic courses: drafting, surveying, well-logging techniques and mineral exploration methods.

- Companies expressed a strong preference for geology and geophysics graduates of engineering programs and also for (Waterloo's) co-operative work-term program.

- Some professors stated that the geosciences have become so complex that specialization at the undergraduate level is a necessity.

- Other professors stated that breadth is desirable, training should be diversified and students encouraged to think and relate one subject to another so that they are flexible, adaptable and innovative upon graduation.

- Two authors from outside the university circle (Baillie, 1979; Keen, 1979) agreed with the latter group and suggested that the specialized topics of geoscience should be taught only within the framework of more basic courses in geology, physics, chemistry, mathematics and biology.

- Many people within and outside the university circle feel that the present training period must be extended in order to graduate qualified professionals.

Graduate students

- There were 943 graduate students enrolled in 1979-80, a decrease of 3 per cent over the previous year but roughly 30 per cent more than 10 years ago (Fig. 1.1). About 15 per cent of graduate students are female.

- Enrolments included 263 Ph.D. students and 573 M.Sc. students in geology and 46 Ph.D. and 61 M.Sc. students in geophysics.

- During 1979, 51 geologists and 8 geophysicists received Ph.D. degrees and 140 geologists and 12 geophysicists received M.Sc. degrees.

- M.Sc. degrees require an average of three years and Ph.D. degrees an average of six beyond the baccalaureate. This is much more than in most countries.

- Approximately 30 per cent of graduate students come from abroad, chiefly from the U.K. and U.S.A.

- In more than half the departments, any professor is free to supervise graduate students, regardless of his research record and personality. Of those schools which require an examination of competence, few make any subsequent checks on those who qualify as graduate supervisors.

- University professors fear that the slight decline in enrolment experienced recently (Fig. 1.1) is the beginning of a trend. The best graduates of our universities are being lured into early employment and it is increasingly difficult to obtain work permits or financial support of any kind for foreign students.

- Almost all Canadians and some of the foreign students who complete advanced degrees remain in Canada. A few are employed in frontier research[1] with government or in frontier types of applied research with large service corporations. The rest join mineral or petroleum exploration companies where they are chiefly involved in operations, a few in special service roles.

- It is estimated that support of the average graduate student and accompanying research required $15 000

[1]This term is used in the sense of Bonneau and Corry (1972) to mean heavily empirical research based on experiment and observation. The usage is discussed in Chapter 5.

per year in 1978-79. The funds for this come from a variety of sources but chiefly from the university and from NSERC grants to faculty members. The contribution by government geoscience agencies is small, and from industry very small.

Research

- In terms of international awards and honours, the geosciences rank close to the top.

- This report provides critiques and appraisals of academic research by the academics themselves, by scientists from industry and government, and by a variety of scientists from abroad. Our top researchers generally have a more favourable and optimistic view of our national efforts than do those more marginally concerned with frontier research. Not surprisingly, those from abroad have generally a better opinion of our research in geoscience than do those at home.

- Almost all academics interviewed stated that all university professors should be engaged in research in order to remain competent teachers. Most agreed that although some recognition was given to good teaching and other activities, research was the prime criterion for promotion in all except the small departments. Nevertheless, the Council's committees found that undergraduates identified as excellent teachers some professors who carried out little research.

- Most academics felt that we lacked overall first-rate departments on a par with those at Cambridge, California Institute of Technology or the Australian National University. A few stated that Toronto came close to filling this role. The authors of this report conclude that it does.

- Researchers have been slow to move into fields such as organic geochemistry, coal geology and diagenesis despite a small but continually growing need for this type of work.

- Most Canadian departments strive for excellence in the traditional subdisciplines although several have individuals who are pioneering new paths. The Waterloo department has attracted international recognition for its innovative, interdisciplinary approach to problems of engineering and environment through hydrogeology, hydrogeochemistry and Quaternary geology. The Guelph Department of Land Resource Science is also breaking down rigid disciplinary barriers.

- The basic and greatest expenses of academic research come from the universities themselves, i.e., the provinces which support them. This includes the salaries of professors and most of their support staff, provision and maintenance of laboratories and equipment and at least half the cost of graduate students.

- NSERC grants-in-aid of geoscience research (Fig. 1.2), peer-awarded to individuals on their merits, are free from restrictions. These have made world class frontier research possible in serveral geology and geophysics departments over the past 15 years. In 1979 a total of $6.5 million in operating and equipment grants was awarded to 456 geoscientists. In 1980 this was raised to $7.3 million for 456 geoscientists. These include awards to physical geographers, geotechnical engineers and others but most go to academic geologists and geophysicists, 70 per cent of whom receive grants. In addition, for 1979-80, they received 22 strategic grants valued at $914 800 for energy, environmental toxicology and ocean research.

- NSERC grants to individuals are not necessarily a measure of the worth of their research. Some require far less than others to carry out their projects. Also, younger researchers have to prove themselves over several years before receiving large grants. The total grant to a middle-sized or large department, however, is probably a fair measure of its activity in frontier research. These figures are provided in tables in Chapter 5.

- NSERC has traditionally awarded larger grants to laboratory-oriented scientists, e.g. geophysicists and petrologists, than to dominantly field-oriented scientist, e.g., regional geologists and biostratigraphers of equivalent merit. The rapidly escalating cost of field work in remote areas makes this type of research inaccessible to university geoscientists, unless they are in a position to take advantage of industrial or governmental transportation in the region. This latter, primarily designed for other purposes, usually restricts the scope of university projects.

- Governmental agencies aid university research in various ways. The Geological Survey of Canada currently awards about $0.5 million in research agreements. The Ontario Department of Mines has initiated a five-year plan of awards valued at $0.5 million per annum. These and several other provincial and federal agencies also award contracts on a year-to-year basis for mission-oriented projects. Many of them supply logistical support, particularly in regard to transportation.

- Geology departments at Alberta, Waterloo and Toronto were each receiving over one million dollars annually in outside research funds in 1978-79. This included grants and contracts with both domestic and foreign governments and some sponsorship by companies.

- Companies supply relatively little direct support to university research. Baillie (1979) estimates that the petroleum company contribution amounts to only $200 000. Support from the mineral industry is probably three times this amount. Both also supply some logistical support. One mineral exploration company (Riocanex) has recently introduced an imaginative program that grants about $200 000 annually to fundamental research in mineral deposits at universities.

- Respondents from industry generally had rather negative views of academic research, the mineral industry's views being generally more critical than the petroleum industry's. Both lamented the lack of research addressed to problems of economic geoscience.

- Those from abroad generally admired the close relationships between our academics and their government and industrial counterparts, and the pragmatic nature of much of our university research. Some respondents worried that the relationship was too close and may have hampered advances at the cutting edge of research, especially in theoretical and experimental fields.

- Views of government scientists varied from strongly positive and supportive to decidedly negative. Those who had the most interaction with university scientists

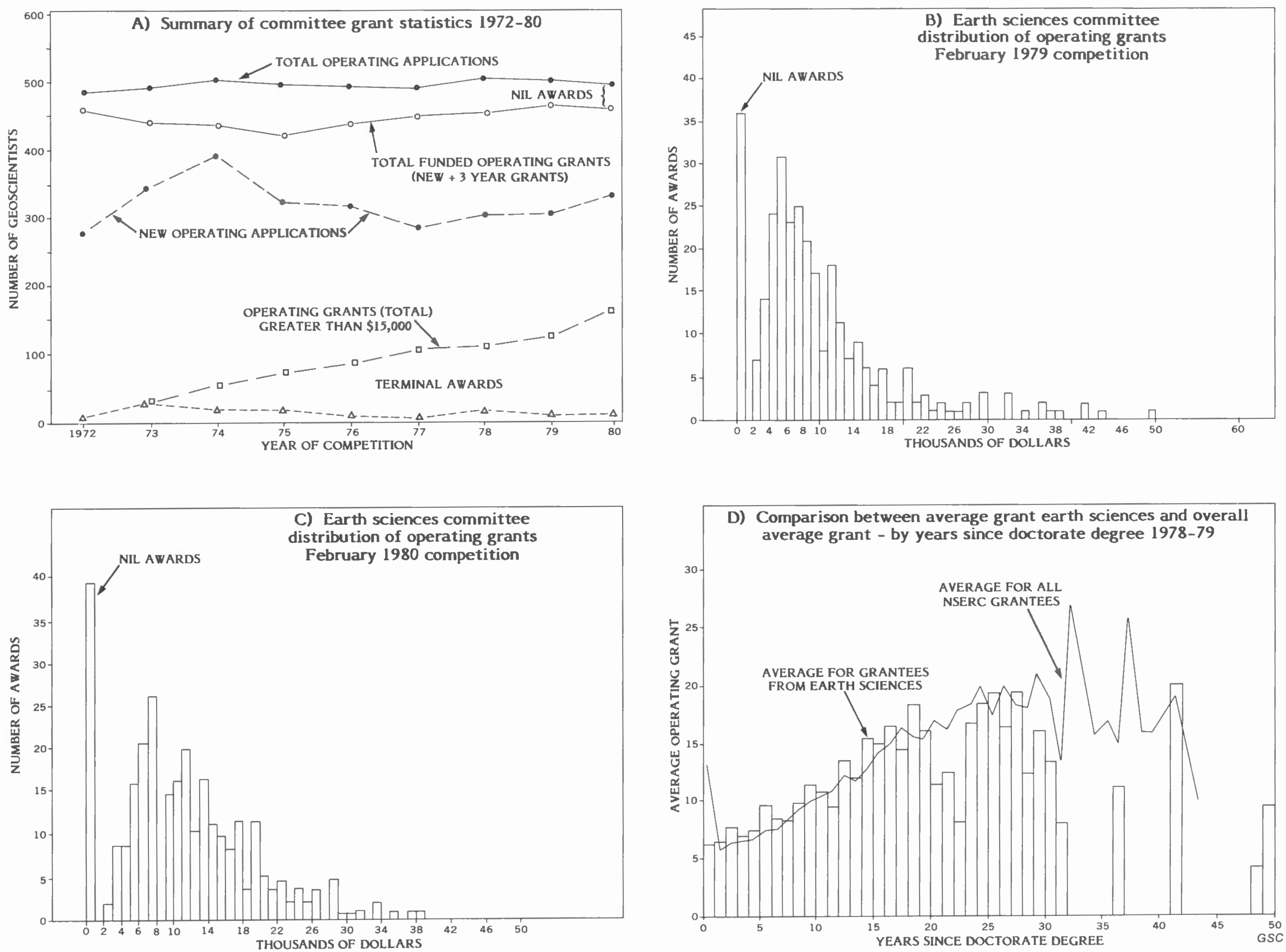


FIGURE 1.2. Statistics on Recent NSERC Operating Grants to Geoscientists

were generally the most positive. In the case of provincial agencies, viewpoints were generally restricted to the performance of nearby universities.

- Names of Geological Survey of Canada scientists were often cited when rating university accomplishments, not only those abroad but by some Canadian respondents, including academics!

- Most respondents agreed that our academic community had made world class contributions in regional synthesis, mineral deposits geology, exploration geophysics and solid earth geophysics. Some subdisciplines singled out for their excellence were: sedimentology, regional biostratigraphy, theoretical petrology, hydrogeology, low temperature geochemistry, Quaternary geology, rock magnetism and terrain sciences with a northern regions emphasis.

- Some distinguished scientists, at home and abroad, assessed Canadian geoscience overall as highly competent, one small step behind the very best. We lead in several subdisciplines and we have a few conceptual leaders of world class but very few. Mainly this is due to our conservative funding system -- the fear of putting a great deal of money into a bold and different type of project -- but in part it may be due to lack of full, wholehearted co-operation between the various elements of geoscience.

Relationships with other departments

- Overlap is probably greatest with physical geography which, in several schools, undertakes research and teaching in Pleistocene geology, geomorphology, sedimentology, glaciology and hydrology. Co-operation is very good in several schools, e.g. British Columbia and McMaster, but weak in most. Joint appointments between geology and geography departments are comparatively rare.

- Geophysicists, apart from those in geology departments, generally teach regular courses in physics departments. Most universities with engineering faculties call upon geology departments to teach basic courses to all students and more advanced courses to those in certain subdisciplines, e.g. civil and mining engineering.

- There are a few good examples of joint courses with biology (e.g. at Saskatchewan) and of using chemistry professors to help teach geochemistry (e.g. at Waterloo). On the whole, however, there are remarkably few examples of those teaching required courses in the ancillary sciences being asked to use examples and design problems related to the geosciences.

- Considering that geoscience is interdisciplinary in its approach to Earth problems, astoundingly little joint research is undertaken with professors in other disciplines. Physics and geology at Toronto and Calgary; chemistry and geology at Alberta, Toronto and Western Ontario are some of the few examples brought to the attention of Council's representatives.

- Although relationships between geology and geophysics have improved immensely over the past decade, there is still a lack of rapport and interaction in at least half the schools where they exist as separate departments.

Relationships outside the universities

- Relationships with other estates within the community of geoscience are good. Most contacts take place through the scientific societies but there are many other forms of interaction.

- Relationships outside the community are weak. Geoscientists write less in popular journals. No popular books on the subject have been written since J. Tuzo Wilson's of the late 1950s and early 1970s, although another major work is reportedly on the way. Very few Canadian geoscientists have commented publicly on matters of national or international concern. Academic geoscientists have generally not taken advantage of the growing national dependence upon their work to make their profession and their views known to their fellow citizens.

- Some old established geology departments make excellent contacts with the public through their association and co-operation with museums. Toronto's association with the Royal Ontario Museum and McGill's with the Redpath are best known. Good relationships with museums are also known at Regina and Winnipeg. A few departments have done a splendid job with public exhibits within their own departments, e.g., Laval, Waterloo and Saskatchewan.

RECOMMENDATIONS

The Council has selected the following important recommendations and suggestions from those which the authors have included within the body of this report. They recommend that those addressed seek background material by reading appropriate parts of the pertinent chapters. They also endorse all the many recommendations within the report.

Council addresses the following groups:

Senior administrators of universities

(1) We suggest that faculty members, university administrators, and members of selection committees re-evaluate the roles of department heads of geology and geophysics departments and place high priority on proven management capabilities which will enable departments to meet the challenges of the 1980s. This includes the abilities to initiate or enhance co-operation and interaction with industrial concerns and government agencies.

(2) We recommend *that those geology departments which do not have a geophysicist on staff, or a geophysical teaching unit in the university, should attempt to remedy this serious deficiency at the time of their next professional appointment.*

(3) We also recommend *that these departments should introduce geophysics major and honours degrees, possibly in co-operation with physics departments and engineering faculties, following the lead of Queen's, Saskatchewan, Manitoba, Calgary, McGill and other geology departments that are now helping to meet an increasingly strong demand for exploration geophysicists.*

(4) We further recommend *that independent geophysics units and those associated with departments of physics should redouble their efforts to create teaching and research ties with geologists. In the case of Victoria, this would necessitate the hiring of professors of geology. Goals would be increased enrolment and broader training of students and redirection of some of the current research into more pragmatic channels, following the leads of Toronto and Ecole Polytechnique.*

(5) We ask administrators at Saskatchewan, Manitoba, Toronto, Carleton and New Brunswick take cognizance of the burgeoning state of geology and geophysics in this country and the importance it has assumed on their own campuses in terms of student enrolment and/or research activity. They should contrast this with the decrepit or the overcrowded facilities they provide and should take immediate stepts to remedy this long ignored anomaly.

(6) The cosmopolitan aspect of our geology departments deserves admiration -- 73 per cent of faculty members have received their higher degrees abroad. We note, however, that there has only been a net increase of one Canadian trained geoscientist per year for the past ten years and we urge search committees not to disregard the products of Canadian geology and geophysics departments when filling vacancies or new positions.

(7) External committees with revolving memberships including representatives of all three estates of geoscience regularly visit three Canadian departments of geology and report to senior administrators on their strenghts and weaknesses. We recommend this very successful practice to all other geoscience departments.

(8) To promote good teaching, to promote communication with the public, and to cut back pedestrian research, administrators should ensure that the university reward system does not unduly concentrate on research production. Excellence in several domains should be rewarded and clear guidelines established for its recognition.

(9) To promote interdisciplinary research, teaching and other interaction between departments, university administrators are urged to encourage joint appointments between separate departments of geology and geophysics and also with such departments as chemistry, geography, civil engineering, physics and biology. Faculty members involved in cross-appointments should be given some perks and rewards rather than being penalized as some now claim to be.

(10) We recommend *that departments consider the possibility of adding an extra year beyond their degree programs for professional training of geologists and geophysicists. Such a professional diploma program would permit broad training desirable at the baccalaureate level followed by the specialized instruction demanded by many employers and students.*

Heads and faculty members of geology and geophysics departments

Concerning undergraduate programs

(1) We recommend *that lectures and practical technical writing be introduced at all levels of undergraduate training, preferably in courses that require written reports, e.g. field school, and preferably by people who have demonstrated skills as scientific writers or editors.*

(2) Where geology and geophysics are taught in separate departments in the same university we recommend *that geology and geophysics departments co-operate more closely in their teaching and in the planning of their curricula. They should call on senior people from industry to aid and advise in such joint planning ventures.*

(3) We recommend *that those geology and geophysics departments in universities with engineering faculties which are not already offering degree courses through these faculties should make every effort to do so.*

(4) We further recommend *that geology and geophysics departments endeavour to establish work term programs in co-operation with industry, following the lead of Waterloo and Victoria. These could be implemented through existing engineering co-op programs or initiated through faculties of science.*

(5) We recommend *that all geology and geophysics departments regularly call upon scientists from government and industry to help plan and revise their undergraduate programs, and invite specialists from these domains to give series of lectures in appropriate courses following the example of several geology departments, e.g., Calgary and Toronto. Further, we advise that they widely advertise this external consultation as soon as it comes about.*

We repeat a recommendation made to senior administrators, namely:

(6) We recommend *that departments consider the possibility of adding an extra year beyond their degree programs for professional training of geologists and geophysicists. Such a professional diploma program would permit broad training desirable at the baccalaureate level followed by the specialized instruction demanded by many employers and students.*

Concerning postgraduate studies

(1) Students, employers and professors all state that thesis-based M.Sc. degree programs are excessively prolonged. All except a few professors feel the same way about the Ph.D. degree. We recommend that:

(a) *There should be stricter quality control of students admitted to graduate studies. Many students not inclined or suited to* *research could be diverted to postgraduate Diploma programs recommended above or to non-thesis M.Sc. programs*

(b) *Heads of departments should ensure that deadlines for degrees should be established at the outset of studies and reasonably adhered to, e.g., comprehensive exams and Ph.D. orals should not be repeatedly postponed as in many current practices.*

(2) Departments should encourage direct entry into Ph.D. studies instead of requiring a proving process at the M.Sc. level. Four years should be set as the common maximum duration of Ph.D. studies and those involved with complex problems encouraged to pursue them as postdoctoral scholars.

(3) Department heads should firmly guide inadequate researchers and inept supervisors away from direct supervision of graduate students even though such professors may be officially approved supervisors on the basis of past records.

(4) Faculty members, individually and collectively, should seek to impress upon management of petroleum and mining companies the importance of graduate studies to these industries and the true cost of supporting student research projects.

(5) Faculty members make special efforts to advise their best undergraduate students of the challenges of postgraduate work. Visiting distinguished lecturers should be asked to touch on the importance of advanced studies and special guests from industry and government should be invited to talk of the career advantages of postgraduate work.

Concerning communications and control

(1) We recommend *that those departments that do not invite student representatives to attend departmental meetings on a regular basis should make every attempt to do so.*

(2) We further recommend *that those departments which do not have an outside review committee should make every effort to establish such a committee and to arrange for it to visit at regular intervals.*

(3) We commend those departments of geology and geophysics who voluntarily practice one or several rigorous methods of internal and external assessment of their activities. We strongly recommend that others investigate the systems practiced in sister universities and consider their adoption as proven aids in the quest for excellence.

Concerning relationships with government

We recommend:

That government agencies and university departments examine the full range of the following useful practices now in existence and adopt some or all of those that might suit their circumstances. These include: appointing government scientists as adjunct professors and sessional lecturers; calling upon many of them to give appropriate individual lectures; attending lectures and seminars at each others establishments; involving professors when partially supporting their students' research; each inviting representatives of the other group to policy and planning meetings; discussion of new staff appointments and new facilities.

Concerning relationships with industry

We recommend:

(1) *University departments assign a principal liaison person to communicate with each of the industries (minerals, petroleum, engineering, etc.) where links would be beneficial in regard to employment, research and other matters. The persons chosen should be those faculty members whose interests lie closest to the industry concerned. This would be following successful examples already set by several universities, old and new.*

(2) *University departments should seek to involve more mineral exploration and petroleum geologists and geophysicists in lecturing, particularly in informal presentations of case histories.*

(3) *University departments should involve more mineral exploration and petroleum scientists, on a rotational basis, on advisory committees of many kinds. Benefits would accrue to both as each became more familiar with the other's methods of operation and ultimate goals.*

Concerning relationships with the public

We recommend:

(1) *University departments of geology and geophysics should upgrade their exhibits and displays (if necessary) and open them to the public on a regular basis, especially in the winter term. Where possible, this should be done in co-operation with the local museum. Several examples that bear emulation are cited in the text of this report.*

(2) *University geoscientists should appreciate the importance of communicating with other scientists and with the public through the news media, books and public lectures. Department heads should encourage those with the requisite talents to devote some significant part of their time to such pursuits.*

(3) *University geoscientists should appreciate the growing need for informed commentary on matters concerning resources, the environment and other important issues confronting the nation. They should not flinch from debate with other geoscientists providing the subject is treated objectively. They should aggressively seek out opportunities for themselves and their colleagues to contribute the viewpoints of geoscience to some of the major issues of our day.*

Concerning research

The Council notes an overemphasis on the importance of frontier research in many large and middle-sized departments of geology and geophysics, often to the detriment of other important activities. In many cases this has led those who have proved themselves incapable of first-class work, including former leaders who have lost their drive and zest, to continue with projects that are costly in time and money. We recommend that:

(1) *Those who are no longer excited by empirical studies should be encouraged to concentrate on the reflective inquiry[1] aspect of research rather than on the expensive frontier elements.*

(2) *Professors no longer active in any kind of research should be assigned larger roles in teaching or in communication with the public and should be given convincing evidence that they will by justly rewarded for capable performance in those roles.*

(3) *Good researchers should be recognized by a lessening of their undergraduate teaching loads if they request this. All should participate in some form of undergraduate teaching for it is important that beginning students be exposed to some of those working at the cutting edge of research.*

(4) *That those departments, particularly small departments, making new appointments should seriously consider departing from the normal practice of completing their rosters with full complements of the traditional subdisciplines of geology and geophysics. They should seek to appoint those capable of bridging major disciplines and opening up fresh new fields of research.*

(5) *That a completely laissez-faire attitude toward research in a department can be wasteful and nonproductive. It does not produce a focus that allows for the sharing of ideas, space, funds, equipment, and graduate students. Heads of departments should endeavour to build up units with similar interests and similar goals, using as models those departments that have become successful by using regional, disciplinary or other research focuses to build viable teams.*

(6) We commend NSERC for its imaginative new program of strategic research support and we urge geologists and geophysicists to combine with their colleagues in other disciplines to devise projects in the national interest which will merit funding through such strategic grants.

With increasing costs of field logistics it is vital that academic geoscientists explore all available methods of access to remote areas. We recommend that:

(7) *They impress upon government agencies and mineral and petroleum exploration companies the potential value of their research, and the importance of some freedom of field operations for themselves and their graduate students. They should seek to have a voice in the planning of major operations so that their projects are not unduly restricted by the sponsors' logistical demands.*

NSERC

Scholarships

We recommend *that NSERC set an example to other agencies by increasing their postgraduate scholarships by 50 per cent or more over 1978-79 values. Also, that their national awards committee seek out and publicize the reason(s) for the relatively few awards made in geology and geophysics.*

Research funding

Our Council applauds the increase in awards effective in 1980-81 which restores support of university research to 1969-70 levels. We also applaud the moves by NSERC to close the gaps between both total and per capita grants to the geosciences and those awarded to some other disciplines.

We recommend:

(1) *That the increase relative to other sciences be greatly accelerated to take cognizance of: (a) the vigorous activity underway in almost all subdisciplines of the geosciences; (b) the large enrolment of graduate students in the geosciences; (c) the measurable esteem which university geoscience commands around the world; and (d) the prevailing feeling at home and abroad that increased funding could produce excellence in several more subdisciplines of Canadian academic geoscience.*

Also that:

(2) *Cognizance be taken of the escalating costs of fieldwork in the geosciences, particularly transportation in remote areas. In the past, highest awards have been made to laboratory geoscientists - chiefly to support technicians and to maintain instruments. Field scientists have had to rely on logistical support from companies and government agencies. This usually restricts the scope of projects which must conform to demands of the sponsor's own logistics and virtually precludes major academic field projects.*

(3) We praise the continuing attempts of the Grants Selection Committee to continually be more selective in their awarding procedures. NSERC grants should be aimed at those engaged in first-class frontier research and those not capable of producing it should be eliminated from the system and encouraged to develop other pursuits or seek other sources of funds. We recommend that the Grants Selection Committee stiffen their selection process.

(4) We recommend *that the NSERC earth science grant selection committee, as part of their rotational visitation process, arrange meetings with senior officials of federal and provincial agencies to discuss rationalization of research support.*

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[1] As defined by Bonneau and Corry (1972) reflective inquiry is concerned with the synthesizing aspect of research whereas frontier research includes the empirical-analytical aspects. Many scientists, of course, combine both approaches.

(5) We commend the peer selection process practiced first at NRC and now at NSERC. The anonymity of external referees is an integral part of this system and we urge NSERC officials to continue to press for exemption of the scientific refereeing system from the regulations of the Canadian Human Rights Act.

Canadian Geoscience Council

Concerning secondary education

We recommend *that the Geoscience Council and its member societies initiate a campaign directed towards provincial Departments of Education to have earth sciences introduced into junior high school curricula as an introduction to later courses in biology, chemistry and physics.*

Concerning postgraduate studies

(1) The Canadian Geoscience Council should continue to make representation to elected members of Parliament and also should directly contact Immigration officials regarding the need of work permits for foreign graduate students and their spouses during a forecasted period of declining enrolment in geology and geophysics in our graduate schools at a time of critical national need.

(2) The Canadian Geoscience Council should send informed individuals or groups to talk with industrial policy-making bodies, such as the Canadian Petroleum Association and the Mining Association of Canada, on the importance of strong graduate schools of geology and geophysics to the mining and petroleum industries and the need for much greater industrial support of such schools.

(3) The Canadian Geoscience Council should discuss with Cabinet Ministers and senior civil servants methods to encourage research in applied geoscience by mining and petroleum companies based in Canada so that more of our graduating Ph.D.s can continue with fundamental studies instead of having to accept employment in operational or service roles. In the long term this would produce more refined and sophisticated exploration methods and would result in greater economic gains to the companies and the country.

(4) The Canadian Geoscience Council commends NSERC for its continuing policy of re-assessing the needs of the various disciplines but presse for a greater acceleration of the amounts awarded to the geosciences in keeping with rapidly growing national demands for terrain evaluation, environmental protection and in the exploration for and conservation of resources.

Scientific societies

Because those geoscience societies first established were specialist societies, and because academics belong chiefly to the general societies, membership of which represent only a small percentage of total geoscience population, Canada has developed disciplinary provincialism. The size and political divisions of our country has led to examples of geographic provincialism. We recommend:

(1) *That specialist societies, such as the Calgary-based petroleum societies, continue their splendid efforts to reach out into other parts of the country by working in close co-operation with local societies and with local sections and divisions of GAC and CIM.*

(2) *That local societies and sections of national societies, such as those in Winnipeg, Regina and Edmonton, should annually stage a meeting preferably centred on a university campus with the main objective being a tour of facilities and an explanation of activities of the local geophysics and geology department and the provincial geoscience agency.*

Council of heads of Canadian geoscience departments

(1) We recommend *that the Council of Chairmen continue to annually compile a list of bona fide undergraduate majors, honours and engineering students in geology and geophysics departments across the country and a list of graduates of these programs during the year under review. These lists should be forwarded annually to groups that regularly compile such data, e.g. the American Geological Institute and the Canadian Institute of Mining and Metallurgy. Individual department chairmen should be asked to refer to these lists when completing any questionnaires asking for such statistics.*

(2) The Council of Chairmen should continue to produce annually a report on national enrolment in graduate studies, degrees completed and postgraduate research projects underway. This report should be widely circulated and articles based upon it prepared for the Northern Miner, Oilweek and other widely read technical news magazines.

We repeat a recommendation addressed to our Geoscience Council, namely that:

(3) *The Council of Chairmen, possibly working under the aegis of the Canadian Geoscience Council, should formally approach groups such as the Canadian Petroleum Association and the Canadian Metal Mining Association to point out the value of research and graduate studies in geoscience to the resource industries. They should provide facts and figures concerning the relatively low level of funding from these industries and point out the advantages to be gained by increased support.*

(4) The Council of Chairmen of Earth Science Departments, in co-operation with national societies such as C.I.M., C.S.P.G., and C.S.E.G., should commission continuing series of short review articles in various journals and sponsor workshops at a variety of meetings to describe and explain research underway in universities across the country. Case histories should be given illustrating how basic research has produced fallout of practical concepts and techniques that could be immediately adopted by scientists in industry and government.

Government agencies

Concerning support of postgraduate work

(1) Government agencies and companies which sponsor projects used as theses should involve students' supervisors in the planning and field supervision of such theses.

(2) The commendable practice of some federal and provincial agencies of involving graduate students in their research projects should be expanded. This practice allows graduate students to serve apprenticeships for later permanent jobs with agencies. Expanding and broadening the practice could permit training in those specialized fields which presently require recruitment abroad.

Concerning joint facilities

We recommend *that provincial government geoscience agencies which plan to construct laboratories to service their own needs do so in conjunction with their local universities. As they grow in size and strength, these agencies should become more aware of their responsibilities to avoid duplication and to nurture a wider geoscience community both in the interests of their own mandates and to promote harmony and co-operation in the geosciences.*

Concerning relationships with university departments

These are generally good, but there are many possibilities for improvement and some examples where co-operation and collaboration are at a minimum. Personalities of heads or managers play very important roles in establishing or maintaining relationships. We recommend:

The government agencies and university departments examine the full range of the following useful practices now in existence and adopt some or all of those that might suit their circumstances. These include: appointing government scientists as adjunct professors and sessional lecturers and using them for individual lectures; attending lectures and seminars at each others establishments; involving professors when partially supporting their students' research; each inviting representatives of the other group to policy and planning meetings; discussion of new staff appointments and new facilities.

Concerning research

Increased transportation costs and other logistical expenses make it increasingly difficult for all members of the geoscience community to carry out major operations in remote places. The academic community, relying chiefly on grants-in-aid of research are hardest hit of all. We recommend that:

(1) *Academic researchers and their graduate students be invited to participate in major projects so that they can take advantage of transportation facilities and the lower costs of shared logistics. They should be invited to participate in planning at the earliest stages so that the operations may meet several individual and joint objectives.*

(2) *That other provincial agencies follow the successful Ontario example and provide grants-in-aid of applied research to academic geologists and geophysicists within their province, in addition to the traditional contracting out of specific projects.*

(3) *That the G.S.C. fulfill its mandate for the well-being of national geology by increasing its support of university research by contracts and by research agreements. It should strive continually to augment and complement NSERC awards in those fields that it favours.*

(4) *That EMR management appoint external reviewers to pass judgment on applications for research support following the example of the Ontario Ministry of Natural Resources and NSERC.*

Mineral and petroleum exploration companies

(1) We recommend *that industrial firms, through lectures, letters and other recruitment programs, encourage qualified students to become involved in postgraduate work before embarking on careers in industry. We suggest also that they consider deferred starting dates and interim financial aid while such deserving students complete post-graduate training.*

Although Canadian academic geoscience has a good name abroad for its close relationship to industry and for its research pertinent to exploration needs, we found remarkably little financial support from industry. We recommend that:

(2) *Company geoscientists familiarize themselves with current research activities across the country and endeavour to convince their principals that support of continuing programs of frontier research in applied geology and geophysics would be in the long-term interests of their companies. They should examine the model of research support recently established by Rio Tinto Canadian Exploration Ltd. (Riocanex).*

(3) *Senior company scientists invite appropriate professors to join their companies in operational or specialist roles for part sabbaticals or during summer breaks. This would enable professors to become more familiar with the training and research needs of industry.*

(4) *Senior company scientists endeavour to incorporate university field research projects into more of their major operations in remote places. By advertising the plans for such operations during their recruiting tours, they would permit professors and graduate students to submit proposals for logistical support in such regions.*

(5) *Senior petroleum geoscientists should encourage their colleagues to attend at least one GAC/MAC annual or sectional meeting per year outside of Calgary in order to exchange ideas with academic geoscientists from central and eastern parts of the country.*

A BRIEF CONCLUSION

Canada is well-served by its university departments of geology and geophysics. Enrolments in geology have increased and come close to meeting the steadily rising demands of the past five years. Those in geophysics have continued to fall short of demand but the increasing involvement of geology departments in the teaching of geophysics may soon remedy this. Departments remain under pressure to redesign curricula to suit the special needs of various employers. There is certainly need for much more communication in this area, but most professors deserve commendation for maintaining that they owe the students broad training, and a sense of the interrelationship of the sciences so that they will graduate as thinking people adaptable to any one of several forms of employment.

Graduate studies and research have flourished in the last decade although undernourished financially and in other ways. We have produced few superstars, but Canadian academic geoscience is recognized as world class in several subdisciplines. Most of these are directly or indirectly related to major problems of regional geology, resource development, and environmental conservation: all major elements of our national quality of life.

ACKNOWLEDGMENTS

By the Council

This study was undertaken by a committee that was appointed by Council and charged with describing and appraising the activities of our university geoscience departments. In the fall of 1979, almost a year after it was commenced, Council agreed to restrict the study to departments of geology and geophysics in order to ensure completion of the report within a reasonable time. Thanks are extended to the co-chairmen of the committee who served as authors of the report and to the members who designed questionnaires sent to mining and petroleum exploration companies, analyzed responses and participated in site visits to some of the departments involved in the study. The committee membership was as follows:

Co-Chairmen: J.E. Armstrong, Geological Survey of Canada, retired (Vancouver)
E.R.W. Neale, Geological Survey of Canada (Calgary)

Members: M.J. Keen, Geological Survey of Canada, (Halifax)
R.Y. Lamarche, Ministère des Richesse Naturelles (Québec)
Lloyd Clark, Saskatchewan Mineral Development Corporation, (Saskatoon)
P.L. Money, Texasgulf Incorporated, (Toronto)
P.J. Savage, Pan Canadian Petroleum Ltd., (Calgary)

Financial support to permit travel and other expenses came from special grants by the Geological Survey of Canada and the National Science and Engineering Research Council.

The companies employing three of the committee members also donated their travel expenses.

Many Council members read and criticized drafts of the various chapters of the report. Finally, the Council joins committee members and authors in thanking the faculty members of 40 of the departments of geology and geophysics and approximately 20 other geoscience departments for their full and open co-operation in welcoming visiting committee members to their campuses, talking to them by telephone and in person on many occasions and filling in countless questionnaires. Their reward is a very complete report and, we hope, a series of helpful, thought-provoking recommendations.

Submitted for publication by the 1979 Executive

C.R. Barnes - President
A. Sutherland Brown - Vice-President
K.A. Morgan - Secretary-Treasurer
R. Ericson - Committee Member
G. Roberts - Executive Director

August 1980

By the authors

Our thanks are due to our colleagues on this committee for their perception and penetrating questions during site visits and to them and members past and present of the Canadian Geoscience Council for reading and commenting on several drafts of this manuscript. In addition, we received helpful comments and suggestions for rephrasing of parts of chapters from colleagues in the Geological Survey of Canada and many friends in universities and in industry. We accept full responsibility for the completed manuscript, however, as time constraints did not permit circulation of all revised portions to critical readers.

Typing and corrections of many drafts were shared by cheerful volunteers who included Pat Greener, Hilde King, Jamie Gaetz, Linda In't Veld and Lynn Machan. Lynn also proofed and assembled the final manuscript.

Processing, arrangements for translation, word-processing, layout and publication were handled by Dr. R.G. Blackadar, Director, Geological Information Division, Geological Survey of Canada.

We are most grateful to them for their patience and many kindnesses.

Many distinguished geologists in other countries were contacted to gain their impression of Canadian status in both their pertinent subdiscipline and across the whole Geoscience spectrum. Their views are liberally quoted in Chapters 5 and 7, some anomalously (where requested) and others above their names. These views from abroad add important dimension to the report for which the authors are most grateful.

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2. FACULTY AND FACILITIES IN GEOLOGY AND GEOPHYSICS

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

--Henry Ward Beecher, Life Thoughts

INTRODUCTION

Teaching and research in geology and geophysics are carried out in 40 separate departments or other units devoted wholly to one or both of these subjects. These are located in 34 of Canada's 53 degree-granting universities. Other departments in these universities and in some of the other 19 universities also carry out some teaching and research that could be classified as geology or geophysics. Our report is mainly concerned with the 40 groups whose mandates are in geology and geophysics. In this chapter we shall explain how they developed, who works in them and what they are required to do, the extent of their physical facilities, how the operations are managed and assessed, and some of the extraneous influences upon them. In subsequent chapters we shall examine and assess, in sequence, the main products of these departments: undergraduate training, postgraduate studies and research; their relationship with other departments, with industry, government and the general public and, throughout, we shall make suggestions and recommendations designed to enhance the contribution of university geology and geophysics to Canada.

DEVELOPMENT OF GEOLOGY AND GEOPHYSICS IN UNIVERSITIES

The following brief account is taken chiefly from Stearn (1968) supplemented by information from Garland (1968) and Blais et al. (1971) and brought up to date by the present study. It covers only the establishment of departments and undergraduate and graduate teaching within them. A brief history of research activity is deferred until Chapter Five.

Geology departments

"The first regular lectures in mineralogy were given at the Seminaire de Québec (forerunner of Laval University) by Abbé Jean Holmes in 1822. After Laval was founded lectures in geology were given by T. Sterry Hunt beginning in 1860. Despite this early start Laval did not have a full-time professor of Geology until 1923. Toronto can claim the first Canadian department of geology. It was founded in 1853 by E.J. Chapman who continued to teach there for 42 years. J.W. Dawson began teaching geology at McGill when he became principal in 1855. However, the Logan Chair of Geology at McGill was not established until 1871. Geology was taught at Dalhousie in 1865 and Rev. D. Honeyman was appointed professor in 1879. It was taught at Acadia beginning in 1866 although an independent professorship was not established until 1913. Ecole Polytechnique was established in 1873 and lectures in geology were given by C. A. Pfister. The first geologist appointed to the faculty was Joseph Obalski in 1885.

Queen's began the teaching geology about 1876. Other universities started later: University of Manitoba in 1904, McMaster in 1909, at Alberta in 1912, and U.B.C. in 1914. By 1920, thirteen universities in Canada offered programs of study in departments of geology. By 1960 this had increased to 22 and then there was a rapid rise to the 30 departments reported by Blais et al. (1971) in their 1968 study. Only three departments have been established in the last 12 years, those in the Université de Québec at Montreal and Chicoutimi and that in the University of Regina.

Twenty of Canada's geology departments now offer a doctorate program and 28 give masters degrees. The 33 departments exist under a variety of names:

Departments of Geology (or Geologie)	20
Departments of Geological Sciences	6
Departments of Earth Science	4
Department of Land Resource Science	1
Department of Geology and Geophysics	1
Département de Génie Minéral	1

They also range greatly in size of staff:

5 have 5 or less staff
9 have 6 to 10
8 have 11 to 15
6 have 16 to 20
5 have 20 or more

Basic information on staff and enrolment of all 33 universities is given in Table 2.1.

The Canadian universities did not become involved in postgraduate studies until around the turn of the century - Toronto awarded its first Ph.D. degrees in 1900 and one was earned by the distinguished paleontologist, W. A. Parks. McGill awarded its first M.A. in geology in 1901 but did not confer a doctorate in this subject until 1924. Most of the other universities awarded M.A. or M.Sc. degrees after 1920 but doctorates in geology came much later: the first at Queen's in 1943, 1952 at Laval, 1956 at British Columbia, 1960 at Manitoba, and 1966 at Western Ontario. Until the 1960s most Canadian students went abroad for higher degrees, chiefly to the best known U.S. schools, or enrolled at McGill or Toronto. Slowly this trend has changed so that now very few go abroad and some of Canada's largest geology graduate schools are in universities that were not established in 1960."

Geophysics departments

Theoretical geophysics was probably taught in one guise or another in physics departments in the early part of the century. However, the recognized starting point was in 1928 when A.S. Eve at McGill and Lachlan Gilchrist at Toronto began research in their respective physics departments on methods of geophysical prospecting. From this beginning university research moved from the applied to the theoretical where its main thrust has since remained. However, the location of instruction in geophysics remained chiefly in physics departments (Garland, 1968) until very recent times. Thus, there are now seven groups in Canada associated with physics departments that offer B.Sc., M.Sc. and Ph.D. degrees in geophysics. Four of these are divisions within physics (Memorial, Toronto, Alberta and Victoria) and three are independent - the Department of Geophysics at Western Ontario, the Department of Geophysics and Astronomy at British Columbia and the Department of Earth and Environmental Science at York. These are the chief research schools in geophysics and, as pointed out by Blais et al. (1971), they tend to concentrate on physics of the Earth rather than exploration geophysics and most of them do not produce many B.Sc. graduates.

In recent years several geology departments have added one or two geophysicists to their staffs and now graduate honours and majors in geophysics with a strong geological background. Industry's endorsement of this trend may be seen in the recent sponsorship of a Chair of Geophysics in Calgary's Department of Geology and Geophysics.

However, as in 1968 (Blais et al., 1971), half of our universities with geology departments do not have a single geophysicist on staff.

The geology/geophysics relationship

We have pointed out that Canadian university geology and geophysics developed differently than in many other countries due to the early and continued association of geophysics with departments of physics. Relationships have improved over the years (Garland, 1967) aided recently by the appointments of geophysicists as heads of geology departments and by a newly created division of our national geological association. Nonetheless, half of our geology departments have no person on staff capable of teaching geophysics; our separate and independent geophysical groups produce too few graduates to satisfy the long continued demands of industry; and research in applied geophysics is carried out in only a few centers despite the long known requirement (Blais et al., 1971) for greatly increased activity in this field.

We recommend *that those geology departments which do not have a geophysicist on staff, or a geophysicist teaching unit in the university, should attempt to remedy this serious deficiency at the time of their next professional appointment.*

We also recommend *that these departments should introduce geophysics major and honours degrees, possibly in cooperation with physics departments and engineering faculties, following the lead of Saskatchewan, Manitoba, Calgary, Queen's, Ecole Polytechnique, McGill and other geology departments that are now helping to meet an increasingly strong demand for exploration geophysicists.*

We further recommend *that independent geophysics departments and those associated with departments of physics should redouble their efforts to create teaching and research ties with geology departments. Goals would be increased enrolment of students and the direction of some of their current research into more pragmatic channels, following the leads of Toronto and Ecole Polytechnique.*

FACULTY MEMBERS

Who and how many?

There were 456 academics teaching geology and geophysics in Canada in 1979-80 with the rank of assistant professor or higher. This compares with 319 (278 geologists and 41 geophysicists) reported by Blais et al. (1971) in 1968. This 43 per cent increase in teaching staff has been accompanied by a 65 per cent increase in postgraduate students and a doubling of undergraduate majors. Geology and geophysics professors represent 1.8 per cent of the 25 660 faculty members in our universities, slightly less than they did in 1968. The relative loss as a percentage of the whole is due to the enormous growth of the social sciences, business administration and similar programs. By holding its own, geology and geophysics have gained relative to the other science departments most of which have been in a static growth position for over 10 years.

The average faculty member is very male - we know of only eight females among the 456 full-time faculty members. They are located at Dalhousie, Acadia, New Brunswick, Ecole Polytechnique, Queen's, McGill, Waterloo and Regina. The average age in 1979 was 43.4 in the 25 departments which responded to our questionnaire on this subject (Table 2.2). This compares with an average age of 40.7 in 1974 and of about 37.5 in 1968 (Blais et al., 1971). Our professors as a group are growing older but not as fast as in most other science departments. Only one department, the fast growing group at Waterloo, shows a decrease in average age over the past five years but several others have remained fairly stable. Some departments, e.g. McMaster which had one of the lowest average ages in 1968 now has one of the highest, an example of a fate that could befall those departments which expanded rapidly for a brief period and then ceased growth abruptly. Fortunately at least half the geology and geophysics departments exhibit a wide age spread, due to slow steady growth, so that retirements and young replacements should retard the departmental "aging" that afflicts several other disciplines.

The man-years of full-time experience of faculty members in government and industry is shown in Table 2.3. At Ecole Polytechnique, this represents 32 per cent of the faculty's experience, at Toronto 21 per cent, at Memorial 19 per cent, at British Columbia in Geology 16 per cent. In some departments the outside experience is spread fairly evenly between several faculty members, others (e.g. Toronto and Memorial) have at least one faculty member who joined in mid-career with nearly 20 years of industrial experience behind him. Most department respondents stressed that in addition to their full-time experience several of their professors had worked during many summer breaks with government agencies or industrial concerns. These figures should be of interest to industry respondents, many of whom regretted the seeming lack of outside experience among university professors. Paradoxically, the one department whose members admit to no full-time experience with industry or government, British Columbia's Department of Geophysics and Astronomy, produces graduates in geophysics who are highly rated by the oil undustry! (see Chapter 3).

Although academic experience in industry and government is more extensive than most respondents realized, there is ample room for improvement. One way to effect this would be to instigate term exchanges between senior academics and their counterparts in industry and government. This could be particularly useful to those departments in static growth positions as it would bring in new faces and new approaches. Council recommends that:

Department heads and individual professors investigate the possibility of exchanges for varying lenghts of time with appropriate counterparts in mining and petroleum companies and within government agencies.

Almost all faculty members in Canadian Geology and Geophysics departments hold doctorate degrees. The two to three per cent who do not hold this qualification are chiefly older people whose appointments predated this requirement, specialists (e.g. in mineral deposits geology), or young faculty members in the final stages of their doctoral dissertations. Until the 1960s most Canadian geoscientists went to Toronto, McGill or U.S.A. universities for their advanced training. The rapid expansion of university departments in the 1960s brought in an influx of professors trained outside the country, chiefly in the U.K. Their influences are reflected in Appendix 2A wherein we list the universities where Canadian academics received their doctorates. Twenty-seven per cent of geologists came from Canadian departments (half of these from Toronto and McGill), 33 per cent from U.S. departments, 26 per cent from U.K. departments, and 12 per cent from elsewhere in the world (with the Australian National University the largest producer). In 1968 (Blais et al., 1971), 67 per cent of geology professors had received their highest degree outside the country, this had increased to 73 per cent in 1978-79. Six of the eight heads of Atlantic geology departments were trained abroad as were 7 of the 11 heads of Ontario departments and all of the heads of the departments in Saskatchewan and Alberta. Many of those who received their advanced training in Canada were born abroad and many of those trained abroad were born in Canada. We applaud this healthy mixture. With the great burgeoning of postgraduate training in Canada, however, we find it strange that more of the products have not found their way back to our academic institutions. Council recommends that:

Geology department heads and search committees do not overlook those who have received their doctorates from Canadian universities when seeking additions to their faculties.

Of the 77 geophysicists in our universities (including those in Geology departments), 61 per cent received their doctorates in Canada (chiefly at Toronto and British Columbia, 17 per cent from U.S. departments, and 22 per cent from elsewhere (chiefly U.K.). In 1968 (Blais et al., 1971), 49 per cent of academic geophysicists held doctorates from foreign schools compared to only 39 percent in 1978-79. Geophysicists obviously rate the home-trained product higher than do their geological colleagues.

Our schools of geology and geophysics are remarkably cosmopolitan if we can judge by the origin of faculty doctorates and also by the origin of their first degrees (Appendix 2A). It is surprising that some of the foreign commentators regretted what they saw as our growing tendency to become ingrown and inbred. This prompted an examination of the seven campuses of the University of California where we found that only 25 of a faculty of 187 had received their doctorates from outside the U.S.A. Let others worry about recessive genes becoming dominant - our Canadian geology and geophysics departments are healthy hybrids indeed!

What do they do?

Faculty members in geology and geophysics departments do much more than the average outsider suspects. They teach, usually at both undergraduate and graduate levels, almost all of them carry out research and publish the results in technical and scholarly journals, they serve on committees within the university, they are involved with scientific societies and associations at the local, national and international level, they edit journals, write textbooks and consult for industry and government.

Teaching

This involves all faculty members to various extents. Most schools, especially those where the faculty are unionized, have settled on four term courses (i.e. two full year courses) of undergraduate teaching as an average load. Depending on whether the courses involve two or three lectures and a two hour or a three hour laboratory, this can comprise anywhere from eight to twelve contact hours per week. Usually it is closer to the latter. However, teaching contact hours vary widely from this average. Field trips, which often take place on the long weekends, and field schools, generally scheduled between terms, also make heavy demands on the time of some faculty members. Some departments, e.g. Laval and Waterloo, look at a faculty member's overall load and apportion his teaching accordingly. Thus a professor with little research or graduate student involvement might teach six or more term courses to undergraduates whereas a prominent researcher in the same department might teach only two term courses. More often than not teaching assignments are more haphazard and willing workers may find themselves with 15 or more contact hours despite a heavy involvement in research and graduate studies. In some of the universities with high student:faculty ratios there is no alternative to averages of 5 or 5.5 term courses per faculty member.

Teaching geology or geophysics majors is only part of the story. Most departments schedule special courses for non-majors in subjects such as general geology, environmental geology and earth history. Several professors stated that introducing large classes of non-majors to the geosciences and creating an awareness of the Earth and its limitations to future leaders in many walks of life was probably the most important function they performed. Special service courses for engineering students are common: usually mandatory for civil or mining engineering students and optional for other specialities. At some universities, e.g. Saskatchewan and Queen's geology courses are mandatory for all of the engineering students. In those universities where the geophysicists are part of or closely allied with physics departments (e.g. British Columbia, Toronto, Alberta, Memorial) the geophysics professors teach service courses in physics. In several universities, geology professors have joint appointments in other departments e.g. at Waterloo in biology, geography and civil engineering.

Using the formula of two hours preparation for each contact hour, professors are involved anywhere from 18 to 45 or more hours per week with teaching duties during terms. Surprisingly almost none of them have had any instruction whatsoever in teaching methods, elocution, debating or any other form of oral communication. Undergraduates and graduates at almost every school we visited had comments about the quality of teaching of some of their professors--it is only surprising that there were not more complaints. The reason is probably that relatively small classes generally prevail beyond first year in the sciences and a lecturer may be forgiven for not being particularly articulate providing he or she is enthusiastic, prepared, orderly, and promotes and is receptive to informal discussion. If the lecturer has few or none of these qualities, the undergraduates can complain singly or jointly to the department head or register their criticisms through a class evaluation form, now common at many universities. Undergraduates mentioned that those professors who receive very high ratings for their teaching may receive 'Master Teacher Awards.' Those who receive very low ratings, however, seem to carry on from year to year with no sign of improvement!

Very few department heads are bold and brave enough to visit classrooms unannounced to evaluate a lecturer's performance and to discuss shortcomings. The Head of Geology and Geophysics at University of Calgary follows this procedure. At Universitié de Montréal it is a university-wide practice that the head and other senior members of the department monitor the classroom performance of junior faculty members.

This seems to us to be a very sensible procedure--giving junior faculty members possibly the only constructive criticism of their teaching that they will receive throughout their careers. We recommend it to other departments of geology and geophysics.

Research

Most university geology and geophysics professors carry out research. About 72 per cent of the 456 received NSERC grants in aid of their research in 1978-79. Many of the others who did not qualify or did not apply to NSERC, received grants in aid of research from other federal and provincial agencies and, to a lesser extent, from mining and petroleum companies.

There is little doubt, in all but a few small departments dedicated to teaching, that most academic staff are hired almost solely on the basis of their research records or their research potential. Most professors interviewed stated that it was essential to remain active in research in order to instruct competently at the graduate and senior undergraduate levels. Despite this, at various places across the country, individuals who produced little or no publishable research were identified as outstanding teachers of undergraduates at all levels.

One major complaint of productive researchers at many schools across the country was the fact that no recognition was given to the time required for good research. Despite outside opinion to the contrary, in many Canadian universities research is something you do when you're finished all the other jobs you are supposed to do. In most departments there is no remission of teaching and other duties for leading researchers--Laval, Waterloo, Memorial and Toronto are among the exceptions in this regard. Some department heads cheerfully said that their leading researchers were their activists, "live wires" or whatever as they also taught the best and the most courses and were leaders in other activities. Their rewards, if any, were accelerated promotions and peer recognition. Leading researchers, when questioned, stated that money was generally adequate--their main worry in life was finding the time for the projects they had embarked on.

With a few good examples around the country of excellent undergraduate teachers who do not publish research papers, Bonneau and Corry (1972) are right when they state that frontier research activity is not necessarily a prerequisite to being a capable undergraduate teacher. Maybe some of those who are devoting long hours to rather pedestrian efforts on mundane topics should be encouraged to spend those hours giving more lectures and keeping up with the literature. Those who are identified as being at the peak of their research productivity, could then be allowed some respite from undergraduate teaching, but not complete remission of teaching for it is important that undergraduates be brought into regular contact with leading researchers. A description and analysis of university research is given in Chapter Five.

Other duties

Universities, almost by definition, are much less hierarchical than industry and government. This means that most university professors, including junior people, find themselves invovled with committees at the departmental, faculty and university levels. Some of these committees, dealing with student affairs, can be very time consuming throughout the entire year. Others, dealing with tenure promotion and space allotments can be very pressing for short periods. In addition to the permanent committee structure, there are *ad hoc* committees struck by Senates and Faculty Councils to probe urgent matters of the moment. Faculties in older universities have learned to live with the painful fact that up to 15 per cent of their time might be consumed in some such duties. A few of the newer schools, e.g. Waterloo and Memorial, temporarily escaped enmeshment in management by committee but it is increasing. Others, such as the University of Calgary, were apparently immersed at the outset. There is a price to pay for academic freedom and democratic procedures and it is paid in hours.

Senior administrators of universities generally consider the organization and well-being of the sciences as part of their mandate. Whereas government and industry might give their people the time and money to attend conferences, partly in the hopes of immediate benefits through the exchanges, universities actually encourage such participation and credit it to the scholarly contribution of the participants. The result is that many local, national and international meetings are held on university campuses, and secretariats of national and international associations, unions and co-ordinating committees are set up in departments of geology and geophysics. Our national geological association and the Council sponsoring this report both have their homes rent-free in the university that supplies their volunteer executive directors. Half a dozen international geoscience journals and several national publications have editorial offices in our universities. In addition, professors may be called upon as advisers and resource people by secondary school educators and as commentators on energy and natural disaster problems by the news media.

These and other aspects of geology and geophysics professors' relationships to the community are mentioned further in Chapter 7.

Consulting

Many faculty members consult sporadically for industry or government agencies. Most universities have rules regulating the time professors can encumber, ranging from one to two months per year, and the money they may earn. In some cases, earnings beyond a certain modest amount must be turned over to the university and administered in much the same manner as a NSERC research grant or a government contract. There are, however, few attempts to enforce such rules and we learned that some faculty members consulted regularly to augment their incomes. A few, in fact, have thriving businesses that cannot help but distract from their teaching duties and research activities.

Some professors claim that consulting is essential in certain fields, e.g. engineering, mineral deposits geology and applied geophysics, in order to remain au courant in their fields and in order to make the contacts that could lead to graduate student support. Some company and government respondents, particularly in Quebec and parts of the West, regretted the excessive amount of consulting by some individuals at the expense of other, more pertinent activities.

Our visiting committees did not pursue the topic in sufficient depth to determine what proportion of consulting activity was genuinely related to research and what to routine services. Nor were we able to determine whether or not consulting work interfered with the legitimate activities and overall performance of many or even any departments.

We did note that university administrators were generally aware of and often proud of their professors' participation in special outside committees and their roles as consultants to commissions or judicial inquiries on resource policy and similar subjects. Administrators and department heads however, did appear remarkably sensitive about or ill-informed on the amount and nature of routine consultation for industry in which their academic colleagues were involved.

We recommend *that department heads and senior administrators keep themselves fully informed concerning the external consulting activities of professors so that they can curtail such activities when they are obviously interfering with teaching, research and other legitimate activities of geology and geophysics departments.*

Hiring and terms of employment

Openings in Canadian universities are usually widely advertised in national and international journals such as *Nature* and *Science*, in national newsletters and, by widely accepted general agreement, in the academic monthly *University Affairs*. In addition, deans and department heads commonly write many people within and outside universities, soliciting applications. Applicants who are short listed are generally brought in for interviews at which time they also present lectures on their specialities. Other things being roughly equal most department heads admit to judging candidates on their research records or potential and how it will integrate with research currently underway in the department.

Appointments are made generally at or near the bottom of the assistant professor scale to candidates with a few years of postdoctoral experience but, in some cases, to newly graduated Ph.D.s. In the boom years of the 60s many appointments were made at senior levels in order to attract experienced people from government or other universities. In the past year we know of only three geology appointments at senior levels, presumably due to tightening of university budgets and concerns about the high average ages in some departments.

Tenure

Tenure or appointment "without term" is granted following the term of a provisional appointment. Tenure means that the conditions of a teacher's employment shall not be unilaterally modified to his disadvantage and that the appointment shall not be terminated wihout cause. It is a jealously guarded prerogative of academics, guaranteeing their academic freedom to teach and search for what they regard as basic truths. Initial appointments are for short terms, and two or three years is common. Later contracts may be longer or of the same duration after which the candidate may be considered for permanent appointment, i.e. tenure. After receiving tenure a candidate may only be dismissed for cause (although in these days of financial restraint lack of funds may be cited as a cause!). During the 1960s when the universities were desperately seeking qualified people, tenure was often granted after only three years of satisfactory service. In senior positions it was granted upon appointment of after the first year of service. Now it is hard won. Although rules vary from place to place, those at McGill University as cited by the Head of the Department of Geological Sciences represent a good example, possibly tougher than average:

> "Tenure is only attained after some 10 years, specifically at the end of the first five-year contract as associate professor. Tenure is recommended by a faculty committee chaired by the Dean but largely composed of members of other faculties. The criteria are 'superior' performance in two of the activities of teaching, research and 'contributions to the university'. The research aspect is based on reports from three referees external to the university. The candidate's department contributes through preparation of a report by the Chairman with the help of an elected committee."

Promotion

The promotion from assistant to associate professor became almost automatic in the 1960s, in some schools at the end of the first, satisfactory three year contract, seldom after more than five years. A six years up-or-out procedure is now more common, much as practiced in some of the larger U.S. Ivy League schools two generations ago. Committees, usually involving other science departments but sometimes also other faculties, make the decisions on promotion to associate professor, which can be the lifetime working level at an increasing number of universities.

Promotion to full professor is becoming increasingly difficult. In the 1960s and early 1970s it too was virtually automatic, especially in the newer universities. In the last few years, however, it has again become a well-earned honour. Some of the old, well established schools make no bones about it now being a reward for very distinguished research as assessed by external reviewers. Others state that it requires proven excellence in any one of research, teaching, and community or university service but admit that research is the most easily measured of these. Scanning the records and questioning department heads about the young scientists who have received accelerated promotion to full professorships shows that in every case, that in geology and geophysics, it is in recognition of outstanding research. You can move up to the top in other ways but the paths are slower and less sure.

Unionization

Approximately one half of the universities are organized. This permits the faculty to bargain with the administration for salaries and terms of employment. The other universities have faculty associations which negotiate with senior administration regarding salaries and, in some places, terms of employment. In other nonunionized universities terms of employment might be decided by Senate which includes faculty and administrative representation. Several nonunion university respondents noted that although they negotiated, i.e. talked, with the president and his advisers about salaries, the decision was his and they were never sure if their representations had had much if any impact.

As outsiders we were unable to assess the effects of unionization. Unionized departments seemed to have just as many inequities and just as wide a spread in teaching loads as others. Those with unions claimed to have better salaries than they would otherwise have had; this is probably true in Quebec universities, all of which are unionized except McGill. On the other hand we encountered one Maritime university where morale was very low because union management negotiations had broken down repeatedly and faculty had been without a contract for two years.

Salaries

These vary greatly from one university to another, even within the same province, and from one department to another within a single university. Large universities generally pay higher average salaries for any given rank than small universities. Far western universities, those is Quebec and the larger Ontario universities pay well above the national average; those in the Atlantic region well below the average. Average salaries for all three professorial ranks for 1979-80 in some representative Canadian universities are shown in Table 2.3. Due to ages, the prestige of the faculty members and many imponderables, the average salaries in a geology or geophysics department may be well above or well below the average shown for the university. Two large and very well known geology departments in 1979-80 did not have a single professor earning over $36 000; in contrast, this was the overall average salary in some other geology and geophysics departments where many individuals earned over $40 000.

Opportunities for accelerated promotion are sometimes better in the smaller and lower paid universities so that bright young faculty members may temporarily move ahead faster than in the large, old established institutions. However, salaries in the lower ranks are open-ended in some universities and the bright, young, newly promoted full professor might find that his income never catches up with the slower older person frozen in an associate rank who regularly receives the annual cost of living increment which seems to have replaced merit raises at most universities.

Generally, junior faculty members are parid less than their counterparts in government and much less than those in industry. Middle ranks and the average senior professor is paid about the same as government equivalents but somewhat less than in industry. Those few very distinguished, mature scholars who have stayed with the rocks rather than moving into administrative roles receive very similar remuneration from all three types of employers.

We heard very few complaints about salaries during our visits to universities. Faculty members were generally much more concerned about grants in aid of research, their needs for technical support, obsolescence of equipment declining enrolments of graduate students. Also, we encountered several young people who had declined or left much higher paying jobs to embark on faculty careers. We conclude that financial reward is not the prime motivation of our professors of geology and geophysics!

SUPPORT STAFF

The situation has changed radically from 25 years ago when the average department had a secretary and one or, in rare cases, two technicians to grind rock sections, project slides and do odd jobs. This situation now applies in only a few of the smallest departments. In many of the larger geology departments the combined support staff is equal or almost equal to the number of faculty members. In some geophysics departments the support staff is twice (British Columbia) or even three times (Alberta) that of the academic staff. The total of technicians, research assistants and research associates is shown in column 2 and administrative support in column 3 of our departmental data survey (Table 2.1).

Administrative support in the larger departments commonly includes an administrative officer, a chief departmental secretary and junior secretaries and clerks, some of whom are trained operators of sophisticated word-processing machines. In medium-sized departments the senior secretary or the chief technician may fill the role of administrative officer, handling departmental finances and purchasing and serving as a manager or spokesman for the nonteaching staff.

Technicians traditionally take care of tasks such as photography, drafting, lapidary work and displays. In some departments highly trained technicians also look after the costly, highly specialized equipment such as scanning electron microscopes, microprobes, mass spectrometers and X-ray fluorescent analyzers. The chief technicians in such departments are generally graduates in science as are some of their assistants. Even so, individual pieces of expensive, sophisticated equipment are usually under the direct surveillance of a faculty member and the technical staff operate and repair it under his or her direction. In other departments, the major equipment is operated by research assistants or research associates. These people range from newly graduated scientists to people with advanced degrees who are considered equivalent to junior faculty and commonly share authorship of research papers with their professorial colleagues.

Technicians range from highly skilled tradesmen to very competent professionals and their salaries in some schools range well into the assistant professor levels. Research assistants (R.A.) are initially hired at the minimum prevailing rate for graduates, research associates usually have assistant professor status, salary and privileges. All this is expensive and explains why universities, during the current financial constraints, do not always welcome a new piece of equipment unless a grant to support its operation accompanies it. Most professors of geophysics, geochemistry, petrology and mineralogy spent some or most of their NSERC and other grants on support of technicians or assistants to operate instruments and equipment. Such assistance is also required by paleontologists, biostratigraphers, and others although their needs are often overlooked because they do not require expensive instruments in their laboratories. The recent enormous increases in wages combined with reluctance of skilled tradesmen and professionals to accept the insecurity of a grant-supported job on a year to year basis makes it increasingly difficult to attract competent and dedicated technical and professional assistants. The result is inadequate maintenance and a great deal of "down-time" for expensive and important equipment and decreased productivity for university scientists. Recent announcements from NSERC suggest that this and other growing problems of university research have finally been recognized by government. We discuss this in Chapter 5.

BUILDINGS AND EQUIPMENT

University geology and geophysics departments were traditionally housed in the basements of the oldest and shabbiest buildings on campus, possibly because they worked with dirty rocks or maybe it was considered warranted by the outdoor wardrobes many of them affected in the classroom and at faculty meetings. Some, like Saskatchewan or Manitoba, remain in quarters which must have been substandard 30 or 40 years ago. Others, such as the geology departments at British Columbia, Memorial, Queen's, Calgary and Waterloo are in handsome new buildings (or parts of buildings) specifically designed for the needs of their earthy inhabitants. Most lie somewhere in between these extremes.

In Table 2.1. we list information that was supplied on the floor space available to some departments. A simple comparison of total faculty, students and technicians in relation to area tells some of the story, thus geology at Alberta is obviously very cramped for space while at Brock it obviously is not. This is not the whole story, however. Thus, New Brunswick would seem to be very well endowed for a medium sized department but it really isn't as the building is ancient and not easily adaptable to geology's current needs. Toronto also suffers from an ancient building on its main campus. Dalhousie's space is barely adequate in terms of faculty and enrolment but less than adequate when we consider than they are split between two widely separated quarters.

From our own visits and views expressed by faculty members we feel we can rate 36 of the 40 departments as follows:

- 6 have good to outstanding space and furnishings
- 18 have adequate space and furnishings
- 7 have barely adequate space and furnishings
- 5 have inadequate space and furnishings

We recommend *that administrators at the universites of Saskatchewan, Manitoba, Concordia, New Brunswick and Dalhousie take cognizance of the burgeoning state of geology and geophysics in this country and the importance it has assumed on their own campuses in terms of student enrolment and research activity. They should contrast this with the inadequate facilities they provide and should take immediate steps to remedy this long ignored anomaly.*

Library facilities

Undergraduate training normally requires only a good selection of reference texts and subscriptions to the better known national and international periodicals. Graduate students and research-oriented faculty members require a large collection of books and back numbers of journals, often rather rare and specialized journals. They also require current subscriptions to a large number of geoscience and related journals. Until recently the library systems in most older, large and medium sized Canadian universities adequately supplied these needs; newer and smaller universities could do so less promptly through interuniversity loans. Recently, with declining university funds and incredible escalation in the prices of books and scientific journals, libraries are cutting back drastically on purchases and subscription lists and many professors fear they will be inadequately served in the near future.

Most of the larger geology and geophysics groups have a departmental reference or reading room or, in some places, a library within their premises. That at Queen's is the third largest geoscience library in Canada (after two Geological Survey of Canada libraries) and it is operated as a branch plant by the main university library. Other excellent departmental libraries are found at Calgary and British Columbia. Facilities range from these impressive, well-stocked shelves to small, crowded reading rooms which consist chiefly of donations of journals and texts from faculty members supplemented by a display of current journal numbers circulated by the main campus library. Most faculty members feel that it is essential to have a collection of some kind within the department, no matter how humble, as it is the most effective way of introducing undergraduates to the literature--by example and through convenience.

Industrial concerns could scarcely find better ways to support and encourage geoscience departments than by endowing such departmental facilities and contributing regularly to their support. The Gallagher Library in Calgary's Department of Geology and Geophysics is an excellent example of a first rate departmental facility developed through generosity of a donor and (reluctant?) co-operation from the main campus library.

We recommend *that both the petroleum and mining exploration industries realize their responsibilities to the institutions that provide their professional manpower (and bear the brunt of their criticisms!) by contributing funds to endow chairs and to equip laboratories and departmental libraries. The fruits of such generosity can be seen at British Columbia, Queen's, and Calgary and serve as an encouragement to spread such largesse more widely and more often.*

Equipment

The amount and sophistication of equipment varies greatly in departments across the country. This variation is related to the size of the departments, their research needs and the effectiveness of their importuning of granting agencies and the administrators of their individual universities.

Small departments, such as that at Mount Allison, have very little equipment more complex than petrographic microscopes. Other small departments such as Acadia and Brandon have simple analytical facilities (e.g. X-ray diffraction, atomic absorption) to satisfy the research requirements of one or two faculty members and graduate students. However, these faculty members may rely in part on facilities at nearby universities. Some medium sized schools, for example Saskatchewan, with current research strengh in paleontology, biostratigraphy and sedimentology, have less expensive analytical equipment than schools of equivalent size, such as Carleton, or McGill with a long time research bias towards geochemistry and petrology.

The largest and oldest established schools, particularly those with powerful geophysical research teams such as Toronto, Alberta and British Columbia have the most expensive instrumentation which has been built up and patched up over many years. When we realize that some have as many as half a dozen mass spectrographs in operating condition--almost equal in number to Mount Allison's microscopes--we gain some idea of the range in university research facilities. In Appendix 2B, we list major equipment holdings of a few representative universities in order to convey some idea of the range of research facilities.

Major equipment has chiefly been purchased directly by the universities. To a lesser, but important extent, it has come through NSERC major equipments grants. In recent years NSERC committees have commonly sought university committments to share capital costs and to guarantee adequate technical support before making a major equipment grant. In several departments across the country expensive equipment is ill-used or under-used, and this includes a few cases where the purchases were made with peer-awarded NSERC funds. Even such committees are occasionally vulnerable to grantsmanship!

We know of a few cases where departments have acquired equipment on hire-purchase, with university backing, and paid for it by devoting one or more shifts to industrial and government contract work. Memorial and Regina have done this successfully. There are also a few cases of industry donating major equipment. British Columbia and Queen's have both benefited from mineral industry gifts. Departments of geophysics are commonly the beneficiaries of gifts of slightly out-moded equipment donated by oil companies.

There are stories of leading scientists in some other countries who draw on research equipment a thousand miles from their own universities in order to carry out their work. On our tour we heard stories of graduate students who had been sent abroad to use special instrumentation because this was easier to arrange than working through a Canadian facility. We recommend that:

The Council of Chairmen of Canadian Earth Science Departments perform a valuable service by tri-annually listing the equipment available in our departments of geology and geophysics and by devising methods to facilitate exchanges in its use.

Two final points: (1) equipment wears out faster if it is not properly maintained and (2) equipment becomes obsolete. Following the boom years, cuts in university and NSERC funding have left most university departments short of adequate technical assistants and, because of this, "down time" on expensive major laboratory facilities is increasing in many departments. Obsolescence has also taken its toll, e.g. although the early model microprobe at Saskatchewan is still probably a useful teaching device, it would be more efficient and less expensive for professors at that institution to travel to other centres to carry out research requiring microprobe analysis. Just as the earth sciences became most exciting our funds were cut-back (Strangway, 1976) and those who relied on major equipment and skilled technicians were among the first to suffer. As we conclude this report (spring 1980), the Minister of Science and Technology has announced federal recognition of and remedies for this situation. We recommend:

That provincial agencies also interest themselves in this matter and set up and maintain laboratories in nearby universities, through grants or contracts, which will satisfy their needs for analyses and isotopic dates while at the same time providing the universities with research and teaching facilities. Some success in such co-operation has been reported from Newfoundland, Ontario, Saskatchewan and British Columbia. As provincial agencies grow in size and power, perhaps it is now time that they extend themselves beyond token pilot projects and build bridges to the university community through the establishment of major joint laboratory facilities.

MANAGEMENT

Geology and geophysics departments have a great deal of autonomy, much more than exists in scientific groups of similar size outside of the universities. Keen (1979) has referred to university departments as "...democratic collectivities...on the whole, semi-autonomous fiefdoms, and the relationship between departments is perhaps one of sovereignty association."

The department heads or chairmen (no Canadian geoscience department has yet had a female in this position) can be very powerful people. Democratic collectivities can be led into common projects for the common weal and even the most outrageous prima donnas can be shown the advantages of co-operation or at least channelled into pursuits that do not upset the creative activities of their colleagues. The importance of a department head can be seen in several examples across the country. Departments with low morale, no clearly defined goals and poor reputations among employers have had their images completely refurbished within a year or two after the appointment of a new, dynamic head. The reverse is also true although deterioration is slower and less noticeable than is the sudden marked improvement in performance.

The methods of choosing department heads seems to vary greatly across the country but there may be one common thread--selection committees do not generally rate management highest on their list of desirable criteria. Selection processes include: (1) a decision by a vice-president or dean after consultation (hopefully!) with members of the department; (2) a decision by members of the department which is relayed to senior administrations for rubber-stamping; (3) a decision by a formally constituted committee which includes a senior administrator and members of outside departments. The first two methods can cause either unhappiness by an unpopular appointment or continued mediocrity by an appointment designed not to rock the boat. The third method is most satisfactory except that (particularly when they search outside the university) there is a strong tendency to fasten upon a person of great academic distinction regardless of other qualities. Presumably, if very good at managing personal research interests, a person should readily adapt to wider managerial responsibilities. In a surprisingly large number of cases this has worked out well but there have also been some notoriously poor performances. Assuming management of a department does not mean giving up all one's research interests but it does mean subjugating some of these to the interests of students and faculty members in the department. A large part of the head's reward must come from pride in the accomplishments of his colleagues rather than in his own performance but not everyone can derive joy from the accomplishments of others.

In a perceptive paper, Keen (1979) has pointed out some of the duties and challenges facing the manager of a geology or geophysics department. He points out that this person should see that the Department is clearly aware of its mission. If this includes good teaching or good research or both, then it requires monitoring of departmental activities and support of those that contribute to the overall goals and containment of those that are detrimental to them. In the interests of good teaching it might mean restriction of enrolment even though the administration encourages a higher head count and it might mean restraining bright young faculty members (and those not so young) who want to introduce additional high powered specialist courses to lure the undergraduates even farther away from the basics. It might also mean sitting in on lectures, checking over lists of assignments and then telling a colleague that he or she has to improve or else. . . . . . In the interests of good research it might mean ensuring that a brilliant creative colleague's work is not impaired by petty jealousies of others and their resulting obstructions. It could involve removing another brilliant colleague from the mismanagement of a research facility even though he or she acquired the initial purchase funds.

Few of the faculty members we talked with across the country had any appreciation of these challenges, several spoke with a mixture of pity and scorn of those on their own and other campuses who had sacrificed their research to take on a term as head. The terms of appointment are also not always conducive to accepting the challenges outlined by Keen (1979). In some departments the chairmanship is rotated regularly so that an incumbent has no great incentive to arouse the wrath of his colleagues by checking on their performances during his short term in office. Also, in some cases, very junior people are rotated into the chairmanship, in several universities with no financial rewards for assuming this position of command. These people would be foolish indeed to take more than the minimum time away from their research or to risk offending senior colleagues by introducing any radical innovations. In other departments, heads are appointed for three-year renewable terms. If they are unpleased or unpleasing they can ease out or be gracefully removed at the end of the first term, if satisfactory they can be renewed until they have achieved some of the goals they have established for the department.

One other point deserves mention. Two of the most successful heads of geology departments in the past 10 years were geophysicists, brought in from other departments of their respective universities. In addition to good management, they hastened breakdowns of the barriers between geology and geophysics in their schools. Recently other geophysicists have been appointed as a heads. Possibly some of our independent geophysics groups across the country should seek outstanding geological leaders.

In conclusion, we recommend renewable term appointments of heads to those departments that don't practice this system.

We recommend that faculty members, university administrators, and members of selection committees re-evaluate the roles of department heads of geology and geophysics departments and place high priority on proven management capabilities which will enable their heads to meet the challenges of the 1980s. This includes abilities to initiate or enhance cooperation and interaction with industrial concerns and government agencies in many aspects of teaching and research.

ASSESSMENTS AND OTHER INFLUENCES ON PERFORMANCE

How do geology and geophysics departments assess their own performances or have their performances assessed by others? Presumably senior administrators rate them relative to other departments but on what data base? Student course questionnaires are now common but how effective are they? How useful are external committees, do they just intensify problems by gathering up the dirty laundry and washing it in public? We asked these questions of administrators, faculty and students wherever we encountered them and present here a summary of our findings.

Student assessments

Most courses with fairly large enrolments are now evaluated by students, usually by completing questionnaires. In some places these questionnaires go no further than the professor in charge of the course and, possibly, the department head. In others, hold-overs from the 1960s, they are prepared and administered and the results published by student societies and, in yet others, they are handled by university administrators with or without student participation. Faculty members admit that these are useful methods of identifying poor delivery and organization of some courses and lack of interest by some lecturers. However, they claim that students in introductory courses in particular, are often hoodwinked by lecturers who entertain rather than teach and who curry favourable reports through easy marking of exams. Faculty also point out that student criticism of course content is seldom valuable as it is often heavily influenced by experience gained in summer jobs and lacking in awareness that their education is designed to give them some breadth and flexibility. Students complain that little action is taken to effect improvements in lecturers who are identified year after year as inadequate. At least some university administrators stated that they found student evaluations very useful in identifying and rewarding good lecturers.

The role of senior administrators

In our visits to universities we had the opportunity to meet with senior administrators including three presidents, several vice presidents and many varied and assorted deans. Obviously in those places where department heads made a point of introducing us to their senior administrators, personal relationships between them were good. Despite this, we were rather surprised that in several cases these people did not seem to be fully aware of recent exciting developments in the geosciences nor of the sustained high enrolment that had prevailed across the country since the energy crisis of the mid 1970s. Some senior administrators told us that although they realized that their chemistry and physics departments were temporarily in the doldrums and that geology was temporarily experiencing a surge in enrolments and research activity, the first two still received the lion's share of the university budget because "it would be difficult and unwise to upset this balance too precipitously". Change is slow in some universities!

We wondered if the former specialities of senior administrators had any influence on the accelerated development of some departments, especially as there are so very few geoscientists in the upper echelons of university administration. Several deans told us stories of their counterparts elsewhere who, in the past, pushed their own disciplines to excess or, in a few cases, retarded the growth of geology departments because geology wasn't "hard science". Only two very senior people would admit to any prejudicial judgments themselves. Both admitted that they felt that strength in geology and geophysics was essential to rational development of our country and that they favoured and supported these disciplines unashamedly. Departments at these schools show abundant evidence of having benefited by this blessing from above. Neither of these mandarins was a geoscientist.

We conclude that university geologists and geophysicists should ensure that at least some members of the hierarchy are well-disposed towards their discipline and, more important, that they are kept well informed of developments in the local geoscience department.

External review committees

Faculties of science or engineering in some universities bring in scientists from outside to review, either all at once or in progression, the programs and status of their component departments. Geology and/or geophysics departments at British Columbia, Alberta, Saskatchewan, Brock and New Brunswick and geophysics at Memorial have recently been subject to such reviews. These visiting committees commonly report to the appropriate dean or to the vice-president (academic) after a two or three day visit and a great deal of background reading. During visits they generally talk with representative groups of undergraduate and graduate students, faculty members, heads of related departments and, on occasion, people in local industry and government agencies. These committees are usually able to make perceptive observations and strong recommendations, many of which seem to be implemented within a reasonable time following the visit. The members of such committees receive travel expenses and, in some cases, honoraria for their work. The pity is that such visitations are *ad hoc* affairs and there is no guarantee that the department will ever again be visited to appraise improvements or to modify earlier suggestions.

Several universities, e.g. Laval and Calgary, have formal committees of local visitors from industry and government who appear once a year for a show-and-tell event, interested questions and, maybe, a good dinner. This is an excellent way to inform the local geoscience community of current activities and the state of the physical plant. It is, however, a case of best foot forward and the visitors never come in contact with the workings and problems of departmental minds! Such committees are not sufficiently informed to recognize, analyze or advise the department on its operation. However, they serve important roles in communication and understanding.

At three-year intervals, each university geology and geophysics department is visited by a team form the NSERC Earth Sciences Grants Sub-Committee. These scientists from universities and industry interview those who hold NSERC research grants, those who are applying, and any other faculty member who wishes to discuss policy procedure. They also inspect equipment and facilities and, if warranted, talk to senior administrators. In the course of their three year voluntary tours of duty, members of this subcommittee become familiar with a wide spectrum of university research in geoscience from their visits, and from reading confidential referee reports. Unfortunately their NSERC reports are confidential and much valuable information is withheld from university people who could benefit from it. We recommend that such reports should be made available on a confidential basis to deans and departments heads at some time during the calendar year in which they are produced.

Those departments in which some of the degrees are taken through Engineering faculties receive periodic visits of teams from the Accreditation Board of the Canadian Council of Professional Engineers. These teams investigate course content and other aspects of curriculum and decide whether or not the training meets minimum standards of the Board.

Still rare are those assessments by external committees who operate like those first described but who visit on a regular basis, at one or two-year intervals, and who keep in touch with the department and with senior administration during the interim period. There are only three such committees - those which visit the geology departments at Queen's and Memorial and both geology and geophysics at Toronto. At Queen's the geological visitors are part of an engineering advisory board that meets annually. At the other two the committees were independently set up at the request of the geology departments and report to the deans of science. Administrators at these universities state that the regular visits of such committees and their frank, unvarnished appraisals give them confidence in the operation of their geology departments. Department heads state that these committees introduce fresh new ideas into their programs, act as safety valves which defuse potentially explosive situations, and generally carry a great deal of weight in their constructive recommendations to senior administration. So far as we can ascertain, the scientists from industry, government and universities who serve on such committees do so without recompense for their time, in fact in some cases their employers cheerfully volunteer to assume their travel expenses. They seem to enjoy the experience and feel honoured to have been invited to serve a university community.

All forms of assessment are helpful providing, as Keen (1979) states, that they are not carried to excess. We like the combination of student course evaluation and a regular visit by an external committee at two year intervals. These, combined with confidential copies of NSERC assessments should keep faculty members alert and aware and should provide senior administration with some hard facts and objective opinions on which to base their evaluations of departmental performance.

We commend those departments of geology and geophysics who voluntarily practise one or several rigorous methods of internal and external assessment of their activities. We strongly recommend that others investigate the systems practised in sister universities and consider their adoption as proven aid in the quest for excellence.

THE SMALL UNIVERSITIES

Small is beautiful

Five well-known small universities which have geology departments deserve special mention. Four are in the Maritime provinces: St. Francis Xavier, St. Mary's, Acadia and Mount Allison. The other, Brandon, is in Manitoba. All five were originally church-affiliated colleges and some vestiges of religious ties remain although all now are publically funded universities. Four have faculties of only three or four, small enrolments and no postgraduate programs. The fifth, Acadia, differs from the others in its large undergraduate enrolment (Table 2.1) and its involvment in graduate studies.

Research is not emphasized at these institutions. In some, the most successful and admired geology professors have devoted themselves to teaching, reading and community activities. Nevertheless, most keep active in useful scientific investigations, supported by companies or government agencies. Some of these schools have at least one vigorous researcher on staff, supported by NSERC and building up a national reputation. These researchers commonly share equipment and work in co-operation with colleagues at nearby large universities or with provincial agencies.

Small faculties make it difficult to teach competently a wide range of courses. Professors have to instruct in fields far removed from their specialities and may not always be able to impart the sense of excitement and discovery desirable at the senior level. For this reason, industry does not generally accord top ratings to the newly graduated geologists from these schools. Also, those accepted for postgraduate training elsewhere often have to make up many deficiencies in their undergraduate backgrounds.

Nonetheless, many of Canada's scientific and managerial leaders in the geosciences have graduated from these small departments the number being quite out of proportion to their size. In part, this may be because they attract students for other reasons than geographic convenience. Students choose these schools because of family or religious ties, because of recommendations by alumni or because they wish to avoid large cities or large institutions. This could mean a higher percentage of bright students than the norm. For such reasons, and because of the personal attention possible in small departments or even the air of serenity and confidence exuded from the ivy covered walls, these departments have survived many attempts to weld them into single provincial superdepartments in modern steel and glass surroundings.

Branch plants

Other small, semi-autonomous geology departments, not separately listed in Table 2.1, are attached to the branch campuses of universities. Some are one person efforts such as those at Memorial's Cornerbrook campus or the College of Cape Breton in Sydney (which is loosely affiliated with Saint Francis Xavier). Slightly larger are the departments at Toronto's Scarborough or New Brunswick's St. John campuses with about three faculty members. Most of these departments offer only the first two years of instruction. Faculty members at some carry out highly regarded, NSERC-sponsored research and supervise graduate students in co-operation with colleagues at the main campus. These campuses have been chiefly designed for the convenience of students from the local areas.

UNIVERSITIES WITHOUT GEOLOGY DEPARTMENTS

Several of the newer universities, e.g. Trent, Lethbridge, Simon Fraser and Victoria have chosen not to establish geology departments. All have geography departments which include physical geographers among the faculty members. Victoria also has two geophysicists within its physics department and offers postgraduate degrees in geophysics. Simon Fraser includes at least one geologically trained palynologist in its biology department.

The decision not to establish geology departments in some universities is understandable. Good cases can be made for questioning the existence of many of the independent geology departments in Ontario and Nova Scotia. The decision not to hire bona fide geologists to teach basic courses to undergraduates and to advise graduate students in certain fields is much harder to understand. Despite physical geographers' overlaps of interest and their competence to instruct in some spheres of geology, it is still inconceivable that a modern university would not offer some of the basic courses in geology so necessary for understanding of Earth resources and their conservation. This is particularly true in the case of Victoria where students receive postgraduate degrees in geophysics and whose B.Sc. graduates in physics commonly seek employment as geophysicists in the petroleum industry. Other aspects of this problem are covered in Chapter 6. Meanwhile Council recommends:

That senior administrators in those universities which do not have geology departments ensure that competent, broadly based geologists are appointed to appropriate departments such as Geography or Physics to provide instruction and to carry out research related to local needs.

CONCLUSIONS AND RECOMMENDATIONS

Geology and geophysics have grown greatly in strength on campuses across the nation since they were last examined twelve years ago. Only a few new departments have come into being but many of the existing ones have bloomed in this period, acquiring new equipment and facilities and, overall, increasing their faculties by 40 per cent. Departments that were small and virtually unheard of in 1968 are now among the largest and most innovative in Canada. Undergraduate enrolment doubled in the early 1970s and has remained high, encouraged by continually increasing demands from industry. On many campuses, geology departments now have the largest single groups of science majors. Research has blossomed and, as we shall see in later chapters, in several fields Canadian schools rank among the best in the world. Although NSERC grants have not kept up with inflation in recent years, several departments and individuals have successfully sought financial support elsewhere. Our status among the sciences has grown and has regained some of the emminence it held in the last century as the skills of geologists and geophysicists become increasingly necessary to help the nation solve some of the most important problems of the age.

Even more could be accomplished by greater interaction between our major subdisciplines, better management of our departments, more support from other elements of the geoscience community, and the sensible use of effective evaluation techniques.

TABLE 2.1

1979-80 DATA SURVEY OF CANADIAN UNIVERSITY GEOLOGY AND GEOPHYSICS

UNIVERSITY AND DEPARTMENT	STAFF			UNDERGRADUATES								GRADUATE STUDENTS			PDF	SPACE
				SCIENCE				ENGINEERING								m^2 (ft^2) in addition to common lecture rooms
	Profs	Techs (T) Res. As. (RA)	Admin.	2nd	3rd	4th	Tot	2nd	3rd	4th	Tot	Msc	PhD	Tot		
ACADIA (geol.)	5	1T 0.25RA	1		74		74					11	-	11	-	969m^2 (10,430)
ALBERTA (geol.)	20	14.5T 1RA	7.6	30	28	25	88					32	13	45	2	3753m^2 (40,400)
ALBERTA (geophys.)	10	17T 9RA	3	6p	5p	5p	16p					7p	11p	18p	2	1082m^2 (11,650)
BRANDON (geol.)	3	1T	1	6	9	3	18					-	-	-	-	1161m^2 (12,500)
BRITISH COLUMBIA (geol.)	23	16.5T 4RA	7.5	43	37	37	117	21	22	16	59	35	12	47	2	3345m^2 (36,000)
BRITISH COLUMBIA (geophys.)	8	8T 2RA	5	15p	19p	12p	46p		1p	2p	3p	11p	6p	17p	-	1911m^2 (20,570)
BROCK (geol.)	9	2T	2	21	14	13	48					7	-	7		2960m^2 (27,500)
CALGARY (geol. & geophys.)	23	10T 1RA	5	63 7p	67 12p	44 8p	174 27p					17 4p	12 1p	29 5p	4	4274m^2 (45,950)
CARLETON (geol.)	16	9T 2RA	3	30	22	27	79					22	19	41	-	2322m^2 (24,850)
CONCORDIA (geol.)	7	-	2	28	14	14	56					-	-	-	-	854m^2 (9,200)
DALHOUSIE (geol. & geophys.)	12.5	8T 2RA	3	28	20	20	65 3p					11 4p	8 2p	19 6p	2	1488m^2 (16,140)
ECOLE POLYTECH. (geol. & geophys.)	14	12T 7RA	5	-	-	-	-	48	14	17	80	18 1p	11 1p	29 2p	3	?
GUELPH (geol.)	3	1T	5	3	3	3	9					4	1	5		?
LAKEHEAD (geol.)	7.5	3T	1	10	18	11	39					5	-	5		682m^2 (7,340)
LAURENTIAN (geol.)	8.5	2T	2	5	4	10	19					20	-	20		1765m^2 (19,000)
LAVAL (geol.)	13	5T 2RA	4		43		43				123	25	8	33		1783m^2 (19,196)
MANITOBA (geol. & geophys.)	15	9T 1RA	3	19 2p	45 2p	4 1p	68 5p	18	23	11	52	29 5p	8 4p	37 9p		2420m^2 (26,500)
MCGILL (geol. & geophys.)	15	5T	3	31 5p	18 3p	11 3p	60 11p					35	13	48		3251m^2 (35,000)
MCMASTER (geol.)	13	7T 3RA	5.5	25	20	18	63					20	16	36	3.5	2937m^2 (31,600)
MEMORIAL (geol.)	20	5T 7RA	4	38	20	24	82					21	15	36	3	2657m^2 (28,600)
MEMORIAL (geophys.)	6	?	?		1p	5p	6p					4p	-	4p		?
MONTRÉAL (geol.)	12	5T 1RA	5	43	26	17	86					11	9	20		3391m^2 (36,500)
MOUNT ALLISON (geol.)	4	1T	1	5	7	6	18					-	-	-	-	985m^2 (10,600)
NEW BRUNSWICK (geol.)	12	6.5T	3	4	10	17	32					16 1p	9 1p	25 2p		3252m^2 (35,000)

TABLE 2.1 (cont'd)

UNIVERSITY AND DEPARTMENT	STAFF			UNDERGRADUATES								GRADUATE STUDENTS			PDF	SPACE
				SCIENCE				ENGINEERING								m² (ft²) in addition to common lecture rooms
	Profs	Techs (T) Res. As. (RA)	Admin.	2nd	3rd	4th	Tot	2nd	3rd	4th	Tot	Msc	PhD	Tot		
OTTAWA (geol.)	10	5T 1RA	3	26	13	7	46					12	11	23		1214m² (13,180)
*QUE.-CHICOUTIMI (geol.)	9	?	?	-	-	-	-	19?	20?	18?	57?	17?	-	17?	?	?
QUE. MONTREAL (geol.)	11	8T	2	?	?	?	147					13	-	13		1204m² (13,000)
QUEEN'S (geol.)	19.5	8T	5	40 1p	38 1p	19 1p	97 3p	30 14p	18 6p	9 4p	57 24p	45	21	66		4125m² (45,370)
REGINA (geol.)	7	5T	1	6	7	3	16						11	-	11	706m² (7,600)
ST. FRANCIS XAVIER (geol.)	3	1T	0.5	6	7	7	20					-	-	-		?
ST. MARY'S (geol.)	4	1T 2RA	1	12	9	10	31									587m² (6,350)
SASKATCHEWAN (geol. & geophys.)	16	9T 3RA	2	28	14 2p	16 3p	58 5p	10	8 4p	11 5p	29 9p	19 2p	9	28 2p		1650m² (17,750)
TORONTO (geol.)	28	21.5T 3.5RA	10	73	20	27	120	29	31	26	86	39 3p	25 4p	64 7p	9	?
TORONTO (geophys.)	9	5T	?	10p	2p	2p	14p					12p	8p	20		?
VICTORIA (geophys.)	4	?	?	Not identified as undergrad majors								1p	1p	2p		279m² (3,000)
WATERLOO (geol.)	21	19T 4RA	5	53	66	29	148					45	8	53		2880m² (31,000)
WESTERN ONT. (geol.)	14	14T 2RA	3	25	20	10	55					17	33	50		2384m² (25,670)
WESTERN ONT. (geophys.)	7	4.5T	1	7p	11p	6p	24p					4p	3p	7p	1.5	836m² (9,000)
WINDSOR (geol.)	10	5T 3RA	2	18	10	13	41	11	5	3	19	17	-	17		1314m² (14,140)
YORK (environ. sci.)	4	?	?		43p		43p					3p	3p	6p		?
TOTAL							2017 203 2220				562g 36p 598			836g 107p 943		

[1] Academics (profs) listed include cross appointments but not adjunct professors.
[2] Enrolments provided by Department heads except for *Que.-Chicoutimi where it is estimated from 1978 C.I.M. figures.
[3] Memorial's 5th year Honours Science is included with 4th year; Ecole Polytechniques 1st year Engineering is included with 2nd year.
p = geophysics

TABLE 2.2

AVERAGE AGE AND MAN-YEARS OF OUTSIDE EXPERIENCE OF SOME UNIVERSITY GEOSCIENTISTS

UNIVERSITY DEPARTMENT	AVERAGE AGE 1974	AVERAGE AGE 1979	TOTAL MAN-YEARS EXPERIENCE GOV'T	TOTAL MAN-YEARS EXPERIENCE INDUSTRY	TOTAL PER STAFF MEMBER
Geology, Alberta	40.0	43.0	12 (0.6)	24 (1.2)	1.8
Geophysics, Alberta	40.0	45.0	15 (1.5)	10 (1.0)	2.5
Geology, British Columbia	42.1	45.5	24 (1.0)	47 (2.1)	3.1
Geophysics, British Columbia	39.1	43.7	-- (0.0)	-- (0.0)	0.0
Geology & Geophysics, Calgary	40.5	41.8	10 (0.5)	25 (1.2)	1.7
Geology, Carleton	43.0	48.0	25 (1.6)	22 (1.3)	2.9
Geology, Brock	41.5	44.3	32 (3.5)	1 (0.2)	3.7
Geology & Geophys., Ecole Polytech.	39.5	45.0	34 (2.1)	42 (2.6)	4.7
Geology, Laval	41.0	45.0	32 (2.5)	17 (1.0)	3.5
Geology, Memorial	39.5	41.0	20 (1.0)	30 (1.5)	2.5
Geology, Manitoba	43.6	46.0	28 (1.9)	27 (1.8)	3.7
Geology, Montreal	42.0	43.5	16 (1.3)	-- (0.0)	1.3
Geology, McGill	42.0	44.7	11 (0.8)	21 (1.3)	2.1
Geology, Mount Allison	47.5	52.5	1 (0.2)	15 (3.8)	4.0
Geology, McMaster	41.0	46.0	4 (0.3)	1 (0.1)	0.4
Geology, New Brunswick	39.0	43.0	17 (1.4)	15 (1.3)	2.7
Geology, Ottawa	39.0	43.5	26 (2.6)	6 (0.6)	3.2
Geology, Queen's	40.6	42.8	21 (1.0)	29 (1.4)	2.4
Geology, Regina	39.6	41.4	37 (5.3)	13 (1.8)	7.1
Geology, Saskatchewan	40.3	43.5	17.5 (1.1)	57 (3.6)	4.7
Geology & Geophys., Toronto	40.2	42.3	33 (0.8)	47 (1.7)	2.5
Earth Sciences, Waterloo	39.4	37.8	26 (1.4)	10 (0.3)	1.7
Geology, Western Ontario	41.5	46.2	-- (0.0)	26 (1.9)	1.9
Geophysics, Western Ontario	44.0	49.0	-- (0.0)	10 (1.4)	1.4

TABLE 2.3

AVERAGE SALARIES AT SOME CANADIAN UNIVERSITIES IN 79-80

UNIVERSITY (and total faculty members)	Average Full Prof.	Average Assoc. Prof.	Average Ass't Prof.	Average All Ranks
Memorial (660)	35,836	27,919	22,600	27,478
Acadia (191)	34,083	26,105	20,813	25,439
Mount Allison (131)	35,140	27,161	21,159	26,862
*McGill	44,825	32,704	24,818	---?
*Other Quebec universities	42,985	34,923	27,962	---?
Ottawa (734)	43,320	32,726	26,302	32,527
Queens (696)	40,898	30,226	24,318	32,822
Toronto (1592)	40,808	31,016	22,278	32,146
Waterloo (734)	42,266	32,857	24,434	34,358
Western Ontario (899)	40,918	30,781	23,855	31,196
McMaster (572)	40,513	31,215	23,863	33,465
Brock (217)	38,416	29,084	23,748	29,021
Laurentian (254)	38,971	30,361	25,003	27,910
Regina (339)	38,123	30,509	23,644	30,479
Alberta (1354)	42,939	31,434	23,634	34,688
Calgary (848)	42,880	31,449	23,566	33,935
British Columbia (1395)	42,585	32,825	26,890	33,965

Data from Statistics Canada, 1979 (Average salaries include those with administrative duties, e.g. department heads and deans; excluding medical/dental faculty).

*Salaries not available, calculated from 1977-78 figures by a faculty member at a Quebec university

3. UNDERGRADUATE INSTRUCTION

T'is education forms the common mind:
Just as the twig is bent the tree's inclined.
Alexander Pope, Moral Essays

INTRODUCTION

Training of undergraduates is obviously one of the most important functions of our geology and geophysics departments. Many outside of the academic world and some within it state that it is the single most important function and all other activities should be subjugated to this role. Regardless of whether this is so or, as some faculty members state, it shares its importance with research and graduate studies, teaching of undergraduates is becoming increasingly demanding of time and effort. With minor fluctuations (Fig. 1.1) enrolment has increased steadily over the past 12 years and is now twice that in 1968 (Blais et al., 1971).

Our study has tried to determine what motivated students to study geology and geophysics, what they are taught, their own views and their professors' views on their training and the appraisals of those who hire them. To get answers to these and other questions we studied calendars, queried faculty members and students in person, and asked heads of geoscience departments and representatives of industry and government to respond to questionnaires.

Our findings have shown a rich diversity of programs and varying standards of rigor and concentration in universities across the country which could suggest that Canadian students have an enviably wide choice of approaches to their first degrees. But, it has also shown that most students attend the universities which are physically closest to their homes and that most are completely unaware of the programs offered in geology and geophysics until at least the beginning of their second year of studies.

We have also found that there is some agreement between students and employers on shortcomings in present university training. Some of these criticisms have the ring of truth about them, others are founded on ignorance of the university's role. Together they point to the need for some revision of programs and increased communication with employers.

ENROLMENT

The increase in enrolment in geology and geophysics since 1968 has been accompanied by a decrease in numbers in some other sciences, notably chemistry and physics. The result is that on most campuses geology departments are now either the largest science departments or are second only to biology or psychology in undergraduate (and graduate) enrolment.

Our inquiries have shown that there were 2606 geology and geophysics major and honours students in our science and engineering faculties in 1978-79 and 2818 in 1979-80. During 1979 convocations, 485 geologists and 36 geophysicists received science degrees and 112 geologists and 14 geophysicists received engineering degrees. The total, 597 geologists and 50 geophysicists, is slightly below the graduating classes of the last few years, representing a small drop in 1st year enrolment in 1975 (Fig. 1.1). These figures differ from those reported by other agencies. With one exception we feel that they are valid as they were double checked with department heads. The erroneous statistics published in some journals and by government agencies can seriously impede analysis and forecasting.

We recommend *that the Council of Chairmen of Earth Science Departments of Canada annually compile a list of bona fide undergraduate majors, honours and engineering students in geology and geophysics departments across the country and a list of graduates of these programs during the year under review. These lists should be forwarded annually to groups that regularly compile such data, e.g. the American Geological Institute and the Canadian Institute of Mining Metallurgy. Individual department chairmen should be asked to refer to these lists when completing questionnaires asking for such statistics.*

Tables 2.1 and 3.1 show the enrolment of most departments that teach geology and geophysics. Five of the eight largest undergraduate departments were also in that group in 1968 (Blais et al., 1971). They are Toronto (Geology, 206), Calgary (201), Queen's (181), British Columbia (176) and Manitoba (125). Three (McGill, McMaster and Alberta) have recently been displaced by Laval (166), Waterloo (148) and Québec à Montréal (147). The average of the eight largest was then 80, in 1979-80 it was 170 students. The ratio of majors to staff then averaged 5.2, now it averages 8.8 among the eight largest departments. The national student major:staff ratio is now 6.2. Probably more significant is the enormous range in student:staff ratios. Acadia is the highest at 14.8, followed closely by Québec à Montréal with 13.4 and Laval with 12.7. At the other end of the scale are University of New Brunswick at 2.6, Regina and Laurentian at 2.2. Several large, successful schools with ratios between 7.0 and 9.0 admit to being pressed for facilities and for the time that staff should devote to other essential endeavours. Some have curtailed enrolment for that reason. This problem must be more serious and student instruction must be in jeopardy when the ratios are far above that. On the other hand, geology departments with ratios well below the national average should ask themselves why they are not attracting more students at this time of buoyancy and high employment in geology and geophysics.

We recommend *that Acadia and Laval universities, with student: staff ratios twice the national average, should press for additional staff in the light of this statistic or, failing that, should seriously consider curtailing enrolment of majors and honours in geology and geophysics.*

Geophysics teaching units generally have much lower student:staff ratios than do geology departments. The most populated department is at the University of British Columbia where the ratio of majors to faculty is 6:1. At the other end of the scale are the Universtiy of Alberta at 1.6:1, University of Toronto at 1.5:1 and Memorial at 1:1. It should be remembered, however, that geophysics student:staff ratios are high in schools such as University of Saskatchewan and University of Calgary where geophysics majors, honours and engineering students are taught within the geology departments. Also that professors of geophysics in the specialist departments, such as Toronto and Alberta, commonly teach regular courses in physics in addition to their involvement with geophysics majors. Nonetheless, three well-staffed geophysical units associated with physics departments have remarkably low undergraduate:faculty ratios. In each case they are in universities with fairly large geology enrolments which makes one wonder why more of the joint geophysics/geology graduates prized by industry are not produced.

We recommend *that the Geophysics teaching units at Memorial, Alberta and Toronto enter into dialogue with the geology departments at those institutions in order to devise joint degree programs that will prove attractive to some of those currently majoring in geology.*

THE STUDENTS

We tried to collect some basic facts and attitudes of 2818 geology and geophysics students as we talked to them, their professors and, in some cases, their deans in universities across the country.

Where do they come from?

Most students of geology and geophysics attend the university closest to them. Universities in large cities such as Toronto and Vancouver seem to be drawing most of their undergraduates from the immediate surroundings. Few departments reported more than 10 per cent of their students from outside the province. The exceptions are chiefly residential campuses in small centres where an esprit de corps is established, traditions are built and the suggestions of parents or alumni send a new generation back to the old alma mater. Queen's is the most notable of the large departments in this regard. Less than 15 per cent of its geology students come from the immediate area of Kingston, most are from elsewhere in the province and over 25 per cent come from outside (chiefly Alberta, Québec and Nova Scotia). Small departments that receive a steady influx of undergraduates from outside the province are St. Francis Xavier and Mount Allison universities. Undergraduates from outside Canada are commonly rare, however Laval has received a substantial sprinkling of African francophones in the past few years, and Atlantic universities seem to receive a small but steady stream of students from the West Indies.

Sex facts

Women were few in Canadian geology departments a decade ago (Blais et al., 1971; Neale, 1973). This has changed radically within the past few years as employment opportunities have opened up to women on an equal basis in almost all fields. Only the petroleum industry still shows a certain reluctance to employ women as geologists and geophysicists. Queen's 1979 graduating class in geology was 40 per cent female and in geological engineering 20 per cent female. Enrolment of women in some geology departments is shown in Table 4.4.

How do students get into geoscience?

The inspiration to study geology or geophysics comes chiefly after a student arrives at university and then often by chance. In this regard the situation hasn't changed much in the last 12 years (Blais et al., 1971) despite redoubled efforts by professional associations to educate high school students concerning opportunities and careers in earth science.

Only about 10 per cent of the students we talked with had arrived at university with the intention of studying geoscience. The percentage was slightly higher at University of Calgary where relatives of petroleum geoscientists not uncommonly seek to follow the same career but, even there, most made their decision to major in geoscience only after taking an introductory course or learning of job opportunities from casual conversations with upper classmen. Very few had learned of the challenges and opportunities of geoscience through their high school teachers and counsellors, and those few were chiefly in the Atlantic region where "earth science" is offered as a matriculation subject.

One of the major problems that confronts university geoscience remains the need to create an awareness of the subject at the high school level. Several professors in the Atlantic region told us that teaching of earth science in senior high school was a mixed blessing for it tended to attract those who were trying to avoid maths, physics and chemistry. They and others (e.g., Wynne-Edwards and Neale, 1976) would prefer to have the seed sown in the early years of high school where earth and planetary science could serve as a logical and comprehensible introduction and illustration of the major principles of the chemistry, physics and biology taught in the final years of high school.

We recommend *that the Canadian Geoscience Council and its constituent societies interest provincial boards of education and faculties of education in experimenting with geoscience as an introduction at the junior high school level to all the basic sciences taught in the final years of high school.*

We recommend *to university Departments of Geology and Geophysics that they redouble their efforts to have articulate members of their faculty proffer their services to high school counsellors on a regular basis in order to advise students of the variety of careers and courses in the earth sciences.*

We compliment *the Geoscience Council on its recent career booklet and urge that copies be delivered in person by geoscientists to their local high school principals and counsellors.*

How good are our students?

Most professors we talked to felt that there had been improvements in the quality of students over the past few years. Thus, the Geophysics group at UBC claimed that it is now attracting some of the brightest students in physics, the calibre who in earlier years would have probably opted for theoretical, atomic or engineering physics. The Dean of Engineering of the University of Saskatchewan rated engineering geophysics at the top of the intellectual pecking order in his faculty and geological engineering not far behind. The Head of Geology at University of Toronto reported that by stiffening requirements in the ancillary sciences, his group began to attract a better class of student, particularly in the engineering option where it is now necessary to limit enrolment. Professors at Memorial University reported a better overall quality than ever before with some very good students transferring in from physics and chemistry programs. Carleton professors stated that they were attracting many of the best Ottawa high school graduates, e.g., three of the top ten of 1978-79. Some departments, e.g. at University of Calgary and the geology group at British Columbia, reported that the average quality was about the same but that there were more bright stars than in the past.

A few schools reported some deterioration in quality of students. In at least some of these places we detected morale and other problems which made us suspect that these views reflected a general despondency rather than a true appraisal of student intellect.

Another negative comment concerned the remarkably few geoscience students who qualify annually for the prestigious N.R.C. Centennial Scholarships. We confirmed this. It could mean that we just don't attract the best minds to geology and geophysics. There are other explanations: (1) Straight A's are remarkably rare in geology and geophysics by the very nature of the subjects in comparison to the cut and dried, right or wrong results expected in some sister sciences and in mathematics. In this regard, one professor called to our attention the careers of a few young superstars of Canadian geoscience each of whom had won international acclaim before the age of 30 but who had initially graduated with a B average that would never have merited the slightest consideration for a Centennial or any other scholarship. (2) Many of the brightest geoscience students join industry at the B.Sc. level without ever applying for scholarships. We recall encountering one student in our visits who had applied for and won a Centennial Scholarship but had turned it down to join a petroleum company.

Members of our committee, having talked at length with many groups of undergraduates across the country, believe the professors when they state that the quality of undergraduates is improving noticeably.

What do students want?

Students of geology and geophysics want jobs. Jobs have probably never been so plentiful and, for once, have coincided with high enrolments which in the past have always been out of phase with the immediate needs of boom-or-bust industries. Students everywhere are accepting employment immediately upon receiving their first degrees. In the west in the spring of 1979, large geology graduating classes such as those at UBC, Alberta, Calgary and Saskatchewan were at most sending only one or two students on to graduate school. In the central and eastern parts of the country the situation was only slightly better with several schools having as many as five undergraduates interested in pursuing further studies. However, some fairly large eastern departments such as Dalhousie and Memorial reported that the entire graduating class had signed on with industrial concerns despite some offers of prestigious and remunerative fellowships and scholarships.

This situation, with probably only 5 per cent of Canadian graduates continuing on to graduate school contrasts with the situation in the late 1960s when roughly 50 per cent were continuing their studies (Blais et al., 1971, p. 109). It is difficult to understand for, in the past, even in boom times, there was always a substantial core of students whose interest in pursuing further studies transcended immediate economic rewards. The explanation may not be that during a long continued period of high unemployment students of all disciplines have become oriented towards employment as a major goal and, despite their own enviable employment situation, geology students have become caught up in this pervasive feeling of insecurity.

Many of ther larger petroleum companies and about 20 per cent of the mineral exploration companies stated that they preferred to hire at the M.Sc. level. The desirability of this policy both for the industry and for the future career of the students has been capably stated by Baillie (1979). However, M.Sc. graduates are not available and so a decreasing percentage are currently hired at this level. Senior undergraduates advised us that there was no point in continuing their studies because (a) company recruitment teams told them that advanced academic studies were either not necessary or were better acquired through an in-house training program; (b) there was no financial reward for a higher degree and indeed, there was financial loss while obtaining it.

We recommend *that industrial firms, through lectures, letters and their recruitment programs, encourage qualified students to become involved in postgraduate work before embarking on careers in industry. We suggest also that they consider deferred starting dates, educational leave without pay, and other interim financial aid while deserving students complete their postgraduate training.*

COMMUNICATIONS

Informality and good rapport are traditions in geology departments, possibly stemming from the camaraderie that builds up during fieldwork. We found it prevailed across the country wherever we had an opportunity to talk with representative undergraduates. It is best in medium and small sized departments where senior undergraduates and faculty members are sometimes on a first name basis. It is also better in smaller centres, where evening lectures, social events and geology club activities are centred around the department, than in larger centres where commuting problems often relegate student-faculty contacts to an 8 to 5 routine.

Despite this generally good rapport, there were some grievances expressed by undergraduates concerning items such as quality of teaching and facilities on which they couldn't get any action despite long talks on the subject with their most approachable professors. Such complaints were less in those places where undergraduate representatives were invited to sit in on faculty meetings and they were virtually unheard in those few departments (e.g., Toronto, Queen's, Memorial) which have external committees that visit at regular intervals. Reports from such outside groups carry weight and promote actions in university circles. We shall return to this subject elsewhere in the report.

We recommend *that those departments that do not invite undergraduate student representatives to attend departmental meetings on a regular basis should make every effort to do so.*

We further recommend *that those departments which do not have an outside review committee should make every effort to establish such a committee and to arrange for it to visit at regular intervals.*

ENTRANCE REQUIREMENTS

Each university and in some cases each faculty controls admission standards and policies. These are published in the individual calendars.

Admission is based on matriculation from secondary school systems. In Newfoundland this is at Grade 11, in Ontario Grade 13 and in all other provinces it is Grade 12. In Québec, following matriculation, students attend junior colleges (CGEP) for two years prior to admission to university.

School leaving exams were formerly set by provincial education departments. Recently such exams have been discontinued in many places and school leaving has been based on the exams or records of individual schools. In some cases this has led to inflation of grades as schools compete to turn out honours students. Professors mentioned that the products of some secondary schools were preferred to others because their grades had proven to be a more reliable index of ability. Another complaint of university staff members concerned the low standards of written English which prevailed in high schools. Some universities, e.g., British Columbia and Calgary have devised English entrance exams and remedial courses for those who fail.

In view of both the apparent less rigorous matriculation standards in the high schools and the accusation that at least some universities are lowering their entrance standards in the face of growing competition for ever fewer students, it is heartening that most department heads across the country notice improvement in the quality of geology and geophysics students.

UNIVERSITY CURRICULA

The range

There is a great variety of courses of study available in universities across the country. At one end of the spectrum is the three-year pass degree where a student need take only eight term courses in geology, no mathematics and very little ancillary science. At the other end are rigorous four-or five-year, highly structured programs leading to an honours science or an engineering degree that produces a well-qualified professional.

Most universities offer three types of programs in their science faculties: pass degrees which may require three or four years depending on the school, majors in geoscience which require four years or equivalent, and honours which requires four years or equivalent. In Québec, university entrance is through junior college (CGEP) so that only three years are required for all these programs. In Newfoundland, where students matriculate from Grade 11, the pass degree requires four and the major and honour programs five years. In addition, ten Canadian universities offer geology or geophysics options in their engineering faculties which require four, and in one case five, years of study. The complete range of programs in most Canadian universities is shown in Appendix 3A.

The pass degree, common to most universities, satisfies the minimum requirements of the faculties of science (or arts and science). Students are generally discouraged from taking this route by their geology and geophysics professors unless their goals are other then becoming professional geoscientists. Nonetheless, when job opportunities are plentiful many of them enter the profession and at least a few perform successfully.

Geology majors and honours

Twenty-three departments offer a major program which some of them might refer to as an advanced major, a specialization program or, in a few cases, a pass degree. This usually consists of a mandatory core of geology courses: physical and historical, crystallography, systematic and optical mineralogy, petrology, sedimentology, stratigraphy, structure, field geology, paleontology (in some places optional), regional geology (in several places optional) and economic geology (optional in more than one half of these departments). It is notable that a first course in geophysics is lacking from this required core. The remaining half of the geology courses may be chosen from the offerings of the department, usually the larger the faculty the larger the selection, depending on the advice of faculty members and the choice of specialization of the student. Appendix 3A lists representative samples of these optional geology courses. Ancillary science requirements are:

4 term courses in chemistry	the second two are optional in some departments
4 term courses in physics	the second two may be optional or replaced by geophysics in some departments
4 term courses in mathematics	the second two may be optional or replaced by statistics and computer science in some departments
2 term courses in biology	required in some schools where students opt for paleontology emphasis.

Generally a major in geology has no rigorous grade requirements. Many of the students in such programs are those whose grades did not meet standards at one stage or another in an honours program or those who decided on specialization too late to meet the requirements of a structured program. There are some students, however, who purposely choose a major rather than a more specialized degree in order to experiment with a variety of courses in other faculties.

The honours degree involves somewhat different requirements at different Canadian universities. At most institutions however, it is the acknowledged prestigious first degree whose recipients have followed a structured course and received at least second class grades in their major subject and certain allied subjects. Generally the course offerings are the same as those for a major, more geology courses are mandatory and, in some places, the second two courses in ancillary science may be mandatory. Most universities require a thesis or dissertation of their honours graduates and most encourage their students to base this on a combination of field and laboratory work. Some, e.g. McGill and Acadia, have never required theses for their honours degrees; others now offer the option of a thesis or an extra course and some, e.g. Toronto, have dispensed with the thesis in their science faculties and refer to the ultimate degree as a "specialist major".

Departments of geology and geophysics, particularly the large ones, generally offer far more courses than students are permitted to take in a four-year program. This allows streaming in the last year or two so that students can concentrate on subjects such as sedimentology and stratigraphy or on igneous and metamorphic petrology combined with metallic mineral deposits. Firm direction within these streams is common in honours courses, less so for those taking a major in geology when a certain "buffet" approach is often permitted after the student has taken the required core courses.

Technical courses such as drafting, surveying and core analysis are usually confined to engineering faculties. Faculties of science in some schools refuse to recognize these courses as science credits; in others, timetable conflicts make it virtually impossible for engineers and scientists to exchange courses.

P.L. Money, a member of our Committee, sent a questionnaire to geology and geophysics departments requesting information on courses pertaining to economic geology. Thirty departments replied. Because of widespread interest in this topic by potential employers, we have summarized replies in Table 3.2. Economic geology is a compulsory core course in only ten departments, applied geophysics in only five.

Most universities offer opportunities for majors or honours degrees that span two disciplines (Table 3.3); geology and physics (or geophysics), geology and geography, geology and chemistry, geology and biology are the most common. These are generally not popular, particularly at the honours level, as the faculties in the departments concerned each attempt to make so many of their own courses mandatory that the student is often left with no flexibility, a good deal of hard work and possibly no chance of achieving the particular combination of courses that initially prompted interest in a joint degree.

Appendix 3A shows the difficulty of equating the various geological programs. A three-year program with minimal concentration on geology is advertised as a major in some universities and as a pass degree in others. Most universities regard their four-year major (three in Québec) as a degree that qualifies the recipient as a professional geologist. The requirements for it in some schools seem more difficult than the requirements for honours in others. Honours degrees should rank as the prestige degree in all departments but at least one department head advised us that his school's special degree resulted in a better-trained student! The whole matter is a mystery to employers who would like to consider an honours degree, a major, or a pass to have the same meaning from Victoria to St. John's. Their only hope at the moment is to wrestle with university calendars, past experience and information obtained from interviews.

Geophysics majors and honours

First science degrees in geophysics are awarded by seven groups closely allied to Physics Departments and eight allied to Geology Departments.

Of the first seven, three are independent departments: Western Ontario, York and British Columbia and the remainder are units in Physics Departments (Alberta, Memorial, Toronto and Victoria). They grant major and/or honours degrees in geophysics or in physics with a geophysics specialization. In co-operation with their geology departments they can also give geophysics degrees with geology options.

The eight Geology departments that grant geophysics or geology and geophysics degrees are Brock, Calgary, Carleton, Laurentian, Manitoba, McGill, Regina and Saskatchewan. All seem to work in collaboration with Physics departments and most of them with engineering faculties. Calgary, Manitoba, Saskatchewan, McGill and Queen's produce as many or more new graduates in geophysics as do the independents and those which are part of physics departments (Table 3.1).

The programs vary so much from one school to another and even within a single school that it is difficult to identify a core program common to all. Most seem to require a minimum of:

- 4 term courses in mathematics
- 8 term courses in physics or geophysics
- 4 term courses in geology (including 2 introductory courses)
- 2 term courses in chemistry

Our impression was that a few students in the departments linked with physics took the geology option. Several professors in these departments regretted this and stated that attempts were underway to make more geology mandatory in all undergraduate geophysics programs. Several also stated that until recently it was not unusual to graduate geophysicists without even an introductory course in geology (a fact which has been regretted by the oil industry which currently hires most of the graduates!).

We recommend *that geology and geophysics faculties at British Columbia, Alberta, Western Ontario, Toronto and Memorial co-operate more closely in their teaching and in the teaching of their curricula. They should call on senior people from industry to aid and advise in such joint planning ventures.*

Geology and geophysics in engineering faculties

Ten university geology departments offer degrees in geology and four in geophysics through engineering faculties. In the three Québec universities these degrees require four years of study past the CGEP program and are thus equivalent to a five-year program in other parts of Canada (six years in Newfoundland). Only two Canadian schools, British Columbia and Waterloo require five years for an engineering degree, the others require four years.

Engineering programs are more structured than those for honours degrees and allow even less opportunity for options as they have to conform to certification requirements of professional associations. Generally they provide at least as much ancillary science (chemistry, physics, and mathematics) as honours science programs although in some universities most of these science courses are taught within the engineering faculty and are more focused on special problems than are those within science departments. Contact hours (lectures and laboratories) are as much as 50 per cent more in engineering than in science programs. This permits instruction in basic engineering courses such as material science, in technical skills such as drafting and surveying, and in pragmatic subjects such as technical writing.

The larger departments offer a variety of specializations in their engineering programs such as mining, coal and petroleum, geotechnical, exploration. The smaller departments offer only a single program in engineering geology and (in some places) geophysics.

Typical curricula for two options in two schools, Toronto and Queen's, are presented in Appendix 3B. As with honours science, theses are required in some schools of engineering and not in others.

As we shall record later in this chapter, mining exploration and petroleum companies generally prefer engineering to science graduates. This seems to be partly because of the consistency of product regardless of school and partly because of the grounding in basic skills and methods which are commonly lacking in science graduates. We recommend *that those geology and geophysics departments in universities with engineering faculties which are not already offering degree courses through these faculties should make every effort to do so.*

Co-op programs

The system of alternating academic and outside work terms was introduced by the Engineering Faculty at University of Waterloo almost at its inception in 1957. The success of the venture led to its establishment in engineering programs elsewhere (e.g. Memorial and Sherbrooke) and also in other faculties, e.g. business administration.

The Department of Earth Sciences at Waterloo and the Department of Physics at Victoria are the only two who have decided to train geologists and/or geophysicists in this manner. At Waterloo students may opt for the regular honours program or the co-op program. The latter requires an extra year but the student has two years of supervised training in industry at the end of it. The program is available with geology or geotechnical specialization. Mineral exploration and petroleum companies extol the virtues of this type of program and the Waterloo success in particular is cited by many, including those who only know it at second hand.

Some professors in other universities are cautious in their endorsement of the co-op program in geology. They state that it is expensive and that geology students do not require it as they are assured of summer fieldwork in their profession. Our committees were impressed, however, with the care with which co-op assignments were selected and the fact that students were required to report formally on their work term experience.

We suggest *that geology and geophysics departments investigate the establishment of work term programs in co-operation with industry, following the lead of Waterloo and Victoria university geologists and geophysicists. These could be implemented through existing engineering co-op programs or initiated through faculties of science.*

EVALUATIONS OF CURRICULA FROM WITHIN

The students' views

We have already mentioned that probably more than in any recent interval, students' main motivation is employment opportunity. This manifests itself in their opinions of study programs, courses, and ancillary sciences.

Students in at least some universities are registering for majors rather than honours degrees in order to avoid thesis requirements and the necessity of taking "irrelevant courses", particularly in ancillary sciences. In the face of this declining enrolment in honours science, those schools which have engineering programs, which in their different ways are at least as rigorous as honours, report continually increasing enrolments. The answer must lie in job opportunities; most students realize that industry places a premium on engineering degrees with geology or geophysics specialization.

One of the major complaints about the curriculum centred on the usefulness of the geology and geophysics courses. Several groups resented the fact that plate tectonics and other unifying concepts played important roles in so many of their courses when they could be engaged in more practical endeavours. This is an abrupt swing-around from opinions of a few years ago when students regretted the lack of unifying themes in their courses (Blais et al., 1971)! Several student groups regretted the lack of emphasis on petrophysics, wireline logging etc., however one of these was a group of engineering geologists and geophysicists who were already receiving a full term course in this subject! Others regretted the lack of applied field problems, visits to mines and prospects, and practical petroleum-oriented laboratory exercises associated with their sedimentary geology courses. Some students regretted the emphasis on igneous and metamorphic petrology and geochemistry at the expense of courses in mineral deposits, petroleum and coal geology. Science students pointed to the lack of training in drafting and surveying, subjects they were apparently supposed to learn by osmosis during field courses.

There were many complaints about the teaching of and the need for ancillary sciences, particularly chemistry and physics. Students said that no attempt was made to tailor these courses to the requirements of geologists and geophysicists by pointing out some aspects of their potential usefulness. This even though such students were commonly present in sufficient numbers to warrant a separate section of a class. Students also claimed that their own professors were commonly incapable of incorporating material from other science courses into their geoscience lectures. The larger engineering faculties have confronted this issue (successfully?) by teaching their own versions of science within the faculty. Student pressure is moving some geology and geophysics groups in the same direction, e.g. Memorial has created an extra geochemistry course as an option to second year courses offered by the Chemistry Department, and Saskatchewan is moving to supplant a physics course by a more appropriate course designed by the geophysicists. Although it is easy to sympathize with students' complaints - for many are the same as those of an earlier, less articulate generation--it is hard to condone the remedy. As one professor states, "Those aspects of chemistry, physics and maths which will be most relevant to geoscientists in the next decade will be found in the basic courses given by the specialists in those fields. These relevant aspects are unlikely to be anticipated by those in geoscience departments because their attention is focused on present applications of the basic sciences."

Student enrolment in the geosciences is at a long-continued high and yet there is little hope for large increases in staff to cope with it; majors in chemistry and physics are temporarily at an all-time low and undergraduate activities of these departments are confined almost wholly to service roles. Surely university authorities can ensure that this service is performed to the specifications and satisfaction of the clients in geoscience.

We recommend *that geology and geophysics departments take advantage of the fact that they are now among the largest science departments in terms of majors and honours students and that they insist that other science departments tailor sections of service courses to their needs.*

Faculty views

The various curricula have been designed primarily by the faculty of geology and geophysics departments, sometimes but certainly not always with input from students and recent graduates, very seldom indeed with direct input from the employers of students. Naturally, faculty members in general defend their choice of programs for majors and honours degrees in science. They also point out that the so-called pass degrees are beyond their departmental jurisdiction and minimum requirements are generally set by Faculties of Science or Arts and Science to apply to all departments.

Most faculty members we talked with stated that their main responsibility was to provide a background of essential facts and to teach students to reason geologically. This is possibly best summed up in the words of Professor W.G.E. Caldwell of Saskatchewan:

> "the Department of Geological Sciences attempts to inform students of the relationship of geology and its allied fields to the other natural and the physical sciences; to acquaint them with the vast body of knowledge that exists about the materials and processes of the Earth; to familiarize them with old and new theories . . . .; to explain to them how the guiding principles of geology and its related fields were formulated; to give them an appreciation of the 4.5 billion year history of the Earth, and of the place and role of Man in that history; to explain to them how their knowledge may be applied to the solution of theoretical and practical problems posed by the Earth in local, regional, and global contexts."

Faculty members generally inclined to the view that engineering programs quite properly devoted part of the course work to technical training and methodology because this was professional training from the outset; the students presumably knew where they were going and the employers expected a fully qualified product upon graduation. On the other hand science students are less certain of their goals and their training should offer more flexibility so that they can adapt more readily to the variety of situations in which they might find themselves on graduation. A host of methodology courses will produce technicians who are adept at following well charted paths in the search for hydrocarbons but hardly the type who will ponder CO_2 emissions and the global carbon budget. Both levels of activity are essential and training should produce both types of people.

There are, of course, extremes of opinion. Every department has at least one elitist who feels the graduates should be advanced thinkers whose ultimate role is to advance the science and revolutionize industry. Any mundane tricks of the trade necessary to effect this should be learned on the job following graduation. Probably more numerous (but less vocal) are those at the other end of the spectrum who feel their departments' course offerings have been partly developed to suit their colleagues research interests and that some curriculum concessions should be made to the fact that 80-90 per cent of their graduates are currently going directly into industry.

THE PETROLEUM INDUSTRY'S ASSESSEMENT OF UNDERGRADUATE TRAINING

The assessors

A committee organized by P.J. Savage (Pan Canadian Petroleum Ltd.) and including P.L. Gordy (Shell Canada Resources) and A.D. Baillie (Gulf Canada Ltd., retired) devised a questionnaire which was sent to 20 companies chosen as representative of the industry. Replies were received from 18 companies including multinationals and independents which together employed 1338 geologists and geophysicists in 1979. The largest employed 160 and the smallest 13 geoscientists. Statistics on the academic backgrounds of our respondents employees are given in Table 3.3. Approximately 30 per cent of these scientists hold advanced degrees.

The oil companies' top choices

The companies were asked to rate the undergraduate training, as it pertained to their needs, in those universities with which they were most familiar. Fourteen of eighteen companies responded to this question, the others felt their experience was not broad enough to make such a rating. Departments receiving less than five mentions were not included in our lists. Our committee decided that those schools receiving 3.0 or more points from five or more companies were providing a very satisfactory service to the industry and we list them below. Several not mentioned are also providing students training considered adequate or better.

	University	No. of Ratings	Point Average
Geology			
	Calgary	13	3.7
	Carleton	6	3.66
	Manitoba	7	3.4
	Alberta	11	3.3
	Memorial	9	3.3
	Queen's	9	3.3
	McMaster	8	3.25
	Waterloo	7	3.1
	Saskatchewan	10	3.0
	McGill	8	3.0
Geophysics			
	Western Ontario	5	4.0
	Saskatchewan	8	3.75
	British Columbia	11	3.45
	Calgary	9	3.3
	Alberta	9	3.1
	Queen's	6	3.0

It is obvious from these ratings that western universities are generally held in high regard by the oil industry. Putting the natural interpretation on this, we assume that these universities have made special efforts to tailor their training to the needs of the largest local employers. Answer to other parts of our questionnaire bear this out. Eastern universities that rate highly all offer training in subjects of interest to petroleum companies. Also, each has one or more scientists on staff who visit Calgary regularly and keep abreast of activities in petroleum exploration.

It is also worth noting that three of the top-rated geophysical schools (Saskatchewan, Calgary and Queen's) are associated with geology departments and, in two cases (Queen's and Saskatchewan) award most of their degrees through the Engineering Faculty.

Hiring, present and future

Most of the large petroleum companies and a few of the small ones would prefer to hire at the M.Sc. level. They state that sufficient candidates are not available at that level and so they are forced to hire at the B.Sc. level. As pointed out by Baillie (1979), present competition for new graduates is keen and there are no financial rewards for the M.Sc. so the material incentives to continue studies are few indeed.

During 1978 our 18 respondents hired 140 new graduates. This represented about 11 per cent of their existing staff and probably one half to one third of their total hiring, for the industry is presently experiencing a rapid turnover of staff. Less than 25 per cent of these new graduates had advanced degrees, i.e. lower by 5 per cent than the proportion within the existing staff.

Respondents were asked to comment on hiring of new graduates over the next six years. Most felt that they would be hiring about 10 per cent more for each of the next four years (1980-83) after which hiring would return to the present rate.

Currently almost all of the new graduates hired are products of Canadian universities. A few companies have had to recruit abroad, despite immigration obstacles, in order to obtain the quality and level of training they seek, especially in the case of geophysicists. Most companies state that the current levels of enrolment in geology departments is just about right although several emphasized that they would prefer graduates of a higher quality than those currently available. There was virtual unanimity concerning the existence of a small but long-continued and serious shortage of graduates in geophysics.

Criticisms of training

We have selected the half dozen most common criticisms of undergraduate programs and list them in order of importance:

- Too much emphasis on hard rock and metallic mineral exploration so that students are oversaturated with igneous and metamorphic petrology and with magnetic and gravity techniques at the expense of proper training in sedimentology, biostratigraphy and seismology. This complaint was most commonly directed at the "eastern schools".

- A general deficiency in technical writing skills.

- Graduate geophysicists from physics departments are generally weak or lacking in geological background and geology graduates are too commonly devoid of useful geophysical training.

- Too little field training incorporated in the undergraduate program and that little often too early in the program. As much of petroleum geology is concerned with subsurface work, companies feel it essential that graduates enter their service with an appreciation of rock relationships gained from experience in regions of good surface exposures.

- Students from many universities seem to lack a background in regional geology.

- Many students have not taken the time or been given the opportunity to think about their science as a whole and to relate one course to another. This was a criticism made by a few only of the larger companies.

Suggestions for improvement

- Cut down on the options permitted for majors so that there will be time slots available for fundamental courses such as field school and technical report writing.

- Introduce career counselling with the aid of representatives from industry so that professors and students become more aware of the training requirements important to industry.

- Make courses in structural geology, sedimentology and stratigraphy mandatory for students of geophysics.

- Provide more opportunities for students to study modern analogs such as deltas and carbonate banks (Note: several schools in both eastern and western parts of the country do this, some with support of the petroleum industry).

- Use case histories in teaching petroleum geology and geophysics. Laboratories should provide practical exercises in subsurface interpretations using logs and seismic data.

- Several companies suggested the need for an additional year of study for the first degree. This would provide students with the opportunity to pull together their gleanings from diverse courses and to receive some of the career oriented training presently lacking. Some respondents suggested that petroleum companies should help sponsor such an additional year for their prospective staff members.

There were noticeable differences in the responses of small and large companies. The small companies pressed for more pragmatic training and some even regarded courses such as crystallography as "exotic". In contrast, large companies appeared to seek graduates with a good grounding in the fundamentals and a proven ability to reason well. Most of the large firms, of course, have their own training programs to take care of the pragmatic aspects. Nevertheless, the overall impression is that petroleum companies would like to see a decrease in the number of options available and increased use of case histories in laboratory exercises.

COMMENTS FROM THE MINERAL INDUSTRY

The views of the metallic mineral industry were sought on undergraduate training and allied subjects through a questionnaire prepared and distributed by a member of this committee, P.L. Money, Regional Manager of Exploration for Texasgulf Inc. Replies were received from 150 companies which included large and small exploration groups, mining operations and consulting firms. A summary of replies was prepared by one of us (J.E.A.) and is presented as Appendix 3C of this report. From it we note that these companies together employed 1210 graduate geologists and geophysicists of whom approximately 30 per cent hold advanced degrees. Although the ratio of higher degrees to bachelors was almost exactly the same as in the petroleum industry it is notable that the distribution was more evenly spread in the mineral industry - many employees of small mineral exploration companies held advanced degrees whereas these were confined to medium and large companies in the petroleum industry. The summaries below are drawn chiefly from the replies of the 78 companies engaged in exploration who together employ 1008 geoscientists.

Top-rated schools

Companies were asked to rate universities with which they were familiar in regard to their training of geoscientists. Forty-one of 78 companies answered this question. On a point scale where adequate was 2.0 and superior 3.0, seventeen departments were rated adequate or better based on a minimum of 5 ratings each. The top-rated geology departments were:

University of Western Ontario	3.0
Memorial University	2.8
University of Waterloo	2.8
University of Toronto	2.7
McGill University	2.7
Queen's University	2.6
Carleton University	2.6

Hiring practices, preferences and supply

Most of the companies prefer to hire at the B.Sc. honours, B.A.Sc. or M.Sc. levels. A significant number expanded in writing on their preference for graduates of engineering programs or for the M.Sc. level of training. Most stated that they preferred to hire Canadians but a few stated that they had to recruit outside the country to hire specialists. Several stated that they found British and European graduates better trained than Canadians.

A handful of respondents felt that there was an oversupply of graduates in a variety of geological and geophysical fields. In contrast, others noted short supply especially in exploration geophysics, geological engineering and Pleistocene geology.

Criticisms of training programs

A summary of criticisms from mining and mineral exploration companies is presented in Appendix 3C together with a broad selection of comments from the respondents. Some of those we considered most important are presented here, a few of the most common criticisms are identical to those of the petroleum industry:

- Students' incompetence in writing or oral expression in either English or French. In fact, inability to write an understandable technical report was the most common single criticism made of recent graduates.

- Students and their professors remain divorced from primary contacts with industry so that most have no understanding of business, finance and, particularly, mineral economics.

- The lack of training in essential technical subjects such as mapping methods, surveying, drafting, geophysical and geochemical techniques and core logging. Some of the more thoughtful respondents noted that these skills could be acquired in technical colleges or during the first months of employment. Even they, however, felt that some such training should be interwoven with science courses so that students did not embark on their industrial careers lacking all such basic skills.

- Too much emphasis on theory, statistical and computer modelling at the expense of emphasizing practical and observational aspects of the science . . . . . "the perfect skyscraper built upon bentonite!"

- Too much emphasis on local geology at the expense of acquiring some regional concepts. Very few new graduates are even vaguely familiar with the geological framework outside their own province.

- Studies are too compartmentalized so that students graduate without learning to tie together the facts they have gleaned in mineralogy, petrology, structural and economic geology.

- Some subjects seem to be neglected such as: simple petrography, field courses in structural geology, glacial (Pleistocene) geology and the elements of exploration geochemistry and geophysics.

Many of the respondents made suggestions for improvements in the training of undergraduates. These are summarized in Appendix 2A, those that struck us as most important were:

- Instruction in report writing and oral presentation should be an integral part of all geology and geophysics curricula. Exams and term papers should be graded partly on their English (or French). (No favourable recognition was given to the several departments that have been attempting this in recent years.)

- Scientists from the mineral industry should be invited in more often for both special lectures and to give parts of regular courses. (This practice is more common than many people in industry realize - still it is practised in less than one third of the departments examined.)

Some suggested that all permanent appointments to faculty should have at least five years of industrial experience behind them. Others felt that universities should work out sabbatical exchanges with scientists from industry and government.

- Geology and geophysics curricula should include at least one course in business and finance, preferably slanted towards nonrenewable resources.

- More emphasis should be placed on field courses and visits to active mines and less on laboratory courses. Some suggested that up to six months fieldwork with government or industry should be mandatory before graduation. Others stated that the work term concept as practiced at Waterloo ensured that new graduates had most of the necessary skills and field experience.

- Pressure should be brought to bear on other science departments, e.g. chemistry, physics and economics, to teach their subjects in a manner useful and comprehensible to geoscientists.

- Some respondents were conscious of their industry's shortcomings, e.g. many companies assign new graduates to routine chores instead of providing enough challenges to keep them interested. Others stated that salaries and living conditions in mining and exploration do not compare favourably with those in other professions.

We have cited what we consider the most important criticisms and suggestions of the mining and mineral exploration community. They contain important messages for curriculum changes. Some of the comments and criticisms included in Appendix 3C are not constructive and some are based on ignorance of the university's role in the geosciences. They too are important for they indicate a lack of communication which both sides should seek to remedy.

OPINIONS OF PROVINCIAL GEOSCIENCE AGENCIES

Provincial departments of mines and energy and their equivalents have traditionally played an important part in undergraduate training by staffing their field parties with students in the role of junior field assistants. Newly graduated students and postgraduate students usually serve as senior assistants and the latter, in some cases, as party chiefs.

With the recent expansion of surveying activities by provincial agencies, over 200 undergraduates are employed each summer across the country. The value of this training is highly regarded by future employers and some petroleum company respondents singled out departments whose good rapport with provincial agencies had produced students consistently well-trained in field techniques. A questionnaire sent to provincial agencies included queries on undergraduate training which elicited the following replies:

- Provincial agencies hire junior summer assistants within their own province, going outside only when they cannot fill their needs from within. Although each agency's views on training thus pertain to only one or a few local universities, all views were remarkably similar suggesting that the needs of provincial surveys are very much the same.

- All find the supply of summer field assistants adequate. All find the supply of new graduates inadequate and most find they have to go outside of their province to hire senior assistants. (Obviously, with a little experience behind them, students wish to explore new terranes.)

- Four out of eight respondents pointed out strongly that courses in technical English and report writing were essentials missing from most undergraduates' training.

- Most respondents stated that classroom and laboratory training was adequate with a few exceptions. Several stressed that the intelligence and motivation of the students themselves was more important than the training and that some university departments attracted brighter, more committed students than others. (They did not mention which departments or why this was so.) Specific weaknesses mentioned were:

(a) Lack of classroom and field training in Quaternary geology, an increasingly important area of interest in western provinces (Alberta).

(b) Lack of geophysics, geochemistry and geochronology in undergraduate curricula (Ontario).

(c) A concern with mega-concepts at the expense of basic data collection and applications of science (New Brunswick).

- Provincial respondents were unanimous in pointing to the inadequacies of field training in the universities.

Specific lacks emphasized were: visits to operating mines, experience with geochemical and geophysical methods, and mapping of surficial materials. One respondent mentioned the uneveness of training at the local university field camp where the specialities of the leaders were emphasized to the detriment of other subdisciplines.

- Two replies emphasized that universities should stress the basics in geoscience and discourage students from specializing (and limiting their options for employment) at the undergraduate level.

The provincial agencies' major criticism of university training concerned the lack of enough supervised field projects. This was also a major criticism by mineral exploration companies and petroleum companies so there is obviously a strong message to geoscience departments to improve and lengthen field training. There is another interesting aspect to this criticism: some of the undergraduates told us that the reason they worked with local provincial surveys, and sacrificed the higher wages and glamorous travel opportunities offered by industry, was because their professors told them they should regard summer survey work as an integral part of their academic training. If the professors now offer this field training during school terms will there be any incentive for them to work for provincial agencies during the summer months?

COMMENTS BY FEDERAL AGENCIES

The questionnaire sent to federal agencies was prepared with the help of senior government geoscientists who suggested deletion of the questions pertaining to classroom and field training of undergraduates. Thus we lack opinions comparable to those received from the provinces.

Most federal agencies state that they hire undergraduate assistants for summer field and laboratory work from nearby universities. If an insufficient number are available, they then spread their recruitment net farther. This is in compliance with a Public Service Commission ruling. The largest employer is the Geological Survey of Canada (G.S.C.) which hired 150 undergraduates for operations during the summer of 1979. The Earth Physics Branch employed a few undergraduates for work in their Ottawa and Victoria (Pat Bay) laboratories. Other branches of E.M.R. and branches of D.O.E. and D.I.N.A. also regularly employ students of geoscience in the summer months.

One G.S.C. division commented on the lack of Quaternary training in most undergraduate programs. Another stated that, in its experience, training in Canada is much above the world average. A third, the largest employer of field assistants, states that the quality is good and improves each year.

RECOMMENDATIONS TO ACCOMMODATE CRITICISMS FROM INDUSTRY AND GOVERNMENT

A wide selection of programs and an enormous variety of courses are offered at the undergraduate level in most of the medium and large sized departments. At the less intense end of the spectrum (the pass degree) this is probably good as it allows those who are planning careers in other professions (e.g., teaching, resource, law, mineral economics) to choose courses that suit their needs. At the other end of the spectrum it unfortunately has tended to permit specialization at an early stage and to reduce the flexibility and options open to graduates. Rightly or wrongly it has been stated that the buregoning number of undergraduate courses has grown in response to the diverse specialities of new faculty members rather than to perceived needs. In order to accommodate these additional courses, many of the classical courses have been cut back and basic courses in chemistry, physics and maths have been eliminated. Comments from the major employers of graduates suggest that they would prefer a return to a more structured undergraduate training that stressed basic geoscience and ancillary science courses. In addition they stressed the need for training in basic skills such as report writing, surveying, drafting, mapping and core logging that could be interwoven with laboratory and field courses. Two approaches that seem best to satisfy these needs are the co-op and engineering programs. Both are complimented by industry and are increasingly attractive to students. Where these are not possible, and even where they are in effect, we feel that department heads should seriously consider the following recommendations:

That an extra, postgraduate diploma year be added to the training of those who seek to become professional geologists. This year would permit the student to integrate and relate the material of the first four years and also to develop special skills and problem-solving abilities in a speciality.

That geology and geophysics departments introduce, reinstate or give additional emphasis to a comprehensive thesis in the final year of honours and majors programs.

We recommend *that field courses should be an integral part of each year of undergraduate studies in geology and geophysics. Departments should consult with industrial concerns and provincial agencies concerning planning, loan of equipment and volunteer aid in field school instruction.*

We recommend *that lectures on technical writing be introduced at all levels of undergraduate training, preferably in courses that require written reports, e.g., field school and preferably by people who have demonstrated skills as scientific writers or editors.*

We recommend *that all geology and geophysics departments regularly call upon scientists from government and industry to help plan and revise their undergraduate programs, and invite specialists from these domains to give series of lectures in appropriate courses following the example of several geology departments, e.g., Calgary and Toronto. Further, we advise that they widely advertise this external participation as soon as it comes about.*

SOME OUTSIDE APPRAISALS

At one time foreign professors, particularly Americans, were in an ideal position to assess the quality of our undergraduate training. This was because most Canadiar students continuing their studies did so in U.S. universities. This situation changed slowly in the 1960s and today scarcely any of our students go abroad for postgraduate work (C.C.E.S.D., 1978). We asked distinguished scientists from other countries to evaluate our national effort, chiefly research, in the geosciences. Several of them gratuitously inserted comments on our training of undergraduates based of their recollections of former years or on their more recent experience in Canada as consultants and visiting professors. We reproduce a few, admittedly out of context, because they are interesting in their diversity.

"As far as practical training is concerned, I believe that Canada's record is spotty. It was once outstanding, providing a fine blend of experience, training and scientific endeavor. Now there are many students who seem to seek only the degree credentials and care little for the intellectual content of the subject. I suppose this attitude is fostered by the industry hiring almost anyone who graduates, but it also is supported by universities' dropping their standards and letting weak students through when they should have been failed. (Please note that this is a problem of the whole western world at the present time.)...but I can say that I have been impressed in recent years with some undergraduates from British Columbia, Toronto and Queen's."

--Professor from Yale

"The reason why Canadians were some of my best students is based on the fact that Canadians have had the opportunity to acquire a field background that is difficult to match elsewhere . . . ."

- - Professor at Johns Hopkins

"If I were a student I should expect to get as good a training in Canada as anywhere and better than in many of the universities of U.S.A. and Europe. Universities such as Memorial, Queen's, Ecole Polytechnique, McMaster and Western all offer exciting courses..."

- - Scientist with the Greenland Geological Survey

CONCLUSIONS

Undergraduate studies in geology and geophysics at Canadian universities has probably never been in a healthier state. Approximately 2800 students are following majors, honours or engineering courses in geology and geophysics. This high enrolment has been maintained for several years and, for once, coincides with a period of high demand. Faculties have built up to moderate sizes so that there is a confortable national average of about six majors per faculty member. In many schools, faculty members feel that they are attracting more bright students than ever before. In many places and in many ways the barriers between geology and geophysics are breaking down and these subdisciplines are not the teaching solitudes that they were ten years ago.

Although the situation is healthy, it is far from perfect. Most undergraduates still enter geology or geophysics through contacts made after their arrival at university as little awareness of the exciting career opportunities in geoscience is created among bright, scientifically-oriented high school students. Increases in faculty size have not kept pace with growing enrolments and several well-known geology departments with student:staff ratios above the national average have restricted enrolments. Others should follow this lead where it appears that quality will be diluted by quantity. Despite a continued, partially unsatisfied demand for graduate geophysicists, our large research schools of geophysics still attract only a few undergraduates to their programs. More interaction with geology departments might remedy this situation. Companies, provincial agencies and students are critical of the curricula in many geology and geophysics departments. In part their comments are based on ignorance of the university's role, but in part they are justified by curricula that have been re-arranged to suit the special research interests of professors. More communication between university departments and employers is obviously required. The possibility of introducing an extra postgraduate, professional diploma year also deserves study. Finally, more than in any other period of high employment in the profession, the best students are joining mining and petroleum companies immediately upon graduation. The substantial core whose interest in pursuing advanced academic studies transcended immediate economic rewards has disappeared. If unchecked, this trend could have harmful, long-term effects on graduate studies, research and innovation in Canadian geology and geophysics.

These and other shortcomings have been addressed and some remedies suggested. The problems themselves reflect the growing enrolments of undergraduates in geology and geophysics, itself a reflection of the unprecedented activity in these sciences.

TABLE 3.1

ENROLMENT, STUDENT/FACULTY RATIOS AND DEGREES AWARDED

Department Name	1978-79 Fac.	1978-79 Undergrad	1978-79 Stud/Fac. Ratio	1979-80 Fac.	1979-80 Undergrad	1979-80 Stud/Fac. Ratio	1979 Degrees Awarded BSc	1979 Degrees Awarded BASc
Acadia, Geol.	5		13.60	5	74	14.80	4	-
Alberta, Geol. Alberta, Geophys.	20 10	99 13	4.95 1.3	20 10	88 16	4.40 1.60	38 5p	-
Brandon, Geol.	3	15	5.00	3	18	6.00	3	-
British Columbia, Geol. British Columbia, Geophys.	23 8	146 41	6.35 5.12	23 8	176 49	7.65 6.12	21 6p	15 1p
Brock, Geol. Sc.	9	52	5.80	9	48	5.33	9	-
Calgary, Geol. & Geophys.	23	197	8.52	23	201	8.74	31+7p	-
Carleton, Geol.	16	103	6.44	16	79	4.94	26	
Concordia, Geol.	7	42	6.00	7	56	8.00	14	
Dalhousie, Geol.	12.5	65	5.20	12.5	68	5.44	20	
Ecole Polytech. Gen. Min. Montreal, Geol.	16 12	89 57	5.53 4.75	14 12	80 86	5.70 7.16	- 12	20+4p -
[2]Guelph, Land Res. Sc.	3	9	3.00	3	9	3.0	3	-
Lakehead, Geol.	8	43	5.37	7.5	39	5.20	9	-
Laurentian, Geol.	8.5	21	2.47	8.5	19	2.25	8	-
Laval, Geol.	13	156	12.00	13	166	12.77	13	28
Manitoba, Earth Sc.	15	107	7.14	15	125	8.33	29+3p	6
McGill, Geol. Sc.	15	59	3.93	15	71	4.60	21+1p	-
McMaster, Geol.	12	61	5.08	13	63	4.85	20	-
Memorial, Geol. Memorial, Geophys.	20 6	70 5	3.50 .83	20 6	82 6	4.10 1.00	13 2p	
Mount Allison, Geol.	4	16	4.00	4	18	4.50	4	
New Brunswick, Geol.	12	43	3.58	12	32	2.66	14	
Ottawa, Geol.	10	31	3.10	10	46	4.6	12	
[1]Quebec-Chicoutimi Sc. de la Terre	9(?)	57(?)	6.33	9(?)	57(?)	6.33	-	15(?)
Quebec-Montréal Sc. de la Terre	11	125	11.36	11	147	13.37	29	
Queen's, Geol. Sc.	21	143	6.86	19.5	181	10.30	31	11+4p
Regina, Geol. Sc.	7	21	3.00	7	16	2.28	7	-
St. Francis Xavier, Geol.	3	21	7.00	3	20	6.66	6	-
St. Mary's, Geol.	4	30	7.50	4.5	31	7.00	6	-
Saskatchewan, Geol. Sc.	16	88	5.50	16	101	6.31	12+1p	5+5p
Toronto, Geol. Toronto, Geophys.	27 9	198 7	7.33 0.77	28 9	206 14	7.36 1.55	20 2p	9 -
[2]Victoria, Geophys.	4	NA		4	NA		NA	NA
Waterloo, Earth Sc.	21	154	7.33	21	148	7.05	23	-
Western Ontario, Geol. Western Ontario, Geophys.	14 7	66 21	4.71 3.00	14 7	55 24	3.93 3.43	22 5p	-
Windsor, Geol.	10	39	3.90	10	60	6.00	5	3
[2]York, Earth & Envir. Sc.	4	28	7.00	4	43	10.75	4p	
TOTALS	458	2606	[3]-	456.5	2818	[3]-	485 +36p	112 +14p

[1] All data supplied by Department Heads with exception of that from Quebec Chicoutimi where figures were extrapolated from 1977-78 CIM statistics.

[2] Guelph, York geoscience units are part of larger departments which also turn out students in other specialities. Victoria does not graduate geophysics majors although it has geophysicists on staff and some of its graduates are employed as geophysicists.

[3] National student/faculty ratio in 1978/79 = 5.7, in 1979/80 = 6.2.

TABLE 3.2

ECONOMIC GEOLOGY COURSES OFFERED IN THIRTY UNIVERSITY GEOSCIENCE DEPARTMENTS

Name of Course	Compulsory	Recommended	Optional	Not Offered
Metallic Mineral Deposits (often called Economic Geology)	10	9	10	1
Industrial Mineral	--	--	--	30
Coal	--	--	5	25
Oil/Gas/Coal	4	8	10	8
Applied Geophysics	5	10	6	9
Applied Geochemistry	2	8	6	14
Mineral Utilization	--	--	1	29
Ore Mineralogy (and metallography)	--	--	4	26
Mineral Exploration	1	2	1	26
Mineral Economics	--	--	2	28
Finite Natural Resources	--	--	1	29
Nuclear Fuel Geology	--	1	--	29

TABLE 3.3

ACADEMIC QUALIFICATIONS OF GEOLOGISTS AND GEOPHYSICISTS EMPLOYED BY PETROLEUM COMPANIES WHO RESPONDED TO OUR QUESTIONNAIRE IN 1979

Name of Company	Geologists			Geophysicists			Other	TOTAL
	BSc	MSc	PhD	BSc	MSc	Phd		
Aquitaine	18	10	4	14	3	2		51
BP Canada	21	10	7	7	2	-	1	
Canadian Superior	25	3	3	18	1	-		50
Chevron Standard	36	11	7	30	21	0		105
Esso Resources (Can.)	43	16	5	45	10	1		120
Gulf Resources (Can.)	58	21	10	52	13	6		160
Home Oil	22	11	3	10	1	-		47
Hudson Bay Oil & Gas	46	14	6	32	3	-		101
Kaiser Oil	18	--	-	4	-	-	1	23
Mobil Oil (Can.)	30	19	2	37	4	1		93
Norcen	24	4	2	6	-	-		36
PanCanadian Petroleum	32	5	1	14	1	1		54
PetroCanada	52	15	17	43	13	4	2	146
Petrofina Canada	9	2	--	1	1	-		13
Shell Resources	55	22	10	23	17	8	1	136
Sun Oil	13	1	--	6	2	-		22
Texaco Canada	18	13	2	16	6	-		55
Union Oil (Can.)	33	14	4	19	6	2		78
	553	191	83	377	104	25	5	1338

4. POSTGRADUATE STUDIES

All graduate students need to find themselves on the frontier in some sense. They must catch the excitement of 'something lost behind the ranges .

Bonneau and Corry, 1972

IMPORTANCE

Most of those who have contributed to the conceptual growth of the geosciences in this century and many of those who have been able to understand such new insights and to translate them into practical applications to Canadian problems have been scientists who stayed in, or returned to university for study beyond their baccalaureates. In addition, almost all teachers in universities must have acquired some such advanced training as a minimum requirement for appointment. If there is a need to understand more fully the composition and structure of our vast terrane, and a need to instruct others to intelligently harness its resources, then there is a need both for strong postgraduate programs in our departments of geology and geophysics and inducements for our brightest graduates to enter them.

Whereas there are marked differences of opinion on the importance of research activities in relationship to undergraduate teaching, there are no such queries in regard to graduate studies where it is commonly understood that teaching and research go together. As stated by Bonneau and Corry (1972): "Given adequate support, there are no doubt many kinds of research that would go better and faster without the distraction of graduate teaching. But involvement of graduate students in research is axiomatic. It is also axiomatic that it should be heavily frontier research."

DEVELOPMENT AND PRESENT STATUS

Graduate studies have achieved an increasing importance in our geology and geophysics departments in the past 20 years. Prior to that time only McGill and Toronto produced significant numbers of geoscientists with Ph.D.s and most Canadians seeking doctoral level training studied abroad. For many years geoscience lagged behind other university disciplines in postgraduate training (Stearn,1968). This was probably because (as explained in Chapter 5) most research was tied to government and mining company field activities. The enormous increase in university research activity which began with the advent of NRC grants and the growth of staff in geology and geophysics departments in the 1960s led to rapid enrolments in graduate programs. Within a five-year span (Blais et al., 1971, Tables 11.36, 11.39, 11.40) the number of graduate students doubled and by 1968-69 there were 684 registered, which included 332 M.Sc. and 217 Ph.D. students in geology and 72 M.Sc. and 63 Ph.D. students in geophysics. This rapid growth and the keen competition for graduate students probably resulted in lowering entrance requirements in geoscience as it did in other disciplines (Bonneau and Corry, 1972). It also encouraged a large influx of foreign students so that in 1968-69 about 44 per cent of all geology and geophysics graduate students were non-Canadians and several departments were completely dominated by students from abroad. The rapid growth also upset the balance with undergraduate studies so that there were barely twice as many undergraduates as graduate students enrolled in geology and, the reverse of this in geophysics. Blais et al. (1971) pointed out another disturbing feature, the low graduation rate in M.Sc. and particularly in Ph.D. programs. For example, only 28 Ph.D.s in geology were granted in 1969 out of an enrolment of 217 and an enrolment three years earlier of 157. This suggested both a high drop-out or failure rate and an inordinate amount of time spent in completing degree requirements.

The rate of increase in enrolments levelled off somewhat in the 1970s, increasing about 30 per cent over a ten-year span. In 1978-79, there were 969 graduate students in the system comprising 278 Ph.D. and 579 M.Sc. students in geology and 54 Ph.D. and 58 M.Sc. students in geophysics. During 1979, 51 graduated with Ph.D. and 140 with M.Sc. degrees in geology and 8 with Ph.D. and 12 with M.Sc. degrees in geophysics. (Table 4.1)

The ratio of graduate to undergraduate students in geology is now about 1:3 and in geophysics about 1:1.5. Due partly to the increasing number of Canadian first-degree graduates to feed the system, but also due to immigration restrictions at home and abroad, the percentage of non-Canadian graduate students has declined from 44 to about 30 per cent. According to most department heads, entrance requirements are much more rigidly enforced now than ten years ago and a good second class honours degree (or equivalent) from an accredited university is the common, minimum entrance requirement.

In over half of our universities, geology now has the highest graduate student enrolment of any of the science departments. Although some of the 30 per cent growth over the past ten years is accounted for by new departments such as Waterloo (Tables 2.1, 3.1, 4.3), which soared from few or no enrolments to become among the largest in the country, many of the older departments such as Toronto, Western Ontario and Queen's have continued to grow steadily in the face of falling enrolments in sister sciences.

Although undergraduates now greatly outnumber graduate students in most departments, the numbers are roughly equal in geophysics at Alberta and in geology at McGill and Western Ontario. Only in geophysics at Toronto do graduate students outnumber undergraduate majors.

After comparatively late entries into graduate studies and not wholly successful attempts to become large and productive almost overnight, Canadian geology and geophysics appears to have settled into a period of slow, stable growth and rising standards of performance.

There are still trouble spots, however. Recent increases in employment opportunities have deterred most of our best new graduates from proceeding to advanced studies and are luring away many of those already enrolled. Immigration laws make it increasingly difficult to attract and support foreign students and a major decline in enrolment appears imminent. The average time required to complete a M.Sc. or Ph.D. degree, always long in comparison to other countries, is increasing and might account in part for the large number of dropouts in graduate programs. Graduate students in some departments protest the rigidity of formal academic requirements and the inadequacy of supervision. Scientists from outside the university circle regret the lack of innovation and slow response to national needs in graduate programs. Despite a vast increase in graduate enrolment, a lesser percentage of faculty members than ten years ago hold their highest degrees from Canadian departments. Industry queries the relevance of training in some of our graduate schools and faculty members regret industry's lack of support of graduate programs.

In the rest of this chapter we shall address these and other problems of graduate studies in geology and geophysics.

THE REQUIREMENTS OF POSTGRADUATE PROGRAMS

Two advanced degrees are offered in our geology and geophysics departments: the Masters which requires knowledge in a specific set of subdisciplines and proven ability at problem solving; and the Doctorate which requires a broad background in the fundamentals of the science and completion of a piece of original, frontier-type research.

The Masters

The Masters degree in geology or geophysics may be in Arts, Science or Engineering, according to the faculty or faculties with which a department is related. The degree awarded may, hence, be a M.A., M.Sc., M.A.Sc. or M.Eng., depending largely on the traditions of the university awarding it. An applied sciences degree (M.A.Sc. or M.Eng.) is usually only awarded to a candidate whose first degree is in engineering or applied science, although the course of studies and thesis may be no more pragmatic than that of a fellow student who may receive the M.Sc. or M.A. degree at the same university. In the ensuing text, for simplicity, we shall refer to all Masters as M.Sc. degrees.

Minimum entrance requirement is usually a good second class B.Sc. in geology or geophysics. Geophysics departments also commonly accept those with degrees in related subjects, e.g. mathematics, electrical engineering, and physics. Geology departments less commonly admit those from other disciplines although candidates with honours in biology, chemistry, and some branches of engineering are now being welcomed in a few departments. Geology's continually increasing interfaces with other sciences suggest that more departments should spread their postgraduate recruiting nets to attract graduates from other disciplines.

Three courses extending a full academic year (or six term courses) in addition to a thesis used to be a minimum requirement. Many departments have now lowered this to two full-year courses. However, students commonly have to make up undergraduate courses, particularly when they transfer to another university to commence their M.Sc. studies. Also, many students are asked to or elect to audit lectures in pertinent subjects often in different disciplines, as an aid to their thesis investigations. In a few special topics, e.g. mineral exploration, applied geochemistry and environmental geology, in universities such as McGill, Queen's, Toronto and Waterloo, a degree can be earned solely on the basis of course work. Some of these programs are especially designed for people from industry who wish to update themselves. In such cases, two full academic years are required in residence in order to complete ten or more full-year courses. The normal M.Sc. in Canadian schools is a thesis degree. Such programs usually have a one year minimum residence requirement (presumably to complete the course work requirements) and they have in common the fact that no one ever seems to complete them in this time! The average time required to earn a M.Sc. which involves a thesis is about three academic years. The maximum is usually four years but extensions are commonly granted.

Standards of theses vary. In many departments, particularly those oriented towards frontier research, the M.Sc. thesis is a substantial piece of research which is ultimately published in whole or part in one or more international journals. Such theses commonly go to outside readers for appraisals and faculty members proudly told some of our visiting committee members that such readers often suggested M.Sc. theses met doctoral standards elsewhere. At the other end of the spectrum are departments whose students produce descriptive works of mainly local interest which are seldom published except, rarely, as preliminary government reports or notes in trade journals. Despite these differences, however, there are minimum requirements for Canadian M.Sc. degrees in geoscience, wherever they are taken, that set them apart from some of the same degrees in other sciences and from many of those taken abroad. In this country the degree generally implies that the student has proved capable of reflecting upon and critically analyzing some of the fundamental tenets of our science and of undertaking and completing a research project.

In some old established U.K. and Irish universities, the Masters degree is obtainable merely upon payment of a fee some years following the award of the baccalaureate. In many leading U.S. universities, it is regarded as a casual interim step en route to the Doctorate, or as a consolation award for those who cannot meet the doctoral hurdles. Some science departments in Canadian universities have followed this U.S. practice and downgraded the M.Sc. into a stepping stone to Ph.D. studies (Bonneau and Corry, 1972). Our geology and geophysics departments, however, have hewed to traditions established before most of them became involved in Ph.D. studies. The terminal Masters degree is a sought-after goal in its own right and is highly respected by certain groups of employers who are fully aware of the high level of problem-solving ability that it represents.

The Doctorate

Twenty Canadian university geology departments offer Doctorates in geology and six of these also award them in geophysics (Table 2.1). In addition, seven geophysics departments (or sections of physics departments) offer Doctorates. The degree awarded is the Doctor of Philosophy which is abbreviated Ph.D. The Doctor of Science degree, D.Sc., is usually an honorary degree in Canada but at least one university, Saskatchewan, follows British counterparts by awarding D.Sc. degrees to former graduates who have published a substantial amount of scholarly work in their specialities.

Requirements for the Ph.D. are very similar across the country. The candidates must demonstrate proficiency in their general field of study and the ability to critically evaluate both old established concepts and the latest contributions in those subdisciplines closest to their special interests. This is accomplished by course work, seminars, oral and written qualifying and/or comprehensive exams, all of which must be completed with distinction. Finally, the candidates who survive these hurdles must present theses based on original investigations that represent worthwhile contributions to knowledge. These must warrant publication in whole or in part.

Entrance to Ph.D. studies varies slightly from one university to another. A few will accept direct entry with a first class Bachelor's degree, if the applicant has received high recommendations from his or her previous professors. Others require initial registration for the Master's degree and then arrange a transfer to Ph.D. studies if the candidate's performance warrants it. We estimate that over 75 per cent of current Ph.D. candidates in geology had completed all requirements for the M.Sc. degree before admittance to Ph.D. studies. Direct entries to Ph.D. studies are much more common in geophysics (or physics) departments.

Most Ph.D. programs require two academic years of residence, although one of these may be waived if the applicant has completed a Master's degree. The minimum requirement is three years beyond the Bachelor's degree commonly two years of course work with the candidate beginning thesis research during the second year and successfully writing it up at the end of the third year. The failure rate and dropout rate is high (possibly 30 per cent) up to and including the final comprehensive exam. It is at least as high beyond that point. Those who complete Ph.D. theses represent only about 40 to 50 per cent of those who register for them and, on average, the degree requires six years beyond the B.Sc. Although some complete it in less, many request and receive extensions beyond the usual seven-year limit.

Our Ph.D. degrees probably vary less in quality from one university to another than do our other degrees. They are prestige degrees. The subsequent performances of those few who receive them reflect not only on the department but on the individual supervisor(s) and on the university. The dean of graduate studies is commonly as interested as the department head in maintaining a high minimum standard. For this reason, most universities call on scientists from outside the university to read and appraise theses and to attend oral defences. Widely acknowledged experts are often brought in from across the continent or from overseas to sit in judgment on performances at this final hurdle.

British Ph.D. programs, in contrast to ours, are relatively unstructured and devoted almost wholly to the candidate's research. At the other end of the spectrum, American Ph.D. degrees involve a great deal of course work and comprehensive examinations before condidates embark on their research programs. It has long been maintained that the specialized U.K. graduate and the liberal arts U.S. graduate arrive at approximately the same state of competence by the time they earn Ph.D.s in their own countries. Canadian doctoral requirements fall in between those of the U.K. and U.S.A. but are skewed towards the latter. Correspondents from abroad inform us that our Ph.D.s, especially in recent years, are comparable in quality to those from the U.S.A. and the U.K. But, the average time required to gain a Ph.D. in Canada is almost double that in U.K. universities, and significantly longer than in U.S. universities. Further, there are some indications that the value of our advanced degrees, particularly in geology, is not fully appreciated by the community at large. This is not surprising in the case of industries that maintain only low levels of research activities in this country. It is astonishing in the case of the academic community, which guides and shapes our graduate programs, but resists hiring its output.

THE STUDENTS

Who are they?

Thirty per cent of the 946 graduate students enrolled in geology and geophysics in 1978-79 were from abroad (Table 4.2), studying in our universities on student visas and, presumably, scheduled to return to their own countries upon completion of their degrees. The remainder were Canadian-born or landed immigrants, practically all of whom were graduates of Canadian universities. Those from abroad are chiefly from the U.S.A. and U.K. with small but significant numbers from Australia, New Zealand, Middle East and Mexico and a wide, erratic scatter from many other countries of the world. Some schools consistently attract far more than the average from one locality or another, e.g. geophysics at Toronto has drawn in several Mexican graduate students over the past few years. Typical distributions of nationalities are illustrated by a very large and a medium-sized geology graduate school.

Queen's (1978-79): Afghanistan - 1, Argentina - 1, Brazil - 1, Canada - 36, Chile - 2, Colombia - 2, Guyana - 1, Mexico - 1, Trinidad - 1, U.K. - 4, U.S. - 5.

Memorial (1979-80): Canada - 20, Denmark - 1, Guyana - 1, New Zealand - 1, U.K. - 5, U.S. - 7.

In 1978-79, foreign students outnumbered Canadians at only one university, Acadia, and were approximately equal to them at British Columbia and Calgary. This is a great change from ten years earlier when several of our departments were dominated by graduate students from abroad. The present 70/30 mix is satisfying to faculty members and graduate students alike but it is doubtful that it can be maintained if job opportunities continue to lure our graduating students away from advanced studies, e.g. no graduates from Calgary, one of the country's largest undergraduate schools, have opted to continue on to graduate school in the past few years. The decline in postgraduate enrolment which began in 1979-80 (Figure 1.1) must be checked not only by pointing out the rich intellectual challenges to our own graduating students and making the programs less costly to them in time and money but also by relaxing government rulings to make it easier to attract and support first-class students from abroad. Currently foreign students are not eligible for Canadian NSERC grants and scholarships and cannot obtain work permits. Worries about cyclical increases in foreign student enrolment seem groundless as long as high standards are maintained. For example, many of the geology departments in the U.S. Ivy League schools had large numbers of Canadians enrolled following World War II and in some, such as Princeton, Canadians dominated the graduate schools for many years. Most of these U.S. schools are now proud of the distinguished contributions made by their foreign students of that era. Most Canadian professors state that students from abroad bring in fresh approaches that stir their peers (and their teachers) into new ways of thinking. They agree that a lively graduate group should include about one third foreign students.

We recommend that:

(1) *Faculty members make special efforts to advise their best undergraduate students of the challenges of postgraduate work. Visiting distinguished lecturers should be asked to touch on the importance of advanced studies and special guests from industry and government should be invited in to talk of the career advantages of postgraduate work.*

(2) *Company recruiters encourage the better students to continue their studies, possibly even employing them on a part time basis while they finish their postgraduate degrees.*

(3) *NSERC set an example to other agencies by increasing the value of their postgraduate scholarships by 50 per cent or more, and that the national awards committee seek out and publicize the reason(s) for the relatively few awards made in geology and geophysics and consider scholarship quotas to ensure graduates enter this most essential field.*

(4) *The Canadian Geoscience Council should directly contact Immigration officials regarding the need of special work permits for foreign graduate students in geology and geophysics.*

Interviewing representative groups of graduate students across the country gave the impression that at least half of them had worked for a year or more with industry or government before embarking on advanced studies. While many returned to their old alma mater for M.Sc. studies, almost all who continued to doctorates went to another school, usually upon the advice of their professors. In this practice we follow U.S. departments to advantage more than we do U.K. and European schools where all degrees are quite commonly taken at the same institution.

Females probably constitute about 15 per cent of our total graduate enrolment. This is somewhat less than the percentage of current undergraduate enrolment. Several department heads reported a steady increase in female enrolment and it is likely that the undergraduate percentage will soon be reflected in our graduate schools. Table 4.4 illustrates female population of geology departments from which data were readily available. We have no data on geophysics but our impression from visits was that there were relatively fewer female graduate students in this field.

What are they studying?

Graduate students have the opportunity to focus on a great variety of subdisciplines according to the advertisements of our geology and geophysics departments (Appendix 4A). Listing of areas of research by 28 departments (Table 4.5) and a breakdown of faculty members' NSERC research grants by topic (Table 5.1) bear out this wide availability.

These data also show the areas that attract the most students and the areas that are relatively neglected, if only in a general way, however, because professors and others who categorize the subdisciplines vary in their emphases and terminology. Thus, what is classified as economic geology by one might be called mineralogy by another; similarly, inorganic or physical geochemistry to one might mean petrology to another. Nonetheless, some fields of strong concentration and others of neglect are clearly indicated.

The strongest emphasis in 1978-79 was in economic geology (Table 4.5) which occupied 150 graduate students. Economic geology is virtually synonymous with metallic mineral deposits in the minds of most respondents although a few studies of nonmetallic industrial minerals are also included in this list. The 13 students involved with exploration geochemistry and the 23 with exploration geophysics also focus on metallic minerals so nearly a quarter of all Canadian graduate students are directly involved in study and research involved with this commodity.

The second most common area of focus is petrology, with rather more emphasis on igneous than metamorphic rocks, an area stated to involve 95 students. Most of those 36 listed under physical and inorganic geochemistry, many of the 48 in isotope geochemistry and geochronology, and some of the 13 in mineralogy are closely allied to those in petrology. We can safely state that a quarter of our students are concerned with petrology and closely related fields. Most of these students would be most adaptable to metallic minerals if considering employment in industry, hence half of our M.Sc. and Ph.D. enrolments is slanted towards this economic area.

Structural geology and tectonics occupied 52 students who could probably be equally useful to either the petroleum or mineral industries. The 55 in sedimentology, 49 in paleontology and palynology and the 36 in stratigraphy, less than one quarter of total enrolment, could gravitate towards the petroleum industry if suitable jobs in government or universities did not materialize.

Despite the increasing demand for terrain research related to road and pipeline construction and to the disposal of toxic wastes, relatively few (23) graduate students are registered in Quaternary studies. Encouraging, however, is the surge of registrants (26) in hydrogeology, a field where we have belatedly acquired research competence, chiefly at Waterloo and British Columbia.

Surprising are some of the geological fields that seem to have attracted little or no response from graduate students, e.g. coal geology, petroleum geology, organic geochemistry and marine geology. In 1978-79, coal geology had only two adherents. Understandable when one realizes that, until a year or two ago, no research in this field was underway at any Canadian university. Modest starts have now been made at Alberta, British Columbia and Regina but the response has been slow to continuing demands on the universities to initiate activities in this field (Neale et al., 1975). Meanwhile, companies and government agencies continue to import coal researchers, especially petrographers and geochemists, from the U.K., U.S.A. and Australia, and to attempt to retrain other scientists.

The dearth of graduate students in petroleum geology may be more apparent than real. Only one department (Regina) lists it as a major interest (Appendix 4A), only two professors receive NSERC grants for research in it, and only five graduate students are listed as concerned with it (Table 4.5). About one quarter of all graduate students, however, are enrolled in studies such as stratigraphy, structure, paleontology, and sedimentology that are directly related to petroleum geology. Some petroleum company respondents to our questionnaire regretted that these studies were not more pointedly related to petroleum problems, e.g. porosity, permeability and diagenesis. They also deplored the reluctance of universities to promote graduate studies in new fields such as organic geochemistry, so pertinent to hydrocarbon exploration and resource evaluation. Graduate students and professors reply that petroleum companies show little initiative and less hard cash in promotion of research oriented towards their speciality and that they offer little or no extra rewards for those who undertake advanced studies. There is obviously a need for company and university groups to meet, discuss and make recommendations concerning the emphases and financing of graduate studies in geology and geophysics. The few satisfactory arrangements underway, e.g. financing a chair of geophysics at Calgary, merely point the way to the much greater collaboration needed on the national scene.

The most popular area of specialization in geophysics departments is seismology, partly or wholly inspired by employment in the petroleum industry. The 28 M.Sc. and Ph.D. students in that area in 1978-79 (Table 4.5) represent nearly a third of all geophysics students. At Alberta almost all of the 22 students were engaged in seismic studies. The regret of some of them, particularly the Ph.D.s, was that in order to continue in research they would have to leave the country and join the laboratories of the multinational oil companies. The other strong enrolment trend is in exploration geophysics which includes 23 students concerned with metallic mineral deposits, chiefly at Toronto but also at Ecole Polytechnique and McGill. Geomagnetism and paleomagnetism, two fields where Canada has gained international acclaim, attract few students (Table 4.5) because employment opportunities are limited.

Marine geology and geophysics can be pursued at the graduate level in six universities: Rimouski, Dalhousie, Queen's, British Columbia, McGill and Victoria. Only nine geologists and two geophysicists were enrolled in 1978-79. The programs in these schools are underfunded and understaffed and they are also insufficiently advertised. Canada has opted to fund its oceanographic research through government agencies rather than universities and, if we plan to produce our own marine geoscientists instead of sending students abroad for training or relying on immigrants, our government scientists must play a more active role in graduate training and supervision as they now do at Dalhousie University. Ultimately marine geoscientists in the universities must attract large amounts of money from both government and industry to establish adequate facilities and ensure ample ship-time. This has been successfully accomplished for research in marine engineering at Memorial and the nation would benefit from a similar aggressive university initiative in marine geoscience.

In summary, over half of our graduate students programs are involved with crystalline rocks and their economic deposits, divided equally between metallic minerals and petrology/geochemistry/geochronology. Our graduate schools are slow to move into new fields, e.g. organic geochemistry, or to strengthen classical areas where demand is growing, e.g. Quaternary studies. Praiseworthy growth is taking place, however, in hydrogeology and, finally, starts have been made in coal geology. Those segments of the community who criticize the weaknesses and gaps in our graduate programs make very few serious initiatives to remedy them. This might be partly due to staking out of preserves and an unwillingness to share by government scientists and partly by the lack of frontier-type research in our dominantly branch-plant mineral and petroleum industries.

Respondents from industry seemed particularly unaware of the scope of graduate studies, government geoscientists were also partly uninformed. Professors in several departments were out of touch with postgraduate activities at other schools and unaware of criticisms levelled by government and industrial scientists. We recommend that:

(1) *The Council of Chairmen of Earth Science departments should produce annually a report on enrolment, number of graduates in the past year and postgraduate research projects underway. This report should be widely circulated and articles based upon it prepared for the Northern Miner, Oilweek and other widely read technical news magazines.*

(2) *Views on the annual report of graduate studies should be sought from provincial scientists in industry and government and also from the appropriate divisions of national societies such as GAC, MAC, CIM, CSPG, KEGS, CSWL and CSEG. Constructive comments on current projects and suggestions for new emphases should be circulated by the Council of Chairmen to all geoscience departments.*

Where they study and why

The largest group of geologists and geophysicists are at Toronto where 91 were enrolled in two departments in 1979-80 (Table 4.3). The next is Queen's geological sciences which was once the largest individual department with 78 students in 1977-78 and now, with 66, ranks second only to geology at Toronto (71). Other large graduate enrolments are at Waterloo (53), Western Ontario (50), McGill (48), British Columbia (47), Manitoba (46) and Alberta (45).

Two of those named, McGill and Toronto, are our oldest established graduate schools. McGill's enrolment is practically identical to that of 30 years ago, although it has been higher in some of the intervening years. Toronto's, which in the past was smaller than McGill's, has fluctuated but has increased steadily and rapidly over the past several years. Geology at Queen's, British Columbia and Alberta has had a comparatively long history of graduate studies by Canadian standards. The first two have for many years been the largest undergraduate departments in Canada and undoubtedly have drawn many of their M.Sc. students from among their own graduates. Also, the three have had long and successful ties with industry, particularly the metallic mineral industry, where their graduates are prominently placed. All five of these schools attract graduate students on the basis of their reputations and by referrals from former graduates, in addition to those they attract on the basis of their programs and faculty specializations.

The other departments with large graduate enrolments are new or relatively new to the scene even though some are in old established universities. Waterloo (53) and Western Ontario (50) are the largest of these. Others include Manitoba (46), Carleton (41), McMaster (36), Memorial (36), Calgary (34) and Saskatchewan (30). The students who are referred to or independently choose to attend these schools are commonly attracted by specific fields of excellence, e.g. low temperature geochemistry and environmental geology at Waterloo, mineral deposits geology at Western Ontario, or sedimentology at McMaster. Random queries of graduate students suggest that most but not all of this second group of departments were the first choices of most of the students in them. In this regard they were at least equivalent to the five traditional schools; in fact, some of them had many students who claimed to have turned down offers from one or more of the established five.

Many of the smaller departments also attract first-rate students through their specialities, e.g. Dalhousie (25) where marine-oriented geoscience is probably the best in the country. Other small schools are populated with a fair sprinkling of students who have been turned down by the larger, stronger schools. They also, of course, attract some very good students for a variety of reasons: personal whims, the drawing power of outstanding researchers and staff, or the recruiting (promotional?) abilities of some individual faculty members. Most of the smaller departments do not offer the doctorate - in Ontario by government (ACAP) decree, elsewhere by decisions taken within individual universities. It is interesting to note that many of these "small" departments have twice the staff that McGill had in 1950 when it had 50 students enrolled with about a third of them in Ph.D. programs. How times have changed!

The Francophone universities of Québec are special cases. Chiefly their students come from within the province, graduates of one of the three major schools: Laval, Ecole Polytechnique and Montréal. Their several distinguished scholars also attract a handful of Francophone and bilingual students from elsewhere in Canada and from abroad. One former department head complained that the present language policy should not have been extended to advanced studies. He claimed that it was producing an ingrown situation whereby many students took all three degrees at the same university.

SUPERVISION OF GRADUATE STUDIES

An M.Sc. student will have a single faculty supervisor in some schools whereas in others there will be an advisory committee of three, one of whom will be chief adviser or supervisor. A candidate for the Ph.D. degree will generally have a major supervisor who is chairman of an advisory committee of three or four. One or more scientists from industry, government or another university may be members of the advisory committee, especially when they have been involved with the research project. Rarely is an outsider the main supervisor but there are examples of this, particularly in the case of adjunct professors drawn from government agencies.

One of the most common complaints we heard from graduate students concerned lack of adequate supervision. It was also a complaint levelled at some universities by members of government agencies.

In most departments, all faculty members have permission to supervise M.Sc. students. Recently, in some departments, those aspiring to a supervisory role must have some published research to their credit and suitable personalities to undertake close working relationships with students. It is not a tough hurdle (although it is becoming more so) and currently few aspirants are rejected for an M.Sc. supervisory role.

In the past, supervisors for Ph.D. students were chosen in much the same manner with assignment taking place within the department without screening and assessment. Within the past ten years, graduate schools have been setting minimum standards and establishing screening committees to study the research records of potential supervisors and, in some cases, to examine their success in M.Sc. supervision and on Ph.D. committees before approving them as supervisors. The procedure is irksome to vigorous young faculty members with active research programs underway who regret the time lag occasioned by the proving process. More serious, however, are those who are on the approved list by virtue of a "grandfather clause", the almost two thirds of our faculty members who had approval to supervise graduate studies at all levels before screening processes were introduced. Also worrisome is the seeming lack of future checks upon those who have received initial approval. Professors with passing years, may switch their main focus from research to undergraduate instruction or community service (not necessarily to golf and sailing as detractors claim!) but still retain the permission to supervise Ph.D. students who may be attracted to work with them on the basis of earlier accomplishments. So much status is placed on research and graduate studies in most of our universities that many professors are reluctant to relinquish their activities in these fields even when their interests have shifted to other, probably equally useful endeavours.

Department heads advised us that the possibility of students ending up with inadequate supervisors is relatively small. They claim that word spreads through a department quickly and students tend to avoid becoming entangled with the less capable advisers. Students disagree, claiming that this might work for those who stay on in the same department from which they graduated but leaves newcomers at a disadvantage.

In many departments incoming students are assigned a supervisor or adviser either before arrival or upon arrival. In the best cases, this person corresponds with the student long before his arrival, outlines possible thesis topics, sends him copies of pertinent reprints and describes the financial support he is likely to receive. In the worst cases, students are assigned almost on an ad hoc basis to any faculty member who has the grant money to support them or who has mild interests in their fields of interest or who feels it is "his turn" to supervise a graduate student. Graduate students are free to change from one supervisor to another with mutual consent. It may take a year of residence, however, for a student to realize that his assigned supervisor is incapable (temperamentally or scientifically or both) to provide much help with his research project. He may think twice about wasting part or all of this year in order to switch supervisors, possibly topics and possibly universities. In his exploration of the grounds for belief in science, Ziman (1978) states: "It is impossible to learn a science without a good deal of faith in the competence and sincerity of one's teachers....". Such faith is lacking among some of our graduate students.

One discovery that surprised us was that inadequacy of supervision was not necessarily related to numbers supervised. Some faculty members who supervised eight or ten (hopefully with some relief from other duties) were highly regarded by their students. Others, who supervised only one were disliked as selfish and incompetent!

Graduating students commonly choose a graduate school at the suggestion of favourite professors in their departments. Our visiting committee found many professors remarkably ill-informed or misinformed about the strengths and weaknesses of other Canadian geology and geophysics departments, often including those within the same province. This criticism was especially applicable to some of those in the smaller departments but by no means confined to them. The best informed professors were those who were currently or had recently been involved with national lecture tours or committee work which had taken them to universities around the country.

Geology and geophysics departments almost all emphasized a research-based thesis as the major requirement of an M.Sc. Such theses surely require supervision by active researchers or by people whom their colleagues recognize as concerned, informed scholars whose involvement with reflective inquiry will provide a major resource to the graduate students under their supervision. All of our geology and geophysics departments regard Ph.D. studies, not as a training program based on a narrow problem but rather what Bonneau and Corry (1972) call"...an arduous apprenticeship on the upper slopes of the unclimbed peaks of knowledge, with the possible honour of sharing in a first ascent". Most Canadian Ph.D. candidates are in good company on such climbs but, if we can judge by recent research records, some are being led by flabby gurus who don't know the ropes sufficiently well to guide the final precipitous ascent.

We see two potential solutions to the problem of inadequate supervision. A strong department head can steer students away from incompetent supervisors or convince such faculty members that it is not in their interests to supervise graduates. As mentioned in Chapter 2, our university system does not necessarily encourage the appointment of good managers as department heads. Nevertheless, we have some and a few of these exercise great care in choosing supervisors of graduate students. The other solution is in the hands of the graduate students themselves. With declining interest in graduate studies, good students are in great demand so they can insist on good training and competent supervision of their research. They should write before graduation to potential advisers in several departments, find out what these people have published, how active they are currently and what choices of thesis topics they can offer and competently supervise. Moral: Don't rely on the advice of your kindly old Prof. (who might be 25 or 30 years out of date) but do it yourself. We recommend that:

(1) *Before enrolling in graduate studies elsewhere, students should seek the views of graduate students currently enrolled (possibly through the graduate student club) on the quality of supervision practiced in the various subdisciplines. They should also correspond directly with their potential supervisor to obtain some measure of his or her activity in the chosen field.*

(2) *Department heads should firmly guide inadequate researchers and inept supervisors away from direct supervision of graduate students even though such professors may be officially approved supervisors on the basis of past records.*

HOW ARE STUDENTS SUPPORTED?

Whereas undergraduate students rely chiefly on parental support, savings from summer employment and bank loans, postgraduate students seek and generally receive less precarious support. It comes in a variety of ways: NSERC scholarships, provincial scholarships, university scholarships and teaching assistantships, contributions from professors' research grants, part salaries or retainers from industry or government agencies, and from summer employment.

Possibly the most prestigious awards are the NSERC 1967 (Centennial) scholarships which, in 1980-81, will be valued at $11 200 per annum. These are awarded to students with top marks following personal interviews by a national committee. Very few geology or geophysics students have been awarded these, possibly because it is very difficult, if not impossible, to score very high marks in the geosciences. There are also a few prestigious industrial scholarships, open to the physical sciences and engineering, which are occasionally won by geology and geophysics students.

NSERC scholarships, valued at $7000 per annum in 1979-80, are awarded by a national committee whose members choose between candidates nominated by the graduate schools of our universities. As nominations at the university level involve competition between disciplines, grades play a large part in the decisions. As shown in Table 4.6, geology and geophysics fare badly in comparison with other sciences either because of the difficulty of obtaining high grades or because only the duller students enter the geosciences. If it can be shown that the latter is not the case, possibly NSERC could be convinced to set up scholarship quotas for the various disciplines just as they have set up certain sums of research grant money for each of the many science groupings. As NSERC scholarship winners can hold their awards at a university of their choice, some professors maintain that the number of scholarship holders captured by a department is a good measure of its quality. Queen's, with eight such scholarships is the obvious leader in this regard (Table 4.6). Needless to state, there are many who challenge the significance of this interpretation! We recommend that:

NSERC set an example to other agencies by increasing the value of their postgraduate scholarships by 50 per cent or more. Also, that their national awards committee seek out and publicize the reason(s) for the relatively few awards made in geology and geophysics and consider scholarship quotas to ensure graduates enter this most essential field.

Recipients of NSERC research grants are currently permitted to support their graduate students up to a maximum of $520 per month. In some departments, faculty members pool portions of their grants to jointly support one or more students. As faculty members have to bring their research to the stage of publication in reasonable time in order to have their grants renewed, they have a vested interest in prodding students to complete and publish theses. On the whole it is a very effective system although it does lead to some abuses, e.g. multiple publications and unearned co-authorships.

Universities, particularly the older ones, have several or many endowed scholarships, some open only to geoscientists, others open to all scientists. Most provinces also offer scholarships only open to residents and only tenable at universities within the province. These currently range from $2000/term in Ontario, $6000/annum in Alberta to $2500/annum in Newfoundland.

Teaching assistance is another common source of income. Assistants aid with laboratory preparation and instruction, correction of tests and other related chores. Contact hours vary from three to six per week and incomes from $1500 to $2000 per term. The experience is valued by most graduate students, including those with adequate other income.

Finally, many graduate students work with industry or government agencies at prevailing rates during summer months. In some cases this work is related to partially sponsored theses projects, in others it represents a complete break from their research in order to bolster finances and gain practical experience. Some departments encourage this latter practice, others strongly discourage it for it greatly lengthens the time required to complete a thesis.

Most departments attempt to even out the financial rewards by combinations of scholarships, grant money and teaching aids. They establish minimum incomes for those who are not working for salaries in the summer months. The minimum total stipends were remarkably uniform in 1978-79: slightly over $6000 in western universities and slightly under $6000 in the central region. In the Atlantic region, however, they varied from a high of $6000 at Memorial to $3300 at Acadia. Students generally have to pay their fees from these stipends, $500 to $800 for Canadians and double that for foreign students.

A major problem of financing concerns foreign students. They are not eligible for NSERC scholarships or support from grants. Present immigration and manpower rulings make it very difficult for those on student visas (or their wives or husbands) to obtain work permits which would make it possible for them to accept summer employment. University scholarships are usually the only source of income open to them. It is increasingly difficult to provide them with the stipends that departments consider desireable minimums. We recommend that:

The Canadian Geoscience Council should continue to make representation to elected members of Parliament and also should directly contact Immigration officials regarding the need of special work permits for foreign graduate students and their wives during this period of declining enrolments in geosciences in our graduate schools.

At present almost all basic support of graduate studies comes through Provincial support of the universities and through Federal scholarships and grants-in-aid of research. In a mixed economy it would be healthy to spread this support to include more than the present token industrial contributions. We recommend that:

(1) *Faculty members, individually and collectively, seek to impress upon management of petroleum and mining companies the importance of graduate studies to these industries and the true cost of supporting student research projects i.e. a minimum of $15 000 per annum for the simplest of projects).*

(2) *Managers of industries related to the geosciences offer scholarships (at least the equivalent in value of NSERC scholarships) to those university departments that have consistently supplied them with capable M.Sc. or Ph.D. graduates in the past. Further, that they undertake full support of some postgraduate projects in fields related to their industrial interests instead of relying almost wholly on government to support such applied training.*

WHY DO THEY TAKE SO LONG?

The fastest, surest way to attain an M.Sc. is to enrol for a degree without thesis requirement such as those offered in special applied topics at McGill, Queen's and Waterloo. They require two academic years. Although the M.Sc. thesis program requires only a mandatory year in residence, the degree actually takes an average of over three years for geologists and geophysicists. There is no sure way to a Ph.D. but the best possibility of attaining this degree in minimum time would be to register at a U.K. or Irish university where it could be achieved in three to four years rather than the average of over six for geology and geophysics in a Canadian university.

Most professors regret the excessive time spent on M.Sc. degrees. They feel that two academic years should be an absolute maximum and many department heads, especially in geophysics, claim to be applying pressures (e.g. cutting off financial aid) to force students to complete programs on schedule. In interviews with students, we encountered many exceptions to such stated hard lines! Table 4.1 tells the tale in terms of the percentage enrolled in 1978-79 who received their degrees in that year.

Professors have mixed feelings in regard to the time spent on Ph.D. degrees. Some state that three years should be common and four the average. Others state that this is often the only time or one of the few that a scholar has in his lifetime to work singlemindedly towards the solution of a fundamental problem in science. This latter group of professors feels that a Ph.D. student should be supported financially as long as he or she is working productively towards a worthwhile goal. Our visiting committee members were more influenced by the first point of view, again we quote from Ziman (1978): "Experienced scientists know that real progress in research is slow and painful, and that it is often better to publish an interesting and novel idea, however incompletely explored and inadequately comprehended, than to keep it private until all its implications have been understood". Students deeply involved in complex problems should be encouraged to write up preliminary or interim results as Ph.D. theses and to pursue their problems, without break, in the capacity of postdoctoral fellows. This policy could lead to less malingering Ph.D. students in the system (many of whom never complete their studies) and more postdoctoral fellows, possibly at no greater cost to the country.

Reasons given by professors for the length of the Canadian postgraduate degree programs are: (1) Involvement with summer jobs not related to thesis topics; (2) Part-time service and consultative work for industry (most prevalent in some large western universities); (3) A fondness for academic social life and a consequent lack of drive to complete projects; (4) Tendencies to take on overly complex problems and to spread their interests widely instead of focussing on specific aspects; (5) Accepting jobs before completion of degrees and attempting to complete theses in absentia. Those not-in-residence (N.I.R., Table 2.1) have a high rate of non-completion and those who do finish usually require time extensions that add greatly to the statistical average for duration of studies. Manitoba has the largest number of students attempting to complete their degrees in absentia, almost two thirds of their large enrolment.

Graduate students see the problem from different viewpoints, and cite these reasons for their lengthy sojourns: (1) An excess to repetitive, unnecessary course work - a common complaint of those with M.Sc. degrees who transfer to Ph.D. studies elsewhere; (2) Inadequate supervision and guidance - starting with ill-advice on choice of thesis topics; (3) Inadequate financing which requires months away from research in order to augment income to subsistence level; (4) Demands of teaching assistantships, far in excess of the stated hours; (5) Pressures from faculty members, often in other subdisciplines, to expand projects in order to take advantage of new facilities and equipment in departments.

Our committees' conclusions were that serious attempts should be made to drastically reduce the time involved in M.Sc. and Ph.D. studies. This would require strong departmental managers who could eliminate incompetent or disinterested supervisors from graduate programs; adequate remuneration (with NSERC setting the examples) so that students need not seek outside income; and reasonably enforced deadlines at various stages in the system. This would probably result in lower enrolments, for the first deadlines would cut many from the system, but in the long run it would result in far less wastage and probably more and better theses submitted annually. To return again to an analogy used by Bonneau and Corry (1972), those who are in a position to make "a first ascent on a peak of Knowledge" should be encouraged to continue the climb for a few years, but as postdoctoral scholars with the perks, privileges and salaries of assistant professors. Those who have proved themselves capable of achieving respectable altitudes but with little hope of attaining the summit should be allowed to leave before they become bored with climbing, so that they can chart new or follow old routes up other peaks of Knowledge. We recommend that:

(1) *There should be stricter quality control of students admitted to graduate studies. Many of the marginal students could be diverted to the postgraduate Diploma programs recommended in the preceding chapter.*

(2) *Heads of departments should ensure that deadlines for degrees should be established at the outset of studies and reasonably adhered to, e.g. comprehensive exams and Ph.D. orals should not be repeatedly postponed as in many current practices.*

(3) *Departments should encourage direct entry into Ph.D. studies instead of requiring a proving process at the M.Sc. level. Four years should be set as the common maximum duration of Ph.D. studies and those involved with complex problems encouraged to pursue them as postdoctoral scholars.*

EMPLOYMENT OF M.Sc. AND Ph.D. GRADUATES

During 1979, 51 geologists and eight geophysicists received Ph.D. degrees and 141 geologists and 16 geophysicists received M.Sc. degrees. Our information suggests that this may be a record high for geologists although more geophysicists have graduated in past years. We unfortunately have no hard data on employment but conversations with faculty members across Canada suggest that 10 to 15 per cent leave the country upon graduation. This includes a few Canadians and landed immigrants taking jobs abroad but consists chiefly of about half of the visa students returning permanently to their homelands. Most of the other visa students arrange employment connections in Canada and then return briefly to their home countries so that they can return as landed immigrants. The remainder of the postgraduate students join federal or provincial agencies or industry, chiefly in mining and petroleum with a small but increasing number going to engineering and utility companies. A few, about five per cent, go elsewhere, e.g. M.Sc. graduates into high school teaching and Ph.D.s into university teaching or postdoctoral research.

University professors in graduate schools are commonly accused of turning out students in their own images, fit only to be employed in universities. Sad, if true (it isn't) because very few of our geology Ph.D.s are hired by Canadian universities. Ten years ago (Blais et al., 1971), 90 of our geology professors held their highest degrees from Canadian universities. Today, 100 professors have this distinction - a net gain of one per year! A Canadian geology student aspiring to eventually become a professor is well advised to seek training in a university abroad! Geophysicists fare somewhat better, 21 had Canadian doctorates 10 years ago and 47 have them today (61 per cent of total staff in our geophysics departments). The few who take geophysics doctorates in our universities have a very good chance of becoming academics. Canadian doctorates in geology are highly regarded outside of our country and two professors estimated that about 30 of our Ph.D.s (nationals or landed immigrants) had joined faculties abroad (chiefly in the U.S.A.) during the last ten years.

Geologists and geophysicists are recruited at the doctorate level by federal research agencies. Although much of their research is mission-oriented, it often does not differ greatly from that undertaken during thesis projects, and federal scientists commonly publish part of their research results in the same international journals as their academic counterparts. M.Sc. graduates generally become involved in applied research, research support, or regulatory roles in federal agencies.

Provincial agencies hire both M.Sc. and Ph.D. graduates. Their work is similar to some of that of the federal agencies, concerned with building up data bases and with resources appraisal. On the whole it is more pragmatic and descriptive, however, and most results appear as government maps and reports with relatively little appearing in the scholarly journals. Newly hired postgraduates are apt to find themselves more heavily involved in gathering and assessing factual material and less concerned with conceptual advances than in the university milieu.

Many of those who join industry find themselves even further removed from the atmosphere of frontier research that pervades graduate schools. Only a few of the very large metal mining companies and a few small, highly innovative service companies have laboratories that employ research geoscientists on fundamental problems of metallogenesis and exploration science. Similarly only a few of the major petroleum companies in Calgary have research divisions, one being the recently formed national company, PetroCan. Most of the large multinational concerns carry out their research elsewhere and if Canadian Ph.D.s are hired in a basic research capacity, they are likely to end up in Texas or Oklahoma as did most of our small crop of Ph.D. geophysicists in 1979. Unless tax laws make it attractive or even imperative to relocate parts of the multinational research laboratories in Canada, they will continue to remain abroad, conveniently close to headquarters. Tax incentives or penalties might also be used to press some of the larger Canadian-owned companies into fundamental applied research, either in their own or nearby university laboratories.

Apart from the few who join industrial research laboratories, those with advanced degrees have two initial career possibilities with industry: specialized service work or operations. The approaches to each differ between industries, mainly because the large petroleum companies have traditionally provided intensive, carefully structured training programs for their recruits and most of the mineral exploration companies do not provide elaborate, formal training.

The larger petroleum companies hire specialists in fields where only a few people are required and where in-house training would be expensive and impractical, e.g. micropaleontology, palynology and, to a lesser extent, geochemistry, sedimentary petrology, clay mineralogy and geophysical data processing. These positions are filled by recently graduated Ph.D.s and also by senior researchers lured away from government or academic posts. Such specialists are not usually part of a company's hierarchical administrative system. Unless they transfer to operations, they are unlikely to end up as senior managers. Smaller companies call upon consultants, both at home and abroad, for such services. The need for such specialist services has caused a recent growth of consulting firms offering sophisticated, high technology services employing many scientists with postgraduate research training.

The operations divisions of the large petroleum companies, concerned with outlining plays and developing fields, rely on teams of scientists who have trained together and continue to work closely together. Recruitment for these posts places no premium on postgraduate research training. Most companies claim that they prefer to hire at the M.Sc. level (although they provide only small initial compensation for the extra training), but they are generally quite satisfied with bright, well-trained, B.Sc. graduates. They see little advantage in hiring Ph.D.s as such recruits have to start training on an approximately equal footing with M.Sc. and B.Sc. counterparts. A few senior company people stated that the only advantage to hiring Ph.D.s was that they represent an upper stratum of intelligence. Most stated that they were reluctant to hire Ph.D.s because, with their narrow research fixations, they tended to be inflexible and slow to reconcile themselves to the very different objectives of applied research in petroleum operations. Despite these attitudes, we estimate that the percentage of geologists with advanced degrees in the upper echelons of senior management is well above the 25 per cent population in the industry as a whole. Also, there are a surprisingly large number of Ph.D.s, many taken in subjects completely unrelated to petroleum, who are now chief geologists, exploration managers or vice-presidents of major companies. Possibly they succeeded in spite of their university training! The smaller petroleum companies tend to seek the services of those who have received in-house training with the larger companies. Most of them seem to hire at the B.Sc. level, less commonly at M.Sc., and rarely if ever at the Ph.D. level.

The mineral exploration companies resemble the petroleum companies in that about 25 per cent of their geoscientists hold advanced degrees. The spread differs, however, in that many small companies employ Ph.D. and M.Sc. scientists. Their role, presumably, is to bridge the gap with researchers in government agencies and universities, translating new concepts into exploration techniques. This, presumably, is the mineral industry's equivalent to the training programs of the major petroleum companies. Instead of building up platoons of in-house specialists apart from their operational groups, mineral exploration companies have traditionally relied on consultants for sophisticated analyses and surveys. There are many old established consulting firms, small and large, well stocked with Ph.D.s and M.Sc.s, which have established fine international reputations for sophisticated geophysical, geological and geochemical surveys. Geologists and geophysicists with advanced degrees have traditionally filled major technical posts and senior management positions in small mineral exploration companies. However, unlike the oil industry where almost all senior management people are geologists or engineers, the large mining exploration companies have always leaned towards accountants and business school graduates. There are indications of change in the past few years and more geoscientists, including Ph.D.s, are moving into the higher echelons.

Operational divisions of industry are, ultimately, the largest group of employers of geoscience postgraduate students. In their replies to our questionnaires, many operations managers made unflattering comments on university postgraduate studies and research. Nonetheless, most of them seem to prefer those with M.Sc. degrees to any other level of training. Those with Ph.D.s are certainly more welcome in mineral exploration than in petroleum operations. Regardless of welcome, many of them have met with highest success in both.

We recommend that:

(1) *The Canadian Geoscience Council should petition Cabinet to encourage frontier research in applied geoscience by mining and petroleum companies based in Canada so that more of our graduating Ph.D.s can continue with fundamental studies instead of having to accept employment in operational or service roles.*

(2) *The Canadian Geoscience Council should send informed individuals or groups to talk with industrial policy-making bodies, such as the Canadian Petroleum Association and the Mining Association of Canada, on the importance of strong graduate schools of geology and geophysics to the mining and petroleum industries and the need for much greater industrial support of such schools.*

(3) *The commendable practice of some federal and provincial agencies of involving both faculty members and students in their research should be expanded. This practice allows graduate students to serve apprenticeships for later permanent jobs with agencies. Expanding and broadening the practice could permit training in those specialized fields which presently require recruitment abroad.*

(4) *The cosmopolitan aspect of our geology departments deserves admiration - 73 per cent of faculty members have received their higher degrees abroad. We note, however, that there has only been a net increase of one Canadian trained geologist per year for the past ten years and we urge search committees not to disregard the products of Canadian geology and geophysics departments when filling vacancies or new positions.*

SOME VIEWS ON GRADUATE STUDIES

Discussions with graduate students at about half the universities we visited, faculty members representative of most departments and a few individuals from industry and government introduced additional, partly contradictory views on graduate studies.

Graduate students' opinions

Our visiting committees concluded that graduate students were generally more dissatisfied than the undergraduates to whom we talked. There were notable exceptions to this generalization which only served to underscore its validity. In addition to complaints about poor supervision and lack of adequate financial recompense when employed upon completion of their degrees, students in some departments were disenchanted by their poor communication with the faculty members. Graduate students today tend to regard themselves as sought after young professionals (like their classmates in industry) rather than the humble apprentices of yesteryear. They resent the paternalism and the relatively rigid rules they find in some of our graduate schools. Those who have earned M.Sc. degrees elsewhere are often particularly bitter about demands for extensive additional course work before they are allowed to proceed with research projects. In several departments the graduate students emphasized the lack of rapport and informal contacts with any except the very youngest faculty members. As one put it: "After the warm Madison Avenue-type welcoming letters that attracted us here, we arrive to find no one is remotely interested in us...".

New graduate students undoubtedly have an exaggerated sense of their importance which is unfortunately ignored by faculty members who have seen hoards of them come and go over the last 20 years. Our visiting committees were impressed, nonetheless, that departments with genuinely close, easy relationships between faculty members and graduate students were commonly the departments with good reputations for research and for the quality of their graduate students.

Some comments from industry

Petroleum industry

The major criticism of petroleum company respondents is directed at the overemphasis that most eastern schools and some western schools have placed on metallic mineral deposits and crystalline rocks in both undergraduate and graduate training. Many also question the "soft rock" thesis topics and ask why more of these are not focused on topics of practical interest such as:

(1) Organic geochemistry as related to the origin and maturation of petroleum.

(2) Clay diagenesis particularly as related to secondary recovery.

(3) Paleontology and palynology of Paleozoic and Mesozoic fauna and flora in Arctic regions.

Some of the petroleum company responses seemed out of touch with current situations. For example, several urged concentration on seismic and refraction problems instead of overindulgence in magnetic and gravity studies. However, current NSERC supported projects suggest that such switches in emphasis have already taken place. Other, possibly more realistic, responses state that graduate students in most universities could not carry out seismic studies of direct interest unless in close collaboration with industry because of the enormous expense involved.

Several companies made the point that there should be more co-operation with industry on thesis projects and implied that Canadian university geoscientists lagged far behind their U.S. counterparts in aggressively advertising their capabilities and seeking industrial support.

Mineral exploration companies

Of 78 exploration companies that replied to a questionnaire, 47 stated that they had provided and partially sponsored postgraduate theses in the past five years. The greatest beneficiaries were Queen's (18), Western Ontario (15), Toronto (10) and Carleton (7). Twenty-three of these companies noted that they had given grants in aid of research and again the major beneficiaries were Queen's, Western Ontario and Toronto with five apiece; British Columbia received four.

Mineral economics was cited as a major lack in graduate training. Several companies praised Queen's for adequately covering this topic. Fields most commonly mentioned as requiring more graduate students were: mineral exploration geophysics, exploration geochemistry, geological engineering at the M.Sc. level, and Pleistocene and Quaternary geology.

A criticism levelled at graduate theses was that they required too little observational fieldwork and too much laboratory and statistical manipulation of poorly gathered data.

Assessments by government scientists

Useful views from federal geoscientists came chiefly from the Geological Survey of Canada, the Earth Physics Branch and the National Museum. Members of some divisions of these groups have established fairly close relationships with universities through partial sponsorship of theses and aid with supervision and participation as critical readers and examiners. On the whole they seemed pleased with graduate teaching and research and some point to performances well above world average in fields such as regional tectonics, exploration geochemistry and geophysics, isotope geochemistry and petrology, and sedimentology. The most common complaint, voiced by those mentioned and by other federal groups, was that too many graduate students were led to research based on numbers obtained by instruments without gaining sufficient experience in direct observation of characteristics and relationships of rocks and minerals. Some respondents were concerned with the proliferation of departments engaged in graduate studies, others with the lack of activity in subjects such as marine geoscience and resource appraisal. One pointed out that his group had to go abroad to find doctorates in coal geology and special branches of paleontology. He suggested that faculty members should consult more frequently with potential employers regarding the expected future requirements of specialists.

Provincial geoscience agencies are all involved in graduate studies, mainly with universities within their own provinces. They sponsor theses by providing some or all of the logistical support, summer salaries, laboratory analyses and other aid. Some staff members become involved in supervision and examinations. Others attend the local universities for part-time studies leading to doctorates written on provincial projects. Most agencies seem generally satisfied with such relationships. Some wrote that the practice provided good returns for investment in research and also allowed them to groom graduate students for future permanent posts. Three responses noted a lack of innovation in university graduate programs and a general tardiness in pointing the research leaders of the future along the paths of new challenges, particularly in applied research. One reply regretted the lack of planning of graduate projects so that, in some schools, students are assigned to ill-conceived topics with poorly defined objectives and inadequate supervision. The result, in those schools familiar to the respondent, has led to a low completion rate for theses.

The professors reply

The major current concern of geoscience faculty members is the diminishing interest in postgraduate studies by the best Canadian graduates in the face of increasing employment opportunities and strongly competitive recruiting. Added to this are the earning restrictions imposed on foreign students by our immigration authorities. Most academics fear an immediate decline in graduate enrolment at a time when the need for first-rate research in geosciences has never been greater.

Some professors spoke with regret of the lack of scientific motivation of many of their graduate students. Many were solely employment oriented and lacked the zest to tackle important problems in the geosciences. Added to this is the 37-hour-week syndrome which afflicts most areas of our affluent society and makes it harder to convince graduate students that good research requires long evenings and weekends in their laboratories. The scientific curiosity or the work ethic that kept ill-paid scientists at their benches twenty or even ten years ago is fast disappearing from university life.

Professors generally were critical of those outside who lamented the lack of applied and field research in graduate work. These views, they claimed, were based on ignorance. Summaries of geoscience research activities in Canadian universities suggest that, proportional to enrolment, we carry out far more applied studies than other western countries. One professor listed six exploration methods now in wide use that had evolved from recent postgraduate studies at his university, some of the studies being of the type that many company geologists would term "theoretical". Many deplored the lack of support from companies some of which considered "sponsorship" of a thesis to mean supplying a few metres of core, or a few thousand dollars or a summer job. Many industrial donors seem to have no appreciation of the real costs of a graduate student's support which one department head places at $15 000 per annum for the simplest type of investigation. Soliciting the requisite number of small grants to support his graduate students often consumed so much of a professor's time that little remained to supervise the research!

Some professors appreciated the support of government agencies in sponsoring theses. This is particularly true in those places where one or more of the professors are also involved so that they can supervise and work closely with their students on related projects. Others are not as happy to have their students work under the aegis of federal or provincial government scientists who leave all the teaching, laboratory advice and service work to professors who are not considered part of the research project and have no part in its initial planning or final publication. Ultimately, they claim, this leaves them in the role of dormitory keepers. Some leading university geoscientists resented criticisms of the relatively low field component in postgraduate research. They claimed that leading government geoscientists had had the opportunity to support and strengthen university geology and geophysics in the same way that NRC had taken on the responsibility for chemistry and physics. Instead, the Department of Energy, Mines and Resources and its predecessors had opted to concentrate on in-house research. When support for university geoscience finally came it was from NRC. NRC experience was in laboratory research and this is where their strongest support was directed, for they had no concept of the enormous cost of field logistics. According to these professors, industry and government agencies do not deserve to have post-graduate training and research carefully tailored to their needs for they have done very little to spiritually or materially support it. Little wonder that half or more of our graduate students are involved with curiosity motivated frontier research when most of the available grants in aid of research are for that type of research. Little wonder that most of them do not spend three months field seasons in the Arctic Islands or the northern Canadian Shield where the cost of logistics alone would be three times their professor's total research grant.

The queries and comments of company and government scientists and the responses of university professors suggest the need for dialogue on the practice and purpose of graduate studies. Not on the one-to-one basis that generally prevails but between action groups from all three domaines. Meetings between academics and provincial scientists that led to establishment of the Ontario Geoscience Research Grants Program can serve as a model of the effectiveness of such communication.

SUMMARY

Graduate studies are inextricably linked to research in our universities. Their growth and development accompanied the enormous increase in university geoscience research associated with the enlargment of faculties and the advent of NRC grants in the 1960s. Postgraduate enrolments in geophysics have declined since the 1960s, possibly because faculty research specialities are in fields other than those (e.g. seismicity) where employment opportunities are greatest. Postgraduate enrolments in geology increased drastically in the 1960s and have grown slowly and steadily in the 1970s. There are, however, indications that they are about to decline. In the face of continuing increases in undergraduate geology enrolments, graduate enrolment has decreased since 1977 (Fig. 1.1). This decrease is chiefly attributed to the current excellent employment opportunities for new graduates and to the difficulties of financing the 30 per cent foreign students currently enrolled. To a lesser extent it may be due to the inordinate amount of time required to complete M.Sc. and Ph.D. degrees, the relatively low stipends paid to most graduate students and the lack of adequate supervision in some fields of study in some universities - all of which may contribute to a low completion rate.

Despite complaints from industry that studies are too academically oriented, one-quarter of all geology graduate students are working on problems related to mineral deposits and another quarter on problems associated with sedimentary rocks and hence pertinent to the petroleum industry. Close to two-thirds of geophysics graduate students are engaged in studies pertinent to the metallic mineral or petroleum industries. M.Sc. graduates commonly find employment in operational roles in industry and demand for them greatly exceeds supply. Ph.D. graduates mainly assume research roles in government and specialist or operational roles in industry. The approximately 50 geoscientists who receive Ph.D. degrees annually presumably have no difficulty finding employment although many of those who join mining or petroleum companies have to leave frontier research unless they join laboratories abroad. Demand for those with Ph.D.s must exceed supply as some government agencies and companies state that they currently recruit Ph.D.s abroad for specialist assignments.

Government agencies are generally complimentary about Canadian graduate studies in geoscience, industry less so. Government agencies offer partial support of much graduate work, industry less so. There is a great need for organized dialogue between all three domaines on the emphases and financing of graduate studies.

TABLE 4.1

POSTGRADUATE DEGREES AWARDED IN 1979

DEPARTMENT	MSc	PhD
Acadia	3	-
Alberta (Geol.)	13	2
(Geophys.)	2p	2p
British Columbia (Geol.)	14	5
(Geophys)	2p	1p
Brock	3	-
Calgary	4	3
Carleton	4	1
Dalhousie	6	1
E. Polytechnique	3	1p
Guelph	0	0
Lakehead	0	-
Laurentian	6	-
Laval	2	0
Manitoba	6+2p	2
McGill	6	2
McMaster	4	6
Montréal	4	0
Memorial (Geol.)	5	2
(Geophys.)	1p	0
New Brunswick	1	5
Ottawa	3	1
Quebec-Chicoutimi*	6	-
Quebec-Montreal	2	-
Queen's	8	8
Regina	0	-
Saskatchewan	5	-
Toronto (Geol.)	11	6
(Geophys.)	2p	3p
Victoria	2p	0
Waterloo	6	2
Western (Geol.)	9	5
(Geophys.)	1p	0
Windsor	6	-
York	-	1p
Totals	140+12p 152	51+8p 59

p = geophysicist

* = rough estimate from 1977/78 enrolment

Percentages of those enrolled receiving degrees in 1979

MSc (Geology) - 24%

MSc (Geophysics) - 21%

PhD (Geology) - 18%

PhD (Geophysics) - 15%

TABLE 4.2

CANADIAN AND FOREIGN GRADUATE STUDENTS, 1978-79

DEPARTMENT	CAN	NON-CAN
Acadia	3	8
Alberta (Geol.)	40	14
(Geophys.)	9	8
British Columbia (Geol.)	25	24
(Geophys.)	9	6
Brock	4	4
Calgary	20	19
Carleton	37	14
Dalhousie	?	?
Ecole Polytechnique	25	3
Lakehead	3	0
Laval	25	0
Manitoba	?	?
McGill	25	17
McMaster	24	11
Memorial	21	14
Montréal	15	4
New Brunswick	18	3
Ottawa	23	6
Quebec (Mont.)	11	1
Queen's	36	19
Regina	9	4
Saskatchewan	29	10
Toronto (Geol.)	48	22
(Geophys.)	18	6
Victoria	?	?
Waterloo	44	11
Western (Geol.)	31	25
(Geophys.)	2	5
Windsor	?	?
York	?	?
Totals	569	258

for 27 departments where information is available.

TABLE 4.3

POSTGRADUATE ENROLMENTS IN GEOLOGY AND GEOPHYSICS

	1978/79		1979/80		1979/80
DEPARTMENT	M.Sc.	Ph.D.	M.Sc.	Ph.D.	TOTALS
Acadia	11	-	11	-	11 (0)
Alberta (Geol.)	45	11	32	13	45 (-11)
(Geophys.)	8p	11p	7p	11p	18 (-1)
Brandon	-	-	-	-	-
British Columbia (Geol.)	32	16	35	12	47 (-1)
(Geophys.)	8p	6p	11p	6p	17 (+3)
Brock	8	-	7	-	7 (-1)
Calgary	18+4p	15+2p	17+4p	12+1p	34 (-5)
Carleton	35	13	22	19	41 (-7)
Concordia	-	-	-	-	-
Dalhousie	11+4p	7+2p	11+4p	8+2p	25 (+1)
Ecole Polytechnique	16+1p	15+2p	18+3p	11+1p	31 (-3)
Guelph	2	1	4	1	5 (+2)
Lakehead	3	-	5	-	5 (+2)
Laurentian	17	-	20	-	20 (+3)
Laval	17	8	25	8	33 (+8)
Manitoba	31+6p	10+3p	29+5p	8+4p	46 (-4)
McGill	31	19	35	13	48 (-2)
McMaster	16	19	20	16	36 (+1)
Memorial (Geol.)	22	13	21	15	36 (+1)
(Geophys.)	5p	-	4p	-	4 (-1)
Montréal	11	9	11	9	20 (0)
Mount Allison	-	-	-	-	-
New Brunswick	14+1p	7+2p	16+1p	9+1p	27 (+3)
Ottawa	7	14	12	11	23 (+2)
Québec-Chicoutimi*	(?)17	-	(?)17	-	17? (0)?
Québec-Montréal	14	-	13	-	13 (-1)
Queen's	32	23	45	21	66 (+11)
Regina	11	-	11	-	11 (0)
St. Francis Xavier	-	-	-	-	-
St. Mary's	-	-	-	-	-
Saskatchewan	28+2p	9	19+2p	9	30 (-9)
Toronto (Geol.)	39+3p	25+4p	39+3p	26+3p	71 (0)
(Geophys.)	9p	11p	12p	8p	20 (0)
Victoria (Geophys.)	1p	2p	1p	1p	2 (-1)
Waterloo	45	9	44	9	53 (-1)
Western Ontario (Geol.)	21	35	17	33	50 (-6)
(Geophys.)	3p	5p	4p	4p	8 (0)
Windsor	25	-	17	-	17 (-8)
York	3p	4p	2p	3p	6 (-1)
TOTALS	579+58p	278+54p	573+61p	263+46p	943 (-26)
	637	332	634	309	

P = Geophysicist *- estimates only, based on 1977/78 C.I.M. statistics

TABLE 4.4

PERCENTAGE OF FEMALE STUDENTS IN SOME GEOLOGY DEPARTMENTS, 1979-80

DEPARTMENT	BSc	BASc	MSc/PhD
British Columbia	25%	5%	25%
Alberta	23%	N.A.	11%
Regina	13%	N.A.	9%
Saskatchewan	11%	16%	10%
Toronto	?	?	10%
Carleton	17%	N.A.	8%
Queen's	39%	24%	20%
Laval	13%	?	13%
New Brunswick	40%	N.A.	18%
Mount Allison	12%	N.A.	N.A.

TABLE 4.6

AWARDS ON NSERC POSTGRADUATE SCHOLARSHIPS IN 1978-79

1386 scholarships were awarded in science and engineering of which 65 went to geologists and geophysicists at the following universities.

Victoria	5	Waterloo	5
*British Columbia	2	Western	1
*Alberta	5	York	1
Calgary	2	Quebec (M)	2
Saskatchewan	3	Laval	2
Regina	1	McGill	3
Manitoba	1	Montreal	1
Lakehead	1	Polytechnique	2
McMaster	1	New Brunswick	1
Ottawa	1	Memorial	1
Queen's	8	U.K.	1
*Toronto	4	U.S.A.	10
		Australia	1

*Awards to two separate departments.

TABLE 4.5

AREAS OF RESEARCH BY GRADUATE STUDENTS IN GEOLOGY AND GEOPHYSICS DEPARTMENTS, 1978-79*

Speciality (*see* table 4)	Number of Graduate* Students**	Speciality (*see* table 4)	Number of Graduate* Students**
1. Coal geology	2	25. Vocanology	5
2. Economic geology, also included are those in mining geology, no. 11	150	26. Other fields in geological sciences	0
3. Engineering geology, does not include geotechnical engineering	31	27. Exploration geophysics	23
4. Environmental geology	2	28. Geodesy	1
5. General and regional geology	14	29. Geomagnetism and paleomagnetism	13
6. Geomorphology, does not include physical geography	2	30. Geophysical instrumentation	3
7. Historical geology	1	31. Gravity	4
8. Hydrogeology	26	32. Heat flow	0
9. Marine geology	9	33. Magneto-telluric studies	2
10. Mineralogy and crystallography	13	34. Marine geophysics	2
11. Mining geology, *see* number 2	-	35. Physical properties of rocks and minerals	3
12. Paleobotany	0	36. Remoting sensing	0
13. Paleontology	39	37. Seismology	28
14. Palynology	10	38. Tectonophysics	4
15. Soil science, all research in other departments	-	39. Other fields in geophysics	17
16. Petrology	95	40. Biogeochemistry	1
17. Petroleum geology	5	41. Exploration geochemistry	13
18. Photogeology	0	42. Inorganic geochemsitry	15
19. Quaternary geology and research	23	43. Isotope geochemistry and geochronology	48
20. Rock mechanics, most research in other departments	1	44. Physical geochemsitry	21
21. Sedimentology	55	45. Organic geochemistry	0
22. Soil mechanics	1	46. Other fields in geochemistry, includes solution geochemistry and groundwater geochemistry	6
23. Stratigraphy	36	47. Mathematical geology	5
24. Structural geology, tectonics and geotectonics	52	TOTAL	798

* The information in this table was supplied by 28 of 35 departments involved in graduate studies.

** Many of the graduate students undertake research that could be included in more than one discipline, for example many of those listed in 16 could as well be listed in one or both of 43 and 44.

5. RESEARCH

...If scientific knowledge is to evolve, it needs more than the accumulation of new 'facts' enlivened by occasional accidental discoveries...each scientist is encouraged to be an imaginative source of interpretation, both of his own contributions and of the work of other scientists...

--John Ziman, 1978

A TIME TO TAKE STOCK

Research activity in Canadian university geology and geophysics departments has burgeoned mightily in the past two decades. Prior to that, only three or four of our university departments were seriously engaged in frontier research. Most of our geoscience research was undertaken by federal and provincial agencies. Naturally, these organizations concentrated mainly on those aspects of geology and geophysics which fell within their mandates. Beginning in the 1960s, however, university participation in research grew rapidly and the activities broadened to cover the full spectrum of geology and geophysics.

The prestige associated with research has also grown immensely. Whereas two decades ago research was secondary to teaching and other academic pursuits, it now ranks as a first priority item, at least in the minds of professors at most schools. Almost all academic geologists and geophysicists try to become involved in frontier research and to stay involved despite failures and setbacks. Many feel that it is the only route to promotion.

Funding of research has also taken a very different course. Once wholly dependent on aid from government departments and industry and, hence, chiefly involved in mission-oriented research, professors have in the last two decades received relatively large grants from the National Research Council (and now from NSERC) for "free" research in geology and geophysics.

Basic and applied research, almost inseparable in geology and geophysics, are obviously prime national needs in Canada where informed and innovative assessments and management of national resources is not only important to its own, but also to the world's social and economic well-being. At the midpoint of two decades of rapid growth, Canadian university geology and geophysics received a thorough scrutiny (Blais et al., 1971). It is again time to take stock of its production and to attempt to measure its quality.

A BRIEF HISTORY

Research in the geosciences has an eminent place in the history of science in this country but, initially, it was chiefly due to work of government scientists. In the middle of the last century the work of Sir William Logan and his colleagues and successors at the Geological Survey of Canada attracted world renown through their pioneer geological and geochemical studies. Because of their close involvement with resource development and terrain exploration in a developing country, the geosciences probably carried more political weight than some of their sister sciences. Geologists were prominent in establishing our national academy, the Royal Society of Canada, in 1882 and for many years had their own separate section within it. Serious Canadian research in geophysics began in Toronto in 1840 (Garland, 1968) but activity was very restricted until the founding of the Dominion Observatory in 1905.

Prestige and power of the geosciences began to wane somewhat in the early years of this century. Some of the reasons were probably intellectual: scientific revolutions made chemistry, physics and some forms of biology very exciting and challenging fields whereas geology lacked unifying theories and there seemed little opportunity for conceptual advances. Lack of strong, farsighted leadership may also have played a role. There is no doubt that it was such aggressive leadership that ensconced physics, chemistry and biology in National Research Council Laboratories in 1933 and launched the first two of these disciplines into international orbits during World War II and the post-war period.

Although no longer the dominant single force in national science, the Geological Survey maintained its fine international reputation over the first half of this century through its systematic surveys which evolved into the bold and successful helicopter-supported geological surveys and the airborne magnetometer surveys of the 1950s and 1960s. Also, during this period, the Dominion Observatory (later the Earth Physics Branch) developed our celebrated network of seismographic stations, our knowledge of the gravitational field and our research program in several aspects of terrestrial magnetism. Most provincial surveys or their forerunners were established late in the last and early in this century. Those of Ontario and Quebec, and to a lesser extent, that of British Columbia, were large and active enough by the mid-point of this century to make significant contributions to the enviable understanding of the geological framework of Canada which we had achieved by the mid 1960s.

The early history of the development of university geology departments is given by Stearn (1968) and briefly summarized in Chapter 2 of this report. Stearn notes that although thirteen departments had been established in 1920, the total number of faculty members was only 22. Most of the lonely individuals who occupied chairs of geology had little time for creative research in addition to their many other duties. Nonetheless, notable work was accomplished by such as William Dawson and later F.D. Adams at McGill, A.P. Coleman at Toronto, Willet J. Miller at Queen's, R.C. Wallace at Manitoba and J.A. Allen at University of Alberta.

Geophysics developed when professors in the physics departments at McGill and Toronto began investigations of geophysical prospecting techniques in 1928 at the request of the Geological Survey of Canada. From this beginning university activities in geophysics moved away from applied to basic research but, with few exceptions, remained linked more closely to physics than to geology departments (Garland, 1968). This has contributed to a lack of rapport between geologists and geophysicists which is only now being overcome.

It is probably fair to state that most geological research at universities in the first half of this century was closely tied to that of the federal and provincial surveys and to the needs of mining exploration companies. There were no other sources of funds and these ventures not only took care of logistics but commonly provided welcome supplements to the incomes of professors and graduate students. The close ties established between university, government and industrial scientists were the envy of most nations and probably account for the fact that foreign scientists still identify our strengths as regional field studies and research on mineral deposits. However, this practice did restrict research to the traditional subdisciplines practised in survey work and those who took their advanced training abroad usually had to subjugate their newly acquired skills and interests to the realities of the domestic scene. There were some conceptual breakthroughs of vast importance during this period, for example J.E. Gill's and J.Tuzo Wilson's independent and successful attempts in 1949 to subdivide the rocks of the Canadian Shield, but generally Canadian university research could be described as pedestrian but pragmatic.

The great leap forward in all forms of university research came between 1961 and 1971. During this decade the support from various federal agencies increased 5-fold (from ca. $25 to 125 million) and the universities responded by producing 5 times as many Ph.D.s (and probably 10 times as many research papers!). Geophysics benefitted early from this surge in support because its research efforts were already closely linked to the National Research Council through the Council's Associate Committee on Geodesy and Geophysics. The other geosciences were slower to benefit partly because of their relative lack of representation at N.R.C., their existing ties being with government departments that did not become major granting agencies, and possibly a lack of aggressive leaders in their small, overworked departments.

A change was brought about partly by Canadians returning from studies and research abroad and partly by an influx of faculty from other countries (chiefly the U.K.) who soon broadened the range of research topics and began searching for research support outside of traditional circles. Late to benefit from the easy money of the 1960s (very late in some cases), the geosciences did not have long to grow before public reaction to the enormous expansion of *laissez-faire* research resulted in committees of inquiry, curtailment of funds and the zero growth pronouncements of the 1970s. This came about because the realization dawned on administrators that the federal grants in aid of research were just that, grants-in-aid. The provinces which supported the universities had to come up with much more money to provide laboratory space, salaries, and overhead to support ever-expanding research programs. Declining enrolments in some of the physical sciences made them even more wary of the huge infrastructures already built and already requiring maintenance.

The geosciences were probably fortunate in that they had been tardy climbing aboard the gravy train. They certainly had less to lose when the crunch came for they were not main targets of suspicion and envy on campus. Also, due to the surge in energy exploration and a good job market, their enrolments have continued to increase modestly in the face of overall declines in other sciences. The result is that most geology faculties have remained stable or increased in size, facilities have continued to improve (although a few departments are still abominably housed), federal grants continue to slowly improve relative to some other sciences and many more sources of funding are opening up from provincial governments, foreign governments and a few enlightened pockets of industry.

Geoscience research in Canadian universities has never been in a more favourable position. It has weaknesses and it requires rationalization in several areas, but it has deservedly gained enormously in status in the past 15 years, it has at least doubled the number of full time practitioners in that period, and the immediate outlook for funding is excellent. It is the nature of things that these halcyon days will not last forever. We should make the most of them while they are with us.

THE NATURE AND SCOPE OF UNIVERSITY RESEARCH

The variety

A great range of scientific activities is undertaken by Canadian academics. Fifty-three specialities are listed in Table 5.1 which shows the disciplines of geoscience that are supported by the National Science and Engineering Research Council (NSERC). There are other emphases, besides those listed, which are supported in our universities by industry and by foreign and domestic governments. The range in interests is enormous: from concentration on unconsolidated glacial sediments or on silts and muds in modern tidal flats to work on the ancient crystalline rocks of the Precambrian Shield; from descriptions of fossils and classical geological mapping to the operation of integrated laboratory complexes with mass spectrometers, ion microprobes and other sophisticated instrumentation. Some of the academics in geology and geophysics departments have backgrounds that would equally qualify them to teach and research in one or more departments of chemistry, physics, biology, civil engineering or geography and their specialities reflect these very varied interests.

In the geosciences it has always been difficult to draw the line between basic and applied research. The ivory tower tectonists who are unravelling the evolution of the Appalachian and Cordilleran mountain belts are, of necessity, also gathering data and making maps that will be of use, on the very day they are published, to the pragmatic seekers of oil, gas and base metal deposits. The palynologists or micropaleontologists who peer down microscopes, intent on identifying ancient life forms that will enable them to refine zonations in Devonian, Carboniferous or Cretaceous rocks, are providing information eagerly awaited by stratigraphers employed by the coal and oil industries.

Not only is there a great range in type of activity but there is an equally large range in quality. Individuals and team leaders show varying "skills" in designing projects, accumulating reliable data and interpreting results. Some consistently end up with significant results (whether negative or positive) that may lead to major conceptual advances in one or more subdisciplines. Others publish maps or geochemical data which leave readers wondering why the work was ever undertaken. Some, with funds, expensive equipment and graduate students at their disposal work away for years without seeming to have any major impact on geology or geophysics. Others, who seem to rely mainly on reading and reinterpreting colleagues' contributions, have made revolutionary contributions to the geosciences.

Some Canadian geoscientists are accomplished in more than one subdiscipline and have knowledge of many. Others are very narrow and show little appreciation or understanding of their colleagues' work. Our visiting committees encountered laboratory-oriented scientists who wondered whether field mapping could really be considered "research" or whether it was not better classified as "survey work". We also encountered field mappers who wondered about those who spent too much time in the office reading and writing syntheses instead of examining the rocks at first hand.

Practically everyone agrees that science is a process of searching in which the facts of Nature are discovered. But there seems to be some uncertainty among the searchers as to which of the search processes would be described as research. To explore this further we draw upon and briefly summarize Bonneau and Corry's (1972) analysis and classification of research in Canadian universities.

The classification of research

Bonneau and Corry (ibid.) found that "the activity of research is as elusive as the truth it seeks". In their investigation they classified research into two main categories: frontier research, and reflective inquiry. Both were defined rigorously. The premise behind this classification is that although the process of digging up new facts and the process of intellectually winnowing hypotheses both have their roots in human curiosity, they are rather different kinds of activities. People can and do pursue one in virtual isolation from the other. Differences of temperament, experience, interest and education may lead to concentration on one or the other. Some researchers always do both, in varying proportions, but not every academic does or needs to do both to be useful and successful.

Frontier research is limited in Bonneau and Corry's definition to research into phenomena defined by the senses. It is heavily empirical, based on experiment and observation. Naturally it includes intellectual efforts, both in the selection of the original guiding hypothesis and also in the analysis and correlation of the newly won data. But, whether the researcher follows his nose or is led by his mind, it is still exploration on the frontier of Knowledge, trying to gain new ground for the map of Knowledge.

Frontier research as so defined includes both empirical basic (pure or curiosity-oriented) science and applied (problem or mission-oriented) science.

Reflective inquiry is defined as an almost entirely intellectual activity. This is inquiry into thought, examining the principles and theories by which the sum of our knowledge, whether in a narrow sector or over the entire range, has been given coherence and meaning. Talented frontier researchers engaged in basic science move naturally into a stage of reflective inquiry when attempting to fit their discoveries into the existing body of theory; those engaged in applied research possibly find less need to move into this form of activity. Good reflective inquiry must always be in close touch with the most recent findings of frontier research while devising new projections for the map of knowledge.

Some disciplines, such as the humanities, work almost wholly by the process of reflective inquiry. The sciences operate by a combination of both frontier research and reflective inquiry although individuals may make their greatest contributions to either basic or applied science exclusively by one or the other of these two research modes. Bonneau and Corry (ibid.) cite Albert Einstein's Theory of Relativity as a triumph of reflective inquiry. The obvious examples from Canadian geoscience are J. Tuzo Wilson's many great contributions to global tectonics over the past two decades.

Frontier research is expensive. It usually requires instruments, technicians, field assistants and transportation. The bulk of the research council's grants-in-aid are made to frontier research and, partly because of this, it has become the main prestigeous activity on many campuses. Frontier research, especially in a narrow field, is not particularly useful to those engaged in undergraduate teaching although it is an essential to postgraduate supervision.

Reflective inquiry, by itself, is a relatively inexpensive occupation. It requires time to think and read and possibly to travel in order to exchange ideas with distant colleagues. Reflective inquiry is an essential occupation of any professor who aspires to be a good teacher of undergraduates. It is also a helpful component in the instruction of graduate students.

At the time of their study, Bonneau and Corry (1972) decided that universities were penalizing those who stayed out of frontier research. This caused professors who had no talent for it to keep striving, at some pain to themselves and some expense to the country. They pointed out the advantages that might accrue to research, to teaching and to such professors themselves if they could opt out, concentrate on reflective inquiry and set themselves new goals.

Not all geology and geophysics professors accept Bonneau and Corry's two-fold classification of research or their recommendations for rationalization.

Emphasis in geology and geophysics

Our committee members who visited departments across the country were impressed not only with the broad range and high quality of research underway but also with the extreme emphasis placed upon research activity in many departments. Some examples of this are given in a succeeding section on research funding. Many department heads and deans stated that all professors should be active in research as it was an almost essential aid to good undergraduate teaching as well as a necessity for graduate instruction. They left no doubt that they meant frontier research - adding to Knowledge by field or laboratory work. Even in schools with rather weak research performance records, heads seemed to place tremendous emphasis on research achievements. Many pointed out that their best researchers were also their best teachers. Almost all deans and department heads emphasized that both teaching and research were taken into consideration when deciding on promotions. Several cited cases, usually a single individual in each department, who had been promoted to full professor chiefly on teaching ability. Faculty members who were interviewed imparted rather different impressions. Many claimed that perks and accelerated promotions were awarded solely on the basis of published research and that in recent years one had to be very exceptional indeed to gain tenure or climb the ladder of advancement by any other means.

Professors of geology and geophysics generally have very negative attitudes towards the Bonneau and Corry two-fold classification of research and to the recommendation that people who were not good at one of them might usefully pursue the other. They stressed that all research included a large component of reflective inquiry and that, without a component of frontier research, reflective inquiry merely meant keeping up with the literature which every professor was supposed to do routinely. Their attitude on this subject is understandable. Geology and geophysics are still in the late stages of a scientific revolution and this creates the feeling that one has to be involved on the frontier in order to teach about it. Professors also argue that a large number of frontier projects underway means that a wider choice and more yardsticks are available when sorting out the good ones. Some also claimed that even mediocre researchers were producing useful raw data for a large country with many natural resources where every bit of information was useful. Also, although such scientists might not produce many useful conclusions from their data, better researchers could incorporate the data into their more elegant syntheses. (One cannot but wonder if a weak researcher's conclusions are suspect should not his or her data also be suspect!)

The authors of this report were impressed with the Bonneau and Corry (1972) classification and not convinced by geology and geophysics professors' counter arguments. Our committee members encountered enough examples of very good undergraduate teachers who were not engaged in frontier research, and enough examples of dispirited frontier researchers who wished to opt out but were afraid of losing face by doing so, to regret the present over-emphasis on frontier research in most geology and geophysics departments. We feel that those who wish to switch wholly to reflective inquiry should be free to do so. Those who take this route, however, should realize that the results of their new emphasis should bear fruit. This might include increased undergraduate teaching loads, increased participation in public affairs, or the writing of textbooks, popular articles and commentaries, reviews and broad syntheses. The need for such work is covered in Chapter 7. Interim and long-term goals should be set and, when met and the product judged suitable, the professor should receive promotions and other rewards similar to those given to professors judged competent in frontier research. The result would be more funds available for first-rate research, less publication of pedestrian research, more time free from undergraduate teaching for those frontier researchers who need it, and more effort devoted to the many non-research activities that presently lag in many departments. Good management is, of course, essential to bring such an arrangement about as discussed in Chapter 2 and elsewhere (Keen, 1979).

We recommend:

That deans, department heads and other academic managers decrease the current over-emphasis on frontier research by encouraging those who have proven ill-suited to it to concentrate on reflective inquiry and to address their talents to teaching and to the many other legitimate scholarly activities in which departments should be involved. If such professors satisfactorily meet pre-established goals, they should be rewarded and promoted on the same basis as those heavily engaged in frontier research.

THE ORGANIZATION OF UNIVERSITY RESEARCH

Many outside of academia are convinced that university research is totally unco-ordinated chaos at worst and laissez-faire dilettantism at best. Some of their viewpoints are cited in later sections of this chapter. Our own experience through visits and discussions is partly to the contrary. We found that about half of the departments appeared to have clearly defined research goals. This was rather more obvious in the case of new departments or of initially small departments that had mushroomed in the 1960s. It was rather less apparent in some of the old established departments that had built up fairly large teaching staffs before ample research funds became available. Then, with a broad spread of solitary virtuosos on hand it was probably difficult to decide democratically how to build critical masses around only a few of them. However most schools now seem to have successfully solved this problem or are addressing themselves to it.

Many geology and geophysics departments have based their research policies on either regional or disciplinary emphases. We cite only a few examples of each.

Regional emphases

In some cases the entire university research effort is dedicated to problems of the immediate region. Thus Memorial University emphasizes research on Newfoundland and the North Atlantic (Bonneau and Corry, 1972, p. 157). Its geologists and geophysicists have had to concentrate on Newfoundland in particular, the Appalachian/Caledonian orogen in general and also on the Precambrian rocks of Labrador. Many have built up fine international reputations in their subdisciplines through devoting themselves to problems on their geological doorsteps.

The francophone Québec universities devote most of their research to geoscience problems within that province and fine work on Precambrian rocks has been produced by the universities at Chicoutimi and Montreal, on the structure of the Québec Appalachians by Laval geologists, on sedimentology and biostratigraphy by Université de Montréal, on marine geoscience of the St. Lawrence estuary by people from Rimouski, and on mineral deposits of the province by geophysicists and geologists at Ecole Polytechnique.

University of Regina geoscientists have concentrated on problems within Saskatchewan and some of them are achieving notice far beyond the borders of that province for illuminating structural studies of Canadian Shield rocks.

In some cases departments have focused on a set of disciplines pertinent to a regional interest rather than on regional geology. Such is the case at the University of Calgary where a small cadre of petroleum-oriented researchers have grown up to co-operate with local industry.

Discipline emphases

Dalhousie's emphasis on marine geoscience filled part of an empty niche (where there is still room for others!) and at the same time took advantage of its regional location. Several of its geologists, geophysicists and oceanographers have established international reputations while addressing themselves to the sea around them by taking advantage of the facilities of their neighbours, the Bedford Institute of Oceanography.

The University of Saskatchewan experienced rapid growth about ten years ago and took advantage of the opportunity to switch some of its emphasis on crystalline rocks and mineral deposits to sedimentary rocks and studies of the Western Canada Basin. It now has a very respectable reputation as a biostratigraphic research centre.

McMaster, a relatively small department, decided many years ago to restrict its research effort to a few fields. It has since built up an international reputation in clastic sedimentology and in some aspects of geochemistry.

Probably the best example of a carefully planned concentration on specific disciplines is in the Earth Science Department at Waterloo. Started in 1965 this department built up slowly until 1970 when it began to grow rapidly to become one of our largest departments. It has emphasized novel research in the environmental, energy and resource fields. Its hydrogeological-hydrogeochemical-isotope geology group is unique in Canada and it has also built up some of the largest groups of Quaternary geologists and biostratigraphers in a department whose research is tied together by many lines of interaction.

We have mentioned that some of the older, larger departments experienced initial problems in sorting out their research goals. Improvements have come and are coming with time and with changes of leaders. A good example is the University of Toronto which has built up critical masses of first class exploration geophysicists, petrologists, and mineral deposits experts and is now actively building up similar groups in biostratigraphy and structural geology. It seems well on the way to becoming the Canadian Cambridge, A.N.U., or Cal Tech in geology and geophysics and this should please those who regretted this national void. Another example is the twinning of Université de Montréal/Ecole Polytechnique to produce a single unit with strength in several disciplines.

Most of the better-known research departments in geology and geophysics appear to have either well-defined research plans or a group of like-minded scientists who have accidentally come together to work closely with each other. They include about half of the 40 departments in Canada, i.e. far more than the few cited here. We recommend to the other 20 departments:

That a completely laissez-faire attitude toward research in a department can be wasteful and non-productive. It does not produce a focus that allows for the sharing of ideas, funds, space, equipment, and graduate students. Heads of departments should endeavour to build up units with similar interests and similar goals, using as models those departments that have become successful by using regional, disciplinary or other research focuses to build viable teams.

Co-operation between institutions

Some critics on the outside deplore the lack of co-operation and the duplication of effort between university departments. We saw some examples of this: rivalries between universities in the same province for the same funds, rivalries between university scientists and their provincial and federal counterparts, expensive equipment unused because of lack of technical help. On the whole, there probably is not as much co-operation as there could and should be. We heard of examples of graduate students and professors going abroad to use equipment because institutions there were more co-operative than nearby Canadian universities which had the same equipment. We found two universities striving for the same piece of provincially funded equipment, each convinced that the loser would probably be allowed little opportunity to use the black box if it was installed in the rival's laboratory. The possibility of jointly approaching the provincial authorities and planning the location and sharing of the facility for the greatest advantage of all users did not seem to occur to either protagonist.

On the other hand, we were impressed with some very visible evidences of co-operation and joint endeavours. These included large scale, expensive, seismic programs involving geophysicists from western universities and federal government scientists. Also included was a major grant shared by several Ontario universities to establish an ion microprobe facility in the Toronto area. Several major syntheses and regional geology projects are underway across Canada, particularly in the central and eastern areas, with the International Geological Correlation Program or other international programs serving as catalysts. Many other projects develop by spontaneous combustion when university scientists sit down over a beer. They also include sharing of equipment, sharing of research grants and sharing of ideas at seminars, workshops, field trips and invited lectures. In Chapter 6 we cite examples of co-operation with other science departments. Even where we lament the lack of rapport, e.g. between geology and chemistry, there are excellent examples of co-operation, e.g. a Quaternary geologist at University of Alberta has developed an amino acid dating facility in the chemistry department and Toronto geologists are involved in several joint projects with chemistry colleagues. The proof is in the product: a quick qualitative scanning of recent issues of many journals suggests that Canadian academic geoscientists probably publish more joint papers with colleagues from other universities, government agencies and industry than do most other groups of geoscientists in the western world.

We recommend:

That departments which have developed rivalries with those in nearby sister universities study the fruits of co-operation in research and other matters and attempt to build bridges to such departments. Such overtures will probably have to start at the level of working scientists for our committees were surprised and dismayed to find that senior administrators often know of such rivalries and appeared to condone them.

Innovation

One criticism that we have made of university teaching in the geosciences also applies to research - there is a lack of new approaches. Universities, the historical springboards of change, seem remarkably slow to change. Most university research is structured along traditional lines and most departments seem reluctant to break new ground. We have mentioned the Waterloo department as one which has very successfully departed from the norm. The Land Resource Science Department at University of Guelph with its concentration on soils, hydrology and geochemistry is another that appears to be succeeding in a very different way from the traditional geology department. However, despite loud and clear messages over several years, it is surprising that Canada still lacks an adequate academic research program in coal geoscience, although the beginnings are finally underway. Also little is being done in the exciting field of organic geochemistry despite its obvious value in hydrocarbon resource assessment. Apart from small amounts of company-sponsored research in clay mineralogy at Calgary and Ecole Polytechnique, most academics have avoided this field despite its importance to sedimentary diagenesis and, hence, to the geologists and engineers interested in recovery of petroleum from the "tight sands". We recommend:

That those departments, particularly small departments, making new appointments should seriously consider departing from the normal practice of completing their rosters with full complements of the traditional subdisciplines of geology and geophysics. They should seek *to appoint those capable of bridging major disciplines and opening up fresh new fields of research.*

FINANCING OF RESEARCH

The major source of financing

The major support of university research comes from the universities themselves, that is the provincial governments. The universities house the laboratory and office facilities, pay the salaries of the faculty members and decide roughly what percentage of their time can be devoted to research, pay at least some of the research assistants and technicians, at least some of the graduate students' stipends, some of the cost of equipment and many of the basic services. Some universities charge a modest overhead for administering contract research, others do not. None, as far as we know, charge against the grants and agreements that have no mission-oriented strings attached.

Money that comes in from outside through grants, agreements and contracts is merely in aid of research. Most of it relies on the physical facilities and manpower being available at no charge or, at least, less than cost. This is why some universities have been forced recently to take a hard look at expansion of research, for the grants that initiate it often may have no promise of continuity and yet may involve the university in expanded facilities and expanded manpower that may in the long term be a financial embarrassment.

Grants in aid of research

University professors seek funds in aid of many aspects of their research: equipment, technical help, support of graduate students and postdoctoral fellows, and travel are probably their main needs. They seek it from many quarters: federal and provincial governments; foreign governments; philanthropic foundations; engineering, mining and petroleum companies; and from the universities themselves.

Some of the amounts awarded are public knowledge; thus the National Science and Engineering Research Council (NSERC) granted $7.9 million in 1980-81; the Department of Energy, Mines and Resources, through the G.S.C. and E.P.B., awarded over $0.5 million in research agreements annually; the Ontario Department of Mines in 1978 initiated an annual grant of $0.5 million over a trial period of five years. A few Canadian geoscientists hold Killam Awards, administered by the Canada Council, which amount to more than $40 000 annually. All these grants are without strings and the researchers have comparative freedom to pursue their work in a manner or time scale to suit individual situations.

Information on contract and related research support is not so readily available. Some of it is in the public domain, e.g., the contracts from federal and provincial agencies, but it is scattered. Such contracts vary in amount from year to year. However, some of the provincial contracts, especially when influenced by short-term federal assistance programs, have amounted to hundreds of thousands of dollars. Companies award grants and contracts on a variety of topics and also provide samples and logistical support to universities. Baillie (1979) has estimated that petroleum companies support university research directly by about $200 000 per annum. We have no equivalent estimate for mining companies but know that one company alone, cited as a model later in this section, contributes as much as this to university research.

The obvious way to obtain a good estimate of total support of university geoscience would seem to be to ask each department head for a figure. For reasons which we don't understand, many heads were reluctant to give us such information. Thus, amounts of research support are only known insofar as NSERC grants and government agreements are concerned.

However, department heads of three large geology departments (Toronto, Alberta and Waterloo) advised us that their total research income from contracts and grants averaged over $1 million per annum. This may be a good approximation for other departments of equivalent size and activity but we just don't know.

NSERC GRANTS

These are the most sought-after grants if we except a few special prizes such as Killam Awards. Many university department heads who replied to our questionnaires took pains to point out that their department contained the highest percentage of faculty members to qualify for NSERC grants, or the highest average award per faculty member, or the highest total award, or that they showed the greatest percentage improvement over the past five years and so on! There is no doubt that NSERC grants are regarded as prestige awards and as a national measuring stick of ability in the sciences.

There are good reasons for this: NSERC is by far the largest source of science funding in Canada; its peer review system is highly respected and it seeks primarily to support excellence; and its grants have few restrictions attached to them so that the individual researchers are free to re-allocate their funds as changing needs dictate.

Nature of the awards

NSERC grants-in-aid of operational research are made only to bonafide, full-time faculty members in Canadian universities. Currently they range in value from about $3 000 to over $50 000 per annum. The total in 1980-81 amounted to about $6.8 million. Almost all go to individual applicants, currently less than one per cent go to groups of applicants who propose to operate as teams.

Mature, competent researchers generally receive their grants on a three-year basis, paid in annual installments with an inflationary adjustment. Operational grants are awarded only on an annual basis to unproven young researchers, to those whose research appears to be faltering, and to mature researchers who prefer a one-year term for reasons of their own.

Operational awards are sent to the grantee's university where they are administered and controlled by the financial office. They can only be spent, however, by the grantee for purposes of his research.

NSERC also provides funds for equipment, ranging from a petrographic microscope to a mass spectrometer. The total for 1980-81 was about $1.1 million. In addition, a few thousands of dollars are provided for special travel. All decisions concerning these awards are in the hands of an earth sciences grants selection committee (ESGSC).

In 1977, NSERC initiated a special strategic grants program to enable university researchers to apply their research experience to specific areas of national concern. The first three areas identified: energy, oceans and environmental toxicology are all of concern to geoscientists. At the time of writing few groups of geoscientists have qualified for these strategic grants.

NSERC also funds Project Research Applicable in Industry (PRAI) which is not a special concern of the present report.

The judging process

The committee consists of eight academics, two company geoscientists (usually one from petroleum and one from metallic minerals), an ex-officio NRC geoscientist as secretary and an observer from Energy, Mines and Resources. It is representative of both geographical and disciplinary areas. One third of the members are replaced annually and new appointments are made by NSERC on the advice of the committee following suggestions by groups and individuals throughout the geoscience community.

Professors submit formal applications for grants in which they outline their research projects and estimated costs. They also supply information on past publications and other achievements together with copies of their most significant recent papers. Committee members visit universities on a rotational basis once every three years to interview applicants and inspect facilities. They read the recent papers of applicants within their own fields and also the reports of external referees, selected by NSERC following suggestions by applicants and by committee members.

New applicants receive moderately generous starter grants ($7000 to $9000 in 1980) based on their references and research needs. Mature researchers are judged primarily on their recent research records. Those with the best records often receive almost all the funds they request; those with weaker records receive only a fraction of their requests. NSERC grants differ from most other research support in that more emphasis is placed on the applicants' record than on the research proposal.

The selection committee meets for approximately one week each spring in Ottawa, after all refereeing and documentation is complete, in order to allocate the moneys provided by NSERC to those of the 500 applicants considered deserving. Most have their tentative decisions made by that time and it is chiefly a matter of achieving consensus. In some controversial cases, however, it may be necessary to contact further referees by phone in mid-meeting. The process appears scrupulously fair. There have been some long term biases, which are discussed later, and there have possibly been short-term biases caused by geographic and disciplinary emphases of the committee members. However, as one former committee member has stated, it would be difficult for a committee bias towards an individual to linger for more than two or three years due to the thorough rotation of membership.

Unsuccessful applicants who complain to NSERC generally have their complaints brought to the attention of not only the incumbent committee but also the succeeding one. The community owes a great debt to those who have served, always without remuneration, on this very important committee. The committee's task of selection is becoming more difficult since the Freedom of Information Act makes it essential to divulge the names of referees. Many scientists either refuse to give opinions or will give only bland and noncommittal opinions when faced with the possibility of a long feud with an irate, unsuccessful candidate.

We commend the peer selection process practiced first at NRC and now at NSERC. The anonymity of external referees is an integral part of this system and we urge NSERC officials to continue to press for exemption of the scientific refereeing system from the regulations of the Canadian Human Rights Act.

Some examples of funding of recent projects

Table 5.2 lists the departments in which NSERC earth science grants are held and it is notable that, although the lion's share goes to geology and geophysics, many other departments are involved, e.g. archeology, zoology, botany, mathematics, civil engineering, agriculture, geography and physics. The range of projects is enormous, from 'Spatial changes in Canadian insect fauna during the late Pleistocene' and 'Geomagnetic variations and electromagnetic modelling' to 'Reservoir properties of sedimentary rocks' and 'Metallogeny of massive base metal sulphide and gold deposits'.

Table 5.3 lists the highest operating grants held in 1980-81, all those above $32 000. Short titles of projects are given which, although illustrative of the range of projects, are not a true picture of the emphases or numbers involved in the various disciplines. Thus, of the 25 projects listed, seven are in geophysics and six in civil (geotechnical) engineering. This is far in excess of the proportion of either of these disciplines within the geoscience community and reflects the fact that geophysicists and engineers generally receive larger grants than other disciplines of the geosciences. Also, most of those associated with geology are carrying out projects with a large component of instrumental laboratory work. This also is traditional, NSERC has tended to make larger awards to laboratory-based, chemically or physically oriented projects than to those in the classical fields of geology such as biostratigraphy or mapping. This practice is changing, however, and at least one regional geologist with a mapping background, a vertebrate paleontologist, and a physical geographer are now listed among those with the largest grants. Another departure from the past is reflected in the ages of grant recipients: although most are in their forties or early fifties, at least three are barely in their mid-thirties. Also, Waterloo, the youngest department in Canadian geoscience (Table 2.2) receives one of the largest total grants (Table 5.2). This represents another departure from past practice when grants to the best researchers increased slowly with age and there were few quantum jumps for younger scientists.

As pointed out below, although most or all of the geoscience community would agree that those listed as recipients of our largest grants in Table 5.3 rank among our very best academic scientists, many would add other names to such a list; i.e. grant size is not the only criterion of excellence.

Recent practices and statistics

Annual increases in federal support of science did not keep up with inflation after the mid 1960s. There was a 30 per cent decline in the decade following 1969 in terms of 1969 dollars. Geology and geophysics were slower than other sciences to fully benefit from this support and, as described by Strangway (1976), just as Canadian geoscience reached a most important and exciting stage, federal funds were drastically cut. A reversal took place in the program for 1980-81, part of a proposed government five-year plan to increase R and D expenditures from 0.9% to 1.5% of G.N.P.

NSERC's budget was increased 34.2%, from about $118.5 to $159.0 million. The amounts awarded by the various science grants selection committees increased by 14.1% to $93.3 million; that of the earth science group by 13.0% from $6.5 million in 1979-80 to $7.3 million for 1980-81. The average earth science operating grant increased from $12 963 in 1979-80 to $14 629 in 1980-81.

When initially established, the earth science grant selection committee of NRC had a tendency, in relation to other sciences, to award many small grants and few large ones. The rejection rate was low and it was relatively simple to receive a grant of some kind but it was very difficult for a talented researcher to get enough (at least from this source) to embark on an ambitious program. This began to change about 1973 when the committee began advising poor performers that theirs were terminal awards unless marked improvements were shown. Many were thus eliminated from the system then and subsequently so that although the total of faculty members in all the geosciences increased until 1978 (e.g., see Fig. 1.1, for geology and geophysics), the number of grant applicants has remained constant at around 500 (Fig. 1.2A). Grants have become larger and there has been an accelerated increase in the number of awards over $15 000, probably as much due to increase of funds as to tougher selection procedures. It seems to be easy to identify and reward very good people. Thus, in the 1979 competition (Fig. 1.2B), a precedent was set by making several three-year grants of over $40 000 (one has now grown to $55 000 by inflationary increase). However, in the 1980 competition, despite the precedent, the committee felt that none of the applications under consideration that year deserved over $40 000 (Fig. 1.2C).

At the other end of the scale, decisions seem harder to make. There are a few large number of grants in the range between $3000 and $10 000 (Fig. 1.2C). Some rightly go to new, untried Ph.D.s, several go to good physical geographers whose needs are small (or who don't realize they could apply for more!), and a few go to able scientists involved in theoretical studies or reflective inquiry whose needs are also modest. However, many of those in this grant range are earnest, hard-working plodders who should be directed away from frontier research and into more productive channels. This is suggested in some cases by their project titles and long-term performance records, in other cases by conversations with our visiting committee members. Perhaps a special task force should be devoted to sorting the promising from the pedestrian in this grant range.

We applaud the continuing attempts of the Earth Science Grants Selection Committee to be more selective in their awarding procedures. NSERC grants should be aimed at first-class frontier research and those not capable of it should be eliminated from the system and encouraged to develop other pursuits. In order to aid it in an even stiffer selection process, we suggest that the Committee nominate a working group, possibly composed of some of its past chairmen, to scrutinize the records of those receiving less than $10 000 with the object of rapidly terminating grants to those who show little promise of making good contributions to geosciences.

Equipment grants

NSERC provides funds each year for the purchase of capital equipment. The successful applicants are chosen by the same peer committee (ESGSC) that allocates the operating grants. Judging is based on their knowledge of the applicants' research records and their familiarity with the universities' physical plants from site visits. All equipment purchased automatically becomes the property of the grantee's university unless otherwise specified. Beneficiaries of such grants are encouraged to make operating time available to other researchers and this factor is often crucial in deciding upon an award.

During the 1980 meetings $531 126 was allocated to applicants (Table 5.5) for requests less than $75 000; $591 200 to those asking for more than $75 000. In the case of major awards, the committee commonly seeks assurance from the university that it will guarantee space and technical assistance to keep the instrument in operation for a reasonable time. Also, the university or some other funding source is sometimes required to contribute to the initial capital cost. Typical of major awards for 1980-81 were:

- A solid source mass spectrometer for isotopic research and geochronometry at British Columbia ($170 000);
- An X-ray fluorescence spectrometry lab at Saskatchewan ($187 900);
- A closed loop, servo-controlled electrohydraulic testing machine for civil engineering at Saskatchewan ($110 000);
- A mass spectrometer for stable isotope analyses at Waterloo ($123 300).

The range for minor equipment grants is illustrated by:

- A mercury level tiltmeter array awarded to physics at Alberta ($25 000);
- A polarizing research microscope awarded to Dalhousie ($7850).

An ion microprobe is in the process of being constructed at Toronto in co-operation with Western Ontario and McMaster geoscientists. The former head of the Toronto geology department is chief investigator. The university's nuclear physicists are also involved with aspects of the ultrasensitive facility. The NSERC grant of $785 000 is payable in three installments. In addition, the federal Department of Supply and Services is granting $370 000 over a three-year period and smaller sums were received from EMR and Environment Canada. When installation is completed in 1981, the probe will be a national facility and is expected to be of service of geoscientists across the country, initially those involved in ^{36}CL and ^{14}C studies.

Group grants

Shared grants were introduced about five years ago in order to encourage joint research. These include Team, Co-op and Core grants. Team grants support the research of two or more applicants in much the same way as an individual operating grant. Co-op grants contribute toward expenditures of groups undertaking co-operative research projects that could lead to significant contributions to science. Co-op funds cannot be used to support graduate students or to purchase new equipment. Currently a few Team projects amount to an annual total of $56 660. Typical is a joint project of two McGill researchers who are awarded $20 750 per annum to investigate the mining potential of the Cape Smith Fold Belt in northern Québec. The single Co-op project presently active is an investigation of deep electromagnetic sounding funded at $45 000 per annum and managed jointly by a geophysicist and an electrical engineer at Manitoba. The geophysicist, in this case, is also able to hold his own substantial individual operating grant.

Core grants were designed to contribute towards maintenance and operating costs of major specialized facilities where it is unreasonable to expect adequate support through operating grants or other sources. No funds were allotted to the Core program in 1980-81.

There have been relatively few applicants and even fewer awards in any of these categories since they were instigated. This also holds true for the other sciences, except for low energy physics where a vast sum ($3.4 million) went into Core grants in 1980-81, and a similar sum in special project grants went into intermediate and high energy physics, presumably to maintain operations of existing labs.

Frontier researchers apparently like to do their own thing and to co-operate on their own terms without being restricted by shared grants. Also, the selection committee tends to value the quality of the scientist more than the project, so a joint project has to be very good indeed before committee members will allocate funds in addition to those of the normal operating grants.

Several leading geoscientists interviewed by our committees stated that Core grants or something similar to them would have to assume greater importance if universities continued to cut back on the maintenance and technical support of laboratories. Possibly NSERC will have to underwrite geoscience facilities in the same way it has provided massive support to intermediate and high energy physics over many years.

Strategic grants

This is NSERC's largest targeted program. It was initiated in 1977 to stimulate university research in selected areas of national concern. Five areas were designated for support: communications, energy, environmental toxicology, food/agriculture and oceans. For 1980-81, an open or undefined area was added to this group. NSERC is devoting about $10 million annually to this program and plans to increase this by about three times over the next six years if results warrant it and funds are available.

A special committee makes these awards following consultations with appropriate grant selection committees concerning the scientists and the university facilities associated with each application.

Initially geologists and geophysicists were not very successful in their applications. However, in 1979-80 they received a total of 22 grants valued at $914 800: 5 in energy, 4 in environmental toxicology and 13 in ocean research. The largest single grant was $170 520 to a Toronto geologist for an inductively coupled plasmic emission spectrograph for use in environmental toxicology. This program encourages multidisciplinary approaches and among the successful projects we find a McGill mineralogist/crystallographer working with a physicist on development of a photovoltaic electric cell; and a Manitoba geophysicist working with an electrical engineer on the effects of solar geomagnetic currents on electric power systems.

Individuals and groups of geoscientists from 11 universities are receiving grants. The marine geoscientists at Dalhousie are presently the major beneficiaries, receiving about $340 000 per annum in 1978-80.

We commend NSERC for this imaginative program of research support and we urge geologists and geophysicists to combine with their colleagues in other disciplines to devise projects in the national interest which will merit funding through such strategic grants.

The French fact

Blais et al. (1971) pointed out that the number of geology faculty members in Québec was below the national average; it had only 20 per cent of the national faculty although 29 per cent of the population in 1968. In 1980, geology faculty in all Québec universities represented only 17.5 per cent and in francophone Québec universities only 13 per cent of the national total whereas Québec's population is 27 per cent of the national. We do not have reliable figures for other geosciences, but obviously the size of geology faculties is not holding its own in Québec universities.

A perennial worry has been NSERC funding to geosciences in francophone Québec universities which, in the last decade, has hovered between 9.0 and 10.7 per cent of the national total with no significant trend. The 1980-81 grants showed no changes (Table 5.6). Francophone universities receive only 10.4 per cent of earth science operating grants.

The weak performance is spotty, thus geotechnical work flourishes in francophone Québec universities; for example, at Laval the geotechnical group receives twice the NSERC awards of the geology department (Table 5.2). In 1980-81, 11 out of 32 geotechnical grants and 32 per cent of all geotechnical funds went to Québec francophone universities. Although the average grant to Québec francophones in all the geosciences is $13 103 and in geology alone $13 215, the average for geotechnical studies is $16 087 and three geotechnical engineers in francophone universities rank among the highest award holders in the country (Table 5.3). Also, the Université de Montréal, which has devoted itself to frontier research in geology over the past decade or more received one of the highest average geology grants awarded for 1980-81, exceeded only by McMaster and Western Ontario.

Professors in some of the francophone universities offered several explanations for the low percentage of national grant money coming to them: (1) Professors carrying out a moderate amount of research found no difficulty in receiving adequate support from several provincial sources and, hence, there was a lack of strong competition or pressure to publish; (2) consulting and mission-oriented opportunities were plentiful and tended to lure both graduate students and professors away from frontier research; (3) heavy teaching duties and other involvement with students cut into research opportunities. This is certainly credible at Laval and Québec à Montréal; (4) Language laws have made the graduate schools ingrown and they tend to lack the stimulating atmosphere found in those with a more cosmopolitan student body.

The large NSERC grants received by many geologists at Montréal and Ecole Polytechnique suggest that the below-average grants and the relatively few grantees at other francophone institutions is very probably due to a combination of explanations (1), (2) and (3) above. We have already made a recommendation (Chapter 3) concerning those schools with student/faculty ratios far in excess of the national average. Such ratios are obviously a deterrent to research.

Comparisons with other sciences

The geosciences (and also biology, engineering and some other disciplines) have always received less in per capita grants from NRC/NSERC than have chemistry and physics. There have been many reasons given for this, including: (1) late arrival under the umbrella of NRC support; (2) the widespread supposition that support for logistics of most geological research would be undertaken by other federal agencies or, possibly, provincial surveys; (3) the feeling, unfortunately supported by some 'old guard' geologists, that geological research was not very costly.

The problems of science funding were examined in 1975-76 (Neale and Wynne-Edwards, 1975; Wynne-Edwards and Neale, 1976) and the suggestion made that changing national priorities required some reversals in priorities. Even before that time, NRC officials claimed to be making slow and subtle changes in funding. Such changes continue to this date at NSERC, e.g. operating grants in earth sciences increased 12.9 per cent in 1980-81 whereas in chemistry they increased by only 8.9 per cent and in physics by only 6.2 per cent.

Table 5.7, taken from Wynne-Edwards and Neale (1976), shows the rating by average operating grant of most of the sciences supported by NRC in 1975. NSERC figures for 1980 are added to this table and show that the geosciences have improved their position a great deal so that the average operating grant for geoscientists is well above that for all successful applicants. However, they have not made anything like the leap forward by the biological sciences, especially population biology.

NSERC's efforts to bring the support of frontier research in line with national needs deserves much commendation, especially as it seeks to do this without seriously disrupting those fields whose former accelerated progress has left them temporarily out of phase. The relatively slow acceleration of the geosciences, however, seems out of step with the tempo of the times and NSERC should be reminded of this. We recommend:

That the Canadian Geoscience Council commend NSERC for its continuing policy of re-assessing the needs of the various disciplines but press for a greater acceleration of the amounts awarded to the geosciences in keeping with rapidly growing national demands for terrain evaluation, environmental protection and in the exploration for and conservation of resources.

The disciplinary division of spoils

Within the geosciences there has been an established pecking order not unlike that within the whole body of science. Just as the microsciences, chemistry and physics, have received larger sums than sister sciences, so have the micro aspects of geosciences, those that dealt with precise measurements of minute quantities (e.g., laboratory geophysics and isotopic geochemistry), received larger rewards than the classical geoscientists. The microscientists' needs for expensive equipment and laboratory technicians to operate and service it is part of the reasoning behind these large grants, in addition to the fine international reputations of many of the scientists involved. Thus, as an example, the highest average grants to individual departments go to geophysics groups at York ($25 061), Toronto ($24 803), Alberta ($24 564) and British Columbia ($24 198). The average for academic geophysicists is $20 892 compared to the average for all Canadian academic geoscientists of $14 629.

One of the fundamental cornerstones of geological research is mapping. As stated by physicist John Ziman (1978):

> ...a great part of what is known to the science of geology is precisely what is to be found on a map. Of course the data...could have been stored in the memory of a computer...But all the essential information is in the map itself, and the processes of real interest to geologists can scarcely be grasped except in mappable form...

During the period when the microsciences reigned supreme, however, there was a tendency to denigrate those sciences whose results and interpretations could be expressed in relatively simple pictorial fashion rather than in numerical or abstract forms. The result was that geological mapping by academics was not strongly supported by NRC or NSERC. Also, classical subdisciplines of geology such as structure, biostratigraphy and geomorphology together with reconnaissance studies in geochemistry and geophysics seldom received sufficient funds to permit extensive fieldwork, particularly in remote places. Mapping and related field work is labour intensive, logistically expensive and is not comparable to the short "collecting trips" in which other scientists indulge. The earth science grants selection committee has recently recognized this and, as pointed out earlier, a field mapper, a geomorphologist and a paleontologist now receive some of the highest grants (Table 5.3). The grants selection committee has also proposed that NSERC initiate a special grant category, equivalent to that for laboratory equipment, which would fund major field operations, including drilling, travel and logistics in remote areas, ship and observatory time and geophysical instrument array deployment. We recommend:

That NSERC recognize the importance of field study to geology and geophysics by instigating grants for major field operations as recommended by its earth science grant selection committee.

NSERC grants - A criterion of quality?

Deans, department heads and other administrators often tend to use the amount of a professor's NSERC grant as a measure of his ability as a researcher. The practice is understandable due to the respect that the NRC/NSERC peer review system has earned over the years. There are, however, several limitations which should be remembered:

(1) Tradition - although changes are taking place slowly, it is still unlikely that a top-flight paleontologist or biostratigrapher will be awarded the same sum as a geophysicist or isotope geochemist of equal accomplishments.

(2) Real needs - some first-rate researchers require very little money to carry out their work. Unfortunately, some researchers with small needs and good records now apply for and receive large grants in order to gain the prestige that accompanies them.

(3) Better alternatives - some very good scientists find most of their support elsewhere (e.g. government or industry) and may not apply for NSERC grants.

(4) Committee vagaries - membership of the grant selection committee changes radically over a three-year period but, over the short term, those in certain subdisciplines could conceivably be penalized or favoured by current biases of the members.

(5) Although there have been several recent examples of large grants awarded to young scientists, age is still a factor in size of award (Fig. 1.2D).

Although individual grants must be used with extreme caution as a measure of excellence, the total grant received by a department (Table 5.4) is probably a very good general measure of the amount of frontier research underway, as individual discrepancies seem to balance out. Our visiting committees found that those schools with the largest totals and the largest average grants were also those which raised the largest amounts of research funds from other sources. They were also the schools that were mentioned most frequently by correspondents from abroad for their competence in a fairly wide variety of subdisciplines.

SUPPORT OF RESEARCH BY PROVINCIAL AGENCIES

General practices

Most of the provincial geological agencies since their inceptions have hired a few university professors and graduate students for research projects. In the early days this was almost wholly for field mapping projects in the summer months; professors and students would receive summer salaries and logistical support in the field and would carry out laboratory and office work at the university during the winter months before completing their reports. The managers of the agencies selected the map-area and decided on the time and moneys that could be allotted to it - the summer job was certainly a mission-oriented project! Where students were attempting to gain material for theses, however, there was commonly joint participation in the selection of the map-area so that there was reasonable certainty of an adequate problem being defined (e.g., in structure, stratigraphy or mineral deposits) and solutions proposed in the short span of the project.

Provincial agencies now call on universities for a variety of aid and contracts for geochemical analyses, isotopic age determinations and fossil identifications are common. Field mapping projects, either regional studies or detailed investigations of mineral deposits, particularly for students' theses, are still probably the main form of research support. Some of these were given great impetus in the past decade by injections of resource development funds into the provinces by the federal Department of Regional and Economic Expansion (DREE). Rather than build up large permanent staffs during the short life of these DREE grants, the Atlantic Provinces and Saskatchewan drew heavily on university personnel.

Examples from Saskatchewan and Alberta illustrate typical provincial support of university research. The Saskatchewan Department of Mineral Resources has awarded contracts as follows:

a) Precambrian reconnaissance mapping at 1:100 000 scale to Regina between 1975-1980 at $100 000 per annum and to Saskatchewan between 1975-78 at the same rate;

b) Uranium and base metal studies to Regina between 1976-80 at $60 000 per annum;

c) Geochemical analyses and assays to Regina at $40 000 per year. (This would be classed as service work rather than research.);

d) Geochronological studies to Carleton at $25 000 per annum between 1975-80;

e) Petrophysics of oil reservoir rocks to Regina at $25 000 per year.

The Alberta Research Council (ARC) has sponsored thesis research at University of Alberta on:

a) Structural studies of Rockies and Foothills coal measures;

b) Mass movements and rock slides;

c) Regional stratigraphic studies;

d) Quaternary studies.

The research topics for these A.R.C. projects have usually been suggested by the students or professors. Support consists of summer salary, provision of a field assistant and logistical support. Where the project proves of great interest to the Council, year-round support of the student may be provided.

Ontario - A model for research support

The Ontario Ministry of Natural Resources initiated a geoscience grants program for Ontario academics on a five-year trial basis commencing in 1978. Total awards are worth $500 000 annually and are specifically aimed at facilitating mineral exploration by the private sector and aiding the ministry's own earth resources program. The program does not support direct mineral exploration, does not provide for major equipment acquisitions, and does not support basic research. It is in support of applied frontier research as defined elsewhere in this chapter. Grants may be tenable for up to three years. The award committee consists of representatives from industry, government and universities. The awards for 1980-81 went to Brock (1 - $6 310), Carleton (2 - $23 533), Lakehead (1 - $8670), Laurentian (3 - $51 622), McMaster (1 - $21 000), Queen's (3 - $76 188), Toronto (10 - $194 959), Waterloo (2 - $30 490), Western Ontario (5 - $99 625), Windsor (1 - $24 030). The smallest grant was for $6310 and the largest, $34 000. However, one investigator received grants for two separate projects totalling $55 000.

Typical short titles for some of the current projects are as follows:

- "Metallogeny and economic potential of western Lake St. Joseph greenstone belt;"
- "Stable isotope studies in gold metallogeny:"
- "Gold exploration using carbon dioxide, water and alkali anomalies;"
- "Speciation of free gold in glacial overburden;"
- "Horizontal deep drains to stabilize clay slopes;"
- "Magnetism and stratigraphy in Blake River volcanic rocks;"
- "Impact of ground water on mining activities in the Niagara escarpment area;"
- "Immobilization of uranium - thorium - radium in mine wastes."

A seminar is held annually at which recipients of grants present the results of their work to the Ministry and its invited guests. Brief summary reports of each project are published by the Ontario Geological Survey. Grantees are free to publish the full results of their investigations in the scientific journals.

The scientific merit of the proposal and its relevance to objectives of the program are apparently at least as important as the background and recent accomplishments of the researcher in the judging process. Thus, although several of those holding large NSERC grants also qualified for large Ontario grants, others who received only modest NSERC grants qualified for high Ontario awards, presumably on the strength of sound and relevant proposals.

We strongly recommend:

That other provincial agencies follow the successful Ontario example and provide grants-in-aid of applied research to academic geologists and geophysicists within their province, in addition to the traditional contracting out of specific projects.

FEDERAL AGENCY SUPPORT

The role of Geological Survey of Canada

The Geological Survey of Canada (G.S.C.) has had a long history of supporting research in the universities that dates back to the last century. Several of the early professors were former G.S.C. scientists who returned each summer with their graduate students to undertake mapping and other projects under contract. It was contracts from the G.S.C. to physics professors at Toronto and McGill in the 1920s that initiated academic geophysics in Canada. Contracts are still awarded for a variety of service and research projects in disciplines such as geophysics, geochemistry, coal geology and paleontology and some are still awarded for mapping programs. In 1980-81, such personal service contracts amounted to $80 600. Occasionally our committees wondered why professors took on certain types of service contracts from federal or provincial agencies. We ran into some cases where this work did not create employment or theses for students, did not lead to purchases of major equipment and did not produce publishable research, at least not by the professors involved. Still, department heads pointed with pride to the large contracts their faculty members had gained! However, as mentioned in Chapter 4, several students obtain employment each year on contractual projects which supply them with material for M.Sc. and Ph.D. theses.

The National Advisory Committee on Research in the Geological Sciences was formed in 1946, under the aegis of the G.S.C., to monitor the health and promote the development of geology. The G.S.C. provided research funds which were awarded by this committee. It had difficulty finding enough applicants for its initial research fund of $10 000 (a commentary on the university research level at that time) but there was an abundance of applicants when the Committee was disbanded in 1972, at which time total grants were approximately $250 000 (Fortier, 1973). Since then the G.S.C. has participated in the research agreement program of the Department of Energy, Mines and Resources (EMR). Under this program, unlike contractual programs, the project is initiated by the academics who then apply for funds to the department. Applications are screened at the G.S.C. divisional level and then, finally, by a departmental committee. Funds are awarded chiefly on the basis of the research topics and the extent to which they fit into the G.S.C.'s program and priorities, probably less stress is placed on the applicants' research and publication records than by NSERC. Many of the same names appear on E.M.R and NSERC grant lists but it is not unusual to find that those who receive relatively high grants from one agency receive relatively low grants from the other and vice-versa.

The G.S.C. share of the E.M.R research agreement program amounted to 64 projects approved for a total of $439 000 in 1980-81. The range of grants was between $1 000 and $16 000, most of the larger grants being awarded in marine geology. Titles of some typical projects supported were:

- "Stratigraphy, tectonics and metamorphism in the Blue River area of Cariboo Mountains, B.C.;"
- "Acoustic borehole logging in the Canadian Shield;"
- "Sedimentology and stratigraphy of the Hornby Bay and Dismal Lake Groups, N.W.T.;"
- "Gold mineralization in Archean greenstone belts, Red Lake, Ontario;"
- "Taxonomy and stratigraphy of Carboniferous foraminifera and algae, B.C. and Yukon;"
- "Silurian-Devonian paleontology and stratigraphy of the northern Appalachians;"
- "Geological investigations of oceanic crust through development of a shipborne drill."

The G.S.C. grants, although small, still play an important role in university research for several reasons, including:

a) Many are given for field studies to people whose NSERC grants are insufficient to cover travel and logistics in remote locations;
b) Grantees are usually eligible to publish the results of their work in G.S.C. publication series. This is a boon to regional geologists, biostratigraphers and paleontologists whose lengthy descriptive works can usually only be published in a very abridged form in the independent scientific journals.

A worry occasioned by the scrutiny of NSERC, Ontario and G.S.C. grants was that several scientists received moderate awards from all three. Unless the granting committees checked carefully, it would be possible for a rather marginal scientist to recast his grant application three times and to end up with a total award far in excess of the actual worth of his project.

G.S.C. and E.M.R deserve commendation for continuing these grants which, despite their modest size, often serve to supplement other grants and make useful projects possible.

We recommend:

That the G.S.C. fulfill its mandate for the well-being of national geology by increasing its support of university research by contracts and by research agreements. It should strive continually to augment and complement NSERC awards in those fields that it favours.

E.M.R research agreements are slightly suspect in many segments of the academic community because of a feeling that those who make the final decisions on grant applications are themselves involved with in-house research and may be involved in conflicts of interest. We recommend:

That E.M.R management appoint external reviewers to pass judgment on applications for research support following the example of the Ontario Ministry of Natural Resources and NSERC.

Other federal agencies

The Earth Physics Branch (EPB) and CANMET (formerly the Mines Branch) also aid in selection of candidates for E.M.R research agreements. Typical of the $60 000 in grants awarded through E.P.B. to academics in geophysics departments were those for the following projects:

- "Interpretation of refraction and reflection data from Queen Charlotte fault zone;"
- "Relationships between geothermal and other geophysical data in high temperature regions of Alberta;"
- "Rheology of the lithosphere from gravity and topographic data;"
- "Seismotectonics of eastern Canada".

Although CANMET's concerns are chiefly with metallurgy, mining and geotechnical engineering, it has also sponsored a few geological or geophysical studies as, for example:

- "Geochemistry of groundwater in uranium mill tailings."

The Museum of Natural Sciences has in recent years provided grants-in-aid of research in subjects such as mineralogy, paleoclimatology, fungal evolution and palynomorph biostratigraphy.
The Department of Indian and Northern Affairs has provided funds for environmental projects such as:

- Revegetation of mine tailings;
- Disposal of drilling fluids.

DINA's divisions in the Yukon and the Northwest Territories have provided logistical support and funding through professional service contracts for professors and their students carrying out detailed regional mineral deposit studies in the north.

Environment Canada, the Atomic Energy Commission and other federal agencies also award research contracts to geologists and geophysicists in universities but we have no information concerning the projects undertaken.

PETROLEUM COMPANIES' RESEARCH GRANTS

Sixteen of 20 petroleum companies who replied to our questionnaire in 1979 claimed to have had research dealings with geology or geophysics departments. Eleven companies had been involved with Calgary, six with Memorial, five with British Columbia, three with each of McGill, Manitoba, Dalhousie, Saskatchewan, and Toronto, one with each of eight other university departments.

Most of the recent support consisted of partial sponsorship of thesis projects, divided about equally between geology and geophysics. Geological topics included micropaleontology (forams and conodonts), diagenesis, carbonates and heavy minerals. Geophysical projects included subjects such as shear waves, marine studies and deep seismic sounding. Where sums were mentioned they were generally small, only a few thousand dollars per project. Some company respondents mentioned that their support consisted chiefly of supplying cores and other basic data. Esso Canada Resources, Shell Canada Resources and Gulf Canada Resources appear to have had research contracts with the most universities. Esso has by far the most organized and undoubtedly the best financed program. Its "Imperial Oil/University Research Grants" program awarded 15 grants in 1979 to academic geologists and geophysicists in seven universities: Alberta (3 - geophysics, 1 - geology), Calgary (3 - geology), McGill (2 - geology, 1 - mining), Memorial (2 - geophysics), Manitoba (1 - geology), Toronto (1 - geography), Waterloo (1 - geology).

The value of individual grants ranged from $3200 to $6000 and projects covered such areas as:

- Magnetostratigraphy of Cretaceous coal-bearing strata in Alberta;
- Dolomitization of upper Devonian reefs in Alberta;
- Relation of organic matter maturation and mineral diagenesis to burial depth and tectonism in the Quebec Appalachians;
- Laboratory measurements of the physical properties of east coast sediments.

Apart from Esso's program, which could certainly stand improvement, the oil industry's record of support to university geoscience research is abysmal. The situation has recently been examined by A.D. Baillie (1979) who comments as follows:

> Of this number (of professors) only a handful are engaged in research considered relevant to the petroleum industry. The little that is being done is largely in biostratigraphy. With few exceptions, there is scant research being done in such fields as thermal history of sedimentary basins, basin analysis, clay mineralogy and its effect on reservoir quality, diagenetic phenomena, organic geochemistry of petroleum and source rocks, or the generation, migration and accumulation of hydrocarbons.
>
> One would expect that funding for research in these areas would be provided by the Petroleum Industry. This is not the case. Direct financial support to Canadian Universities for Earth Science research by Industry is minimal, amounting to about $200 000 annually. Not much if spread over more than 30 degree-granting Universities. Most of this is from the large multi-national companies who already enjoy the benefits of centrally located research laboratories serving their world-wide operations. I would suggest to the Industry, particularly to those Canadian companies who have limited research facilities, that they would do well to take steps to avail themselves of that wealth of research talent in universities by encouraging and supporting research relevant to the industry and their own needs.

We endorse Baillie's remarks and feel that the industry would reap many benefits if companies would adopt formal, long-term programs of grants-in-aid to university research, possibly patterned after the Imperial Oil university research grants program but with a scale of financing more closely approaching that of the mining company, Rio Canex, cited in the next section of this report. We recommend:

That petroleum companies establish continuing programs of support to university researchers in fields of geology and geophysics pertinent to the industry, using as guidelines the two models cited in this report.

MINERAL EXPLORATION COMPANIES' AID TO RESEARCH

Many of the 150 mining and mineral exploration companies contacted through our questionnaires have partially supported thesis studies in the past five years, some of them at least one per annum. The topics most frequently mentioned include geochemistry, mineralogy of sulphides and wall rock alteration. Joint research projects with university professors and partially sponsored projects in university departments include development of geophysical instruments and methods, lithogeochemical studies and petrogenetic studies.

The universities most frequently mentioned in connection with sponsored theses and joint studies were:

Western Ontario, Toronto, Queen's, Carleton and British Columbia. Others mentioned were Memorial, Ecole Polytechnique, McGill and New Brunswick. Several companies indicated that, through preference or necessity, they carried out their joint research projects with universities abroad, e.g. Imperial College (London), Pennsylvania State or the Michigan College of Mines and Technology.

Replies from mineral exploration companies suggest that many more of them are involved with university research than are their counterparts in the petroleum industry. This is particularly true of the smaller companies, for the small petroleum companies appear to give little or no support to academic geology and geophysics. Several leading academic geologists estimated that mining and mineral exploration companies contributed twice to three times the funds that petroleum companies made available for university research. One recently initiated program by a mining company, Rio Tinto Canadian Exploration Ltd. (Rio Canex), deserves special mention.

A model for research support

Introduced in 1979, the Rio Canex research program employs an established percentage of the exploration budget in support of nonconfidential research in applied geoscience. Projects are developed in joint discussions between senior company scientists and university professors and the goal is to seek solutions to fundamental problems of metallogenesis. Academics are free to publish the results of their research in scientific journals. Currently the research budget is $250 000 per annum of which, in 1980, approximately $70 000 is going to research consultants for instrument development and the remainder in grants ranging from $25 000 to $50 000 for the following studies:

- Lead isotope studies (British Columbia);
- Relationship of massive sulphides to iron formations (Western Ontario);
- Relationship between lead-zinc deposits and organic-rich black shales (Waterloo);
- Kuroko-type ore deposits (Toronto);
- Significance of low temperature organic alteration products (McGill);
- Grenville metallogenesis - with emphasis on the Mont Laurier area (Ecole Polytechnique).

We commend this imaginative and far-sighted industrially sponsored research program and recommend that:

Mining and mineral exploration companies support continuing programs of frontier research in applied geology and geophysics in university departments following the model recently established by Rio Tinto Canadian Exploration Ltd.

QUALITY OF RESEARCH

How do we measure excellence?

One of the sponsors of this project, NSERC, posed this question to us. We do not have a single answer but we think we can provide some useful information and recommend a preferred method of estimating performance of the whole of Canadian geoscience and of the various subdisciplines within it.

The most facile approach and one that has apparently been proposed by some other sciences is to count up the honours and awards granted by peers and open to practitioners in all the sciences. In this way, one could judge the geoscience gong-status relative to physics, chemistry, and other sciences. A first attempt to do this was made in the summer of 1979 and is commented on in another section.

We concluded, however, that the most reasonable way to measure excellence is by peer review, essentially the system used by NRC/NSERC but on different scales. Thus, if you wish to appraise your whole national geoscience research effort, you ask outstanding scientists who have broadened their interests in their later years and who have attained some familiarity with research activities in many parts of the world. If you wish to determine how a certain subdiscipline rates on the world scene you consult leading scientists in that field, preferably avoiding narrow specialists and choosing people who not only have been recognized for their own major contributions but who have been involved with international projects, committees, or journals so that they know who is doing what, and how well it is being done, in their own fields. We have sought such opinions from such people and feel that we have come up with worthwhile appraisals of our performance in several subdisciplines. There are differences in detail in the responses but generally those whom we consulted agreed rather closely in their assessments. We only wish that we had consulted more of them on more topics.

Although we feel that the quality of Canadian research can be best and most objectively judged by distinguished scientists from abroad, we also feel strongly that other views are very important, even when they might seem more parochial, restricted or partially uninformed they still might contain important messages for university geoscientists and particularly for department heads and senior administrators. In our visits to some universities we asked geoscientists to evaluate their own and their colleagues' work. In the questionnaires sent to petroleum and mining companies and to government agencies we also asked for views on university research. Where our respondents were still actively engaged in research, whether basic or applied, and where they had been recently involved in national or international committees and projects, and particularly where they had participated in NSERC (or NRC) granting procedures, their replies were rather similar and did not differ greatly from those of the distinguished scientists from abroad whom we had contacted. Where the responses came from administrators or from scientists who were not personally involved in frontier research, responses were naturally more parochial and less informed. There was a greater tendency to ask what has university geoscience done specifically for my province or my industry? There was less knowledge of the exploits of a distant university, and especially in a remote discipline, unless, of course, it was the old alma mater!

We present some of these views in the following pages. All may not be profound appraisals of our university research efforts but they do reflect on the communications between university people and others in the geoscience community. If geoscientists in several large companies and government agencies feel that our mineral deposits research is weak and that we lack any strong centres devoted to this topic, but if foreign correspondents state that it is one of our areas of excellence and at least one of our schools is among the very best on the continent, then something is wrong that can only be set right by some vigorous information exchange.

As university scientists are in the defensive position possibly they should take more initiatives in explaining their motives, work and goals to the rest of the community. We hope the recital of widely divergent views in the next half dozen sections of this report will alert university geoscientists to the, not always complimentary, opinions of their community and will enlighten the community as to the high regard in which our university research activities are held internationally.

Awards and honours in geoscience

A brief scrutiny of national and international fellowship listings was made in 1979 and revealed the following information:

One Canadian geoscientist, Professor J. Tuzo Wilson, holds the equivalent of the Nobel Prize in geoscience, the Vetlesen Prize. Only one other practicing Canadian scientist is a Nobel Laureate, the distinguished N.R.C. physicist, Dr. Gerhard Herzberg.

The National Academy of Sciences of the United States elects a few Foreign Associates each year. The Academy regards this as one of the highest honours it can bestow on a foreign scientist. Seven living Canadians are Foreign Associates. They include: 3 geoscientists, 1 chemist, 1 physicist, 1 psychologist and 1 entymologist.

The Royal Society (of London) doesn't consider Commonwealth scientists foreigners and it elects them as Fellows - but mighty few of them! In 1979 there were 38 Canadian Fellows. They include 9 physicists, 7 chemists, 6 geoscientists and a few scattered physiologists, biologists, anatomists and the like.

Our own Academy of Science of the Royal Society of Canada is divided into subject divisions. As of 1979 the elected membership was:

Mathematics	37	Applied Science	33
Physics	81	Plant Biology	43
Chemistry	79	Animal Biology	51
Earth Science	113	Microbiology and	
Interdisciplinary		Biochemistry	54
	53	Medical Science	61

Obviously we are doing very well in all these honour societies. We lag slightly behind physicists and chemists only in the Royal Society of London and, as two of our six Fellows were elected in 1979 we could state that we are at the beginning of an upswing which will soon see us better represented in that august body. We can also count up other scientific honours, e.g. three young geoscientists won the coveted Steacie Award of N.R.C. in succeeding years - we are the only discipline to have performed this hat trick.

It can easily be shown that the geosciences are very near the top if not at the very pinnacle of Canadian science. Another science, choosing a different set of awards and gongs could probably show that it had supremacy. One of the major criticisms of the award criterion for merit in a discipline is that many scientists have peaked by the time their peers recognize their merits so that counting up the total of awards doesn't give a true measure of the present state of the science. Another criticism of the award system is that you not only have to be good at your thing to get one but you must have a dedicated individual or group who will take the time and trouble to propose you. Nasty iconoclasts and mad geniuses seldom endear themselves to the nice guys who propose people for awards, at least not until age has mellowed them and removed the memory of their stings.

CANADIAN ACADEMICS' VIEWS ON ACADEMIC RESEARCH

In our visits to western and Atlantic Province universities we sought opinions on research by putting a uniform set of questions forward in our discussions with department heads, faculty groups and individuals. Later we repeated this process in writing or during chance meetings with representative individuals from most central Canadian universities.

We found that those scientists prominent in frontier research, particularly those who had sat on NSERC or NRC committees, answered without reservation, documented their points, and were generally optimistic about present and future research trends. Those less involved with frontier research tended to downgrade our national efforts in geoscience research and to be pessimistic about Canada ever achieving renown in competition with larger countries. However, most geoscientists we talked with agreed on a few points: (1) We do not have a single outstanding geoscience school comparable to the Australian National University, California Institute of Technology or Cambridge; (2) Our greatest strength is team work, particularly regional synthesis, where our researchers from several subdisciplines appear to work together in a manner that is not duplicated in many parts of the world; (3) All university geoscientists should be involved in research or reflective inquiry of one kind or another.

One amusing (and probably healthy) aberration was the tendency of many respondents to mention the names of Geological Survey and Earth Physics Branch scientists when enumerating leading academic researchers, particularly in the subdisciplines of stratigraphy, paleontology, tectonics and paleomagnetism.

The responses to our questions follow.

Which are the top schools?

Many geologists avoided this question having stated that we did not have an A.N.U. or Cal Tech in our midst they felt the question was meaningless. They maintained that the best one could do was to identify certain schools as excelling in one discipline or another. A minority, including some of our leading scientists, contended that the overall research quality, or the spirit that pervaded a department or even "the organizational excellence" gave some departments extra prestige. For what it is worth, their responses suggested that the Toronto Geology Department has the best all around research team closely followed by Memorial and McMaster. Interestingly enough, the heads of these three departments each rated themselves and at least one of the other two as being near the national pinnacle. Other departments mentioned were Alberta, Dalhousie, British Columbia, Queen's, Western Ontario, and Waterloo. All receive large NSERC grants and the University of Toronto receives by far the largest total grant (see Tables 5.2, 5.4).

Geophysicists were far less reticent about rating the overall excellence of research in their discipline. The groups at Alberta, British Columbia and Toronto were mentioned by everyone questioned, with Toronto possibly coming out on top with a slight edge. The University of Western Ontario Geophysics Department was the only other one to receive mention as a first-rate, well rounded research group. All these groups receive both large total NSERC grants and large individual average grants (Table 5.4).

What are we doing well and who is doing it?

Our concern about this question, and it is a real one, is that we talked with relatively few people - about 100 in all - and so our respondents may not have been familiar with a wide enough spectrum of geology and geophysics. Two points came across unanimously so that our worries do not extend into these areas: first regional geology and geophysics is regarded as one of our major accomplishments, and second, almost everyone agrees that we have established a first rate international reputation in sedimentology. Two other cited areas of research that came up frequently enough to deserve special mention concern specialities that are virtually restricted to single university departments: marine geoscience (at Dalhousie) and environmental geology (at Waterloo).

Here are the disciplines where Canadian academics feel that they and their colleagues are doing good work.

Regional synthesis Studies of the tectonic evolution of the Appalachians are highly regarded across the country with the work at Memorial being most commonly cited together with some mention of scientists at New Brunswick and Dalhousie. Cordilleran studies are also highly regarded and here the names of people from Queen's, Calgary and Carleton universities were frequently mentioned, often in association with G.S.C. and E.P.B. scientists. Some mention was also made of work emanating from McGill, British Columbia and Alberta. Precambrian Shield syntheses were seldom mentioned, Arctic Island studies scarcely at all. Logistics obviously prevents university scientists from broad regional studies in these regions.

Sedimentology The work of a McMaster University team appears to have captured the imagination of peers in universities across the country for it was cited everywhere as an example of national excellence. Sedimentological research at Calgary, McGill, Memorial, Université de Montréal, British Columbia (Geography Department) and Ottawa also received frequent and favorable mention. Two respondents pointed out that although our clastic studies have received wider recognition than our carbonate studies, if we looked at the combined work of scholars in the universities mentioned, together with the efforts of their G.S.C. counterparts, we should probably find out that Canadians know more about Lower Paleozoic carbonates than any other group of scientists in the world.

Marine geoscience The work of Dalhousie geologists, geophysicists and oceanographers on the Mid Atlantic Ridge and, more recently, on the shelves and slopes has attracted the admiration of colleagues across the country. Names of G.S.C. (i.e. Atlantic Geoscience Centre) scientists were frequently interspersed with those of Dalhousie workers implying that academics generally regard them as all part of the same research community. Several of those interviewed expressed the hope that the recent establishment of a federal Pacific Geoscience Centre would lead to a similar flowering of excellence at Victoria and British Columbia.

The only concerns about the state of marine geoscience came from marine geoscientists themselves. They felt that policies geographically restricting the scope of studies and our lack of formal participation in major international projects had had very deleterious effects on this subdiscipline.

Geochemistry (including stable isotope studies) several respondents felt that we had achieved international stature due to the splendid work of a few individuals scattered across the country but chiefly found at Alberta, Waterloo, McMaster, British Columbia, Western Ontario and Toronto.

Environmental geoscience Waterloo's combination of low temperature geochemistry, hydrogeology, and Quaternary geology has had an impact on peers across the country who generally sum it up as "environmental science" and feel that it now has international status. Frequent mention was also made of prize-winning work in hydrogeology at British Columbia.

Biostratigraphy and Paleontology Several universities are rated highly in these fields with Montreal, Saskatchewan, and Toronto probably the strongest by virtue of numbers and other schools are strong contenders because of the presence of one or two outstanding individuals, e.g., Alberta, Laurentian, Western Ontario, Waterloo and McMaster. In discussions of biostratigraphic studies it was frequently mentioned that there were so many interesting contributions to make to multidisciplinary regional syntheses that workers seldom found the opportunity to concentrate on rocks within restricted parts of the time scale. It was notable that when discussing Canadian achievements, e.g. Triassic Zonation, our informants not infrequently cited G.S.C. rather than university achievements.

Similarly, when discussing paleontology, several scientists noted that there was so much to do at the descriptive level, and so few to do it, that it was difficult to spare effort for such fundamental studies as evolutionary trends and paleoenvironments.

Petrology This was cited as first rate by many of those in the subdiscipline but surprisingly few outside of the field seemed to know that we were good at it. Practitioners feel that we are very good at metamorphic geology. Petrologists at British Columbia, Calgary, Queen's and Carleton have addressed themselves to metamorphic problems, commonly in conjunction with their colleagues in structural geology. It has been a happy and productive arrangement.

Igneous petrology is also pursued by world class individuals at Toronto, Dalhousie, Memorial and Montréal and by very promising newcomers at Lakehead and Saskatchewan.

A leading Canadian petrologist stated that we excelled in theoretical petrology. Metamorphic theoreticians at British Columbia, Carleton and Queen's were intellectually equal to the best in the world. This person found our experimental petrology disappointing - some important work had been produced but most was useful but not highly original and usually well behind the frontier. An exception was work on silicate melts underway at Queen's. The applications of analytical geochemistry to problems of petrology had not been fully exploited by Canadian academics. Trends of thought tended to follow established lines rather than spear-heading new approaches. This person felt that, with the exception of theoretical petrology, Canadian work was competent but not at the cutting edge. He rated it overall as about fifth in world ranking.

An amusing and not atypical example of academic innocence of happenings in kindred fields was supplied by several respondents who bemoaned the lack of any experimental or theoretical petrology in Canadian universities. They were astounded when told that the very active heads of three departments (Carleton, Queen's and U.B.C.) were so engaged and also that other less elaborate enterprises were underway around the country!

Structural geology Academics across the country generally stated that our record had been rather weak in this subject with the exception of some good work in regional structure studies of the Cordilleran, the Canadian Shield and the Appalachians. However, several stated that more rigorous quantitative approaches to structural geology were underway at Toronto, Queen's, Memorial and New Brunswick.

Planetary science Only a few of the scientific elite made reference to this topic. They felt that although only a few were involved, we had received world recognition by E.P.B. studies of meteorite craters and by recent studies of meteorites at Alberta and Toronto, magnetic fields and thermal histories at Toronto and planetary atmospheres at McMaster.

Mineral deposits geology All university geology departments have at least one faculty member who devotes some or all of his time to applied research. Some have several such people and academics across the country pointed chiefly to Toronto as the best known school in this speciality. Western Ontario, Queen's, British Columbia, Alberta and Memorial were also mentioned.

The largest single group is certainly at Toronto where 10 or more geologists and geophysicists and their graduate students are working chiefly on problems of mineral deposits but also on some associated with hydrocarbon deposits. The department head listed over 20 active projects and provided a list of 6 instrumental techniques developed in the last few years that had been adopted by industrial geochemists and geophysicists.

One prominent, resource-oriented academic stated that Canada ranked first or second in the world in exploration geochemistry and geophysics and in mineral deposits geology. He felt that the reputation in geophysics and geochemistry stemmed largely from a handful of innovative research and development companies but that some of the glory had rubbed off on universities. The mineral deposits research reputation was a Canadian geology department phenomenon, however, as we had not let our interests in this subject decay as had many other countries in the 1960s and 70s. Others, around the world, are now building up strength in this field and our position may soon be challenged.

Quaternary geology Many geoscientists in fields far removed from this one felt that we had attained a fine international reputation in this subdiscipline through a combination of university and government studies. Two heads of departments, neither involved with the Quaternary, went so far as to state that Quaternary and Geotechnical studies may be two of few fields where Canada ranked with the very best in the world. Individuals and groups from Montreal to Vancouver were cited, some in Geology and others in Geography departments.

Geotechnical studies Only a few geotechnical studies are associated with geology or geophysics departments, e.g. at Saskatchewan, Queen's, British Columbia and Waterloo. Most are undertaken in civil engineering units, usually in close association with other geoscience departments. Academic geoscientists generally realize that we have great stature through our research in this field. The Alberta university group seems to be the acknowledged leader with close seconds at Laval and Montreal, as discussed in Chapter 6.

Geophysics Academics state that a good deal of world class work is underway in Canadian geophysics. Some fields were singled out particularly:

- Exploration Geophysics: several academics suggested that Toronto was probably one of the top schools in the world in this field. Other schools contributing to Canada's reputation are Ecole Polytechnique and McGill.

- Seismology: is regarded as one of our great national strengths in the geosciences. Alberta draws the most individual praise for one of its geophysicist's theoretical approach through time series analysis and for deep crustal studies. There was also deep respect shown for the work of other western universities: British Columbia, Saskatchewan and Manitoba. Several geophysicists cited aspects of their work as good examples of inter-university co-operation.

- Magnetism: special mention was made of the work in rock magnetism by young scientists at Alberta and Toronto (Erindale), the magnetic deep sounding work by a senior scientist at Alberta and electromagnetic studies underway at Toronto.

Theoretical studies of various kinds were cited as first rate in many corners of Canadian geophysics. Particular mention was made of studies involving inverse theory by geophysicists at British Columbia and to the broader, analytical studies of a scientist at Memorial and another at York.

THE MINERAL INDUSTRY'S VIEW OF UNIVERSITY RESEARCH

A questionnaire sent out to 150 companies concerned with mineral exploration and mineral development included a few questions relating to university research. Replies are summarized in Appendix 3C. The returns proved very useful for appraising training, as reported in Chapter 3; however, they were less useful in evaluating research. More than half the respondents refrained from answering or gave very terse responses to the queries on research. Some replies were informed and constructive, more showed a tendency to be unaware of research activities that were related to industry and a few showed suspicion or distrust of graduate studies and university research in general. The replies are illuminating chiefly because they point to a sore need for communication between university researchers and the mineral industry.

Asked what areas or topics of research required more work or better quality work in universities, the most common reply was economic geology. This was usually in a context that implied mineral deposits geology but a few specifically included coal, petroleum and other nonmetallic commodities. Other research weaknesses mentioned were: exploration geophysics, borehole geophysics, sedimentology and stratigraphy (especially in "those eastern schools"), structural geology, exploration geochemistry, global geology and geotechnical studies. One respondent points out that: "(a) Much more emphasis needs to be placed on the distribution of ore and alteration minerals in rocks of ore deposits where they are treated and studied in the petrologic context of the whole rock. (b) There is a crying need for solution geochemistry research not only related to processes of ore formation but also rock diagenesis, metamorphism, etc. Work in this area could revolutionize our understanding of geology, and it has been almost totally ignored in Canadian universities."

Another respondent regretted the lack of research in low temperature organic geochemistry and its implications to hydrocarbon assessment and exploration. Still another felt that universities should be leading the way in multidisciplinary approaches to understanding ore deposits and that so far they have failed to do this.

A question concerning the balance of research activities elicited the general response that much more emphasis was required on field work and less on laboratory and theoretical studies. Some replies suggested that the present balance was not bad - if any group was going to look into the theoretical and experimental it had to be the universities - and at present only individuals and a few entire departments were out of step. Most answers, however, suggested a shift in emphases would be required to suit the industry.

The rather negative nature of these replies was probably partly the fault of our questionnaire which tended to look for inadequacies of university research rather than its bright spots. The mineral exploration companies must feel that some of the research activities are tolerable because, as noted in an earlier section dealing with research financing, many companies offer partial support of theses and other university projects. And one mineral exploration company has come forward with an enlightened program of research support that merits emulation across the country.

THE PETROLEUM INDUSTRY'S VIEWS ON UNIVERSITY RESEARCH

We received replies from 19 to 24 companies to which we sent questionnaires: ten were major concerns and nine of intermediate size. Again, our questions probably focused on the shortcomings of research rather than on the highlights. However, 16 of the 19 companies who replied had had research dealings with universities. The replies were generally more informed and more positive than those from the mineral industry although, as mentioned in an earlier section, petroleum companies provide even less support for research than do their mineral industry counterparts.

Petroleum geoscientists feel that research is badly needed in organic geochemistry as it relates to the origin and maturation of petroleum. Five respondents made this point and two noted that it was a field virtually neglected by all North American universities. Clay mineralogy and diagenesis have not received the attention they deserve despite their well-known importance to exploitation of tight gas reservoirs and the problems associated with secondary recovery. Several pointed out that university researchers seemed to be unaware of a host of petroleum-related problems. Thus, in geophysics, there is hardly any activity in data acquisition processing - the new shear wave reflection work for example, interpretation (structural modelling), wireline log-reservoir characteristics, and high resolution engineering seismic methods. Subsurface studies in basinal analysis were also stated to be neglected by university groups. It was also noted that a couple of major, old-established universities did not have a single clastic sedimentologist in their geological research units.

Several respondents regretted that so many geophysical schools concentrated their research on magnetic and gravity studies and virtually ignored seismic methods. However, two major oil companies pointed out that the great expense of most seismic research put it beyond the reach of universities.

In discussing the balance of research activities some replies stressed that the primary requirement of universities was teaching and other forms of information transfer. They felt that research should be a secondary consideration and regretted the prestige accorded to many of its practitioners. In contrast, some others stated that universities were not sufficiently involved in research and too many professors spent their free hours consulting for personal gain (no names or institutions were mentioned!).

More positively, several replies suggested that professors should be invited to partake in company research projects during summer months, either as consultants or observers. One wrote that more professors should be invited (or invite themselves) to spend sabbaticals at company research headquarters abroad thus becoming familiar at first hand with frontier research in petroleum geology. Apparently professors from Memorial and Calgary have recently followed this route and highly recommend it.

PROVINCIAL VIEWS ON UNIVERSITY RESEARCH

All provincial agencies have close ties with at least some universities within their own province. Many of these have been explored in Chapter 4, others are treated in Chapter 7, and examples of financial support of research have been given in a preceding section of this chapter. Although views given by provincial agencies were more in accord with one another than those of any other group, there were several rather different appraisals of the status of academic research as noted in the opinions recorded below:

- Academics and their students producing final reports on provincially sponsored projects have a tendency to focus on specific problems rather than producing well-balanced reports. Economic geology and geophysics generally receives very cursory treatment.
- Academics have a tendency to "rush into print" at very preliminary stages of investigations.
- Most provincial respondents felt that freedom to choose research emphases was a useful tradition in university circles and they rather regretted what one termed "the disjointed approach that often results where the main thrusts are dictated by the aggressiveness of individual faculty members rather than some more objective criteria."
- Admitting that the university geoscientists' main concerns should be with basic research, most provincial geoscientists regret their tendency to ignore or denigrate anything that smacks of the applied. As put by one correspondent: "We have encountered a general reluctance by university faculty members to accommodate any applied elements within their programs that would permit us to consider sponsorship or cost-sharing." Only one provincial agency felt that the university with which it was most closely associated had a wholly appropriate research emphasis.
- One respondent regretted that in a country so dependent on the resource industries, our universities had established little reputation in economic geoscience instead of aspiring to build an equivalent of the Imperial College in London (compare this with opposing viewpoints given by our correspondents from abroad).

Despite the rather negative aspect of these comments, there was a prevailing attitude that university research activities complemented their own provincial survey research and that "university research probably has some impact on our resource studies." And, as stated by one survey head "...the international reputation of Canadian geoscience seems to be rising... In spite of some deficiencies, our economic geology, both within and outside of universities, is highly regarded around the world - but not necessarily for laboratory studies."

THE FEDERAL AGENCIES' VIEWS ON UNIVERSITY RESEARCH

The major geoscience research units in the federal government are the Geological Survey of Canada (G.S.C.) and the Earth Physics Branch (E.P.B.) of the Department of Energy, Mines and Resources (E.M.R.). Other important units are the Natural Science Museum and two major divisions of the Department of Environment and of Fisheries and Oceans (from whom we received no replies). Several other federal units are marginally involved with university research in the geosciences.

Department of Indian and Northern Affairs The Mining Resource Section supports a few projects annually from its regional offices. The respondent from this group states that the major gap in university research is a concentration on field aspects of mineral deposits. A reply from the Environmental Studies Division of this Department notes that contacts with university people are fewer than desirable. They support several studies and note that a major gap is the underpopulation of permafrost researchers. A spokesman for the Oil and Gas Evaluation Division stated that university scientists should be carrying out many of the surveys that are now done by government and industry.

The Resource Management Branch of E.M.R. is a regulatory rather than a research agency. It provides university scientists with access to well samples and resource information and observes that a wealth of material is available for research projects that has scarcely been touched. The respondent for this group felt that Canadian universities had made only minimal contributions to research in petroleum geology and stratigraphy.

The National Museum of Canada's Natural Science's Museum co-operates in research with 9 universities. The reply from this institution states that although post-graduate education in Canada is at least the equal of that of any other country, no Canadian university has attained the reputation of continuing research excellence achieved by some U.S. and European universities - even though we do have some exceptional scientists in some departments. Our drawbacks are the mechanisms of funding, small research staffs and low population density. We may yet overcome these by multidisciplinary and intradepartmental approaches to research.

Earth Physics Branch (E.P.B.) is the largest single employer of research geophysicists in the country. Its scientific establishment is 85, with an equal number of support staff. Its main establishment is in Ottawa, but it also has a small group in the Pacific Geoscience Centre near Victoria, B.C.

E.P.B. has no major concerns about university geophysics research except, possibly, that the efforts are spread rather thinly over many subdisciplines. They acknowledge the existence of duplicate and repetitive publication but state that this isn't confined to universities and "the system from graduate training to salary structure encourages this".

Asked to comment on what was being done well at the universities the E.P.B. response was: "The excellence of research in geophysics at a university in Canada usually depends upon the talents of a very small group - even with this caveat, structural lithospheric geophysical studies using a variety of geophysical techniques have been undertaken by several universities in this country in a fashion which we believe compares favourably with the best in the world."

The Geological Survey of Canada is by far this country's largest geoscience research agency, it comprises about 300 scientists and about 400 support staff. It consists of seven scientific divisions and two service divisions. One division is in Dartmouth, N.S., another in Calgary, Alberta, a third in Vancouver, B.C., with a part of this being in Patricia Bay, B.C. The remainder are located at headquarters in Ottawa.

Some of the G.S.C. divisions relate very closely to university research groups, others less so and one hardly at all. Impressions of university research were favourable and optimistic where contacts were close, less so where contacts and interrelationships were few.

There are many interactions with university geoscientists, including joint projects, contracts, supervision of theses, and co-operation on international projects. The Survey considers these contacts important for several reasons: the opportunity to bring research scientists into the lively company of graduate students; as a means of carrying out low-cost complementary research; opportunities for exchanges between specialists; and the opportunity to have special studies carried out to augment in-house endeavours. Survey scientists see the universities benefitting by the opportunity to acquire competently supervised thesis projects and, in some cases, the opportunity to have funds and research facilities put at their disposal. As pointed out in Chapter 4, some university professors feel that most of the advantages accrue to the G.S.C., fewer to the universities.

Some people in G.S.C. divisions have major concerns about gaps in Canadian university research. One states that Atlantic Province universities almost wholly missed offshore developments, an almost "criminal" case of negligence. Another states that nuclear geophysics has continued to be ignored despite warnings of its importance at various times over the past 15 years. A third asks for more concentration on economic and structural studies and laments the universities' concentration on laboratory projects at the expense of fieldwork. Paleontological research is considered excellent in six university departments but weak in most of the others. Finally, geoscience departments are ticked off for abrogating their responsibility for development of analytical methods to university chemistry departments which are not properly motivated.

Asked to comment on what was done well at the universities we received a wide variety of replies:

- a senior scientist with one division commented: "University geosciences in Canada are generally in a mediocre state with seemingly little or no coordination either with other universities or with federal or provincial surveys. Even within a given university the impression is one of a buffet-style approach to the geosciences."

- Another division stated:

  "In those areas of interest to us there are examples of incompetence and neglect among university teaching staff, e.g. in the supervision of research students, in the utilization of expensive analytical instrumentation (XRF, SEM and electron microprobe); the impression is one of somnolence, in part because of the channelling of research activity time into administrative and other areas."

- A division that had a great deal of interaction with universities felt that although they were generally performing their roles adequately, there was too much emphasis on experimental research and too little on field geology.
- Another stated that although Quaternary geologists were few and widely scattered some good work was underway. Singled out for special mention were:
  Permafrost studies at British Columbia;
  Amino acid dating at Alberta;
  Fission track dating at Toronto.
- Inadequacies in coal geology, resource appraisal, marine geology and geophysics and all aspects of Arctic geoscience research were the complaints of some divisions.
- On the positive side, others identified the very good work carried out in regional studies of the Appalachians and the Precambrian of Labrador by Memorial scientists, sedimentology research at McMaster, palynology at Toronto and Saskatchewan, biostratigraphy at Saskatchewan, "analytical studies" at Toronto, and isotope geology at Montreal.

Some very thoughtful comments from a divisional respondent who is involved in a wide spectrum of applied activities make an apt conclusion to this section: "There are too many university departments, with support too thinly spread...Lack of continuity in university investigations, and failure to make full use of available equipment are criticisms often levelled at universities, and undoubtedly lack of adequate support staff is a major factor. It is one consequence of the apparent (peculiarly North American) social preference for maintaining 'lean' organizations (in parallel with high unemployment!). 'Lean' organizations may appear to be 'cost-effective', but they are hardly conducive to long range creative thinking. I think it all relates back to social attitudes, particularly the obsession with 'productivity', which encourages quantity before quality, because the former is so much easier to measure...Canadian universities are doing a competent job, much above the world average. This is particularly true in exploration geophysics and geochemistry."

WHAT THE OUTSIDE WORLD THINKS OF US

In order to obtain outside assessments of our national effort and some idea of our international standing in geoscience we approached two or three outstanding scientists in each of the major subdisciplines. Most are in government agencies or universities, a few are industrial geoscientists. These people were chosen partly by members of the editorial committee and partly by well-known scientists from across the country. We received replies to over 75 per cent of our requests. A few were rather vague and noncommittal, and a few were terse and mentioned only the names of a few outstanding workers in a subdiscipline. Most were thoughtful analyses that pointed out strengths and weaknesses and in some cases presented reasons for them. Although asked to write only two paragraphs, many wrote several pages of comments and one presented us with a most knowledgeable and provocative 15-page typescript on the status of the geosciences in Canada! Some of these comments are reproduced near the end of Chapter 7.

About half of the respondents requested anonymity and we have respected their wishes. Many replies listed the names of outstanding geoscientists but the Canadian Geoscience Council decided against using the names of individuals except in the cases of a few distinguished retired scientists who have played important roles in our geoscience community.

First let us state that on the whole the replies were very complimentary - people abroad think much more highly of our research efforts than do the average university, company and government geoscientists at home. Further, people abroad have some rather different perspectives of our strengths and weaknesses than do those at home. For example, our own government and company geoscientists generally deplore the lack of resource-oriented, applied geology in our universities and our emphasis on theoretical and experimental studies at the expense of field-oriented research. Most of the replies from abroad are brimming with compliments about our interaction amongst universities-industry- and government (it must look good compared to relations in some other countries), our excellence in mineral deposits research and the fact that some of our universities rank with the world's best in this field. However, as one of our weaknesses many of them point to a lack of theoretical and experimental work to complement our universities' dedication to field studies!

Another interesting difference in opinion - with the exception of one lone GSC respondent (who knew first hand whereof he wrote) most Canadian geoscientists seemed mightily pleased with our efforts in marine geoscience. However, our foreign appraisers feel that our efforts have been disappointing in this field for, despite the efforts of a handful of dedicated first class scientists, we have largely neglected the dialogue of the oceans around us at a time when the answers to many fundamental geoscience problems lay in the seabed.

We asked our scientists from abroad not only their views of our standing within their own subdiscipline but also their impressions of our total geoscience effort. We shall start with a few views of the whole panorama, many more are given in Chapter 7.

The whole scene - Some foreign views

> ...a better balance between field and lab and between basic science and applied science has characterized Canadian geology than has been the case in the U.S.: thus Canada has retained a secure balance that the U.S. in now striving to regain.
>
> - Francis G. Stehli, Case Western Reserve University.

> ...I am very impressed by the excellence of geological field work and tectonics in Canada, but not quite as much by the state of the geochemical disciplines...
>
> - A U.K. geochemist

> ... Finally, I might say it is my impression - and I cannot make the statement stronger - that Canadian geology is far more field-oriented and less laboratory-oriented than U.S. geology...
>
> - Robert M. Garrels, Northwestern University

...I would say you excelled in Paleozoic tectonic studies, including ophiolite analysis; in glaciological studies, seismology and paleomagnetism, ores and mineralization, and in Precambrian studies...

- B.F. Windley, University of Leicester, U.K.

Geophysics

Most of our correspondents on this subject were asked to comment on the whole field of geophysics:

...let me say that, on the world scene, Canadian geophysicists rank with the very best. The quality of their research is widely acknowledged...Canadians are frequently asked to take senior administrative posts in major international organizations...which reflects a genuine respect for their scientific ability and the wisdom necessary to successfully organize international science. It is invidious to mention names but too much credit cannot be given to Professor Wilson...there is hardly an institution in the whole of North America where some member has not come under his influence...Canada has established a first-class network of seismic and geomagnetic stations and has pioneered much work in upper atmosphere and space physics. It has also played a leading role in many important international projects, e.g., the International Geophysics Year, the Upper Mantle Project and the International Geodynamics Project...

- J.A. Jacobs, University of Cambridge

...From where I sit the state of Canadian geophysics is very healthy indeed. In paleomagnetism your government laboratory has one of the world's top two or three scientists. The field of mining geophysics is better developed in Canada than anywhere else in the world and the University of Toronto is the center of much of this activity. In the field of magnetic deep sounding, a scientist at Alberta is an acknowledged world leader...

- Alan Cox, Stanford University

...I pay more attention to individuals than institutions. Just a few of many who have had international impact and are world class scientists are located at: Toronto, Alberta, British Columbia, Memorial, York and E.P.B./Carleton...

- D.L. Anderson,
California Institute of Technology

A few of our correspondents commented on individual subdisciplines as follows:

Seismology

...The Canadian effort is highly regarded...the seismic network is as good as any in the world in spite of your logistical problems. The Canadian program in crustal refraction and deep reflections has consistently produced excellent results for more than a decade. Indeed, Canadians have contributed to most recent advances in seismology, and a very broad-based study of seismology using modern techniques seems to be underway in Canada...the most outstanding seismologist in Canada is at Alberta...Seismology is alive and well in Canada...

- J.C. Savage,
U.S. Geological Survey, California

...I have sensed a problem with regard to reflection seismology. It is not uniquely Canadian, in fact it appears to be universal. Reflection seismology was developed by the oil industry and has advanced to a stage where the technique can provide great detail on shallow high frequency lines, deeper lines as used by the industry and, in some areas, deep crustal information...In the foreseeable future it should make significant contributions to sub-surface mapping and problem definition in: hydrology, mapping of faults, earthquake studies, waste disposal sites, geothermal exploration, etc...Academic training must be beefed up massively if these demands are to be met...the best solution would be for regional seismic crews and processing centers to be shared by academic institutions in a given region...

- A leading industrial scientist, U.S.A.

Mining geophysics

...the entire national geoscience effort is good but there is a weakness in the area of mining geophysics. In spite of this, the University of Toronto boasts an excellent program. One of the outstanding workers in this area is at Toronto. Reasonable work is being done at British Columbia, Queen's, McGill, Ecole Polytechnique and Manitoba...

- A professor of geophysics, U.S.A.

Magnetism

...Canadian rock magnetism and paleomagnetism rate high on the international scene. The Canadian Journal of Earth Sciences has become a key journal in paleomagnetic literature.

Two very good groups in rock magnetism are led by scientists at Alberta and Toronto. These two place Canada at the forefront.

In paleomagnetism Canada rates with the best in the world. This stems from the impact that the Geomagnetic Lab of the Earth Physics Branch has had on the subject... (it) is one of the top three in the world. Their pioneering work on the Precambrian and on chemical demagnetization are notable...University departments that do paleomagnetic work are usually centered on one faculty member...contributions rise and fall with the number of graduate students...There are very good people running labs in Edmonton, Toronto, Windsor, London and St. John's....

- M.W. McElhinny,
Australian National University

Geochronology and isotope geology

...Despite important early pioneering work in this field in Canada...current research effort is on the whole somewhat disappointing and in no way explores the full potentialities of these techniques as applied to the numerous major, fundamental, geological problems... Isotope geochemistry (including geochronology) has now passed the stage where substantial advances are likely to be made solely by physicists and/or analytical chemists...Analytical techniques and the methodology have become sufficiently well established to be fully taken over by geologists, geochemists, petrologists, etc. who are willing and capable of applying the entire methodology to their particular scientific problems, and who can spend a good proportion of their time producing data in isotope laboratories.

Canada has several laboratories which are well-equipped but which nonetheless exude an air of somewhat sterile, analytical virtuosity, without corresponding scientific creativity and productivity...Some appear to concentrate on only one of the age and isotope methods, or even only one aspect of one of the methods (e.g., U-Pb on zircons)...Scattered throughout the country there are several small laboratories run by competent workers, but with comparatively antiquated analytical equipment and without sufficient time...There is a very definite minimum economical size for an age and isotope research group...The result of all this is that every scrap of geochronological and isotopic data is eagerly pounced on by Canadian geologists and discussed and dissected ad infinitum...A laboratory...should nowadays be capable of producing really substantial amounts of reliable data using most or all of the principal age and isotope methods (Rb-Sr, U-Pb, Sm-Nd on minerals and whole rocks, as well as K-Ar for certain more special applications particularly on younger rocks). A modern mass-spectrometer should be capable of producing an average of 4 to 6 high-precision isotopic analyses per day of such elements as Sr, Pb, Rb, Ar etc., although not yet anything like this quantity for Sm and Nd. It should not take more than a week or two to produce 10-to-15 point whole rock Rb-Sr isochron...

If Canada had two or three well-equipped and adequately staffed laboratories...I believe that the study of the temporal evolution of the Canadian Shield and the various mobile zones around and within it would receive a tremendous boost....it seems that one could build on the achievements of the G.S.C. group at Ottawa and of the R.O.M. in Toronto, provided that the outlook becomes much more geologically orientated from within.

Having said all this, I feel that I must pay tribute to the imaginative and creative age and isotope work that has been carried out...at several Canadian universities, particularly at Toronto, Alberta and British Columbia...their work has made more impression on me than that of other Canadian workers...There is an important place for small, imaginative university research groups, which must continue to be supported in addition to the larger type of group mentioned above...

- A leading U.K. worker in isotope geology

Mineral deposits geology

...In my opinion, your effort in mineral deposits ranks with the best in the world.

As far as research is concerned, the case for excellence is easier to make. Because you have a very competent national survey (though stretched pretty thin at present) and a lot of good structural, petrological and other field geologists in your universities, you have an ideal environment for research on mineral deposits. As a result, I believe you rank, on a per capita basis, near the top today. Unfortunately, this is mostly an academic and G.S.C. effort, with a distressingly small input from the very large body of geologists in industry...

The best school for research in mineral deposits is Toronto because it has several good and active people. Indeed, I believe it is one of the top 5 in North America for mineral deposit studies today.

It seems a bit contentious to pick the names of all your outstanding researchers, [he names one from G.S.C. and two from Toronto] ...But since I believe that economic geology is as much a state of mind as it is a discipline, contributions by such people [scientists from British Columbia, Western Ontario and Queen's are named] are just as important for economic geology as contributions concerning the actual deposits, so scientists such as these should also be counted among your best. You are fortunate to have so many good ones...

- Brian J. Skinner,
Yale University

...There are several important schools of economic geology which are internationally well known...from east to west...

...Memorial University has made very important contributions to the relationship of mineral deposits to plate tectonics...the Memorial group is also strong in rock chemistry - important in questions of ore genesis.

Ecole Polytechnique has done some good work in economic geology; in recent years, however, their pattern of production lacks coherence.

Toronto has a lively school of economic geology. They have the leading nickel geologist, not only of Canada but of the world. One of their scientists has contributed greatly to the application of electron microprobe analyses to economic geology. His laboratory has been responsible for the high standards achieved by the economic geology and experimental petrology groups at that school.

Western Ontario has a world leader in the investigation of stratabound mineral deposits. Alberta has a very strong team of economic researchers with emphasis on uranium. They have also maintained excellent relationships with industry.

Despite this...reflected light microscopy does not receive the attention it deserves and there are still many universities in Canada where mineral deposits geology is undernourished...

- Professor in a Mining University, Europe

Petroleum geology

...Canada is weak in its petroleum geologic basic research and consequently, exploration particularly of the frontier areas is not always done with the best technology available (there are clearly a number of exceptions to this). The reason for Canada's weakness in petroleum geologic research has been rightly recognized by many to be the consequence of branch plant type industrial operations...

The U.S. style of government sales for exploration in frontier areas, although slow and unsatisfactory ...does encourage use of the best geophysical technology possible for the evaluation of tracts that come up for sale. The competitive advantage is with the party which has the most advanced geophysics. Therefore, I would consider peak performances of U.S. exploration geophysics generally superior to Canadian performance.

In a general way, I judge Canadian exploration efforts and teamwork to be of much higher average quality than U.S. efforts, but as stated earlier, many of the American peak efforts are likely to be far more sophisticated. In other words, the U.S. has a great potential for widespread high quality work...

- An American petroleum geologist

Petrology

...Canada has some excellent to outstanding metamorphic petrologists, who are doing as original and worthwhile research as anyone anywhere. Institutions that excel in this area are British Columbia, Alberta, Calgary, Queen's, Toronto, Carleton and Ottawa...The general state of health is also reflected in such valuable publications as the M.A.C. 'Short Course in Application of Thermodynamics to Petrology and Ore Deposits', 1977, and Paper 78-10 of the Geological Survey of Canada on 'Metamorphism in the Canadian Shield', 1978. I don't think any metamorphic petrologist anywhere in the world should be without these publications on his bookshelf. In other words, Canada's research effort in my field of interest is as good if not better than any other country I can think of...

- B.W. Evans, University of Washington, Seattle, U.S.A.

...At this time, experimental petrology in Canada is healthy with the best known centers at British Columbia, Carleton and Toronto. I would put Canada ahead of England, Russia, France and Germany, on a par with Australia and surpassed only by the U.S.A. which has a broader and more diversified program. But, as in most other sciences, the U.S.A. is slipping and our advantage is decreasing. In addition, Canada has respectable programs at Alberta, Western Ontario, Laurentian, McGill and others. The particular strength of the Canadian effort lies in the strong field background of the experimentalists, combined with their thermodynamic sophistication. The only possible weakness stems from the unavoidable lack of depth in approach.

- Hans P. Eugster, The Johns Hopkins University

...Ophiolite studies in Canada have centered around the Bay of Islands Complex in Newfoundland...Here a number of new concepts have emerged mainly through the fieldwork of a Memorial professor and his students. His detailed mapping provided the basis for the more detailed studies by his Memorial colleagues and by geologists from Western Ontario and these studies have provided basic insights towards the overall study of world ophiolites. Recently a Laval geologist has provided new and unifying studies on the ophiolites of southern Quebec. In contrast, very little new and exciting work has been done on the ophiolite rocks in British Columbia, leaving this area one of reasonable doubt. This must reflect in part the academic interests at British Columbia and the difficult terrain...Canadian efforts rank very high on the international scene when one compares the contributions made mainly by Memorial University with those in the U.S.A. and Europe.

...the really outstanding work of a Toronto geologist on sulphides and their occurrence in ultramafic lavas. Here Canada is clearly the leader. The publication on Ophiolites and Ultramafic Rocks of the Earth Physics Branch (1972) was a landmark attempt to organize the various occurrences of ophiolites-ultramafics in Canada...

- R.G. Coleman, United States Geological Survey, California

...So far as volcanology is concerned, I have some rather definite opinions...even though (some of the outstanding persons) may not be concerned with physical volcanology in the narrow sense. The dating and isotopic studies (of a British Columbia scientist) are making an important contribution to our understanding of the evolution of convergent plate boundaries and their associated volcanism. (A Queen's scientist's) work on the physical properties of silicate melts is simply unique...in my mind he is one of the finest scientists in Canada. (Another) is doing quite interesting work at Queen's on the characterization of Precambrian volcanism. There are several people at Toronto doing excellent work in petrology...and a good deal of interesting work is coming out of Montreal. [This author also mentions some extraordinarily good work on Precambrian Shield volcanism by a G.S.C. scientist.]

It seems to me that (Canadians) are in a position to make an almost unique contribution through studies of Precambrian volcanism...without which it will be impossible to view magnetism and volcanism in proper perspective...I find one regrettable aspect that undermines its value. There is a tendency to try to interpret the ancient rocks in terms of popular models based on younger tectonic relations that may be quite inappropriate for the Archean...in too many instances they force their observations into a popular model. I wish someone had the courage to look at Canadian rocks with a more open mind and tell us, not how they fit into the subduction model, but what they reveal in terms of the contrast between Archean and Cenozoic conditions...

- Alex R. McBirney, University of Oregon

Structural geology

No answers were received from foreign structural geologists contacted. However, the following interesting and provocative paragraph came from a commentator on another subject when summing up his opinions of the geoscience spectrum:

...Perhaps the weakest area I met with in Canadian geology was structural studies. With certain exceptions where there have been recent imports from British or other foreign schools, I found the standard of structural geology low. This comes out on regional maps produced by the Canadian Survey. Even allowing for the large areas covered, they lack a feeling of structures and resemble 'potato prints'...The rather primitive state of structural geology comes out in discussions with Canadian geologists about the formation of gneisses and the deformation of discordant structures. The idea that layering can be produced by such processes as differential movement in rocks undergoing ductile strain, or that original unconformable structures can be rotated into parallelism, seemed revolutionary to many university audiences... This can only reflect something fundamentally wrong...

- D. Bridgwater, Gronlands Geologiske Undersøgelse

Mineralogy

...The marvelous field geology in Canada seems to have set a course whereby Canada develops outstanding petrologists much more than it does outstanding mineralogists. In mineralogy, the Canadian effort seems concentrated on minerals of economic importance, particularly the sulfides. Canada seems to lack a strong center for mineralogic research such as exists, to cite those best known to me, at Virginia Polytechnic Institute or at the State University of New York at Stonybrook...bright spots in mineralogy in Canada exist at British Columbia, Carleton, Ottawa, Manitoba, Calgary and, for sulfide mineralogy, Toronto.

The Canadian Geoscience Council might consider selecting a particular Canadian university and helping it assemble several outstanding mineralogists (with comparable supporting equipment) so as to develop a center for advanced mineralogy...

- A professor of mineralogy at a U.S. university

...My general impression is that in mineralogy, Canada ranks among the best countries in the world, especially in economic mineralogy. [This respondent then cites names of a few of our outstanding people, most or all of whom classify themselves as geochemists or petrologists. This person goes on to state the following] ...Probably the major weakness is a tendency for parochialism, especially in recruitment...I recommend regular review of research facilities to make sure that obsolete ones are pruned. Make sure that young scientists are mixed with older ones on planning committees...

- Another professor of mineralogy at a U.S. university

Marine geoscience

...This work is concentrated in the two major coastal institutes and the local coastal universities. In the early days..world-class research was attempted (by government scientists)...who produced a definitive (baseline) survey of the Mid-Atlantic Ridge that is still of reference value and some deep-penetration seismic profiles that compare well with survey data currently being used in the selection of deepsea drilling sites. Some years ago the program at (Bedford) Institute was redirected to work on problems related to the economic development of resources beneath Canadian territorial waters. While the work is of high quality, it no longer has much impact on the world geoscience scene, since the east and northeast coastal shelves do not contain the dramatic tectonic structures currently interesting geophysicists. The more recently established west coast Institute still benefits from the surge of energy that usually accompanies the relocation of people to a new facility. They are also fortunate that Canadian waters include areas of complex and interesting tectonic structures that are still active...The geothermal and seismic work spearheaded (by a government scientist) can be singled out as having long-term scientific potential...

- A west coast U.S. professor of oceanography

...The situations in Canada and the U.S.A. are quite different. The major impetus for marine research in the U.S.A. came from private institutions while the major impetus in Canada came from the Government...Thus, the development has been different although one cannot say that one or the other is more productive. I would compare the Canadian model with our NASA system where the major efforts have been made by national laboratories and the research in the universities while good, is less concentrated and less visible...In Canada, the decision was made to concentrate the ships at major laboratories; Bedford and Patricia Bay, and hence, these labs are where oceanography is done. Collaboration with universities, especially Dalhousie and British Columbia has been good, but pressures on the in-house groups are such that conscious and continuing efforts to collaborate with universities must be made.

Canada has a number of distinguished geoscientists in the marine area, some of whom flit back and forth between the universities and the laboratories. Since the principal opportunities for research are at the laboratories, many end up there. Among the leaders best known to me are (university geophysicists and G.S.C. scientists on the East Coast and an E.P.B. scientist and a university geologist on the West Coast). They are all imaginative and productive and well-known internationally.

I can't say whether the U.S. or the Canadian system produces more bang for the buck, but I can say that there is no question in my mind that direct and active student involvement in the research makes it more productive. The students are always asking stupid questions that one can't answer...

- Charles L. Drake,
- Dean of Science, Dartmouth College, U.S.A.

...Canadian marine geoscience seems to me to be quite healthy. I am best acquainted with the staffs and programs at Dalhousie and Bedford, and I don't hesitate to say that both are top notch...I think the international images of many of the staff are somewhat less bright than they could be because the programs are focused so much more strongly on domestic, as opposed to worldwide, research. As colleagues, however, I hold them in the same esteem as an equivalent sized group anywhere.

...when I think of truly outstanding scientists, many tend not to be directly in the marine field. Tuzo Wilson broke a lot of important ground for marine geoscientists with his transform faults, hot spot traces, etc., but he was not generally considered to be a marine scientist. Neither was Harry Hess, for that matter...Marine scientists, Canadian, U.S. or whatever, tend to spend too much time collecting and drying out their data, and someone who has stayed ashore figures out what it all means....

- A senior scientist in a U.S. oceanographic institute

...In the U.S., academic research institutions dominate the scene, while Canada was slumbering for a long time until the G.S.C. jumped into the fray to be immediately engulfed in commitments that in essence tried to duplicate some of the work done by industry with the addition of some fairly routine environmental studies and very few and limited studies (mostly refraction and magnetic based) that could be properly classified as basic research.

Because oceanographic efforts in Canada's academic institutions are only symbolic and because the survey had to do routine chores that were expected from them, output has been by and large pedestrian. Nothing like the ferment and the competition seen among U.S. institutions is visible in Canada.

Probably the most massive 'cop out' was Canada's essential non-participation in the Deep Sea Drilling-IPOD effort. For as little as $1 million, Canada could have had an active role in IPOD and could have had some holes drilled that would have been most relevant to an understanding of the Canadian offshore. Constrast this with the participation of another great seafaring nation: Switzerland, where on most DSDP Legs and even on a number of IPOD Legs, Swiss based scientists actively participated, contributing to establish the worldwide paleontological framework, lithofacies studies, and comparison with alpine sequences, the desiccation of the Mediterranean, etc.

I simply do not understand why Canada did not participate more actively...

- A leading U.S. industrial scientist

Paleontology and biostratigraphy

...In the field of Paleontology,...a larger per cent of the total effort than in the U.S. has gone toward the more applied aspects of the discipline, biostratigraphy, stratigraphic paleontology and the systematics that underlie these areas. For Canada this seems to me right and appropriate. Significant effort has gone into basic studies all the same and some outstanding work has been done, particularly in increasing our knowledge of the Arctic. The Canadian Geological Survey seems to me...to have contributed a great deal toward setting a fine example for the field to follow...

- A U.S. professor of paleontology

...Paleontological work in Canada has been highly respected and well thought of internationally since early in the last century, but there used to be relatively little of it. With the post-war expansion of the Geological Survey and the universities, the expansion has been remarkable. Excellent work comes now not only from old established centres in the east, but from such western universities as Alberta and Saskatchewan. Work by Canadian paleontologists is unquestionably well up to international standards...In the last thirty years Canadian paleontology has made great strides, it is neither a spectacular or particularly costly subject, but an absolutely essential one to the understanding of Canadian geological history. It needs to be encouraged and not squeezed out in the race for money...your policy of having Ph.D. students work with the Survey is very sensible...

- H.B. Whittington,
University of Cambridge

...To me, the great strengths in Canada are in morphology, taxonomy and biostratigraphy...Canadian work in biostratigraphy and taxonomy is proportional to its population of paleontologists and the money available. It does more than Sweden, less than U.S.A., or U.S.S.R.

In the more 'theoretical' aspects of paleontology I would say that Canada is not currently at the forefront. I am thinking of historical biogeography, community ecology (and basin analysis for oil finding using same), evolutionary theory based on use of the fossil record. In these sectors I conclude that Canada is currently lagging behind Britain and the U.S. Nobody else is really in the game. Some might take the view that most of this would be a waste of taxpayers dollars to put much into it rather than into solid descriptive work. I disagree. The location of the more difficult stratigraphic traps might be materially assisted by a more advanced basin analysis mapping of animal communities (chiefly benthic) -- lithofacies has been a most powerful tool for many years, but needs to be bolstered now by crossing it with biofacies...In my opinion we have used paleontologists for too long as merely logging tools -- how old is it, how old is it, ad nauseum -- would have lowered them on a wire down the hole if they hadn't been so fat -- and it's time now to take advantage of their animal community knowhow for basin analysis purposes.

- Arthur Boucot,
Oregon State University

...in terms of strength per individual involved, I would say Canadian palynology is really high-class. If I would like to see more done in more places, and especially in the field of pre-Pleistocene terrestrial palynomorphs, that is really no criticism of a shortcoming, because the market for palynologists is an easily saturated one and enlargement of this field and its applications must go slowly.

The departments of botany at British Columbia and geology at Saskatchewan and Toronto would be competitive with any institutions in the U.S...I would consider the program at Toronto as being extremely strong...the individual work done by a palynologist at Brock has certainly been impressive...

...In non-teaching research, the work (of two G.S.C. scientists) at Dartmouth is truly outstanding, exceeding, in my opinion, in quality (and, therefore, made all the more important by its large quantity) the work being done in this field by any other federal survey in the world...

- A U.S. authority on palynology

...about the status of vertebrate paleontology, one might start with the observation that Canada is definitely among the advanced nations which support this and other esoteric sciences...

The scope of Canadian vertebrate paleontologists is extensive. (A McGill scientist) and his students cover the amphibians and early reptiles thoroughly. Later Mesozoic reptiles are the specialty of workers at Toronto, Ottawa, and Edmonton, with (a National Museum scientist) the current leader in this field. The Royal Ontario Museum specializes in marine reptiles. A scientist at Alberta works on Cretaceous and early Tertiary mammals as well as small reptiles. Later mammals are well covered (by scientists at Dalhousie, Toronto, the Royal Ontario Museum, and the Arctic Biological Station near Montreal). Université de Montréal deals with Devonian fishes and an Alberta scientist has worked with higher bony fishes. Like most advanced countries, Canada is deficient in students of fossil fishes and fossil birds.

Three Canadians are outstanding in this field (vertebrate paleontology) on the world scene: (they are at)...McGill,...Dalhousie, and ...Toronto. Many of the others I mentioned above are widely known...

- Professor Joseph T. Gregory, Stanford University

Sedimentology

...Outstanding are two professors...at McMaster who are the leaders in their field in the world; one at Memorial,...two at McGill, one...at Université de Montréal, one...at Ottawa, two...at Dalhousie, one...now at Toronto, are all internationally known; the latter in particular is gaining a reputation comparable to that...(of those at McMaster). Most of these were educated abroad, reflecting the dependence of Canadian universities on immigrants and reluctance to expand into new disciplines. There are still too many departments which do not have adequate research or teaching in sedimentology. This is surprising considering the importance of the subject for both petroleum and mineral exploration and production...

- Professor Harold G. Reading, University of Oxford

...Canada is second among the leaders in sedimentology in the world. Excepting for the effort in the United States which employs an extremely large community of workers, Canada has no equal in this field. At the University level the contributions of researchers are outstanding...sedimentology in Canadian universities has strength; to be honest, I see no weaknesses, and my only recommendation would be: increase your effort by doing more of the same...

...sedimentology in Canada is in good hands and in good health...

- Professor G.M. Friedman,
  Rensselaer Polytechnic Institute, N.Y., U.S.A.

...In my courses we read and profit from many Canadian articles and I read many more. Hence, in the last twenty years Canada has become a very major factor in sedimentology as far as publications go...To sum it all up - first class!...

- Professor P.E. Potter,
  University of Cincinnati, U.S.A.

Quaternary, permafrost, glacial, geomorphology

...Taking Quaternary research first, I think Canada rates very high internationally, the greatest strengths being in glacial geology and in Quaternary stratigraphy of North American terrestrial deposits. If I were to pick two outstanding researchers in this respect, they would be (scientists from Western Ontario and Waterloo).

With regard to permafrost and periglacial research, Canadian workers are among the best in the world. I know of nobody anywhere who ranks higher than (a British Columbia geographer)...in view of his highly innovative and valuable field experiments in the Mackenzie Delta region. (A Carleton scientist)...has very successfully combined fieldwork with laboratory approaches. A number of other field researchers are also becoming internationally known including (an Ottawa geographer). On the laboratory side, (several engineers at Alberta) are well known, as is...(an Ecole Polytechnique engineer).

As for geomorphology/physical geography in general, I think Canada rates very well, especially so in northern studies. I am thinking particularly of university efforts at British Columbia, Guelph, McGill, McMaster, Ottawa, Toronto. Among these university groups I would rate British Columbia first, in part because of the interaction between geography and geology departments at that university.

All in all, I would say that the health of Quaternary research and geomorphology/physical geography in Canada is excellent and ranks among the best in the world, especially in the aspects I have specifically identified...

- A former director of national and international research institutes

...Geomorphology is strong in Canadian universities, certainly much stronger than in America. Part of this strength is due to the infusion of British- trained geomorphologists in the 1950s and 60s, part is attributable to the stimulating physical environment...as in Australia and New Zealand, native- born geomorphologists have since become predominant and there has been a happy merging of old-world scholarship and new-world drive.

When I think of geomorphology in Canadian universities, I think of its strength in older universities such as British Columbia, McGill and Toronto and its growth in such newer institutions as Guelph, McMaster and Waterloo. In a country so recently glacierized...it is perhaps inevitable that much geoscience effort has been devoted to glacial geomorphology, Quaternary geology and related pedogenic, hydrologic and engineering implications. In the understanding of glacial and periglacial environments,...Canadians are among the world leaders and compare on a one-to-one basis more than favourably with similar scientists in Scandinavia and the Soviet Union.

- Antony R. Orme,
  Dean of Social Science, U.C.L.A.

...Frankly, I believe (Canadian geomorphology) to be in excellent condition. In particular, the western universities such as British Columbia, Alberta and Simon Fraser, are producing very good work in the area of fluvial geomorphology...the work of Canadian Quaternary geologists is well known and is held in high regard...The interaction of Canadian geomorphologists and civil engineers is indicative of a strong practical application of research...

- Professor S.A. Schumm,
  Colorado State University, U.S.A.

...Canada has strong programs (in glaciology) in two major governmental agencies...The effort of the Canadian universities is not as strong as I think it should be in a country that has a considerable proportion of the world's glacial ice...McGill did have a program but...content suffered when (the professor)...moved away. British Columbia has (two professors)...well known to the international community but...they do not constitute an integrated program.

The departments in Canadian universities are not renowned for their cooperation...there is frequently only poor communication between geology departments and those which house geography, archeology and biology...Canada would benefit from at least one university developing an institute that concentrated on the Quaternary.

- Senior scientist in a U.S. Arctic research institute

Hydrogeology

...Canadians have certainly not been backward in hydrogeology if one considers the total population of Canada compared with that in the U.S.A., France, U.S.S.R. or West Germany where hydrogeologic research is very active...In my estimation some of the most prominent hydrogeologic researchers in Canada are (he names scientists from British Columbia, Waterloo, and both federal and provincial agencies). The most active research centers in Canada are the Alberta Research Council, the University of Waterloo (the best general collection of hydrogeology in any university in North America, outside of Arizona), the University of British Columbia and McMaster (because of its speleological research). As far as individuals are concerned (a British Columbia scientist) is the most outstanding scientist...I am convinced that scientific progress is in large part dependent on the personalities of the scientists involved. In this regard Canada is also fortunate...

- Professor S.N. Davis,
  The University of Arizona

...The Canadians, both individually and as a group, are making some of the best contributions to hydrogeochemistry being made anywhere in the world. The expertise and broad competence of the group gathered at University of Waterloo is unique with the possible exception of Russian institutions with which I am not familiar. There is no university in the United States that has the staff to cover the discipline of ground-water chemistry as that group does - no group that has the experience in ground-water flow, geochemistry, isotopes and transport of contaminants.

Aside from the Waterloo, other names that come to mind are (he mentions mainly people from the geology department at Alberta and from the Alberta Research Council)...

- William Back,
  U.S. Geological Survey, Reston, Virginia

Regional geology (and megatectonics

We asked some correspondents to comment on regional synthesis, others on megatectonics. Two were asked to comment specifically on Precambrian studies in view of its importance to Canada.

...plate tectonics was invented by a Canadian, J. Tuzo Wilson, in my view the intellectual successor to Argand. Unfortunately, the ball was caught by other nations, notably the U.S.A., who are now running with it. In spite of this, good work is being done in structure/tectonics at the regional level by (scientists from British Columbia, Memorial, Queen's and G.S.C. were mentioned). (A Regina scientist)...is doing some superb work in reinterpreting larger areas of the Hudsonian by excellent detailed fieldwork combined with a good knowledge of interpetive modern tectonics...

- A U.S. leader in tectonic studies

...Just now I am doing much library research on the Canadian part of the western Cordillera,...I have looked at articles by (McGill and Queen's professors)...on the Rocky Mountains, by (G.S.C. scientists)...and others on the western Cordillera, etc. The various concepts presented are new, vital, and intensely stimulating...Some of the changes result from the new concepts of plate tectonics, and especially from the recent ideas on microplates and 'tectonic collage'. The results are revolutionary, and to this reader quite dizzying. They are making a real contribution to tectonics in the world picture...In short, my impression has been that my Canadian counterparts were thinking in much the same terms as we in the States, and that they were even ahead of us in many ways, so that we have much to learn from them.

- Phillip B. King, U.S.
  Geological Survey

...I would say you excel in Palaeozoic studies largely from the contribution of the staff in Memorial to the unravelling of the Newfoundland part of the Appalachian fold belt...

- A U.K. professor of geology

...My impressions were that some of the earth sciences in Canada is as good as the best in Europe or U.S.A. To go outside the universities, G.S.C. has people who are able and willing to produce regional syntheses of Precambrian geology which can be valuable to those working in the same fields elsewhere. A few university departments had the unmistakeable enthusiasm and high morale which go with productive research. Some particularly useful results seem to have been obtained by selecting a specific area or problem to which several disciplines could be applied...The most impressive work seemed on the whole to be coming from the larger departments, where active groups could be assembled to tackle a particular problem. In my short stay, I was impressed by regional field studies, by some of the work on metalliferous deposits and by some marine geology.

- Professor Janet Watson,
  Imperial College, London (U.K.)

...In my opinion Canadian earth scientists rate very highly in the Precambrian league - this is exemplified by the continuous flow of good research papers on the Precambrian Shield of Canada, particularly in the Canadian Journal of Earth Sciences. As 'truly outstanding researchers' I would single out...(one scientist named from each of G.S.C., E.P.B., and Toronto) for contributions to Precambrian tectonics, paleomagnetism and mineralization...There are hosts of 'good' researchers - at least a couple of dozen come to mind immediately. Of the strong schools/agencies, I would list the G.S.C., E.P.B. and the Universities of Toronto, Western Ontario, Alberta, Carleton, McMaster, McGill, Ottawa, Queen's, Saskatoon, and Memorial. I would not worry about the health of Precambrian Studies in Canada, because you have excellent specialists in most major disciplines relevant to the Precambrian. A field which could be strengthened is geochronology, so important in working out the long history of the Precambrian. In the Archaean, Canadian researchers are first class in their knowledge of greenstone belts, but rather weak (with some exceptions) in their understanding of granulites and high-grade gneissic belts.

- Professor B.F. Windley,
  University of Leicester, U.K.

...Considered across the board, Canada leads the world in pre-Cambrian studies. The greater part of the nation is underlain by, and by far the bulk of its mineral wealth comes from the Canadian Shield. Canada has acted wisely to understand and utilize this resource...nowhere are there so many fine geologists focussed on the sub-Cambrian part of the geological column as there are in Canada.

Canada has, in fact, so many excellent pre-Cambrian geologists that it borders on the invidious to name only a few. Some combine those qualities of mental power, intellectual daring, and commitment that go, with integrity, to make a truly outstanding scientist -- one capable of achieving major insights such as the recognition of sea-floor spreading or the impact origin of Sudbury...The most important contributions of Canadian work on the pre-Cambrian have been in metalliferous geology and petrology, mapping, and regional geology. Until recently, you have not paid enough attention to the sedimentology and historical geology of the old rocks and the contributions such studies can make to the understanding both of crustal evolution and of ore deposits...Now, however, those named above and others are making up for that oversight...

- Preston Cloud,
  U.S. Geological Survey (retired)

...The general state of Precambrian geology...good but not brilliant...Canada has the largest single area of Precambrian rocks of any country in the world. A large amount of its mineral wealth comes from and its future depends on understanding the Shield. It should lead the world in Precambrian research...but...at high level policy meetings...the Precambrian...was not represented directly...the result of this comparative neglect can be seen in recent world-wide advances. These have come from South Africa, Australia and...Greenland. All places with relatively small but lively groups of geologists centered around one or two institutes...Look at the Russians, they have more geologists working on Precambrian geology than the rest of us put together but do major breakthroughs come from them in proportion to their numbers?

I think research groups are probably better attached to universities rather than central government bodies...they have a throughput of bright ambitious people, some of whom go into industry. If they can keep the university administrators at bay they are less bureaucratic than government agencies.

- A senior scientist from a Scandinavian country

DISCUSSION

The disparity in quality ratings

The difference between internal and external views of our universities' capabilities in geology and geophysics is striking. The foreign correspondents rate us near the very top in several subdisciplines and consider our overall efforts world class in all except a few fields. Their opinions coincide fairly closely with those of our top academic researchers, but are generally more favourable. These favourable views will undoubtedly influence the future opinions of those other Canadian academics who feared we weren't doing anything very well. Most of them were suffering from the Canadian "second rate syndrome" which can be quickly cured by recognition from outside the country.

The generally negative views of scientists from industry and from government agencies are initially disturbing because they are in many cases diametrically opposed to those of our external reviewers. Company scientists bemoan the lack of applied research whereas some foreign correspondents praise Canadian efforts in economic geology and, in some cases, hint that we may be overdoing this at the expense of national needs for basic research. Government scientists lament the emphasis on laboratory studies instead of field-based research whereas most of our communicants from abroad praise the balance in Canadian geology and geophysics and a few rather bluntly suggest we have concentrated on field studies to the neglect of laboratory research.

In most cases we accept our foreign assessors' views on research quality ahead of those of our domestic commentators. Foreign replies generally contained an awareness of current activities that was lacking in those of fellow nationals. This was expectable as the foreign assessors were carefully chosen for their familiarity with a broad range of international research whereas the nonacademic Canadian respondents were selected as groups of specialized consumers of university products. As consumers they wondered why universities were not producing more of the product they wanted, e.g., ore genesis studies for the mineral exploration companies, resource mapping for the mineral exploration companies, resource mapping for the provincial surveys. University professors would answer that these are expensive pursuits and would ask who will provide the funds. Also, if they concentrated solely on such studies, who would carry out the analytical, experimental and theoretical aspects of geoscience research? Actually, some of the federal agency scientists do carry out such studies and a few of their negative comments might have stemmed from their rivalry with university groups. Such competition can be healthy and productive - it was the reason why NRC embarked on major university grants program although it had its own highly regarded in-house research activity. Competition only takes unhealthy tacks in those subdisciplines where one or both sides withdraw into protective shells. Otherwise it generally produces faster, better scientific results.

Negative opinions by nationals outside the university circle would seem to belie the views of many foreign correspondents concerning the working harmony between the various elements of our geoscience community. Again, the foreign observers are probably right, at least in terms relative to their own countries. As pointed out in Chapter 7, our three estates do work well together in many ways.

Despite these explanations, there is obviously a great deal of ignorance in government and industry concerning academics' activities, goals and accomplishments in research. The onus is on the academics to remedy this not only through individual departmental efforts but through group activities. Two excellent examples of how it can be done are the Mineralogical Association of Canada's annual short courses on instrumentation, methodology, and the application of physico-chemical concepts and the Geological Association of Canada's series of review articles in the journal, Geoscience Canada, on subjects such as sedimentary facies models. We recommend:

That the Council of Chairmen of Earth Science Departments, in co-operation with national societies such as C.I.M., C.S.P.G. and C.S.E.G., should commission continuing series of short review articles in various journals and sponsor workshops at a variety of meetings to describe and explain research underway in universities across the country. Case histories should be given illustrating how basic research has produced fallout of practical concepts and techniques that could be immediately adopted by scientists in industry and government.

Other recommendations related to interaction and understanding are presented in Chapter 7.

The rationalization of financing

Most grants-in-aid of university research come from NSERC's peer adjudicated system and these also offer the greatest freedom to researchers. Contracts and research agreements from government agencies generally contain more restrictions on the nature of projects. They range from the comparative freedom of the recently introduced Ontario Department of National Resources grants and the EMR research agreements to contracts that are awarded for little more than routine consulting work.

Most of our leading researchers are quite satisfied with their NSERC grants. Some told us that money was no problem, time was their major lack. However, others involved in major laboratory or field logistics are chronically short of funds and despite large NSERC grants find that they have to apply to government agencies and industry for additional funds. They usually receive these funds but regret the large expenditure of time in preparing grant applications and filing interim reports. Many scientists with solid backgrounds in mission-oriented studies do not fare well from NSERC committee decisions but receive much more favourable treatment from government agencies. There would seem to be opportunity here for some rationalization. Greater selectivity by the NSERC committees would eliminate some types of projects best supported by other agencies. This would allow adequate funds for some of those with costly projects working at the cutting edge of research and lessen their needs to apply to several or many sources. It might also induce government agencies to raise their grants and other stipends to attract the services of the best mission oriented academics and their graduate students. We recommend:

That the NSERC earth science grant selection committee, as part of their rotational visitation process, arrange meetings with senior officials of federal and provincial agencies to discuss rationalization of research support.

Mining and petroleum geologists regret that a larger percentage of university research is not devoted to such subjects as: mineral deposits, stratigraphy, and sedimentology. The 1978-80 disciplinary breakdown of NSERC-supported research (Tables 4.5, 5.1) would seem to bear out their complaint. The reason is that industrial support of university research is pitifully small and as a correspondent from overseas pointed out, it is also very unimaginative--Canadian companies tend to support routine consulting work but shy away from anything that smacks of long-term innovative research. In contrast, Australian and South African mineral exploration scientists have supported fundamental research in applied science to their own and some universities advantages. We have cited a Canadian company (Riocanex) which has recently shown the way that this can be done in Canada. Unfortunately, much of our industrial community (particularly the oil industry) has been dominated by multinationals who have carried out most or all of their research abroad. Although many nationals are now springing up in the petroleum industry they have no tradition of supporting long-term research in geology and geophysics. We have recommended above that universities attempt to inform industry and government on the advantages of supporting research in their fields of interest. We further recommend:

That the Canadian Geoscience Council approach senior civil servants and elected members of Parliament to apply tax incentives and penalties that will encourage mineral and petroleum companies to support basic and applied frontier research in Canadian universities.

Financing and excellence

Our external assessors and our best-known Canadian scientists give the impression that we have a few bright stars in the geoscience firmament and that we are world leaders in several subdisciplines but our overall effort ranks as very competent, just below the best. How do we continue our march forward so that most of Canadian geology and geophysics ranks with the world's best?

Some of our leading professors state that what we lack is occasional, really large-scale co-operation in frontier research and the large-scale funding to go with it. An example of the co-operation possible came about a few years ago when a Dalhousie geologist spread samples from a marine deep drill program to university researchers around the country and the results were brought together in a symposium and a subsequent publication. Possibly an example of the big funding possible is supplied by the ion microprobe establishment underway at Toronto. What we need is money and co-operation like this available on fairly short notice when someone or some group comes up with a really bold and different idea. It certainly wasn't available when Canadian geoscientists had the opportunity to participate in the international deep sea drilling program, as one of our foreign respondents points out. Possibly the NSERC strategic grants will eventually fill this role always providing short-term national relevance does not become the dominant criterion for these awards.

Centres of excellence

In the late 1960s and early 1970s, the rapid growth of scientific research and postgraduate training programs led many to worry that our energies were being so widely dispersed across the country that no focuses would result that could lead to excellence. Suggestions were made (e.g., Bonneau and Corry, 1972, and Blais et al., 1971) that science policy makers should provide (a) centres of excellence where several universities departments and, possibly, nearby government research premises could combine on common themes; and (b) centres of specialization in which high quality research is done in more limited spheres.

Such centres have developed in the last decade. Toronto has certainly emerged as a centre of excellence in the geosciences. It receives top rating from our external assessors in several subdisciplines. Geoscientists in five departments interact closely and there is close association with other science departments, with the Royal Ontario Museum, the Ontario Geological Survey and with several mining companies. In breadth and activity it is the Canadian equivalent to the geoscience group at the Australian National University. Alberta and British Columbia, both with many departments involved in geoscience research (Table 5.2) and several centres of specialization probably would also qualify as centres of excellence in the minds of many assessors. They seem to lack the interaction of Toronto's departments and their relationships with local government laboratories are not as strong. Both, however, seem to be working towards greater integration of their geoscience research components.

Within the same decade, centres of specialization such as geochemistry and mineral deposits at Western Ontario, mineral deposits at Ecole Polytechnique and McGill, both sedimentology and isotope geochemistry at McMaster and marine geoscience at Dalhousie all grew and flourished. New centres of specialization sprang up and quickly acquired international reputations such as those in hydrogeology and hydrogeochemistry at Waterloo and that in regional synthesis at Memorial.

The remarkable fact is that most of these developments came about through people and activities on the local scenes, with government assistance but not through government planning and policy-making. Toronto was in a down-phase of its geoscience cycle a decade ago, Memorial and Waterloo geology departments were barely known. University departments where nearby government laboratories, or favourable provincial programs or NRC negotiated development grants made growth and development of excellence almost assured have, for one reason or another, failed to develop. Growth of science should be nurtured but it cannot be forced.

CONCLUSIONS

University research has come a long way in the past two decades. At the beginning of this period only a handful of academics were involved in frontier research, most was carried out in government agencies. Now most of Canada's 460 professors of geology and geophysics are engaged in research activities. Like its sister sciences, geoscience has so far produced only a few international superstars. However, we have emerged as first class, even as world leaders, in several subdisciplines such as mineral deposits, regional geology, clastic sedimentology, hydrogeochemistry, Arctic geomorphology and exploration geophysics--all fields that are closely related to resource development and environmental conservation and, hence, to our national quality of life.

Most support for university research comes from the universities themselves--i.e., the salaries of the researchers and the laboratories and facilities provided to them. The largest grants in aid of research come from NSERC, over $9 million in one form or another in 1980-81. Support also comes from federal and provincial agencies in the form of contracts, research agreements and, in the case of Ontario, grants-in-aid of research. Surprisingly little research support comes from industry, particularly the petroleum industry, although there is one imaginative program of support by a mineral exploration company. Legislation is probably the only method of inducing most segments of industry to support fundamental research in Canada in those fields pertinent to their operations.

On the whole, Canadian university geoscience research is rated as very competent, a shade below the very best. This is really quite remarkable considering how few practitioners there were two decades ago. We have come a long way in a short time. Accelerated progress will require co-operation and large sums of money to support bold imaginative projects. The money might come from several sources: industry; rationalization of NSERC and government agency grants; and the voluntary retirement of those presently making pedestrian efforts in expensive frontier research because they feel that it is the only route to promotion and status in the university community. But, ultimately, we must be able to rely on NSERC to have a reserve that can be obtained when some extraordinarily good idea is advanced.

Finally, research in our universities has progressed mightily and has met most of the important goals set for it a decade ago (Blais et al., 1971). Canada is well served by its researchers in geology and geophysics.

TABLE 5.1

BREAKDOWN OF NSERC EARTH SCIENCE GRANTS BY SPECIALITIES 1979-80

Speciality	No. of Grants	Total Value	Average Value
GEOLOGICAL SCIENCES			
1. Coal geology	1	$ 6,000	$ 6,000
2. Economic geology	26	$270,365	$10,399
3. Engineering geology (exclusive of 20 & 22)	3	$ 24,354	$ 8,118
4. Environmental geology	-	-	-
5. General or regional geology	25	$324,402	$12,976
6. Geomorphology (includes 49)	22	$229,287	$10,422
7. Historical geology	-	-	-
8. Hydrogeology	10	$119,948	$11,995
9. Marine geology	2	$ 25,129	$12,564
10. Mineralogy and Crystallography	17	$241,510	$14,205
11. Mining geology (probably some grants listed in 2 belong here)	-	-	-
12. Paleobotany	3	$ 45,703	$15,024
13. Paleontology	29	$382,533	$13,191
14. Palynology	6	$ 62,592	$10,432
15. Pedology (Soil science)	8	$ 96,719	$12,090
16. Petrology	20	$212,446	$10,622
17. Petroleum geology	2	$ 19,000	$ 9,500
18. Photogeology	-	-	-
19. Quaternary geology and research	21	$266,505	$12,691
20. Rock mechanics (includes 52)	12	$126,483	$10,540
21. Sedimentology	23	$251,090	$10,917
22. Soil mechanics (includes 52)	21	$347,900	$16,567
23. Stratigraphy (mainly biostratigraphy)	10	$115,868	$11,587
24. Structural geology, Tectonics and geotectonics	17	$229,562	$13,504
25. Volcanology	2	$ 24,500	$12,225
26. Other fields	1	$ 4,140	$ 4,140
GEOPHYSICS			
27. Exploration geophysics	6	$113,379	$18,896
28. Geodesy	1	$ 20,000	$20,000
29. Geomagnetism and paleomagnetism	16	$256,225	$16,014
30. Geophysical instrumentation incld. in other geophysical specialities)	-	-	-
31. Gravity	1	$ 3,000	$ 3,000
32. Heat flow	3	$ 40,692	$13,564
33. Magneto-telluric studies	2	$ 21,500	$10,750
34. Marine geophysics	2	$ 37,601	$18,800
35. Physical properties of rocks minerals	4	$ 54,315	$13,579
36. Remote sensing	1	$ 9,490	$ 9,490
37. Seismology	9	$151,335	$16,815
38. Tectonophysics	3	$ 60,551	$20,183
39. Other fields in geophysics	12	$179,322	$14,943
GEOCHEMISTRY			
40. Biogeochemistry	1	$ 7,000	$ 7,000
41. Exploration geochemistry	4	$ 62,729	$15,681
42. Inorganic geochemistry	3	$ 32,808	$10,936
43. Isotope geochemistry and geochronology	32	$580,409	$18,138
44. Physical geochemistry	12	$229,883	$19,159
45. Organic geochemistry	1	$ 9,500	$ 9,500
46. Other fields in geochemistry	1	$ 10,587	$10,587
OTHER FIELDS			
47. Mathematical geology	3	$ 31,607	$10,538
48. Computer applications to Earth Sciences	1	$ 5,000	$ 5,000
49. Physical geography (20 grants listed under 6 also listed here)	51	$463,116	$ 9,120
50. History of Earth Sciences	-	-	-
51. Oceanography	20	$260,862	$13,043
52. Geotechnical studies (all grants listed under 20 and 22 included here)	30	$479,645	$15,988
53. Mining research	5	$ 34,370	$ 6,874

Notes:
1. Many of grants encompass more than one discipline, they are listed only under the prime discipline.
2. This table repeats some grants under major discipline headings, particularly fields 49 and 52.
3. Grants for 1980-81 shown in Table 5.2 but disciplinary breakdown comparable to this one was not available.

TABLE 5.2

NSERC OPERATING GRANTS IN EARTH SCIENCES 1980-81

(Listed from west to east across Canada alphabetically in each province)

University	Dept.	No. Grants	Value	Total
British Columbia	Geol.	13	228,850	
	Geophys.	6	145,185	
	Geography	5	88,297	625,986
	Geotech. engr.	4	82,724	
	Oceanography	5	68,489	
	Soil science	2	12,441	
Simon Fraser	Geography	3	16,046	
	Biology	1	12,046	54,592
	Maths	1	10,500	
	Archeology	1	16,000	
Victoria	Geophys.	2	31,500	31,500
Alberta	Geol.	18	251,908	
	Geophys.	9	221,078	
	Geography	5	27,046	
	Geotech. engr.	5	99,754	666,807
	Soil science	1	14,274	
	Zoology	2	29,447	
	Botany	1	10,500	
	Mineral engr.	1	12,800	
Calgary	Geol. & Geophys	18	176,020	
	Geography	3	20,872	233,126
	Physics	1	36,234	
Saskatchewan	Geol.	13	152,619	
	Geography	1	5,500	193,589
	Geotech. engr.	1	16,470	
Regina	Geol.	3	26,091	26,091
Manitoba	Earth Sci.	12	171,301	171,301*
Brandon	Geography	1	3,000	3,000
Brock	Geol.	5	59,254	
	Geography	1	6,500	65,754
Carleton	Geol.	9	101,003	
	Geography	1	7,500	133,003
	Geotech. engr.	1	24,500	
Guelph	Land Res. Sci.	7	91,979	
	Geography	3	26,300	131,779
	Geotech. engr.	1	13,500	
Lakehead	Geol.	7	68,559	
	Geography	1	3,000	71,559
Laurentian	Geol.	3	29,319	29,319
McMaster	Geol.	10	221,507	
	Geography	6	104,990	
	Physics	1	22,250	362,247
	Geotech. engr.	1	14,500	
Ottawa	Geol.	8	87,110	
	Geography	3	32,323	142,502
	Geotech. engr.	2	23,069	
Queen's	Geol.	13	201,021	
	Geography	3	30,333	250,354
	Geotech. engr.		19,000	
Toronto	Geol.	27	463,398	
	Geophys.	7	173,621	
	Geography	5	52,684	749,251
	Geotech. engr.	2	28,470	
	Zoology	2	31,078	
Trent	Geography	2	15,342	15,342
Waterloo	Earth Sci.	19	273,756	283,638
	Geography	1	9,882	
Sir Wilfred Laurier	Geophys.	1	11,500	
Western Ontario	Geol.	11	226,360	
	Geophys.	7	117,343	
	Geography	4	30,200	430,653
	Geotech. engr.	2	56,750	
Windsor	Geol.	8	87,389	100,573
	Geography	2	13,184	
York	Geophys.	3	75,182	81,887
	Geography	1	6,705	
Laval	Geol.	6	53,356	
	Geotech. engr.	5	106,130	168,127
	Mines & Met.	1	8,641	
I.N.R.S.	Petrole	2	17,000	24,500
	Oceanologie	1	7,500	
McGill	Geol.	9	162,835	
	Redpath Mus.	1	35,000	
	Physics	1	16,024	
	Geography	3	26,260	299,853
	Mining engr.	1	8.500	
	Marine sci.	1	15,000	
Montréal	Geol.	8	152,994	180,994
	Geography	3	28,000	
Polytechnique	Genie Min.	11	146,543	202,293
	Geotech. engr.	4	55,750	
Quebec (Chicoutimi)	Geol.	2	20,372	20,372
Quebec (Montréal)	Geol.	2	25,121	31,221
	Geography	1	6,100	
Quebec (Rimouski)	Oceanography	4	38,864	38,864
Sherbrooke	Geography	1	3,000	28,078
	Geotech. engr.	2	25,078	
New Brunswick	Geol.	10	111,595	
	Physics	1	5,560	126,155
	Surv. engr.	1	9,000	
Acadia	Geol.	1	8,700	8,700
Dalhousie	Geol.	12	184,983	326,298
	Oceanography	7	141,315	
St. Francis Xavier (incl. Col. Cape Breton)	Geol.	2	13,000	13,000
St. Mary's	Geol.	2	32,111	32,111
Memorial	Geol.	15	257,721	
	Geophys.	8	101,739	376,960
	Geography	1	8,000	
	Marine engr.	1	9,500	
Total		456		6,670,780*

Average grant for 1980-81 = $14,629

*includes 45,000 Co-op grant and 56,660 in Team grants.

TABLE 5.3

HIGHEST NSERC AWARDS IN GEOSCIENCE

GRANTEE	SHORT TITLE OF PROJECT	ANNUAL GRANT
R.L. Armstrong Geology, British Columbia	Geochronometry of Cordilleran igneous and metamorphic rocks	$40,911
H.J. Greenwood Geology, British Columbia	Geological phase equilibria	46,116
R.D. Russell Geophysics, British Columbia	Isotopic studies of the early history of the earth	35,685
D.I. Gough Physics, Alberta	Magnetometer array studies and paleomagnetism	42,822
E.R. Kanasewich Physics, Alberta	Geophysical investigations of the crust and mantle	37,000
N.R. Morgenstern Civil Engr., Alberts	Geotechnical behaviour of (a) frozen ground, (b) oil sands, and movement mechanisms in landslides	45,457
H.R. Krouse Physics, Calgary	Stable isotope fractionation	36,234
D.C. Ford Geography, McMaster	Karst studies, cavern genesis, paleothermometry	40,626
D.M. Shaw Geology, McMaster	Geochemical studies of minerals and rocks	37,881
Ian Nichol Geology, Queen's	Geochemical exploration in Canada	34,093
A.J. Naldrett Geology, Toronto	Field and experimental studies relating to origin of mafic and ultramafic rocks and associated ore deposits.	45,457
D.W. Strangway Geology, Toronto	Magnetic and electrical studies of geological significance	47,763
D.J. Dunlop Physics, Toronto	Magnetism of continental and oceanic rocks	32,940
D. York Physics, Toronto	Isotope studies and age determinations	40,626
W.S. Fyfe Geology, Western Ontario	Fluid flow in the crust: the limit on ancient geothermal gradients	54,900
K.Y. Lo Civil, Engr., Western Ont.	Thermal stresses and deformation in underground structures	33,250
D.E. Smylie Physics, York	Dynamics of the Earth	38,000
R.L. Carroll Museum, McGill	Evolution and anatomy of Paleozoic and early Mesozoic reptiles	35,000
R. Young Civil, Engr., McGill	Stability of soil structural units relative to transient and natural environmental stresses	36,234
B. Michel Génie civil, Laval	Mécanique des glaces	32,940
B. Ladanyi Génie civil, E. Polytech.	Propriétés géotechniques des sols gêlés et leur comportement en relation avec les fondations et les souterrains	33,250
P. Larochelle Génie civil, Laval	Propriétés fondamentales et comportement des argiles sensibles	32,940
C.J.R. Garrett Oceanography, Dalhousie	Physical oceanographic wave studies	32,502
D.F. Strong Geology, Memorial	Metallogenic, geochemical, petrological and tectonic studies of Appalachian-Caledonian orogen	38,639
H. Williams Geology, Memorial	Anatomy of an orogen	46,116

TABLE 5.4

TOTAL AND AVERAGE NSERC GRANTS IN GEOLOGY AND GEOPHYSICS 1979-80, 1980-81

University Dept.	Acad. Staff '80	1979-80 No. grants	1979-80 Total Value	1979-80 Avr. Value	1980-81 No. grants	1980-81 Total Value	1980-81 Avr. Value
Acadia, Geol.	5	1	8,700	8,700	1	8,700	8,700
Alberta, Geol.	20	15	224,322	14,955	18	251,908	13,995
Geophys.	10	8	190,472	23,809	9	221,078	24,564
Brandon, Geol.	3	-	-	-	-	-	-
British Columbia, Geol.	23	17	251,531	14,796	13	228,850	17,603
Geophys.	8	7	96,777	13,825	6	145,185	24,198
Brock, Geol. Sc.	9	5	61,500	12,300	5	59,254	11,851
Calgary, Geol. & Geophys.	23	18	145,551	8,086	18	176,020	9,779
Physics					1	36,234	36,234
Carleton, Geol.	16	9	84,581	9,398	9	101,003	11,222
Concordia, Geol.	7	-	-	-	-	-	-
Dalhousie, Geol.	12.5	11	143,675	13,061	12	184,983	15,415
Ecole Polytech., Gen. Min.	14	15	160,661	10,711	11	146,543	13,322
Montréal, Geol.	12	8	137,058	17,132	8	152,994	19,124
Guelph, Land Res. Sc.	3	3	35,117	11,706			
Lakehead, Geol.	8	7	54,386	7,796	7	68,559	9,794
Laurentian, Geol.	8	5	33,795	6,759	3	29,319	9,773
Laval, Geol.	13	7	57,590	8,227	6	53,356	8,893
Manitoba, Earth Sc.	15	10	120,277	12,027	12	171,301*	14,275*
McGill, Geol. Sc.	15	11	181,931	16,539	10*	197,835*	19,783*
McMaster, Geol.	13	12	200,997	16,750	10	221,507	22,151
Memorial, Geol.	20	17	246,835	14,520	15	257,721	17,182
Geophys.	6	6	69,114	11,519	8*	101,739	12,739
Mt. Allison, Geol.	4	-	-	-	-	-	-
New Brunswick, Geol.	12	11	106,360	9,669	10	111,595	11,159
Ottawa, Geol.	10	10	103,060	10,306	8	87,110	10,889
Que. Chicoutimi, Sc. Ter.	9(?)	2	19,000	9,500	2	20,372	10,186
Que. Montréal, Sc. Ter.	11	3	26,200	8,733	2	25,121	12,560
Queen's, Geol. Sc.	20	11	160,410	14,583	13	201,021	15,463
Regina, Geol. Sc.	7	1	8,280	8,280	3	26,091	8,697
St. F. Xavier, Geol.	4*	1	6,000	6,000	2*	13,000	6,500
St. Mary's, Geol.	4	2	29,245	14,622	2	32,111	16,055
Saskatchewan, Geol. Sc.	16	14	145,551	11,901	13	152,619	11,740
Toronto, Geol.	28	25	410,225	16,409	27	463,398	17,163
Geophys.	9	8	167,444	20,933	7	173,621	24,803
Victoria, Geophys.	4	2	26,660	13,330	2	31,500	15,750
Waterloo, Earth Sc.	21	17	206,958	11,498	19	273,756	14,408
Western Ontario, Geol.	14	11	214,128	19,466	11	226,360	20,578
Geophys.	7	7	98,031	14,004	7	117,343	16,763
Windsor, Geol.	10	8	78,957	9,870	8	87,389	10,924
York, Earth & Envir. Sc.	4	3	59,515	19,833	3	75,182	25,061

Average NSERC grants to all earth scientists was $13,141 in 1979-80, and $14,629 in 1980-81.

*Notes: Manitoba includes $45,000 Co-op grant shared with Elect. Engr.;
McGill includes $35,000 grant to Redpath Museum paleontologist;
Memorial includes two new marine geophysics appointees;
St. Francis Xavier includes researcher at College of Cape Breton.

TABLE 5.5

NSERC EARTH SCIENCES EQUIPMENT GRANTS - 1973-80

University	Total no. of grants	Total awards ($000)	No. & Amount ($000) of Major Equipment Awards
Acadia	1	15	-
Alberta	13	560	3 (417)
British Columbia	16	742	3 (414)
Brock	3	160	-
Calgary	7	134	-
Carleton	1	32	-
Dalhousie	14	243	-
Ecole Polytechnique	5	103	-
Guelph	2	24	-
Lakehead	1	34	-
Laurentian	2	39	-
Laval	4	98	-
Manitoba	5	77	1 (135)
McGill	8	328	1 (132)
McMaster	7	142	-
Memorial	2	126	-
Montréal	2	27	-
New Brunswick	2	16	-
Ottawa	4	88	-
Québec-Montréal	1	26	-
-Chicoutimi	2	28	-
-Rimouski	2	32	-
Queen's	3	130	1 (100)
Saskatchewan	5	323	2 (298)
Sherbrooke	1	43	-
Toronto	11	214	-
Waterloo	7	235	1 (123)
Western Ontario	7	·300	1 (150)
Windsor	1	6	-
York	3	36	-

TABLE 5.6

NRC-OPERATING GRANTS IN EARTH SCIENCES TO FRENCH QUEBEC UNIVERSITY SCIENTISTS

Year	71-72	73-74	75-76	77-78	80-81
Ecole Polytechnique	64,500	79,400	101,550	137,284	202,293
Laval	67,500	87,500	110,045	130,092	168,127
Montréal	73,000	83,650	94,900	132,358	180,994
UQ - Chicoutimi	0	5,100	15,995	10,298	20,372
UQ - Montréal	3,000	0	11,120	9,800	31,221
UQ - Rimouski	0	15,250	17,555	31,562	38,864
INRS - Ste-Foy	0	0	15,115	25,500	24,500
Sherbrooke	3,000	8,350	7,315	23,080	28,078
Total:	211,000	279,250	373,595	499,974	694,349
Total Canada:	2,331,693	2,828,598	3,600,452	4,662,455	6,670,780
FQ/Can.:	9.05%	9.87%	10.37%	10.72%	10.4%

TABLE 5.7

AVERAGE NSERC GRANTS IN SOME OF THE SCIENCES
1980-81

Avr. Grant '80 ($)	Avr. Grant 75 ($)	Physical Sciences	Biological Sciences	Applied Sciences
4) 16,115	21,100	*Physics (452), (470)		
1) 20,122	14,300	Chemistry (541), (507)		
5) 16,000	13,000	Space and astronomy (154), (122)		
14,295	11,700	Average operating grant for all successful applicants (4,413 in 1975; 5,296 in 1980)		
2) 18,634	11,600		Cell biology (323), (352)	
10) 14,175	11,000			Mechanical engineering (257), (275)
8) 14,675	10,800			Chemical and metallurgical engineering (317), (323)
3) 17,823	10,600		Plant biology (241), (215)	
11) 13,702	10,400			Electrical engineering (302), (325)
13) 13,329	10,100		Psychology (227), (280)	
9) 14,629	9,900	Earth sciences (423), (456)		
6) 15,586	9,300		Animal biology (316), (326)	
14) 13,318	8,900			Civil engineering (248), (302)
15) 11,992	8,500			Computing and information science (203), (254)
7) 15,148	8,300		Population biology (360), (310)	
12) 13,364	8,300			Interdisciplinary (3), (11)
16) 11,030	7,100			Industrial engineering (46), (66)

Table is arranged according to size of annual grant in 1975 (from Wynne-Edwards and Neale, 1976); grants for 1980 are numerically ranked according to size; figures in first bracket indicate successful cnadidates in 1975, second bracket indicates number in 1980.
*physics in 1975 included both nuclear and high energy physics and major grants, in 1980 it includes only physics and low energy nuclear physics.

6. RELATIONSHIPS WITH OTHER SCIENCES

We must all hang together or assuredly we shall all hang separately...
--Benjamin Franklin, 1776

INTRODUCTION

Geology and geophysics are only two of the several fields that are considered as individual disciplines of the geosciences in Canadian Universities. Others are physical geography, oceanography, soil science and geotechnique. In some countries one or more of geochemistry, mineralogy and paleontology are also treated as distinct and separate geosciences but in Canada and most other countries they are regarded as subdisciplines of geology and taught within geology departments. In this chapter we propose to touch on the relationships of geology and geophysics to the other departments of geoscience and to briefly explore overlap and co-operation.

Our study was originally designed to describe and appraise the practice of all geosciences in the universities. To this end, one of us (J.E.A.) initially began investigations of the activities of physical geography and soil science, particularly the former. Some of these data are incorporated herein, creating an imbalance as our information on physical geography departments far outweighs that on the others. In part this is justified, however, by the many overlapping interests of physical geography and geology departments.

Relationships beyond the circle of geosciences also deserves mention. Many problems that engage geoscientists also involve other sciences. Thus marine and permafrost studies not only challenge geologists, geophysicists, geographers and geotechnical engineers, but also physicists, chemists and biologists. All students in geology and most of those in geophysics have traditionally required a background in at least three of these four basic subjects. As pointed out in Chapter 3, however, there are some disturbing tendencies to minimize the need for this background and to attempt to teach some aspects of these sciences within geology departments. This fact and a seeming paucity interdepartmental research warrants a brief examination of the relationships between some of these departments and geology and geophysics. They are mentioned in the last part of this chapter following an examination of physical geography and the other geosciences.

PHYSICAL GEOGRAPHY

Scope

Physical geography comprises the subdisciplines of geomorphology, climatology, biogeography, glaciology and hydrogeology. Two of these, geomorphology and glaciology, lie close to or, possibly, entirely within geology and geophysics. The others are relevant to geology and geophysics but probably bear closer affinity to atmospheric physics, biology and engineering. Obviously, physical geographers are not a single species although they share some common interests.

It is commonly stated that physical geography (actually meaning geomorphology) differs from geology in that it seeks to describe and interpret the present rather than the past condition of the Earth. This is oversimplification. A two-centuries old maxim of geology is that the present is the key to the past. Also in their interpretation of modern landscapes, geographers probe deep into the past, even back to Precambrian glacial deposits. If there are differences between geomorphologists and Quaternary geologists, they are not in scientific goals so much as in background and departmental setting. The physical geographer may lack some important basic courses in geology, the Quaternary geologists will probably have had little or no exposure to soils, climatology, biogeography or hydrology. The Quaternary geologist is in a department where all colleagues have a common background in the basic sciences, the physical geographer has human geographers with social science leanings as his colleagues. The physical geographer is pulled two ways: colleagues tell him to remain broad and strive for social relevance, whereas some aspects of his field demand rigorous use of the basic physical sciences. Some end up as soft scientists with a global view and an intuitive generalist understanding of process. Others become rigorous field workers and laboratory experimenters, welcome additions to any geology, geophysics or civil engineering department. Others, happily, combine the best characteristics of both.

In the U.S.A. many of the subdisciplines of physical geography such as geomorphology, glaciology, hydrogeology, periglacial and permafrost studies and all types of Quaternary studies are mainly found in university geology departments. In contrast, universities of the U.K. and Europe commonly, but not always, locate these subdisciplines within geography departments. In Canada the approach has been influenced by both and it is not uncommon to find one or more specialists in these fields in both geology and geography departments on the same campus.

Some sense of the diversity of interests of Canadian professors of physical geography is given in Table 6.1. It is apparent that many are doing essentially the same things as those members of geology departments who call themselves Pleistocene geologists, geomorphologists and hydrogeologists.

Location of departments

The 35 geography departments that offer bachelor degrees in physical geography through their geography departments are listed in Table 6.1. Twenty-three offer master degrees and 16 can award doctorates in this topic.

These departments are located in Arts, Arts and Science and Social Science faculties in about equal numbers. That at Waterloo is in the Faculty of Environmental Studies, and that at McMaster in Science.

The faculty

There are approximately 150 physical geographers on staff in the university departments that teach the subject. They constitute between 15 and 50 per cent and average about 25 per cent of the complement of academic geographers. The specialities of 117 of these geographers are given in Appendix 5A and are summarized in Table 6.2. It is notable that about half of them identify themselves as geomorphologists and that some of the other specialities they mention would also fit that heading. Blais et al. (1971) estimated that total faculty in 1968-69 was 87 and that only four geography departments had sufficient physical geographers on staff to make that discipline a viable speciality. Now 12 departments have five or more physical geographers on staff (Table 6.1).

Undergraduate studies

Most geography departments offer 3-year pass and 4-year major of honours degrees. Some universities offer only the B.A. but most offer B.A. and B.Sc. degrees in physical geography. The B.A. programs are designed for those who wish to acquire a sound descriptive understanding of the subject without immersion in the physical science espects. The B.Sc. programs are slanted towards those who seek a detailed understanding of the Earth's surface environment as a prelude to technical employment or a research career. Combined honours or major B.Sc. degrees in geology and geography are offered by several universities including British Columbia, Brock, McMaster and Windsor.

Honours or B.Sc. major programs in physical geography usually require one or two years of chemistry, physics, biology, mathematics and geology. Introductory courses in physical geography, and skills such as cartography and airphoto interpretation are included in the early years of the programs. In their last years the students take courses in geomorphology, climatology, hydrology, soils geography, remote sensing, statistics, and mathematical modelling. Optional courses include geology, soil science and meteorology. The combination of courses, ancillary subjects and emphases vary greatly from school to school and is apparently influenced by faculty members' specialities.

The few large departments with which our committees made contact claimed to graduate about 20 students per year, about 15 majors and 5 honours. All departments reported large introductory course enrolments, usually numbering in the hundreds. Most departments reported small gradual decreases in enrolments over the past few years.

Graduate studies

Based on visits to and correspondence with several geography departments, one of us (J.E.A.) estimates that there are approximately 250 graduate students enrolled in M.A. and M.Sc. programs and 50 in Ph.D. programs. Total postgraduate enrolment a decade ago was estimated at 128 (Blais et al., 1971). Topics vary according to the research interests of faculty members. A good example of the variety is found at the university of British Columbia where theses in the past five years have been concentrated in fields such as climatology, periglacial studies (including geological engineering), geomorphology and hydrology.

Students are financed by NSERC grants, provincial fellowships and university assistantships. Support from industry is very much less than that received by geology and geophysics.

Research

Research activity has increased immensely over the past two decades and there has been a great widening of perspective in fields such as geomorphology which, prior to 1960, had a wholly morphological emphasis in this country. Discussions with several of our best known geographers suggested that Canadian physical geography was performing well in fluvial, costal, karst, alpine, glacial and general Arctic geomorphology which includes permafrost, periglacial, ice and snow studies. Some stated that our quantitative work in slope stability, coastal geomorphology and river studies was equal to that of the world leaders. In periglacial studies (including geotechnical applications) we are possibly leaders in the English-speaking world. In both quantitative hydrogeology and in hot waters and mixing models we rate with the world's best. One senior geographer said that although we had several very innovative scientists, particularly in fields such as periglacial or groundwater studies we might be behind countries such as the U.K. in new conceptual developments. He felt this was as it should be -- the British had to be innovative to stay in business whereas Canadian geographers could be useful by tackling the problems of a vast, virtually unexplored terrain.

When discussing achievements in physical geography with leading practitioners, it was notable that they frequently mentioned the names of geology faculty members and governments scientists, when describing major university achievements in their fields. Rating the status of physical geography research units across the country, most of those to whom our committee members talked placed McMaster and British Columbia in the forefront. Queen's and Toronto also received frequent mention and individuals at Ottawa, McGill, and Alberta were singled out for excellence.

The improved quality of research in physical geography has gained the attention of peers from the other geosciences and this is reflected in rapidly increasing support from NSERC (Tables 6.3, 6.4). It has also attracted the attention of leading physical geographers from abroad. Although Canadians frequently complained that their papers were neither read nor cited as frequently by foreigners as the contents warranted, those foreign scientists we contacted were consistent in their praise of Canadian endeavours. Some have been cited in Chapter 5 but it is worth repeating that most respondents regard Canada as a powerhouse in geomorphology and especially in glacial and periglacial work. Although some respondents regretted the lack of emphasis on fluvial geomorphology, they nevertheless cite the excellence of work in this field carried out at British Columbia, Simon Fraser and Alberta. Several universities were singled out for special mention by scientists from abroad: Western Ontario (geology and geography departments) and Waterloo (Earth Sciences) for their studies of Quaternary stratigraphy; British Columbia, Carleton and Ottawa for permafrost and periglacial studies; McMaster for coastal and karst studies and, together with British Columbia, Toronto, Alberta and Waterloo (earth Sciences) for overall well-balanced and exciting research programs. Again the individuals cited were attached both to geology and to geography departments and, in a few cases, held joint appointments in both departments.

Funding for research is listed in Table 6.4. Our estimate is that only slightly more than a million dollars is received as grants and contracts in aid of research by physical geographers in geography departments, i.e., about the same amount as received by each of the individual geology departments at Waterloo, Toronto and Alberta.

Employment

Most physical geographers, particularly those who take the B.Sc. option, end up in some of the following six categories of employment, often following completion of postgraduate training:

(1) University faculties; generally restricted to those with doctorates.

(2) Federal science agencies; particularly in E.M.R., D.O.E., and D.I.N.A.

(3) Community and junior colleges; generally restricted to those with postgraduate degrees.

(4) Provincial scientific agencies, e.g., the Land Use Secretariat of the Department of the Environment in B.C.

(5) Petroleum, mining and power companies and engineering consulting firms concerned with physical environment studies.

(6) Secondary school teaching.

Some professors told us that many of those with B.A. majors in physical geography became school teachers, others find a variety of positions in business where their geography backgrounds prove helpful.

Relationships with other geosciences

The nature of geography departments

Geography is sometimes cited as the ideal multidisciplinary subject, breaking down and penetrating traditional barriers. Most departments certainly embrace a wide gamut of disciplines taught by individuals who, in some cases, have had their own training in other departments such as geology, civil engineering or economics. Often these faculty members have much more in common with colleagues in other departments of Arts, Social Science or Physical Science than they do with members of their own departments. To some extent this praiseworthy mixing of discipline interests has worked against professors associated with geography departments. Those in other departments have considered their efforts too diffuse, have regarded their research as suspect and their teaching as generalized and weakly duplicating that available in more tightly structured departments. Also, some geography departments have defeated their own potential to break down the tight disciplinary cliques of universities by stressing their own departmental autonomy and promoting rivalries rather than co-operation with other departments. This may be a trait inherited from U.K. universities where departmental autonomy is strong and most students are honours students completing a large part of their course work within the geography department.

Physical geographers were long considered by outsiders as the soft science components of the diffuse melange of arts and social studies that made up our geography departments. Undergraduates in Arts looked upon the introductory course in physical geography (or psychology, where permitted!) as the easiest way to discharge their unpleasant science requirement. This situation has changed, radically in some departments, less in others, so that the introductory physical geography course is now considered quite as rigorous as introductory courses in other fields of science. The average undergraduate honours student in the better departments offering physical geography specialization now receives as stiff a course with as much ancillary science as his counterpart in geology. Some outstanding researchers in fields that geologists would classify as sedimentology, engineering geology or hydrogeology are located in geography rather than geology departments. Slowly, in those schools with large cadres of productive physical geographers, the discipline has won respect. In those schools with weaker groups, the poor image still prevails. Many of our respondents from government and industry are unaware of the changes that have taken place in the last 15 or 20 years and still retain a false image of physical geographers as some of the marginal scientists who were responsible for some of the scientifically weak overstatements that were among the opening salvos on the environmental crisis.

Links with geology and geophysics

Despite the common ground and overlap of interests, or maybe because of it, much friction existed between geology and geography departments in the 1950s and 60s, chiefly over teaching and research in geomorphology and Quaternary geology. These disputes continue today in some universities. In contrast, where we have developed truly strong physical geography units, there appears to be abundant interaction with other departments and relationships are healthy and productive. At British Columbia, where there is certainly overlap in Quaternary interests, co-operation in teaching and research seems to be firmly established. In fact, on this campus, integration of endeavours between physical geography, civil engineering, soil science, botany and geology seems to be on at least as firm if not a firmer footing than that between geology and geophysics. Similarly, at McMaster, although there is less obvious overlap in interests, there are several joint ventures between physical geographers and geologists, even in such rarified fields as isotope geochemistry, and physical geographers commonly act as supervisors to graduate students in geology. At Alberta there are teaching exchanges in subjects such as glaciology and geomorphology and joint programs at the graduate level with both geology and the geotechnical group of civil engineering. These are only a few of the many good examples of fruitful interaction which our visiting committees encountered.

On the other hand, we also ran into some examples of unhealthy, obstructive rivalries. These can be due chiefly or wholly to personality clashes although other petty reasons may be given by one or both sides. For example, in one school the accusation was made that geology was offering "mikey mouse" popular courses in an attempt to steal from the traditional large enrolments in introductory geography. In at least a few places, physical geographers said that their attempts to work more closely with those in geology or other departments were often frustrated by social science oriented departments heads who regarded such attempts as threats on their autonomy. Others, who had cross-appointments with geology, claimed that this fact had hampered advancement within their geography department.

Some of those from very small physical geography units claimed that they would have been happier and more productive if attached to geology departments where they would have been free to associate and interact with people of similar interests. They felt, however, that merging of physical geography with geology was now a lost cause. The proven success of physical geography within the geography environment in schools such as British Columbia, McMaster and Ottawa made it unlikely that this discipline would be removed from geography departments in other universities. Any stronger links would have to come from the positive actions of individuals, just as it had in the institutions mentioned.

Our comittees found very little evidence of close co-operation between physical geography and geophysics. There is some similarity of interests and research co-operation in glacial studies at British Columbia, paleomagnetic studies of stalagmites by a Toronto geophysicist and a McMaster geomorphologist, and some waste disposal site selection studies at Waterloo and Toronto. Fields which seem ripe for exciting and useful joint research projects are still barely explored, e.g., the seismologists' interest in neotectonics and recent fault activity would seem to call for joint field programs with students of land forms. We know of none.

Summary, conclusions and recommendations

Physical geography has long passed the stage of growing pains in this country. Its practitioners are turning out good students and many have built fine international reputations in research. After a long period of doubt and competition, it appears that we have inherited more from the British than the American practices so that most of the strength of physical geography now resides within large, multidisciplinary geography departments. A good deal of excellence still remains, however, within geology departments, particularly in fields such as geomorphology, hydrology and Quaternary studies.

On the whole the organizational situation is likely to remain as it is thus there is no point in recommending that elements of physical geography in geology and geography departments should combine to form separate departments. Universities, our leaders of change, are surprisingly conservative and traditionalist in organization and less commonly subject to drastic reorganization than either industry or government agencies. Fortunately, there are several good examples to prove that overlap of interest need not imply unproductive competition and duplication of effort. Physical geographers and their geological counterparts co-operate in teaching and research in at least a few well-known Canadian universities.

As we shall stress again at the end of this chapter, many of the basic problems that must be solved to ensure harmonious existence on Earth require multidisciplinary approaches. In an age of specialists this will call for the assembly and informed management of teams of scientists of many different backgrounds. Geophysicsits, geologists and physical geographers, with their grounding in several of the basic sciences and their knowledge of the Earth, are natural leaders for future multidisciplinary efforts directed to survival on this planet. First, however, they must put their own houses in order, co-operate in teaching and research, and address themselves jointly to current national problems such as neotectonics, earthquake and landslide hazard prediction, climatic deterioration, construction of land use maps and siting of buildings, pipelines and waste disposal amenities. To this end we make the following recommendations:

(1) Those geography departments located in universities which lack geology departments should endeavour to add fully qualified geologists to their faculties so that all students who choose will have access to introductory instruction in this subject and so that those majoring in physical geography will receive the several geology courses fundamental to mastery of geomorphology, glaciology and hydrology.

(2) Those geology departments located in universities which lack geography departments should endeavour to add physical geographers to their staffs in order to offer basic courses in geomorphology, Quaternary geology and hydrogeology. Universities in New Brunswick and Nova Scotia which still lack professors in these fields (Blais et al., 1971) are particularly urged to add physical geographers to their staffs.

(3) Where geology and geography departments exist in the same university, deans and other administrators should be aware of the co-operation that is possible by studying models elsewhere and should ensure that petty rivalries do not interfere with such co-operation on their own campuses.

(4) Where geology and geography departments exist in the same university, every effort should be made by deans and other administrators to ensure that joint (cross) appointments are made and that those involved in them suffer no restriction in promotion and other advancement.

(5) The Geological Association of Canada should seek to make its Environmental Earth Sciences Division a joint division with the Canadian Association of Geographers in much the same way in which it co-operated with the Canadian Association of Physicists to form the Canadian Geophysical Union. There is no formal nation-wide association of geography-based and geology-based geomorphologists and it makes good sense that the GAC and CAG should join forces to form such a group.

ENGINEERING

Introduction

Almost all engineering structures are built in contact with the surface of the Earth's crust so that the importance of geology in site selection and ground preparation has long been accepted. One of the founders of geology, William Smith, was in fact an early 19th century canal engineer whose site observations led to an understanding of sequence in layered rocks. The geological maps and sections he produced proved invaluable to himself and others, not only in further canal excavations, but in a wide variety of other engineering works. It is, hence, no surprise that one of the great names in recent Canadian geoscience is that of a civil engineer, Robert Legget, a past president of the Geological Society of America and the winner of many prestigeous awards for engineering and for geology. The ties between these two disciplines should be and in most cases are very close. In a few universities, however, closer ties would be to the benefit of both disciplines.

In almost all schools with engineering faculties, introductory courses in geology are required for most engineering undergraduates, usually only those in electrical or chemical engineering are exempt and even they may be urged to take it as an option. In very few schools, chiefly in the Atlantic provinces, can some or all engineers graduate without at least an introductory course taught by members of a geology department. At ten universities, applied geology degrees can be taken jointly through the engineering faculty and the geology department. Engineering geophysics degrees can be taken at four universities. As described in

Chapter 3, such engineering graduates are highly regarded by employers in industry and some provincial agencies, e.g., the B.C. Department of Energy, Mines and Petroleum Resources qualification as an engineer mandatory for employment in geology or geophysics.

Joint research between geology and geophysics professors and those in engineering is chiefly confined to that broad area of geoscience referred to as geotechnical studies. These studies are chiefly carried out in civil engineering departments but also, on a lesser scale, in geology, geography and other departments. During this study, members of the committee visited geotechnical groups at Alberta, Western Ontario and Toronto. In addition they had access to a recently completed report on geotechnical research by the Canadian Geotechnical Society (1979). The following review is based on both sources of information.

Geotechnical studies

Geotechnics (syn. geotechnique) is the application of scientific and engineering principles to materials of the Earth's crust in order to solve engineering problems. Simply, it is the applied science of making the Earth habitable and, in Canada, this includes studies of snow and ice, muskeg, permafrost, rock and soil mechanics.

Faculty

The Canadian Geotechnical Society report for 1979 lists 107 academics in 27 universities as actively involved in geotechnical research. This compares to 70 about a decade ago (Blais et al., 1971). Their distribution in universities is shown in Table 6.5 and their specialities listed in Table 6.6. The largest groups are at Alberta (9), British Columbia (7), McMaster (7), McGill (7) and Memorial (7). About 70 per cent are in engineering (mainly civil), 20 per cent in geology and 10 per cent in geography. Those listed in engineering are engaged full-time in geotechnical work whereas many of those in geology and geography have other specialities but devote part of their time to geotechnical research.

Undergraduate training

Until about ten years ago most formal training in geotechnical work was in civil engineering departments where undergraduates, in some universities, could specialize in their final years. A few geologists and geographers with backgrounds in geomorphology and Quaternary geology also sought geotechnical employment upon graduation. More recently, three schools with geological engineering programs, British Columbia, Toronto and Queen's, have established geotechnical options within these programs. In addition, the geological engineering programs at Manitoba, Windsor, Laval, Ecole Polytechnique and Saskatchewan all include compulsory courses in geotechnical studies and offer further electives in the final year. Waterloo offers a co-op earth science degree with a geotechnical option.

Undergraduates in geotechnical programs in geology departments are included in the total enrolments shown in Table 3.1. We have no data on enrolments within civil engineering departments although faculty members advised us that it is an increasingly attractive option because of the excellent employment opportunities.

Graduate studies and research

Canadian geotechnical research is highly regarded. Several leading practitioners at home told our Committee members that it rated at or near the top on the international scene and this viewpoint was upheld by correspondents from abroad. Alberta is the leading school in this discipline and Laval seemed to be the most frequently mentioned of the other university engineering groups. Researchers at these schools and at Polytechnique receive some of the largest NSERC grants awarded (Table 5.3).

The fields of research pursued in Canada are summarized in Table 6.6. The emphasis is on soil mechanics and it is pursued chiefly by those in civil engineering departments although some members of geology departments also participate. Geologists are chiefly invovled in rock mechanics, engineering geology, permafrost and snow, ice and muskeg studies. A few geophysicists and several geographers are also involved in all of these last named studies, except rock mechanics. The weak spot of geotechnical studies is in marine applications. To the best of our knowledge, the only academic studies underway are at Memorial. Only one 1980 NSERC operating grant two strategic grants were awarded in marine geotechnic (all to Memorial engineers); this is very surprising in view of impending offshore developments.

Graduate studies in geotechnics are carried out chiefly in civil engineering departments but also in geology and geography departments, usually in co-operation with engineering. The geology departments at Queen's and McGill both have two-year M.Sc. programs which do not require theses. They also have regular thesis programs. The handful of students who take M.Sc. and Ph.D. degrees in geotechnical studies through geology departments are included in the totals shown in Tables 2.1 and 4.1. We have no enrolment data on those in civil engineering departments. However, some data on the largest school, Alberta, gives a sense of the magnitude and importance of postgraduate work in this field. The seven professors of civil engineering have 40 graduate students engaged in geotechnical studies under their supervision. Fifteen of these students are involved in one-year M. Eng. degrees which require no thesis. The department head advised us that the geotechnical group were among the top graduate students in the university. Most held NSERC scholarships, in fact this relatively small group formed 15 per cent of the total NSERC scholars at Alberta. They were in great demand upon graduation for positions with industry, government and university faculties.

Funding

Basic data on funding is shown in Tables 6.7 and 6.8. It is notable that geotechnical research attracts more money per capita than the geological research reported in Chapter 5. Is is also notable that industry's contribution to these engineering studies is very meagre just as it is to geology and geophysics.

Relationships

In most schools with engineering faculties, geologists reported that rapport was good. Links are generally strongest through teaching, particularly where degree courses in geological and geophysical engineering exist.

However, this does not necessarily lead to a great deal of joint research activity. For example, at Saskatchewan where cordial relations and many teaching links prevail, only one geology department member is involved in research with the civil engineering geotechnical group. Alberta, which has no geological or geophysical engineering program, has nonetheless a good deal of joint teaching between engineering, geology and geography at both undergraduate and graduate levels. Several graduate students pursue joint studies through two or even all three of these departments.

Harmony and co-operation is not universal. Thus, for example, we find little evidence of interfacing between the geology department at Dalhousie and the nearby civil engineering and geotechnical group at Nova Scotia Technical College. Also, although there are joint courses (with low enrolments) and some co-operation between individuals of the geology and engineering groups at Memorial, the relationships could at best be described as weak and unproductive in comparison with those in many other universities across the country.

Recommendations

It is appropriate here to repeat an important recommendation made in Chapter 3, namely that:

Those universities with both engineering faculties and geology of geophysics departments which do not have joint undergraduate programs should make every effort to introduce such programs in order to produce geological and geophysical engineers to meet the growing demand from industry and government for those with such combined training.

And, in view of the foregoing discussion, we further recommend that:

Where universities include geotechnical scholars in their engineering faculties yet have no joint programs with geology or geophysics, every effort should be made to establish joint teaching and research endeavours in order to produce well-trained professionals in the rapidly growing field of geotechnics.

Geologists, geophysicists and engineering faculties of coastal universities should address themselves forthwith to the dearth of geotechnical research in the offshore areas. The lack of activity is very serious in view of impending resource exploitation developments.

SOIL SCIENCE

Introduction

Soil science is the study of that part of the Earth's surface which has been so modified and acted upon by physical, chemical and biological agents that it will support rooted plants.

Departments of soil science are associated with faculties of agriculture in seven universities: Alberta, British Columbia, Guelph, Laval, Manitoba, McGill and Saskatchewan. Questionnaires were sent to these and replies received from five of them. Visits were made to four of the five: Alberta, British Columbia, Guelph and Saskatchewan.

In addition to the activities in these departments, teaching and research in soil science on a more restricted scale takes place in seven geography departments in universities which lack agricultural faculties.

The following brief account is designed to augment and update a full study of Canadian soil science undertaken by the Canadian Geoscience Council three years ago (Rutherford et al., 1978).

Faculty

The five soil science departments on which we have data have a total of 63 faculty members. Another 20 can probably be added to this to account for McGill and Laval which did not supply information. The 63 professors include 51 pedologists, 5 agrometeorologists, 3 geologists, 2 forestry scientists and 2 remote sensing specialists. About 70 per cent of these academics received their bachelor degrees in Canada but only 20 per cent received their doctorates in this country, a reflection we were told of the previous lack of opportunity for postgraduate study which has been remedied over the past two decades. The subdisciplines of the 63 faculty members is shown in Table 6.10, several listed two distinct fields of specialization.

In addition, eight pedologists are associated with physical geography units within geography departments, two at Queen's and one at each of Carleton, Laurentian, McGill, McMaster, Western Ontario and York.

Undergraduate instruction

Soil science departments place emphasis on a background in chemistry, physics and biology, possibly stronger than in most other departments in agricultural science. The basic soil science classes cover soil chemistry, soil physics, soil microbiology and soil genesis and classification. Offerings have increased greatly in the last decade, however, and St. Arnaud (in Rutherford et al., 1978) listed 26 different undergraduate courses in soil science that are available at one or the other of the departments offering a full program in this science.

Interlocking relationships with geology departments are generally good. At Alberta, geology students take an introductory half course in soil genesis and classification. All soil science majors take an introductory course in geology and further courses to suit their B.Sc. emphases, e.g., glacial geology, geomorphology and microprobe analysis. Some departments have broadened their scope beyond soil science per se such as Guelph's Department of Land Resource Science which includes pedology, agrometeorology, geology and resource management. It has three geologists on its staff and produces a few earth science majors (Table 2.1) in addition to a variety of other graduates.

The five universities that provided data have a total undergradute enrolment of 172 majors. With the two non-respondents, total enrolment is probably over 200. First year introductory courses are very large, e.g., Guelph has 100 in its geology course, 600 in soil science and 120 in agrometeorology.

Graduate studies

The topics of graduate studies in the five universities for which we have data are shown in Table 6.9. Ninety-eight of the 139 graduate students are Canadian, the percentage being much the same as that reported for geology and geophysics. Although employment opportunities are good in soil science there is not a boom situation as in geology and geophysics which lures students away from postgraduate studies. In fact, students with degrees in the basic sciences have been enroling for postgraduate work in soil science to take advantage of the good employment situation for those with advanced degrees.

Research

All five departments responding to our questionnaire indicated a high level of activity in research. Several prominent academics stated that they felt Canadian contributions to soil science research rated well on the international scene. The range of interests of academic researchers in shown in Table 6.10. Some weaknesses in important subdisciplines are apparent, e.g., in soil biology and soil mineralogy. It is notable that the latter corresponds with a weakness in geological research, namely in clay mineralogy. Possibly this weakness could be remedied through judicious joint appointments.

Two universities, Guelph and Saskatchewan, have institutes of pedology on campus. These are co-ordinating agencies which each include the soil science department of the university, the regional soils section of the federal Department of Agriculture, and the soils section of the provincial Ministries of Agriculture. In each case, the chairman of the university department acts as director of the institute. Alberta and Manitoba also have similar ties with provincial and federal scientists but on a somewhat less formal basis. British Columbia soil scientists work closely with a soil section of Agriculture Canada which is located on campus.

Provincial agricultural agencies seem to have much closer ties with soil science departments and make a much larger contribution to research funding than do their counterparts in mines and energy departments. Respondents from soil science departments seemed generally satisfied with NSERC grants although they felt that their colleagues did not take full advantage of this peer group support system.

Relationship with geology

Aside from teaching exchanges there probably are not many joint projects underway between geologists and soil scientists except at Guelph where they are within the same departments. At the other schools, however, both soil scientists and geologists told us of sharing lab facilities and of helpful discussions between individuals concerning aspects of individual projects.

Soil scientists share with geologists and geophysicists the feeling that a much wider segment of the public should be exposed to their disciplines all of which are basic to wholesome and adequate food and fiber, clean water, effective and integrated land utilization and conservation. St. Arnaud (in Rutherford et al., 1978) writes:

> ...There is a need for policy makers who are capable of dealing with these issues (land development) in a rational and informed manner. Yet many graduates who will assume administrative or advisory capacities will have little appreciation of its physical entirety unless significant changes are made in their training. While they need not become soil scientists...they must at least have a clear understanding of the soil system".

The many parallels between soil science and geology lead us to the recommendations that:

(1) *Universities in Atlantic Canada, all of which lack departments of soil science, should appoint one or more soil scientists to their geology departments or, where possible, jointly to geology and geography in order to spread knowledge of soils and their importance through a wide segment of the university community.*

(2) *Soil science, geology and physical geography professors work jointly to devise and teach courses that will bring an integrated view of geoscience and its methods to those students in other disciplines (e.g., political science, economics) who are likely to end up in policy- making positions.*

(3) *Geologists and geophysicists in provincial mines agencies and university departments study the government/university soil science research institutes on various campuses and attempt to evaluate such joint ventures and emulate the more successful aspects of them.*

OCEANOGRAPHY AND MARINE GEOSCIENCE

Introduction

Oceanography is an interdisciplinary science that includes studies of tides and currents, the chemistry of seawater, plants and animals that live in the sea, ocean bottom sediments and underlying crustal structures.

Oceanography groups are active at Dalhousie, British Columbia, Québec à Rimouski, McGill, Memorial and the Royal Road Military College. All of these groups have geologists and/or geophysicists associated with them. In addition, one or more individuals with research or teaching interests in marine geoscience are located at other universities, e.g. Queen's, which do not have formal oceanographic (or marine science) groups.

None of the oceanographic groups presently offer a bachelors degree in marine science. All teach some courses to undergraduates in order to awaken their interests in this exciting field. Their postgraduate students, however, are drawn from graduates of regular science departments, e.g. geology, biology, physics, chemistry and even from applied mathematics. For this reason, graduate students are generally required to take more course work than usual, filling in their general marine science background while, at the same time, learning the special marine aspects of their own disciplines.

Subsequent to commencing the present study, the Canadian Geoscience Council decided to carry out a full-scale study of marine geoscience in Canada. In order to complete our own report, we present below brief notes on most of our marine science groups. No conclusions are drawn or recommendations made, however, as they would presumably be outdated within the year by the study now underway.

Dalhousie

Oceanography at Dalhousie exists as a regular academic department. It has 14 faculty members, teaches a few undergraduate courses and concentrates almost wholly on graduate studies and research. It has a fine international reputation, and it is the best in Canada, according to correspondents from abroad. This reputation extends to its marine geoscience component for well-known work on the Mid-Atlantic Ridge in the 1960s and early 70s. The reputation has been maintained although research interests are now greatly diversified and embrace such subjects as rheology of the Earth's interior as deduced from loading by tides and by offshore sedimentary basins.

Members of the oceanography department receive large NSERC grants and also funds in aid of research from a variety of other sources, foreign and domestic. Their university budget is small, however, for they claim this is based partly on undergradute teaching with which they are not directly involved. Twelve of the 14 professors are full-time appointees, although they volunteer to teach courses in other departments they owe no allegiance beyond oceanography. Two are joint appointments, both with the geology department. Previously there were many joint appointments but this generally worked against the individual scientists in regard to promotions and tenure. They now choose chiefly to co-operate on an informal basis with those in other departments. It is notable that physical geographers made the same complaint about the parent departments' treatment of joint or cross-appointed professors. Dalhousie has, from the outset, maintained excellent co-operation with all units of the federal Bedford Institute of Oceanography, including its Geological Survey of Canada division. Professors have used the federal fleet regularly and have participated in joint research projects. B.I.O. officers teach courses from time to time and supervise graduate students at Dalhousie regularly. The relationship is in many ways a fine example of what is possible in government/indsutry interaction.

British Columbia

The Department of Oceanography was established here in 1979 to succeed an Institute of Oceanography which was established in 1949. The department brings together faculty and graduate students interested in applying their particular sciences to the study of the ocean and offers them laboratories and other equipment and facilities. The head of the newly created department is a marine geochemist. The two geologists and one geophysicist on the faculty are jointly appointed to oceanography from their own departments. Undergraduate courses are given but no first degrees. Research in geoscience is concentrated on the structure of the western-continental margin; marine geothermal zones; recent sediments and processes in fiords, estuaries and coastal zones; seismic studies and development of instrumentation and methods. The pace of marine geoscience has picked up greatly in recent years at least partly inspired by a federal team of geologists and geophysicists at the Pacific Geoscience Centre at Pat Bay on Vancouver Island. Several successful joint ventures have been carried out.

Memorial

Oceanogrpahic studies commenced here in the late 1960s with the opening of the Logy Bay Marine Laboratory. Geoscientists did not fit into the structure of this laboratory, however, and it has since become solely a biology/biochemistry marine research unit. Individual marine research programs were successfully undertaken by geologists and geophysicists and an introductory undergraduate course in marine geoscience has been offered for the past eight years. Training in underwater techniques for undergraduates and graduate students has taken place annually at a field station in the Bahamas for the past five years. In 1975 a Centre for Cold Water Ocean Resources Engineering (C-Core) was established. It has concentrated on problems associated with exploitation of hydrocarbon resources in deep, ice-frequented waters. It has geologists in its research group and a marine geologist from the geology department sits on its governing board. Although C-Core has been well supported and very active, the marine geoscience component has been small and peripheral up to this stage.

When our committee members visited Memorial it was in the process of setting up a marine science institute. The director-elect, a physical oceanographer, advised us that it would consist chiefly or wholly of joint appointments with existing science departments. Although a few classes would be offered to undergraduates, there would be no attempt to set up a degree program. The main thrust would be towards graduate studies, avoiding existing duplication and bringing marine-oriented people together to share ship-time and other facilities.

Québec à Rimouski

One oceanography group here is set up as a regular department. It has graduate students at the M.Sc. level and proposes to introduce a Ph.D. program in the near future. Rimouski has no geology department. There are, however, two marine geologists on the oceanography staff. They are working on problems of biogeochemistry at the benthic boundary layer. Geographically, they have focused attention on the St. Lawrence Estuary and Gulf and the Laurentian Channel.

The scientists in this department work closely with colleagues in a second group, the oceanographic laboratory of the Institut National de Recherche Scientifique (INRS) at Rimouski. The director of this Institute is a well-known marine sedimentologist. He and colleagues are addressing themselves to changes in sedimentation rates in estuaries affected by hydro-electric developments.

McGill

The Marine Science Centre at McGill is interdepartmental in scope. The chairman is a marine geologist and most of the ten staff members are joint appointments with biology, physics or the Redpath Museum. Two of the four research associates are professors of geology whose specialities are carbonate and clastic sediments.

Laboratory and library facilities are available for research and opportunities for fieldwork exist in the Arctic, in the Gulf and Estuary of the St. Lawrence, the eastern shelf area, and at the Bellairs Research Institute in the Barbados. Special interests of the centre include physics of sea ice, energy exchange between atmosphere and hydrosphere, marine climatology, physical oceanography, marine geology and geochemistry, growth and life cycles of marine organisms, marine productivity and biogeography.

With the exception of the director, the geology professors invovled in McGill's marine studies also have research and teaching interests in Phanerozoic stratigraphy and sedimentology.

OTHER SCIENCES

With the exception of those physicists, chemists and biologists involved in oceanography, few in other sciences carry out research related to the geosciences. NSERC's earth science grants committee funds only 18, 4 located in the departments of physics (exclusive of geophysics), 7 in biology, 2 in mathematics and one each in chemistry, archeology, agriculture, epidemiology and meteorology. Most of the ties between geology/geophysics and other science departments, apart from the geosciences, seem to be related chiefly to the teaching of service courses, the geophysicists teaching such courses and the geologists calling upon other departments to have them taught for their students. Although, as mentioned in Chapter 3, there are opportunities for joint degrees between disciplines, the programs are generally unattractive to most students.

Our committee members met with only a few chemists, physicists, biologists and senior administrators. Most of the views we received on interdisciplinary interaction were from geologists and geophysicists and, hence, probably biased. We make the following brief comments with that qualification understood.

Physics

Several geophysical groups are attached to physics departments, e.g. Memorial, Toronto, Victoria and Alberta. Others, although independent entities, are closely related to physics, e.g. Astronomy and Geophysics at British Columbia. The professors in these departments carry out research, supervise graduate students and teach geophysics to undergraduates. In addition, they teach a variety of specialized and general service courses in the physics department. As their own discipline is based on classical physics, they often have little in common with colleagues in plasma and nuclear physics. They find, however, many advantages in their teaching role for it provides the student-contact hours that entitles them to better facilities and larger university budgets that physics departments enjoy. As one geophysics group leader stated "Geology departments, despite their many major and honours students teach relatively few service courses and, on the capitation basis, couldn't justify a large complement of geophysicists". This situation may be changing as many geology departments report very large beginning courses and a variety of second year service courses. Apart from the teaching role there is not a great deal of joint activity between geophysicists and their physicist colleagues. There are exceptions, for example at Toronto a physicist is doing fine work on planetery thermal history in co-operation with geoscience colleagues.

Geophysicists teaching and researching in geology departments seem to have even less interaction with physicists, although they themselves are generally graduates from Canadian physics departments. At least one of them told us that he found physics courses inadequate in subjects such as electricity and magnetism and planned to introduce his own version of this course through the engineering faculty. This struck us as wasteful duplication in a department already overloaded with course contact hours. It makes one wonder about the lack of rapport and administrative direction that seemingly made restructuring the course in the physics department next to impossible.

Geology professors generally operate at arm's length from physics departments. Usually the only contacts are through geology undergraduates who are generally required to take a full year's course in physics beyond the introductory level. In many schools, however, courses in geophysics are now being substituted for traditional physics so that even this weak contact is diminishing. A notable attempt to bridge the gap and show the potential relevance of physics to geology has been made by a McMaster professor who teaches a course entitled "Physics and Geology".

There have been some good examples of fruitful co-operation in research in the past, for example, much of the early work in isotopic geochronology saw physicists and geologists working together. Eventually this co-operative work reached a stage when the best results could only be achieved by those well-grounded in both disciplines: a whole new breed of scientists had evolved! Similar examples of co-operation still exist. The best we encountered was at Calgary where a professor of physics specializing in mass spectroscopy has taken the initiative in joint programs with economic geologists, petrologists, and others in applying isotope fractionation studies to geological problems. More such people are needed to establish joint endeavours at a time when geology has an excess of practical projects that require multidisciplinary approaches.

Chemistry

The main and in most universities the only relationships between geology and chemistry departments are the course requirements for geology undergraduates and the comparatively rare case of graduate students being required to audit advanced chemistry courses. Relationships between geophysics and chemistry are even fewer.

Again, as in physics, even this teaching link is endangered. Students continue to complain about the lack of relevancy of most of their chemistry courses beyond the introductory year. Several geology professors from across the country told us that they felt they could teach better and more useful courses in physical and inorganic chemistry than could their counterparts in the chemistry department. The lack of rapport and co-operation with a science so closely allied to many subdisciplines of geology is hard to understand. Partly it may come from geologists' resentment of the space, facilities and budgets that chemistry still commands on many campuses, relics of years past when chemistry shared with physics an elite status in the sciences. Regardless, there is now every reason to co-operate in teaching and research to the advantage of both sciences. Smith and Boyle (1968) stated that there was a general lack of chemistry, particularly applied chemistry, in our geological training programs and that is as true as 12 years ago. One method of making courses more attractive to geoscience students might be for chemists to involve geology professors in the teaching of crystal chemistry, thermodynamics and similar subjects within regular chemistry classes. Another might be to invite chemists to participate in the geochemistry classes taught within geology departments, as Waterloo does at present.

There have been a few notable examples of co-operation in research. The impetus given to geochemical research at McMaster 25 years ago came from a distinguished professor of physical chemistry. A recent example that deserves emulation is that of a professor of geology at Alberta who solved his space and financial problems by setting up his amino acid dating laboratory in the chemistry department with the collaboration of chemistry professors. A Toronto analytical chemist has a joint appointment in geology, a sedimentologist is organizing joint research with organic chemists, and geologists and a chemical engineer work jointly on a neutron activation program. A new program at the Toronto Scarborough campus on "Terrain and Environmental Science" brings together geologists, geographers, physicists and chemists. Western Ontario geology has teaching and research activities in co-operation with its chemistry department.

Biology

Biologists and geologists have long had affinities for aspects of each other's sciences which is probably why both claim Charles Darwin as their own! Geology students opting for specialization in biostratigraphy and paleontology are usually required to take biology as an ancillary science. Biologists with interests in paleobiology are usually steered into course work in paleontology. The overlaps in research interests between biologists and geologists working with Tertiary or Quaternary flora and fauna are similar to those that exist between Pleistocene geologists and some physical geographers.

Vertebrate paleontology is taught in biology departments at Toronto, McGill and Alberta by professors with joint appointments to geology departments or museum staffs. Paleobotany and palynology are taught at Alberta, British Columbia, Simon Fraser, Toronto and Waterloo, in four cases with close links to geology departments. Paleobiology is taught at Memorial by a professor appointed jointly to biology and geology. Both Waterloo and Alberta have specialists in fossil beetles on their biology campuses.

On all campuses visited we found co-operation full and friendly between geology and biology departments.

SUMMARY AND DISCUSSION

Relationships are generally good between the geosciences in Canadian universities although there is room for improvement. Recommendations for such improvement are made throughout the text. With the exception of geology/biology interactions, relationships with other sciences are much weaker than they should be.

The rivalry and duplication that once characterized the relationships between geology departments and the physical geography elements of geography departments has disappeared in several universities to be replaced by co-operation in teaching and research. Administrators in other universities now have working models to study when eliminating wasteful overlap in these disciplines within their own institutions. Relationships with biology, always good, should possibly be moving beyond animal and plant anatomy and ecology into joint approaches to biophysical environmental problems. Although several schools (British Columbia is a prime example) offer fine examples of co-operation between geology, physical geography, soil science, civil engineering and biology, on individual bases, possibly there are needs across the country for more formal arrangements welding some or all of these groups into loose associations similar to the marine science centres and institutes that have been established at several universities. A professor from the University of Colorado writes that: "Exceptions exist, of course, but... there is frequently poor communication between geology and those departments which house other geoscientists, e.g. geography, archeology and biology. Thus, I feel that Canada would benefit from at least one university developing an institute that concentrated on the Quaternary."

The long-continued demand by employers for geologists and geophysicists with engineering degrees will probably exert pressures on those universities without such joint programs (e.g. Dalhousie, Memorial, New Brunswick, Calgary and Alberta) to introduce them. The ties thus established will probably lead more geology students to join civil engineers in geotechnical programs such as those offered at the M.Sc. level at McGill and Queen's. This fast growing field and other aspects of terrain science shared with physical geography may eventually employ more geologists and geophysicists than the fields of resource exploration and exploitation.

Relationships of geology and geophysics with physics and chemistry, apart from mandatory teaching links, remain weak. Strong research and teaching ties could be most important, particularly with chemistry. The initial approach must come from strong-minded professors who are willing to cross departmental barriers in their own research. People such as Harry V. Warren, the British Columbia geologist who interested medical scientists (chiefly abroad!) in the relationships between geology and health, or McMaster's physical chemist, H.G. Thode, who injected nuclear geochemistry into Canadian geology. NSERC has attempted to encourage such interaction by its interdisciplinary grants but there seem to be few takers (see Table 5.7). However, its new series of strategic grants seem to be involving scientists from several disciplines in fascinating joint projects as described in Chapter 5.

Science, throughout most of this century, has been dominated by the microsciences (Wynne-Edwards and Neale, 1976) that concentrate on sub-atomic and molecular studies. Their practitioners, the physicists and chemists, were at the apex of the pyramid of sciences receiving more sustenance for their research than other scientists and generally being looked upon as the spokesman for all of science. This situation has changed slowly, at times imperceptibly, during the past two decades. Sociological revolts of the 1960s questioned the directions and motivation of prevailing microscience; environmental and energy debates of the 70s helped hasten re-focussing on subjects lower in the pyramid such as geology, biology, and engineering. The re-focussing has progressed more slowly in Canadian universities than in some of those abroad but it has and is still taking place.

Geology and geophysics have slowly acquired the numerical strength and support to address a fascinating set of problems that range from the origin of the planets and their satellites, the formation of the oceans and the atmosphere and the origin and evolution of life to the discovery and careful utilization of Earth resources and life-support systems. To properly and effectively address these and other problems, geologists and geophysicists must call upon their colleagues in other disciplines to help develop new concepts and upon their fellow geoscientists in geography, soil science and engineering to adapt these to the needs of mankind.

It is appropriate to end this chapter with quotations from a recent presidential address (Strangeway, 1979) to the Geological Association of Canada:

> "...We are facing the next decade when the geosciences must solve our most pressing national issues and yet I can see defensiveness. We presumably are supposed to set the pace and yet our conventional approach to instruction requires our students to immerse themselves in all the traditional subjects at the expense of developing broadly-based geoscientists capable of rising to the challenges ahead. With a few striking exceptions we are trying to produce a standard, carbon-copy geologist, forgetting that the problems ahead require a mix of skills and experience. We are erecting barriers rather than drawing people with other skills into our field to help us solve our problems...We must support each other in the quest for excellence. We must recruit the physicists and chemists, the mathematicians and the biologists to help us in our quest for it is us who have the challenge and the exciting problems to solve."

TABLE 6.1

GEOGRAPHY DEPARTMENTS IN CANADIAN UNIVERSITIES WHICH HAVE PHYSICAL GEOGRAPHY OPTIONS

Name of University	Degrees: B, M, D	No. of Physical Geog.
Alberta	B, M, D	10
Brandon	B	2
British Columbia	B, M, D	6
Brock	B	2
Calgary*	B, M, D	6?
Carleton	B, M, D	5
Concordia*	B	2?
Guelph	B, M	3
Lakehead	B	3
Laurentian	B	3
Laval*	B, M, D	3?
Lethbridge	B	3
Manitoba*	B, M, D	4?
McGill	B, M, D	9
McMaster	B, M, D	7
Memorial*	B, M	4
Moncton	B	1
Montréal*	B, M, D	9
Ottawa	B, M, D	5
Que à Montréal*	B, M	2
Que à Rimouski*	B	1
Que à Trois Rivierés*	B	1
Que à Chicoutimi	B	2
Queen's	B, M, D	5
Regina	B, M	2
Saskatchewan	B, M, D	4
Sherbrooke*	B, M	4?
Simon Fraser	B, M, D	6
St. Mary's	B	1
Toronto	B, M, D	9
Trent	B	3
Victoria	B, M, D	4
Waterloo	B, M, D	6
Western Ontario	B, M, D	6
Wilfred Laurier	B, M	3
Windsor	B, M	4
York	B, M	3

*Incomplete information? estimated figure.
Total No. of physical geographers in Geography Dept's.:
identified by name and included in Appendix 1. 117
Not identified by name: 33
Total 150

TABLE 6.2

PHYSICAL GEOGRAPHY SPECIALTIES

	Speciality	N. of Academics
49a.	Geomorphology includes fluvial, glacial, periglacial, alpine, arctic, coastal, karst and arid land geomorphology	60
49b.	Hydrology, water resources, limnology, and groundwater	7
49c.	Climatology and meteorology	12
49d.*	Natural hazards, slope stability, and mass wasting	5
49e.	Energy, water, and heat budgets	5
49f.	Biogeography	5
49g.	Terrain evaluation and land use	2
49h.*	Permafrost, periglacial, ice snow, and glaciology studies	5
49i.*	Physical environment	3
49j.	Pedology and soil geography	8
49.	Unclassified or not identified	5 & 33

*In the broadest sense these are further subdivisions of geomorphology.

TABLE 6.3

CLASSIFICATION OF PHYSICAL GEOGRAPHY NSERC GRANTS BY SPECIALTIES

	Speciality	Number of Projects
49a.	Geomorphology	
	fluvial	4
	glacial	1
	arctic	1
	coastal	5
	karst	2
19.	Quaternary Research	7
21.	Sedimentology	3
49b.	Hydrology	5
49c.	Climatology	2
49d.	Natural hazards, slope stability, mass wasting	4
49e.	Energy, water and heat budgets	6
49f.	Biogeography	3
49g.	Terrain evaluation	2
49h.	Permafrost studies	3
49j.	Pedology	3
49.	Miscellaneous	5
		56

TABLE 6.4

RESEARCH GRANTS AND CONTRACTS AWARDED TO PHYSICAL GEOGRAPHERS IN CANADIAN UNIVERSITIES

University	Number of Academic Staff	NSERC Operating Grants 1979-80 *	Other Grants 1978-79	Total Grants
Alberta	10	$22,248	?	?
Brandon	2	$10,000	$2,500	$12,500
British Columbia	6	$74,170	$52,443	$126,613
Brock	2	$ 5,000	?	?
Carleton	5	-	?	?
Calgary	6*	$18,000	?	?
Concordia	2*	-	?	?
Guelph	3	$ 9,500	$5,000	$14,500
Lakehead	3	$ 3,500	?	?
Laurentian	3	-	?	?
Laval	3*	-	?	?
Lethbridge	3	-	?	?
Manitoba	4*	-	?	?
McGill	9	$28,000	$88,850	$116,850
McMaster	7	$98,464	$82,937 (77-78)	$180,501
Memorial	5*	7,000	3,500	?
Montréal	9*	$37,000	?	?
Ottawa	5	$26,393	?	?
Qué. à Montréal	2*	-	?	?
Que. à Rimouski	1*	-	?	?
Que. à TroisIvieres	1*	-	?	?
Queen's	5	$28,500	?	?
Regina	2	-	small grants	?
Saskatchewan	4	-	?	?
Sherbrooke	4*	$10,150	?	?
Simon Fraser	6	$25,132	?	?
Toronto	9	$47,870	$45,468	$93,338
Trent	3	$10,865	?	?
Victoria	4	-	?	?
Waterloo	6	$ 9,000	?	?
Western Ontario	6	$ 9,874	$20,000	$29,874
Wilfred Laurier	3	$ 9,000	?	?
Windsor	4	$ 6,210	$25,500	$31,710
York	3	$11,107	?	?

(?) no information
(*) incomplete information
(1) At least 34 Canadian universities have groups of physical geographers. 21 universities receive 56 research grants from NSERC for research in physical geography in 1979-80.
(2) Eight universities provided complete records on research funding, they obtained 47% of their funds, $284,088 from NSERC and 53% of their funds from other sources, $321,798. Projecting these percentages for all universities total research funds would be about $1,052,905.
(*) *See* Table 5.2 for 1980-81 NSERC grants.

TABLE 6.5
DISTRIBUTION OF GEOTECHNICAL RESEARCHERS IN CANADIAN UNIVERSITIES

University	Department	Geotechnical Researchers on Academic Staff
Alberta	Civil Engr.	6.5
	Geology	2.5
British Columbia	Civil Engr.	3.0
	Geography	1.0
	Mineral Eng.	1.0
	Geological Sci.	2.0
Brock	Geography	1.0
	Geological Sci.	1.0
Calgary	Civil Engr.	1.0
Carleton	Civil Engr.	2.0
	Geography	2.0
Concordia	Civil Engr.	1.0
Dalhousie	Geology	1.0
École Polytechnique	Civil Engr.	4.0
	Mineral Engr.	1.0
Laval	Civil Engr.	5.0
	Geology	1.0
McMaster	Civil Engr.	3.0
	Geography	4.0
Manitoba	Civil Engr.	3.0
McGill	Civil Engr.	1.0
	Geography	1.0
	Geotechnical	1.0
	Min. and Met. Engr.	3.0
	Geological Sci.	1.0
Memorial	Engr. and Appl. Sci.	4.0
	Geology	1.0
Moncton	Engr.	1.0
New Brunswick	Civil Engr.	1.0
	Geology	1.0
	Surveying	2.0
N. S. Tech. College	Civil Engr.	2.0
Ottawa	Civil Engr.	2.0
	Geology	0.5
	Geography	0.5
Qué. (Chicoutimi)	Applied Sci.	4.0
Queen's	Civil Engr.	4.0
	Geological Sci.	2.0
	Mining Engr.	1.0
Regina	Energy, Res.	1.0
	Physics	1.0
Roy. Mil. College	Civil Engr.	2.0
Saskatchewan	Civil Engr.	4.0
	Geological Sci.	1.0
Sherbrooke	Civil Engr.	5.0
Toronto	Civil Engr.	4.0
Waterloo	Civil Engr.	2.0
	Earth Sci.	1.0
Western Ontario	Engr. Sci.	4.0
Windsor	Civil Engr.	1.0
	Geology	3.0

Total number of universities 27
Total number of academics 107
engineering 77.5 geography 9.5
geology 18.0 other dept. 2.0

TABLE 6.6
GEOTECHNICAL SPECIALITIES

Speciality	Number of Academics Involved			
	Geology Dept's	Geography Dept's	Engr. Dept's	Other Dept's
Engineering Geology	5	2	1	-
Snow and Ice Studies	1	3	7	1
Muskeg Studies	1	1	4	-
Permafrost Studies	3	2	9	1
Rock Mechanics Crustal Movements	1	-	3	-
Rock Mechanics Fluid Flow	1	-	3	-
Rock Mechanics Geothermal	1	-	-	-
Rock Mechanics Mining	-	-	1	-
Rock Mechanics Properties	3	-	5	-
Rock Mechanics Slope Stability	1	-	2	-
Rock Mechanics Strength & Bearing	1	-	3	-
Rock Mechanics Underground Openings	1	-	7	-
Soil Mechanics Compaction	-	-	1	-
Soil Mechanics Embankments	-	-	4	-
Soil Mechanics Foundations	-	-	17	-
Soil Mechanics Earth Pressures	-	-	3	-
Soil Mechanics Frost Action	-	-	2	-
Soil Mechanics Hazardous Wastes	1	-	4	-
Soil Mechanics Marine Studies	-	-	5	-
Soil Mechanics Railways	-	-	1	-
Soil Mechanics Shear Strength	1	-	6	-
Soil Mechanics Slope Stability	2	1	14	-
Soil Mechanics Soil Dynamics	-	-	4	-
Soil Mechanics Soil Properties	1	1	26	-
Soil Mechanics Soil Stabilization	-	-	3	-
Soil Mechanics Tunnelling	-	-	3	-
Soil Mechanics Terrain Vehicle	-	-	1	-
*Totals	24	10	139	2

*These totals do not agree with the total number of academics in geotechnical research as many are engaged in 2 or more sub-disciplines of this field.

TABLE 6.7

RESEARCH FUNDING OF GEOTECHNICAL STUDIES AT CANADIAN UNIVERSITIES

Source of Funding	Total Amount	Percentage
NRC-DSS	$ 57,950	1.1
NSERC	1,678,100*	31.9
Other Federal Gov't Departments[1]	2,058,350	39.1
Prov. Government	569,700	10.8
Industry	160,100	3.1
Foreign	405,500	7.7
Universities	99,100	1.9
Other[2]	233,400	4.4
TOTAL	$5,262,200	100.0

[1] Primarily Environment, EMR, Agriculture.
[2] Crown Corporations e.g. AECL, Provincial electric power companies.
* *See* Table 5.2 for 1980-81 NSERC grants.

TABLE 6.8

RESEARCH FUNDING IN GEOTECHNICAL STUDIES BY AREA OF SPECIALITIES

ENG. GEOLOGY	$ 43,300
SNOW AND ICE	$ 199,600
MUSKEG	$ 368,500
PERMAFROST	$ 755,000
ROCK MECHANICS	
Properties	$ 326,400
Fluid Flow	367,200
Geothermal	755,000
Underground Openings	161,500
Crustal Movement	56,300
Slope Stability	91,700
Strength and Bearing Capacity	32,500
SOIL MECHANICS	
Compaction	$ 4,000
Frost Action	22,000
Marine	486,600
Shear Strength	43,500
Earth Pressures	4,500
Hazardous Wastes	101,700
Railways	101,500
Slope Stability	129,500
Embankments	9,000
Soil Stabilitization	5,500
Soil Dynamics	75,400
Foundations	316,200
Properties	606,700
Terrain Vehicle	147,000
Tunneling	52,100
TOTAL	$5,262,200

TABLE 6.9

RESEARCH SPECIALITIES OF GRADUATE STUDENTS IN SOIL SCIENCE*

Speciality	Number of Students
Soil Chemistry (includes Physical Chemistry and Pesticide Chemistry)	20
Soil Biochemistry	6
Soil Physics	4
Soil Biology and Microbiology	8
Soil Gensis, Classification, Evaluation and Land Use	16
Soil Management	1
Soil Hydrology	4
Soil Mineralogy	4
Agrometeorology and Biometeorology	15
Soil Fertility, including Nitrogen Studies and Fertilizers	22
Remote Sensing	2
Resource Management	2
Forest Soils	4
Soil Science Unclassified 23 cases information not provided, the remaining 8 did not fit above	31
Total	139

TABLE 6.10

SPECIALITIES OF SOIL SCIENCE DEPARTMENT ACADEMIC STAFFS*

Speciality	Number of Academics
Soil Chemistry (includes Physical Chemistry and Pesticide Chemistry)	10
Soil Biochemistry	3
Soil Physics	6
Soil Biology and Microbiology	2
Soil Genesis, Classification, Evaluation, and Land Use	14
Soil Management	3
Soil Hydrology	2
Soil Mineralogy	2
Agrometeorology and Biometeorology	5
Soil Fertility, including Nitrogen Studies, and Fertilizers	11
Remote Sensing	2
Resource Management	5
Forest Soils	2
Geology	3

*Does not include McGill and Laval.

7. RELATIONSHIPS AND STATURE - WITHIN AND WITHOUT

O wad some power the giftie gie us
To see oursels as others see us!
--Robbie Burns, 1786

HISTORICAL BACKGROUND

Geology had many of its roots in common soil, it grew from the attempts of individuals in many walks of life to describe and explain the origin of rocks, scenery, fossils and many related natural phenomena. The early practitioners included physicians, clergymen, stonemasons, engineers and miners. Their writings attracted a surprisingly wide readership and excited much public interest. Some, such as the canal engineer, William Smith, were able to demonstrate that this new science of the Earth could be usefully applied to their own and other professions. Those who occupied the early chairs of geology, eventually established in universities, drew heavily on the wealth of observational data and the many "rules of thumb" of farmers, colliery workers, quarrymen and hard rock miners. In time, the principles and theories developed by academic and government scientists were returned to the resource industries as useful guidelines for development and operation. It is notable that the great Canadian geologist, Sir William Logan, gained his interest in the science through employment in the Welsh coalfields and, when he returned to his birthplace to establish our national Geological Survey in 1842, his initial goal was an assessment of Canada's coal resources.

Some of the earliest geophysical studies grew out of interest in locating and explaining earthquakes in the middle of the 18^{th} century. This is still an aspect of geophysics that elicits great public interest. Although magnetic studies commenced in Canada in 1840 (Garland, 1968) and were successfully used for prospecting near Sudbury in 1893, mining geophysics did not make favourable public impact until after World War II. There were some notably talented pioneers, but many of the early practitioners were people of doubtful ability and rather lacking in scruples (Siegel, 1968). Generally geophysics was overshadowed by the glamour of atomic physics in the public mind until the acceptance of plate tectonic theory in the late 1960s and the energy crisis with its accompanying newspaper accounts of seismic exploration techniques in the late 1970s. In both these cases, geology and geophysics seem to have become merged in the public mind, a welcome development that practitioners of both subdisciplines should strive to maintain.

A cultural interest in geology has grown up in many countries, parallel to the practical interests. It has chiefly focused on mineral and fossil collections and has generally been associated with museums and local natural history societies. These activities were probably never as widespread in Canada as in the U.K. and U.S.A. where gifted 'amateurs' belonged (and still belong) to the same societies as professionals and not uncommonly make important contributions to the science. Many Canadian geoscientists practicing today, nonetheless, first had their interests aroused by their parents' involvement in natural history groups led by university geologists such as G. Vibert Douglas of Dalhousie University or by government scientists such as Alice Wilson or F.J. Alcock of Ottawa.

Both pragmatic and cultural interests in geology and geophysics tend to fluctuate according to how they relate to the material needs of society and how they impinge upon the beliefs or otherwise capture the interest of the populace. A century ago, geology was at the pinnacle of science in Canada (Blais et al., 1971). This was understandable in a young country tremendously interested in its resource potential and also understandable during the decades of intellectual ferment that were stirred up by the Darwinian revolution. Despite its continued importance to resource development geology's influence faded in this century, partly eclipsed by the feats in other sciences, partly also by increasing urbanization and lessening interest in the delights of nature.

In the last decade our science has again moved into the public eye. The plate tectonic revolution prompted the renowned geophysicist, Sir Edward Bullard (1969) to state: "We are in the middle of a rejuvenating process in Geology comparable to the one that Physics experienced in the 1890s and the one that is now in progress in Molecular Biology." Add to this the energy crisis, environmental concerns and the growing shortages of essential minerals of the past decade and there can be no doubt that geology and geophysics should be in the forefront of our national interest in science.

In the succeeding pages, we shall examine the efforts of university geology and geophysics groups to interact with their counterparts in government and industry to keep geoscience in the forefront by working towards important national goals and by communicating some understanding of their methods and objectives to a broad segment of the public. Previous chapters have dealt at length with the major functions of university departments, teaching and research, so that these subjects are now only touched on in relation to mechanisms for their improvement through external suggestions. Instead, stress will be laid on involvement with societies on national and international levels, on relationships with their counterparts in government and industry, and relationships to the public through secondary education, service lectures, popular writing and the news media. Finally, we conclude with an assessment of the status of Canadian academic geology and geophysics by those within it and some of those who see it from the outside.

SCIENTIFIC ASSOCIATIONS

Several correspondents from abroad, commenting on Canadian geoscience, remarked on its apparent co-ordination and integration compared to that in most other countries. They specifically singled out the co-operative projects that took place in widely separated parts of our country, the lack of serious rivalry and friction between our national geoscience associations and the manner in which our various national journals covered the field without serious gaps or overlaps. Much of the credit for this, particularly in the last decade, must be attributed to our 12 national geoscience associations and their umbrella body, the Canadian Geoscience Council, sponsor of this report.

Growth of specialization

The most venerable of the societies in which geoscientists are active include the Royal Society of Canada, founded in 1882, and the Canadian Institute of Mining and Metallurgy (CIM), founded in 1898. Both are multidisciplinary groups but both provided important meeting places and publication outlets for geologists and geophysicists. Many of their earlier functions have now been taken over by other geoscience groups. The Royal Society now functions chiefly as an honour society, involving its small group of geoscientist academicians in multidisciplinary endeavours. The CIM is attractive to our large population of economic geoscientists, chiefly those in mineral exploration, rock mechanics and similar applied subjects.

Specialized geoscience societies began establishing themselves over 50 years ago, although most came into being in the last 30 years. Some have their activities mainly localized within the geographic area of their specialities. These include the Canadian Society of Petroleum Geologists (CSPG), the Canadian Society of Exploration Geophysicists (CSEG), and the Canadian Society of Well Loggers (CSWL) which hold most of their meetings in Calgary. Academics from western universities have had an influence far in excess of their numbers in these societies. Nevertheless, their input must be classified as small, even if important. Similarly, the Toronto-based Canadian Exploration Geophysical Society (KEGS) attracts a small but important group of academics with base-metal exploration orientations.

The Geological Association of Canada (GAC) and, to a lesser extent, the Mineralogical Association of Canada (MAC) have memberships which span a wide range of interests and hold their joint annual meetings at centers from one end of the country to the other. The GAC also has regional sections and topical divisions that meet several times during the year. Most academics belong to the GAC where they form 20 per cent of the membership, the remainder being 50 per cent industry, 20 per cent government scientists and 10 per cent students. Most, if not all, academic geophysicists belong to the Canadian Geophysical Union, a joint division of the GAC and the Canadian Association of Physicists. Many academics also belong to the MAC where they form 15-20 per cent of the membership. Basic facts concerning all the national geoscience societies are contained in Part 2 of this annual report of the Canadian Geoscience Council.

Importance of associations

One cannot exaggerate the importance of many of our associations in providing opportunities for interface between the several segments of Canadian geoscience. Government and mining industry respondents cited meetings of scientific and technical associations as their main opportunities to interact with counterparts from universities. The GAC was mentioned most frequently, followed by CIM and MAC. Such meetings are less important to scientists of the petroleum industry who seem to rely on the few who go on annual recruitment tours to make contacts with academics outside of Alberta.

Participation in technical sessions, symposia and panels at local section meetings and major annual meetings is the prime medium of information exchange and leads to much interagency co-operation in research. Involvement with executive bodies and committees leads to understanding and tolerance of those in other occupations.

Academics' contribution to associations

All Canadian geoscience societies operate on a volunteer basis with varying amounts of full or part-time secretarial aid, with the exception of the huge, multidisciplinary CIM which has a permanent secretariat. Although, in most societies, scrupulous attention is given to election of an executive that is representative of the membership in terms of employment and of geographic area, it is a fact that academics are usually involved out of all proportion to their members. In the specialist societies, where their numbers are few, they commonly play leading parts in technical sessions and as authors. In the broader based societies, where their percentage of the membership is greater, they take on many roles. For example the GAC headquarters and the services of the secretary-treasurer have been donated by Waterloo for 15 years. This university has also contributed headquarters and secretariat to the Canadian Geoscience Council since its inception eight years ago. Local sections and divisions of national societies commonly call jointly upon provincial geoscience agencies and university departments to provide services and facilities. Many local and national annual meetings are held on university campuses. Association journals and other national geoscience publications have been edited and managed in recent years with space and facilities donated by McMaster, Queen's, Memorial, Calgary, Alberta and British Columbia.

Academics' enthusiastic leadership of technical programs is easily understandable - they wish to transmit the results of their own and their students' research to a broad segment of the community. In the case of committee work and volunteer service on secretariats they are usually fortunate in the backing of their senior administrators who consider support of scholarly societies as part of the university mandate. Because of this attitude, faculty members generally receive more material recognition for their participation in society affairs than do their counterparts in industry and government. Nonetheless, the rest of the community owes them a debt for the extra efforts many of them have made, particularly in the last two decades, to ensure that our societies function smoothly and effectively.

Strengths and weaknesses of our scientific society system

Most of Canada's dozen national geoscience associations all grew up in response to special needs of scientists seeking exchanges and fellowship with others in their community of interests. Partly also they were in response to nationalistic impulses; many Canadian geoscientists belonged (and still belong) to U.S. and U.K. societies and this motivated formation of similar organizations here to suit local needs. Unfortunately, several of these specialist societies, such as CIM and CSPG were flourishing long before an attempt was made to form a general society such as the GAC, quite the opposite of the procedure in most other countries. With strong allegiances already formed, the GAC has never succeeded in gaining more than 20 per cent of the country's geoscientists as members. The result is isolation of interests that is most noticeable in the few interactions between central and eastern university professors and petroleum geoscientists, most of whom are based in the west. Although a few professors have successfully broken the distance barrier and although the CSPG in particular has made praiseworthy efforts to stage special meetings in the east, the isolation persists. Possibly the way to reserve the trend and to break down regional and disciplinary parochialism without disturbing present allegiances, is to arrange joint meetings between GAC sections (to which most professors belong) and specialized societies such as CSPG, CSEG and CIM on subjects of mutual interest. University professors are in the best position to initiate such meetings and possibly have the most to gain from them. We recommend:

That specialist societies, such as the Calgary-based petroleum societies, continue their splendid efforts to reach out into other parts of the country by working in even closer co-operation with local societies and with local sections and divisions of GAC and CIM and by holding joint meetings with them on topics of mutual interest.

Those societies that strongly represent a single element of the community can present policy briefs or act as lobbies on behalf of their members. The three petroleum-based societies and the CIM have successfully done this when occasion demanded it. No society is composed mainly of academic geologists and geophysicists and able to state the academic viewpoint even if there were such a thing! It is a tribute to the cohesion in Canadian geoscience that the Canadian Geoscience Council, representing all societies and, hence, many divergent views, has made strong and effective representation on the need for increased governmental support of university research. It has also issued strong and well-publicized statements on the difficulties of accurately estimating oil and gas reserves and resources at a time of public bewilderment in the face of conflicting reports. Generally, the Council and its member societies face controversial issues by staging public forums or panels where opposing views are presented and open discussion follows. One of the most successful of these was the Council's 1978 forum on disposal of high level radioactive wastes.

Society executives usually act slowly or are unable to act at all on many sensitive issues such as resource development within national parks, mineral and fuel import and export policies, and environmental concerns. This is due to the widely differing viewpoints of individual members and the impossibility of obtaining consensus. These are matters that require the informed opinions of individual scientists, presenting objective arguments. If there are advocates of both sides of the issue, so much the better--the public and their elected representatives will have great opportunity to make an informed judgment. Government scientists are not permitted to publicly confront their political masters on such issues and company scientists are seldom able to challenge corporate views, so it remains for the university professors to speak and write common sense (as they see it). Few university geoscientists have taken advantage of their academic freedom to do this and to make views known to the public on controversial issues. There are notable exceptions, mentioned later in this chapter, but most academic geoscientists prefer to perform anonymously in the group activities of societies, devoting themselves to information exchange and noncontroversial endeavours such as improving secondary school education. The growth of our societies in numbers, activities and scientific status over the past two decades owes much to a dedicated and enthusiastic academic community.

INTERNATIONAL SCIENCE

A European scholar, prominent in international scientific affairs, wrote to us that "...Canadian geologists have always played a prominent role in international science. When names are suggested for important committees the list is usually dominated by those of Canadians ..... it reflects the high sense of international responsibility of your geologists". Two decades ago, this comment would not have been valid for geology although it could have applied to geophysics.

Professor J. Tuzo Wilson was the very active president of the International Union of Geodesy and Geophysics (I.U.G.G.) during 1957, the International Geophysical Year. Subsequently, a Toronto geophysicist has served as secretary-general of the IUGG and another, from British Columbia, has co-ordinated its major activity of the last decade, the International Geodynamics Project. Many other Canadian academics have been involved in the organization and planning of international geophysical projects. Their involvement was initiated and partly supported by the National Research Council of Canada which served as the Canadian adhering body for international organizations concerned with geophysics.

Academic geologists were much less involved with international science. Although a few played prominent roles in the Geological Society of America, most of the sparse, formal international activities involved scientists of the Geological Survey of Canada (GSC). This changed in the mid 1960s when the prominence Canada had enjoyed in international geology under Sir William Logan and his colleagues in the last century was restored under the leadership of J.M. Harrison of the GSC. Harrison was charter president of the International Union of Geological Sciences and later became the second Canadian president of the International Council of Scientific Unions. Harrison and his successors at the helm of GSC have encouraged greater participation in international affairs by academic and industrial geologists. This culminated in 1975 when the GSC officially turned over its national co-ordinating role to the Canadian Geoscience Council which then became responsible for constituting the National Committee for Geology. This committee is presently headed by a professor from Queen's who also serves as foreign secretary of the Council.

Academic participation in international projects has increased greatly in the past decade. The Geodynamics Project, now terminating, brought Canadian geologists and geophysicists closer together than had any other joint research projects and invigorated their contacts with foreign counterparts. The International Geological Correlation Program currently underway, has many individual projects headed by Canadian academics. It too has helped break down the parochialism of faculty research and has accelerated joint endeavours with other universities and agencies at home and abroad.

Several leading geoscience journals published abroad have called upon Canadian geoscientists to serve as chief editors. These include Geochemica et Cosmochimica Acta which is edited at McMaster, Chemical Geology at Western, Journal of Petrology at Toronto, and Water Resources at British Columbia. Additionally, there are few if any well known international geoscience journals which do not have one or more Canadian academics included on their editorial boards.

Several flourishing international associations, e.g. the Association of Exploration Geochemists have come into being largely through the efforts of Canadian geoscientists. One of these deserves special mention because unique in membership and goals. This is the Association of Geoscientists for International Development. It includes members from 81 countries and is devoted to sane and honest resource development in the third world countries, a goal that often requires biting the governmental hands that support such development. The seed from which this fast growing organization developed was sown at an International Geological Congress Symposium in Montréal in 1972. A meeting sponsored by the Canadian Geoscience Council in 1974 launched it and two geoscientists, one from Memorial and the other from Montréal, were the catalysts among several Canadians at home and abroad who nurtured it during its five formative years. It now has headquarters in Venezuela and, although many deserve credit for its success, its birth pangs and healthy childhood days will always be a credit to the international concerns of Canadian academics.

GOVERNMENT/UNIVERSITY INTERACTIONS

The main interactions between government agencies and university geology and geophysics departments revolve around research and undergraduate and graduate training as described in previous chapters. Generally, in comparison with other nations, there is a high level of communication and co-operation - enviable in the eyes of some of our correspondents from abroad.

Quite naturally, in many cases, the smaller the distance between government agency and university department, the greater the interaction and co-operation. Regina University enters into more joint activities with the Saskatchewan Department of Mines than does University of Saskatchewan at Saskatoon, a few hundred kilometres away. Toronto seems to have closer links with the Ontario Department of Mines than do more distant universities within that province. Ottawa-based members of the G.S.C. and the Earth Physics Branch have closer liaisons with Carleton and Ottawa than with more distant universities. In some cases university departments have slanted their research emphases to dove-tail with those of nearby government agencies - Dalhousie's relationship with the G.S.C.'s Atlantic Geoscience Centre is a good case in point.

There are also many good examples where close links have been established despite the intervening miles. For example, the G.S.C.'s Calgary division has had joint projects on Cordilleran mapping underway with Queen's and McGill and it commonly calls upon Québec and Ontario university geologists for specialized paleontological studies. Several of the provincial agencies also report that they call regularly on university people outside their province for specialized research, e.g. both Newfoundland and Manitoba have joint projects with Carleton involving geochronological studies. Such exchanges help broaden interests and break down the parochialism which our visiting committees detected in a few places where the local government agency and university department worked closely together, almost oblivious to other influences.

Even in places where relationships were good, our committees encountered a surprisingly large number of both university and government scientists with (usually misinformed) negative attitudes towards the goals and efforts of their counterparts. These were more common among the older scientists. In a few places, despite physical proximity and similar research interests, we encountered groups with little or no productive interaction. In these cases we presumed that senior people with fixed, negative attitudes had emerged as managers in one or both camps.

Apart from meetings of learned societies and individual contacts at the working levels, which almost all government respondents rated as their major means of communication and information exchange, many government agencies have other links which are described briefly below.

The Geological Survey of Canada

The G.S.C., this country's largest geoscience agency, will serve as a good model for the several federal agencies that interact with university geologists and geophysicists. Some of its nine divisions are closely concerned with university work, others hardly at all.

The G.S.C. has, in the past few years, invited a committee with revolving membership nominated by the Canadian Geoscience Council, to examine its operations and to report on them to senior government administrators. General evaluations have been published for the benefit of the public. Leading academic geoscientists have been prominent members of this committee.

G.S.C. scientists have served in the past on the boards of governors of universities and one is presently active on a university senate. They have served on ad hoc advisory groups to many universities; in the last year or two these have included Memorial, New Brunswick, Toronto, Alberta, Saskatchewan, the College of Cape Breton, and a few U.S. schools. Those geology departments that have permanent committees which meet regularly (e.g. Queen's, Toronto, Memorial) always have a Survey scientist as member.

Only one G.S.C. division states that it is formally consulted in regard to appointments at several universities. Individual G.S.C. scientists are, however, frequently asked for their opinion of candidates. Although university scientists are not invited to sit on hiring boards, two divisions state that they regularly call upon university opinions regarding recruitment.

G.S.C. geologists are frequently invited to give one or more lectures annually on their specialities, chiefly in Halifax, Ottawa, Calgary and Vancouver but also in other locations. There are few geology departments that have not had G.S.C. visitors in the last few years. Also, several G.S.C. scientists are active on a regular basis as sessional lecturers or as term replacements for professors on sabbatical leave. Others have been appointed as adjunct professors at British Columbia, Calgary, Carleton, Ottawa and Dalhousie i.e. in cities where G.S.C. divisions are located. A few university professors have spent extended visits on their sabbatical leaves at G.S.C. laboratories. Several G.S.C. employees have had previous experience as professors at one or more universities and many professors are former employees of G.S.C. Some have made the Survey/university moves on two or more occasions.

Obviously the ties are very strong. Despite this, from the G.S.C. divisional replies to our questionnaire and from talks with university staff members, our committees consider that about half the divisions could benefit from increased contacts and closer relationships. These would require increased initiatives by university department heads and G.S.C. managers.

Provincial surveys

The nine agencies with whom we had contact all submitted well-considered reflections on relationships with local universities and a genuine concern to improve them in most cases. Appraising these relationships, the authors of this report rate one or two as very good, four or five as good, two as fair and one as poor.

Apart from meetings of societies, there are abundant opportunities to mix and exchange ideas with people at the universities in the provincial capitals. Three provincial respondents state that professors and students attend their seminars and that they attend special lectures at the local university. Scientists from two of the agencies have been appointed as adjunct professors. Others have been asked to serve as sessional lecturers or to give special series of lectures in regular courses.

Most, but not all, provincial agencies ask university geoscientists to serve as referees or critical readers of their scientific reports. One worries about this practice because of the "confidential nature" of some reports and another fears if it was permitted in his survey "the reports would become too academic".

At least two provincial agencies (Nova Scotia and Ontario) have invited university people to sit on panels when hiring scientists and several more state that they commonly consult university scientists before making appointments. At least two provincial agencies have formally participated in the selection of candidates for special university appointments.

Eight respondents state that university people have some input into their program planning and evaluation. This ranges from semiformal consultation to "Keeping our ears open for good ideas". One stated that it was "not the university's role to have such input". Despite these protestations of consultations, our committees' visits and chats with many university people and a good sprinkling of provincial geologists led us to conclude that there is more need for communication and frank exchange. It was put this way by one provincial correspondent "Information exchange is sporadic and commonly limited to formal presentations or to seminars. There is presently no generalized assessments of each others programs. Co-operative ventures tend to be of an ad hoc nature and to be sponsored by individuals rather than arising from joint gatherings. This situation ....can only be improved through an enhanced liaison between personnel of both agencies."

Some thoughts on relationships with government agencies

Whenever weaknesses were detected in relationships there seemed reasons to suspect personality short comings on one or both sides. This need not indicate negative attitudes but merely a laissez-faire approach on the part of leaders.

Jealousy and suspicion are rampant in all creative communities and science is not immune. Undue fears of territorial invasions or of being "scooped" before going to press must be constantly allayed by those leaders who believe in co-operation and constructive criticism. A few strong minded individuals can, alone, change a relationship around within a few years. Recent, positive examples of this from Toronto and Vancouver are well known to the geoscience community. There are, unfortunately, some negative examples. Universities and government departments both should choose as managers those people who have the inclination, ability and tenacity to build and maintain bridges with related external groups. The advantages to research, teaching, community service and the pocket books of the taxpayers are readily apparent wherever such good relationships have been established.

We recommend:

> *That government agencies and university departments examine the full range of useful practices now in existence and adopt some or all of those that might suit their circumstances. These include: appointing government scientists as adjunct professors and sessional lecturers and using them for individual lectures; attending lectures and seminars at each others establishments; involving professors when partially supporting students' research; each inviting representatives of the other group to policy and planning meetings; discussion of new staff appointments and new facilities.*

Provincialism, in its narrowest sense, is usually harmful to science and particularly to university science. Once common in Atlantic region geoscience, it has all but disappeared and there is scarcely a university professor or a provincial agency geoscientist who has not visited every campus in the region. It is apparent, however, in the west and in some parts of Québec and Ontario. Closely knit communities of government or industry and university geoscientists function together so well through their local association(s) that some of them forget that there is a world of science beyond their city boundaries. One possible remedy might be pioneered by local societies such as the Saskatchewan Geological Society, the Edmonton Geological Society and the Winnipeg Section of G.A.C. holding a joint meeting once a year on a campus somewhere in the prairie region. The purpose would be to illustrate work in progress at the university and at its neighboring provincial agency. To this end, we recommend:

> *That local societies and sections of national societies, such as those in Winnipeg, Regina and Edmonton, should annually stage a meeting preferably centered on a university campus with the main objective being a tour of facilities and an explanation of activities of the local geology and geophysics department and the provincial geoscience agency.*

Some Ontario and Québec universities could profit by similar meetings although they would have to be scaled down to prevent the large numbers which inhibit "know-thy-neighbor" exchanges.

THE LINKS WITH INDUSTRY

Lacking common research interests, the ties with company scientists are commonly not as strong as those which academics have with their government counterparts. There are ties, nonetheless, and many commentators from abroad mention the links with industry and the generally pragmatic approach of our university departments as the great strength of Canadian geoscience. Obviously it shows up best from afar! Considering the most economic geoscientists in this country are graduates of Canadian universities and considering that many Canadian professors have experience in industry (Table 2.2), each displayed a surprising amount of ignorance and suspicion of the other in replying to our questionnaires.

The main contacts and exchanges come from meetings of societies, recruiting tours and personal contacts at the working level. Old school ties often play a prominent part in relationships as the mining industry in particular has strong loyalties and traditions.

Mineral exploration companies

The importance of individuals in building up good rapport cannot be exaggerated. By a combination of well-presented, industry slanted talks on pertinent aspects of departmental research; by playing active roles in economically oriented societies at both the local and national levels; and by purposefully striving to make contacts with company geologists in their offices and field headquarters, professors can break down barriers and build up goodwill and co-operation. Replies to questionnaires sent to exploration companies proved that a handful of professors from St. John's to Vancouver had done this - but probably most successfully at Western Ontario.

Individuals who actively seek to bridge the gaps with industry require the support and backing of their colleagues. Too often attempts to arrange visitations, open-houses and workshops falter due to lack of participation of department members who consider such service work as "showmanship", quite extraneous to their own lofty research interests. Most departments would serve themselves well by appointing one of their members as an official liaison officer to industry. We recommend that:

> *University departments assign a principal liaison person to communicate with each of the industries (minerals, petrolem, engineering, etc.) where links would be beneficial in regard to employment, research and other matters. The persons chosen should be those faculty members whose interests lie closest to the industry concerned. This would be following successful examples already set by several universities - old and new.*

Several of the old-established departments such as McGill, Toronto, Queen's and British Columbia have supplied large numbers of students to mineral exploration over many years and have established influential networks of alumni in a tradition-conscious industry. This has paid off handsomely, in some cases, in donations of equipment, space and endowed professorships as well as in employment opportunities and research sponsorship. Such loyalties must be constantly nurtured, however, for our questionnaires showed that some of the departments that have blossomed in the last 15 years or less have made strong inroads into the affections of the mining companies, particularly Western Ontario, Memorial, Waterloo, Carleton and Ecole Polytechnique.

Mineral explorationists are seldom invited to lecture at universities and they rather resent it. Even CIM sponsored lecture tours more often than not involve academics. Students regret this and point to the need to be exposed to more "practical geologists who tell it like it is in the real world". Academics reply that it is difficult to identify other than a small over-used handful of explorationists who lecture well and it is increasingly difficult to convince these people that they should give the occasional lecture. Possibly the answer lies in enticing scientists from industry into giving simple presentations on case histories to small groups of upper classmen in informal settings such as those of laboratories or seminars. We recommend that:

> *University departments should seek to involve more mineral exploration and petroleum geologists and geophysicists in lecturing - particularly in informal presentations of case histories.*

The willingness of mineral explorationists to serve on grants committees, deans visiting committees and the like should assure university professors that there are many out there who are ready and willing to help if the need is identified and the approach is right.

Petroleum companies

Unlike mineral explorationists, who are located near university centres in many parts of the country, almost all petroleum geoscientists have their headquarters in Calgary. The three major petroleum based societies (CSPG, CSEG, CSWL) carry out almost all of their activities in Calgary, home base of about 4,000 geoscientists. The interaction with university scientists chiefly involves those in the Alberta universities, although a good handful of professors from elsewhere in Canada and U.S. attend annual meetings. This has resulted in a sad lack of knowledge of university activities, particularly among the small companies. One respondent deplored "the complete lack of carbonate studies in eastern Canadian universities", apparently unaware that some of our leading carbonate scholars were located in such universities and that some of their best known studies had been carried out in western Canada.

Major and several intermediate companies carry out annual recruiting tours. Companies attach great importance to these visits. This is their main method of finding out what transpires in the universities and the reports of the individuals or teams that visit are often widely circulated and discussed with colleagues within each company. Unfortunately, not all university geoscience departments, particularly those new to the scene, realize the importance of these visits and the need to provide a thorough tour of their facilities and to convey some sense of the importance of their various activities. One of the weaknesses of this free enterprise method of establishing links with the universities is tradition, some schools are favoured by visits from many companies, others are ignored. For example, Manitoba and Saskatchewan have supplied so many geologists and (more recently) geophysicists to the system that one hears frequent reference to the "Manitoba Mafia" and the student club of the Saskatchewan campus now has a very active alumnus branch in downtown Calgary. Also many of the senior geologists and geophysicists of the industry came from the established schools of 20 and 30 years ago, so we find British Columbia, Alberta, McGill, Toronto, Queen's and McMaster included on many recruitment tours. It has been hard for newcomers to break into these charmed circles. Calgary, after a slow start in the 1960s, has been most successful and now has the close ties with the industry merited by its location. Carleton, Western, Waterloo and Memorial have also been moderately successful. Others, such as nearby Regina, the francophone universities, the smaller Ontario universities, New Brunswick and the smaller Maritime universities remain terra incognita to most Calgary petroleum geologists.

The older universities that have maintained good relationships with the industry have generally depended heavily on one or two staff members. Thus, professors from McGill and Queen's make frequent visits to downtown Calgary offices, lead field trips and invite key petroleum people to workshops in central Canada. The newer schools that are establishing bridgeheads owe these to aggressive faculty members, generally with some background in the industry, who have persistently knocked on petroleum company doors to create awareness of their existence.

On the other side, there are many petroleum geoscientists who are actively interested in academia. An increasing number (if not a growing percentage) of petroleum geoscientists are joining national societies such as G.A.C. and C.G.U. where they are thrown into contact with academics and government scientists from all parts of the country. Just as the mineral exploration industry has a grand old man in the person of Duncan R.Derry of Toronto, so the petroleum industry has its sage in Andrew Baillie, who attempts to arouse colleagues' interest in teaching methods and the need to support university research (Baillie, 1979). When word of this present study was made known several petroleum geologists, including two past presidents of CSPG, sent the compilers copies of briefs and submissions which they had made concerning geoscience education in Alberta universities. We recommend that:

> *University departments should involve more mineral exploration and petroleum scientists, on a rotation basis, on advisory committees of many kinds. Benefits would accrue to both as each became more familiar with the others methods of operation and ultimate goals.*

Representatives from all three Calgary-based petroleum geoscience societies have played active roles in the Canadian Geoscience Council and have accomplished a great deal in getting large segments of the community to work together for common causes. The CSPG, in particular, has moved to reach beyond its original geographic confines. It stages an annual student field trip for nominees from geology departments across the country, it has cosponsored a symposium with the GAC, it sends distinguished guest lecturers on tours to universities across the country and it offers prizes for the best papers given at student meetings. It is also striving, rather less successfully, to hold meetings in a few centres across the country. As pointed out earlier in this chapter, we already have enough specialist activities underway in the country and now need vehicles to keep the various subdisciplines informed of each others activities. Rather than doing their own things, the Calgary societies might be well advised to work jointly with regional sections of GAC and CIM and also with CGU, MAC and other groups to sponsor meetings on topics of local interest, preferably on university campuses. The idea merits investigation by the societies concerned and by their umbrella organization, the Canadian Geoscience Council.

INTERFACES WITH THE PUBLIC

Community service is claimed to be a criterion for academic advancement by many university administrators. Some geology and geophysics professors who have attempted to develop interaction with one or another segment of the public claim that this isn't so in their department. They claim that, although there is some recognition of service to the scientific community by serving on executives or editing journals, involvement with secondary education, public exhibits and displays, writing popular articles and taking stands on community issues are seldom encouraged. According to them, strongly research-oriented department heads and senior professors are at best amused and at worst intolerant of efforts to publicize geoscience. Fortunately not all leaders adopt this attitude, some of our best known researchers from the days of William Logan to those of J. Tuzo Wilson have also been leaders in communication with many levels of society.

The importance of such communication has been put succinctly by Wynne-Edwards (1979): "The task of sharing the perspective of the earth sciences with a wider public is daily more urgent. Improving the level of public awareness is the first step of the decision-making process, as public perception ultimately molds political priorities and the decisions that will follow."

Following are some good examples of university contributions to public awareness and also some shortcomings which could be remedied if the right people could be convinced that it was worthwhile devoting some significant fraction of their time to informing the public of their own and their colleagues' work.

Secondary education

The Science Council report on national geoscience (Blais et al., 1971) devoted several pages to the shortcomings of both geoscience training in our high schools and the backgrounds of those who taught it. Many recommendations were made to geoscience societies, university professors and government agencies to improve the situation. Some commendable attempts to follow these have been made, particularly in refreshing and upgrading teachers qualifications.

One of the most promising attacks on the problem has come through the staging of sponsored workshops and field trips for high school teachers of geoscience. A series of these, held under the auspices of the Canadian Geoscience Council is co-ordinated by a professor from Western Ontario, the concept originating from a similar workshop which he organized at his own university with sponsorship of a major petroleum company. Roughly similar workshops grew up independently at Memorial, Saskatchewan, Acadia, Mount Allison, Manitoba, British Columbia and probably elsewhere. Some of these are now taking advantage of the pool of experience and funding available by operating under the Council's aegis.

A journal of geological education that grew and flourished through the co-operation of university, government and industry people in St. John's is now about to become a national journal for high school teachers under the sponsorship of the Geological Association of Canada. Professors at Laurentian who were putting together a careers booklet on geoscience have now been encouraged to expand it to fill a national need and the Geoscience Council has undertaken to publish it.

Professors are often called upon to give lectures in nearby high schools. Those from some of the smaller schools, e.g. Mount Allison, often travel widely to bring the word to rural high schools.

Improvement in high school geoscience is an important activity for which many university professors are particularly well-suited. It is an area where they can easily find sympathetic support from scientists in government and industry. Many more should be involved with it - marginal researchers who are gifted communicators would be performing a much more useful service by teaching the teachers of the young than by continually and painfully re-inventing the anticline. Department heads and deans should encourage involvement of those who could bring about improvements in secondary school geoscience education by rewarding achievements.

Exhibits and displays

A few large public museums in Canada devote ample space to geoscience collections, those in Toronto and Ottawa are best known. Where they exist, university departments are well advised to establish close links with them and to benefit from this incomparable way of communicating with a very interested segment of the public. Toronto provides such a good example of co-operation, Ottawa rather less so.

A few universities have museums on campus that are associated directly or indirectly with geology departments. The Redpath at McGill is undoubtedly the best known and most professionally managed of these but Waterloo, Laval, British Columbia and Saskatchewan, with much humbler exhibits, still attract a great deal of attention from school children and the general public. As an example, Saskatchewan, whose exhibits are in its shabbily housed geology department, opens it doors to the public every Sunday afternoon in the winter term. Faculty and graduate students volunteer their time to give lectures and show films. They attract approximately 3500 visitors per year, including 1200 who turn out for a special mineral and fossil identification event each fall on National Geoscience (Logan) Day. Laval's exhibits are scarcely better housed, show-cases lining the walls of a seeminly endless corridor. Nevertheless, the public seems grateful for the opportunity to visit these modest, well-maintained collections.

Almost every geology department visited had exhibits in their halls and reception areas. Some of these are very professionally done, e.g. at Memorial and Calgary. They seemed chiefly designed for the benefit of the casual passers-by, students and faculty from other departments, and occasional visitors. Many of these departments, by inexpensive upgrading of present exhibits and by rescuing collections from drawers and packing cases, could emulate the example of Saskatchewan, Laval and others by advertising and opening these exhibits to the public on a regular basis. Visiting museums and other natural history exhibits is a favourite form of Sunday outing, especially in the smaller centres. Department heads could profitably direct faculty members with imagination, artistic talent and interest in public contact towards educational displays. Exceptional performance in this sphere should be rewarded on an equal basis to research and teaching. We recommend that:

University departments of geology and geophysics upgrade their exhibits and displays (if necessary) and open them to the public on a regular basis, especially in winter term.

Rockhounds and amateur naturalists

Many professors across the country give their time (when asked) to lecture or lead field trips for natural history societies, rock and mineral clubs, youth groups and similar organizations. Our visiting committees did not encounter any examples of strong, permanent links between such amateur groups and geology or geophysics departments although such ties were common in the past. This is in contrast to many U.K. and U.S. universities where rockhound groups meet regularly on campuses with some professors and students always in attendance. Field naturalists and rockhounds seem to have closer ties with government scientists in Canada. This is another area where universities could play a larger role, possibly in conjunction with mini-museum activities, to their own and the local communities' advantages.

Public lectures

Over two decades ago, a very successful CBC radio series on geology by Professor David M. Baird attracted favourable editorial comment across the country and an enthusiastic response from listeners. Despite urgings to take further advantage of radio and television to communicate with the public (Blais et al., 1971) and despite the praiseworthy efforts of several individuals, we must conclude that our attempts in the last decade have hardly been commensurate with the excitement of new developments in our science or its growing importance to national well-being.

We have had a successful series of earth science lectures sponsored by Ontario Educational Television and most recently given by a professor from Laurentian University. There have been several national University of the Air series of three to five lectures each, and local programs have occasionally devoted one or more episodes to geoscience. Mainly, however, geologists and geophysicists are involved in one-shot interviews, usually on news programs, where they are asked to comment on some topical subject: an earthquake, a new oil play, an erupting volcano or a newly discovered Pleistocene marine mammal. Geoscience subjects are in the news a great deal these days so university professors are called on quite frequently for comment. They usually acquit themselves well on straight forward topics.

Geoscientists' views seem to be seldom called upon for broader subjects. Energy and environmental debates feature economists, politicians, engineers but seldom geologists (at least who are identified as such). Chemists, physicists, biologists and psychologists bare their souls nightly on both the present state and the future of the world. Geologists and geophysicists only appear when they survive an air crash or perform some feat of derring-do.

Popularization of science through radio and television has made enormous strides during the last decade chiefly through the efforts of David Suzuki, distinguished British Columbia geneticist. It is notable, however, that even on his well-balanced programs, the geosciences have lagged behind most sister sciences. Few geoscientists are called upon as his guest experts.

Public lectures by distinguished citizens in the great halls of universities usually attract a good deal of local and, sometimes, national attention. In recent years the ubiquitous Professor J. Tuzo Wilson together with a professor from Carleton and a former professor from British Columbia have thundered out important messages to the public from such platforms. But few geoscientists are given such opportunities - few relative to the present importance of our science.

Questioned on the lack of public exposure of the geosciences some professors expressed thinly veiled contempt for those who attempt to advertise their own or their departments' work beyond the realm of their peers. There is a feeling that work is suspect if it requires translation or broadcasting. Also, as one professor explained his departments' comparative isolation from the community: "There are no brownie points for this type of activity, they all go to research". These comments are sad and probably at least partly true. They apply also, however, to other sciences which seem to be rather more successful at public communication. One cannot escape the conclusion that geoscientists are more reticent and more fearful than other academics to explain themselves intelligibly, to take stands on important issues and to aggressively seek the opportunity to state their viewpoints rather than waiting humbly for the calls that never come. We suggest that:

University geoscientists should appreciate the importance of communicating with other scientists and with the public through the news media, books, and *public lectures. Department heads should encourage these with the requisite talents to devote some significant part of their time to such pursuits.*

Popular publications

Canadian geoscientists are well served by journals in which to publish their scientific contributions. They also have a fine magazine devoted to reviews and commentary that successfully bridges the many subdisciplines of geoscience. Their newsletters weld together a far flung community of scientists in a fairly close knit circle that is the envy of colleagues in other countries.

When it comes to writing for those beyond that circle, however, Canadian geoscientists fall far short of the marks made by sister sciences. The last books with wide appeal written by an academic geoscientist were Professor J.T. Wilson's accounts of science and life in the People's Republic of China during the International Geophysical Year, over two decades ago. Apart from Professor David M. Baird's book of annotated photographs of rocks and scenery in our national parks, no major work with public appeal has appeared since. The first attempt to remedy this, a volume on the importance of geoscience to the continuation of most aspects of life on this planet, by Professor H.R. Wynne-Edwards, is not scheduled for publication until 1981.

The popular interdisciplinary science magazines, such as Scientific American, seem to attract few contributions from Canadian geoscientists. Those magazines devoted to reviews and opinions on the whole gamut of science and science policy, such as Canada's own Science Forum have received only a handful of articles by Canadian academic geologists and geophysicists over the past decade.

Symptomatic of geoscientists' feelings towards popularization of science was the reaction to the Royal Society of Canada's proposal to establish the Bancroft Award for communication within the geosciences. Those opposed to it voiced many strange reasons, including the fear that only two or three in the country might merit it and once it had been awarded to them there would then be no more worthy candidates! The Society went ahead with its plans regardless and, fortunately, 10 years later is still finding worthy candidates. May the competition increase!

Policy debates

There are many topics where differing and vested interests of society members or society executive rule out any possibilities of group action or group comment. These are the occasions when individual professors must speak out for they are far less constrained by their employers and peers than are their counterparts from government and industry. A few do: Professor J. Tuzo Wilson has set a fine example to his colleagues on many occasions, addressing himself to political advisors and concerning himself with politics, economics and economic policy, and energy and energy policy. Professor F.K. North of Carleton University, with his outspoken views on impending oil and gas shortages, challenged the estimates produced by government and industry. He performed a major service by alerting thinking people to the differing methodologies and the assumptions that could be involved in resource estimation. There are others who could be mentioned but they are few indeed.

Geologists and geophysicists seem to act most effectively in herds whenever they have to leave their own subdisciplines. Alone, they are overcome by fears and uncertainties. Canada has a fine tradition of academic freedom so it cannot be fear of university reprisals. Fears that governments will cut off their grants or companies refuse to hire their students? Unlikely, Professor North's outspoken views didn't prevent Carleton students receiving high ratings from petroleum companies (Chapter 3). Maybe it is due to the fact that Canadian geoscience was dominated by government until 15 years ago and government employees were not encouraged to take controversial stands in public. Most likely of all is the possibility that academic geoscientists are generally more conservative and more timorous than colleagues in other academic spheres. Professors in at least two departments told visiting committees that the image of geoscience had suffered irreparably during the debates on oil resources and reserves in the 1970's. They felt that the public and politicians had lost all faith in scientists who were so far apart in their views on so fundamental a problem as future energy supplies.

As pointed out earlier, in the chapter on research, tolerance of dissent and critical evaluation of all contributions to knowledge are two basic principles of modern science. To quote again from Wynne-Edwards (1979): "Simply put, geoscientists increasingly are required to work on both sides of the street. Consider, for example, that we find uranium and simultaneously insist on far-sighted and geologically sound system for radioactive waste management, find petroleum and simultaneously illuminate the environmental consequences and risks of its extraction and transportation, find fertilizer and simultaneously monitor the effects on soils of intensive agriculture and on rivers of agriculture run off .... If the work is objective and soundly based, however, mutual understanding and respect for both viewpoints should develop. Geoscientists should be as free to cross the street for any given occasion as the lawyers are within their profession. A lawyer does not become labelled with the crimes or causes he is prosecuting or defending. Neither should the members of the geological profession."

Geoscientists have backgrounds that are more useful than those of most other disciplines in the exploration and exploitation as well as the stewardship and conservation of Earth's resources. They owe it to their countrymen to speak out objectively and unemotionally on the myriad of policy matters that concern the Earth. Canadian academia has provided some good examples of leaders who have publically challenged conventional wisdom in terrestrial management. There have been too few! We recommend that:

University geoscientists should appreciate the growing need for informed public commentary on matters concerning resources, the environment and other important issues confronting the nation. They should not flinch from debate with other geoscientists providing the subject is treated objectively. They should aggressively seek out opportunities for themselves and their colleagues to contribute geoscience viewpoints to some of the major issues of our day.

University administrators and department heads should recognize and reward major contributions to public information in the same manner that they presently recognize teaching, research and some favoured kinds of public service.

THE STATUS OF UNIVERSITY GEOSCIENCE

Despite our worries that university professors are not taking full advantage of all opportunities open to them to communicate with the proletariat, there is no doubt that the geosciences have become much more prominent in the public eye over the last 10 or 15 years. Moon rocks, BBC documentaries on our mobile earth and finally energy matters could not fail to make some impact on the subconscious of the man in the street. Mention of geology and geophysics, previously confined to western newspapers, now occasionally creeps into articles in Ontario and Quebec papers, and have become part of daily parlance in the east, particularly Newfoundland. Our visiting committees were anxious to find out how this increased awareness of the geosciences was reflected in the pecking order of the university sciences where, for most of this century including the 1950s, geology was considered the bottom rung on the ladder.

Recognition of Canadian research achievements in terms of international awards have been mentioned briefly in Chapter 5 and it was shown that geoscientists rate very well indeed relative to their colleagues in physics, mathematics, chemistry and other sciences. This was followed up by questioning academics and those who work closely with them at home and abroad. Some of their views on the status of their science follow.

Professors look at their science

The overall atmosphere from coast to coast is modestly positive and optimistic that the growing importance of the geosciences on the national and international scenes is slowly being appreciated on our campuses. Most give credit to the prolonged boom in industry and the resulting increase in students at a time of generally declining science enrolments. Others, particularly in some of the stronger, research-oriented departments, state that new respect from other scientists has come with their realization that the geosciences have passed the mainly descriptive stage. Geoscientists now use the same sophisticated tools and modelling techniques as their sister sciences in their development of intellectually exciting and potentially useful concepts.

Individual views within departments varied somewhat on the question of status, so also did the general feeling of entire departments. There was no regional pattern as might be expected, for example, from the prolonged economic boom in western Canada. Rather, academic group views on the status of their science seemed to be coloured almost wholly by local circumstances, with very few exceptions. At least three of the several departments that painted glowing pictures of present and future prospects in their professions were blessed with senior administrators who looked upon geology as the jewel among their sciences. The president of one university told visiting committee members that he had long looked upon geoscience as the discipline that could do most for his province and possibly for the country. Once the department showed that it was striving to reach its potential, it gained his full support. A regional group that was enthusiastic about the rising star of the geosciences was that of the small Atlantic universities. A respondent from one of these stated that "Material improvements have been accompanied by spiritual improvements. Geology students hold their heads much higher than a decade ago, they now rank among the professional elite on campus!"

Most departments were less euphoric. They stated that although their status was improving and their research had gained respect and their enrolments envy on campus, the old order changed slowly. In many cases, despite the highest undergraduate and graduate enrolments, and research that brought in the highest grants of any science department, they still worked with some of the lowest operating budgets on campus, as less active science departments continued to receive traditionally larger financial allotments. Demands for increased space and staff to take care of continually growing enrolments of majors and honours students fell on deaf ears.

Some groups of academics felt that the status of their science had not improved, in fact may have deteriorated in the past decade. These departments included one in the west, a few of the smaller Ontario universities, all of the francophone and one Maritime university. It is difficult to evaluate the francophone response because some of the departments concerned appear to have sympathetic administrators, adequate research monies and good reputations. Possibly the present climate of political uncertainty is a contributing factor. Some of the other departments are known to have internal problems or unsympathetic senior administrators or both. Two departments deserve special mention: Saskatoon and Carleton. Both are in well-established universities, both have respectable research records and both produce students who are highly rated by employers (see Chapter 3). Gloomy replies were not expected from these flourishing departments and undoubtedly reflect a lack of sympathy by senior administrators for their needs.

Three professors whose activities have made them familiar with a wide range of geoscience activities in and outside of the universities wrote as follows:

(1) "Canadian geology and geophysics is very good and in many subdisciplines is highly respected around the world. Possibly our forte is teamwork - joint projects involving people from several universities and from government and industry. We also do great things through our societies, working together on educational and representational matters. What we do lack are great virtuosos, conceptual leaders of world class. The few that we have are now so well known across the country that their rarity is emphasized!"

(2) "We are good in many fields and have earned great international respect in, for example: Precambrian geology, mineral deposit geology and some aspects of isotopic dating. We are sound - solid but could do much better. The average level and quality of faculty activity is as good as that in U.K. and U.S.A. - but we lack the final big push. Part of this is due to underfunding but part is due to lack of cooperation."

(3) The third professor rated Canada's performance in the ten subdisciplines in which he felt he had some knowledge:

"Canada has made an outstanding contribution, ranking first or second, in exploration geochemistry, exploration geophysics and mineral deposits geology..... The strong showing in exploration geophysics and geochemistry is due more to the innovativeness of certain companies than to industry or government.... The standing in mineral deposits comes partly from the tradition of this subject in Canadian departments and the fact that it was not allowed to decay in the 1960's and early 1970's as it did in so many other parts of the world."

The range of government scientists' views

Responses from government scientists were mixed but positive on the whole, suggesting that our universities rated well internationally and probably near the top for training and research in some disciplines. Most of their comments applied to teaching and research and have been extensively cited in previous chapters. A negative comment of one senior federal scientist was: "University geosciences in Canada are generally in a mediocre state with seemingly little or no coordination either with other universities or with federal or provincial surveys. Even within a given university, the impression is one of a buffet style approach to the geosciences." More typical of federal assessments was the statement "Judging from the capabilities of students we see, the recent graduates we encounter, and the continuing demand from overseas for training in exploration-related geoscience, Canadian universities are doing a competent job, much above world average. This is particularly true in exploration geophysics and geochemistry."

It is interesting to contrast this last viewpoint with that of a provincial agency which stated: "We do not have any departments or even any specializations with truly international reputations. For example, by now some geology department should have built up a reputation in exploration geology comparable to that of the Royal School of Mines. Also, we should be world leaders in exploration geophysics". Generally, provincial agencies were more negative about the status of geology and geophysics than any other single group - two stated that they had not noticed any change over the past decade. However, one which had been critical of university science in detail, concluded positively: "International repute of Canadian geoscience seems to be rising - whether this is the result of a better knowledge of it or the attention a few giants like Tuzo Wilson have brought to it, we are not sure... We feel that economic geology in Canada, both in and out of the universities, is held in high repute internationally...."

AS OTHERS SEE US

Leaders from around the world in one or more subdisciplines of the geosciences were not only asked their views on research in their fields (Chapter 5) but also to appraise the status of Canadian geoscience. Although some declined this invitation, many provided thoughtful commentaries. In reproducing a few representative comments, your compilers have endeavoured to keep them in context. Authors of these invited comments are only named where they specifically stated that they had no wish for anonymity. The excerpts commence with those which note weaknesses in the system and conclude with laudatory comments representative of most of the replies.

Constructive criticism

- "In a general way, I judge Canadian exploration efforts and teamwork to be of much higher average quality than U.S. efforts, but as stated earlier, many of the American efforts are likely to be far more sophisticated... having seen Canadian, European and U.S. academic earth science institutions, I am struck by the great difference in attitude. U.S. institutions were and still are despite severe funding restrictions in great ferment - ideas get tossed out, tested, thrown away or else elaborated. The U.S. academic community are always talking to each other while at the same time being very competitive. European institutions are sedate, conscious of the hierarchy and somewhat constipated while Canadian institutions fit somewhere in between but tend to lean to the European side. In the U.S. there is greater willingness to try out new concepts without debunking them a priori. Obviously, the taxpayer and his representatives are more willing to fund such efforts..... maybe one gets closer to a constructive perspective for Canada when looking at the price for all this marvelous intellectual ferment.... My impression is that teaching in Canada is more systematic and the standards higher, which can only be for the good of the profession. Canadian universities far more than U.S. universities adhere to Ortegay Gasset's basic concepts as institutions whose aim it is to transmit knowledge."

- An International Petroleum Geologist

- "While Canada remains world class in this field (mineral deposits), and in some disciplines of theoretical seismology related to exploration for oil, the level of general geoscience seems to be good rather than outstanding. Many university departments seem to be rather well equipped, but the intellectual spark or drive seems to be lacking. Perhaps it is an inevitable result of the funding structure, where small but steady funding encourages complacency and provincialism. It would be sad if this were so, and that the only ways to encourage high quality work involve human wastage and cruelty; like the frenetic competition that seems to characterise the U.S. system."

- A U.S. Professor of Marine Science

- "In general Canadian geoscience is very strong. This is of course natural considering the importance of basic resources to the national economy. A danger has been that too much university effort has been put into the direct application of geology to industry; though it is changing as older staff retire, too many staff spend their vacations consulting and give too little time to student field courses and to research. This may partly be due to the inadequate funding by industry for its own research centres, industry depending too much on part-time university staff for its research.... my complaint in the U.K. would be the exact opposite."

- Professor H.G. Reading, Oxford

- "... take any comments in the spirit they are intended, as a general admirer of Canadian geology, not a detractor.... There is a lot of contact between Canadian universities and industry.... However, my view is that it is at a rather unsophisticated level - the universities being asked to consult on a day to day basis or on detailed technical matters rather than tackling fundamental problems of ore genesis.... Many Canadian academics spend their summers in lucrative employment with mining companies. How much of the "know how" comes back into the universities? How much does industry support longer term research in universities? The Canadian mining industry is justly proud of its prospector tradition and the legend that academics never found a mine. Possibly truer than most of us admit, but not the best approach for the 1980's and beyond..."

- A geoscientist from Scandinavia

- "My overall impression of the efforts of the Canadian Earth Science community is one of great strength, particularly in the fields of petrology, economic geology, and exploration geophysics. Perhaps the only overall criticism I would have is that there are not enough multidisciplinary studies orchestrated to solve some of the larger-scale tectonic problems. I think this happens because the truly good earth scientists in your government agencies get caught up in scientific administration... Thus, you lack mature senior earth scientists who could organize and have insights on broader multidisciplinary studies."

- R.G. Coleman, U.S. Geological Survey

- "First, I recognize no outstanding difference in geoscience in Canada and USA. Both appear to be so similar and quite homogenized. The view from the inside may be quite different on this point. However, from outside they are so alike.

Therefore, if the geoscience in USA is first rate internationally, so should be the Canadian. I feel this more or less true. The only trouble is that you and USA are so close that it becomes difficult for you to identify yourselves.

...Among various disciplines, I have a feeling that Canada is very strong in exploration geophysics and geology. I have recently been much impressed by the work in mineral resources investigations in Canada ... If there is some field to be encouraged in Canada, that would be the more basic side of science. I may be wrong but I have a feeling that applied earth science is stronger than pure one in Canada."

- Seiya Uyeda, Earthquake Research Institute, Tokyo

Some lavish praise

- "Canada has always produced and employed scientists strong in the "field geology" and applied geology aspects of the subject. I do not mean that the trend toward more analysis and laboratory study has not occurred in Canada, for it certainly has. What I do mean is that it appears to me that a better balance between field and lab and between basic science and applied science has characterized Canadain geology than has been the case in the U.S.: thus Canada has remained in a secure balance which it appears to me that the U.S. is now moving toward an attempt to regain."

- U.S. biostratigrapher and global synthesizer

- "Canadian Geology is strongest in regional geology. .....one finds that the northern half of the North American story is a Canadian story. The entire post WW II opening up of the northern geology has been fantastic from a global point of view, and we owe Canada a great deal for this. The Tuzo Wilson geophysical stimulus has been globally most important. The search for ore deposits by means of geochemical and geophysical techniques of Canadian origin is first rate."

- Arthur Boucot, Oregon State University

- "I believe Canada has considerably more influence in the field of geophysics than could be expected from the population. Tuzo Wilson is presently the "grand old man" of geophysics internationally. Jack Jacobs holds the most prestigous chair of geophysics in the Commonwealth. Canada leads the world in mining geophysics. There is scarcely a field in geophysics in which Canada is not well represented, and the quality of Canadian contribution has been uniformly high. Textbooks written by Canadians have become standards in geophysics... In brief, geophysics in Canada has been first rate."

- J.C. Savage, U.S. Geological Survey

- "With respect to the geosciences generally...Canada ranks among the best nations in its commitment and popular understanding of these fields. In a country that was so thoroughly glaciated, or at least glacierized, and so recently too, it is perhaps inevitable that much geoscience effort has been devoted to glacial geomorphology, Quaternary geology, and related pedogenic, hydrologic, and engineering implications. In the understanding of the use and misuse of glacial and periglacial environments, their problems and potentials, Canadian geoscientists are among the world's leaders and compare on a one to one basis more than favourably with similar scientists in Scandinavia and the Soviet Union."

- A.R. Orme, Dean of Social Sciences, U.C.L.A., U.S.A.

- "...my personal view of today's leaders in geoscience: the U.S., Canada, S. Africa, U.K., France, and Australia. There can be no doubt that the most significant new ideas in the geological sciences have come from North America in recent years. Canadian geoscience appears, from the outside, to be particularly well organized..... there seems to be more communication between geoscientists of the various subdisciplines in Canada than there is in most other countries."

- Professor Eugen Stumpfl, Mining University, Austria

- "For both the geologists and the publications I have the highest regard, and I have always felt that you are among the leaders in the field, not only in North America, but in the world at large. This applies especially to my own field of interest in tectonics, but it also carries over into other fields... In short, my impression has been that my Canadian counterparts were thinking in much the same terms as we in the States, and that they were even ahead of us in many ways, so that we have much to learn from them."

- Philip B. King, U.S. Geological Survey

- "... impact of Canadian geoscience on the international scale - I can honestly say that Canada holds a top rank. The scientific work done both at the universities and at the Geological Survey appear to be of quite excellent quality. Precambrian geology, radiometric age dating, Paleozoic and Mesozoic paleontology and biostratigraphy look to Canada for leadership in their particular fields...Seen from the outside, the geoscience community of Canada appears to be very healthy and productive. The danger of provincialism, which is always a menace in countries of "intermediate" population size, seems to have been successfully avoided."

- Professor R. Trumpy, Zurich, Switzerland

SUMMARY AND CONCLUSIONS

Canadian university geoscience has established a fine reputation around the world for its research activities, training of students, integration with other elements of the geoscience community and also for some of its activities in the public domain, generally those carried out under the auspices of the learned societies. The fact that geoscience is now more in the news than at any other time in this century, however, is more an accident of resource economics than a reflection on the accomplishments of geoscientists. Canadian geoscientists, skilled in communicating within their own ranks, have rather failed in conveying some sense of the importance of their work to a wider community - and most of the blame for this must lie with academics, the principal communicators of science in our society.

Most of those who praised the overall Canadian research activities singled out the more pragmatic aspects: regional synthesis, mineral deposits studies, and the several subdisciplines of geology and geophysics that relate directly or indirectly to exploration and environmental concerns. In most cases team approaches to problems were praised, although there were some dissenters on this point. Some praise, however, was qualified by distinguished scientists, both at home and abroad, who felt that although they were highly competent in many aspects of geoscience, Canadians all too rarely achieved excellence. In view of the honours Canadian geoscientists have received abroad relative to most sister sciences, this statement, if true, must apply equally to the whole of Canadian science. More vigorous competition and large sums of money to finance single bold and innovative projects were the missing ingredients according to these assessors.

Even if one agrees that excellence is too rare, one must conclude that the nation is well served by its university departments of geology and geophysics. Graduates from these departments have become the leaders of our flourishing resource industries. Now that they stay at home for their post-graduate studies, scientists from abroad write to say how much our lively, well-prepared students are missed. Academics and their graduate students have worked both independently and together with scientists from government and industry on field studies and regional syntheses. These have provided us with good maps and sound interpretations of both the parts and the whole of the country. Canada is far ahead in these regards of other countries which might outpace it in conceptual advances. New concepts can be assimilated by those who work just short of the cutting edge of science, but a solid data base can only be obtained by seeing and touching, testing and understanding. Canadian academics have served their science and their country well by their contributions to the geoscience data base.

Geologists and geophysicists unfortunately have not taken advantage of the prominence thrust upon them in the last few years by a scientific revolution and resource shortages to break down the communication barriers with other scientists and a wide segment of the public. Their contacts through exhibits, natural history groups, popular writing and the news media remain minimal. They do not aggressively seek out opportunities to comment on issues of public concern. When they do these things and their light finally appears at the end of the lava tunnel, government mandarins, politicians and senior university administrators might more fully realize that shifts are required in the traditional ordering of science grants and budgets. Then, possibly, some of the large sums apparently required to produce excellence will magically appear. Those who strive to bring this about must be recognized (or at least tolerated) for their efforts, because they will not necessarily be the same people who reap the rewards!

APPENDIX 2 A

UNIVERSITIES FROM WHICH ACADEMIC GEOLOGISTS AND GEOPHYSICISTS RECEIVED THEIR DOCTORATE DEGREES

GEOLOGISTS

Canadian Universities

1.	Alberta	6
2.	British Columbia	6
3.	Carleton	1
4.	Dalhousie	2
5.	Ecole Polytechnique	1
6.	Laval	5
7.	Manitoba	2
8.	McGill	28
9.	McMaster	12
10.	Memorial	2
11.	Montreal	2
12.	New Brunswick	2
13.	Ottawa	2
14.	Toronto	18
15.	Waterloo	1
16.	Western Ontario	7
	TOTAL	97 (27.2%)

United States Universities

1.	Brown	3
2.	California at Berkley	12
3.	California at Davis	1
4.	California at Los Angeles	2
5.	California Inst. of Tech.	3
6.	Chicago	5
7.	Cincinnati	2
8.	Colorado	2
9.	Columbia	5
10.	Connecticut	1
11.	Cornell	2
12.	Harvard	4
13.	Illinois	7
14.	Indiana	2
15.	John's Hopkins	4
16.	Kansas	3
17.	Massachusetts Inst. Tech.	13
18.	Michigan	5
19.	Michigan State	1
20.	Minnesota	2
21.	New York University	1
22.	Northwestern	2
23.	Oklahoma	1
24.	Pennsylvania	1
25.	Pennsylvania State	1
26.	Pittsburgh	1
27.	Princeton	15
28.	Purdue	2
29.	Rennselar Polytechnique	1
30.	Southern California	1
31.	Stanford	6
32.	Suny (Binghampton)	2
33.	Washington	2
34.	Western Reserve	1
35.	Wisconsin	3
36.	Yale	8
	TOTAL	130 (36.5 %)

United Kingdom Universities

1.	Aberdeen	1
2.	Birmingham	2
3.	Cambridge	11
4.	Durham	2
5.	Edinburgh	7
6.	Glasgow	6
7.	Leeds	1
8.	Leicester	1
9.	Liverpool	7
10.	London	18
11.	Manchester	9
12.	Newcastle	2
13.	Nottingham	1
14.	Oxford	5
15.	Queens (Belfast)	1
16.	Reading	6
17.	Sheffield	1
18.	Southampton	1
19.	Wales	5
	TOTAL	87 (24.5%)

Other World Universities

1.	Adelaide (Australia)	1
2.	Australian National Univ.	8
3.	Bordeaux (France)	1
4.	Brussels (Belgium)	1
5.	Capetown (South Africa)	1
6.	Cleremont-Ferrand (France)	1
7.	Charles (Czechoslovakia)	2
8.	Copenhagen (Denmark)	1
9.	Geneva (Switzerland)	1
10.	Innsbruch (Austria)	1
11.	Jladalpur (India)	1
12.	Krakow (Poland)	1
13.	Latvia	1
14.	Leiden (Netherlands)	1
15.	Lund (Sweden)	1
16.	Munich (West Germany)	2
17.	Neuchatel (Switzerland)	1
18.	New South Wales (Australia)	1
19.	Otago (New Zealand)	2
20.	Paris (France)	1
21.	Parma (Italy)	1
22.	Queensland (Australia)	1
23.	Stuttgart (West Germany)	2
24.	Toulouse (France)	2
25.	Trinity (Ireland)	1
26.	Tubingen (West Germany)	2
27.	West Berlin (W. Germany)	1
28.	Witswaterand (S. Africa)	1
29.	Zurich (Switzerland)	2
	TOTAL	42 (11.8%)

SUMMARY OF GEOLOGY PROFESSORS

Ph.D.'s from Canadian Univ.	97
Ph.D.'s from U.S.A. Univ.	130
Ph.D.'s from U.K. Univ.	87
Ph.D.'s from elsewhere	42
TOTAL	356

Geologists without Ph.D. degree: 14

GEOPHYSICISTS

Canadian Universities

1.	Alberta	4
2.	British Columbia	12
3.	Dalhousie	1
4.	Laval	1
5.	Manitoba	2
6.	McGill	5
7.	McMaster	1
8.	Saskatchewan	3
9.	Toronto	15
10.	Western Ontario	

United States Universities

1.	California at Berkley	2	
2.	California at L.A.	1	
3.	California at San Diego	1	
4.	California Inst. of Tech.	1	
5.	Mass. Institute of Tech.	2	
6.	Princeton	2	
7.	Saint Louis	1	
8.	Utah	3	
	TOTAL	13	(17%)

United Kingdom and other non-North American

1.	Adelaide (New Zealand)	1	
2.	Australian National	2	
3.	Cambridge (U.K.)	4	
4.	Charles (Czechoslovakia)	1	
5.	Cologne (West Germany)	1	
6.	Leeds (U.K.)	2	
7.	London (U.K.)	2	
8.	Oxford (U.K.)	1	
9.	Tohoku (Japan)	1	
10.	Utrecht (Holland)	1	
11.	Witswaterand (South Africa	1	
	TOTAL	17	(22%)

SUMMARY OF GEOPHYSICS PROFESSORS

Ph.D.'s from Canadian Univ.	47
Ph.D.'s from U.S. Univ.	13
Ph.D.'s from United Kingdom and other non-North American Univ.	17
TOTAL	17

FOOTNOTES

1. Total number of geologists and geophysicists employed by Canadian universities: 464.
   Total number of geologists and geophysicists accounted for in this table: 433.
   Information was not available on 31 or approximately 6.7%.

2. The doctorate degrees do not accurately represent the number of Canadians on the staffs as prior to the 1970's many Canadian graduates went to the U.S.A., U.K., and Australia for their doctorate degrees. Listed below are two representative groups of universities indicating where the staff obtained their first and final degree.
   a) Three western universities, British Columbia, Calgary and Saskatchewan

Total staffs	57
Bachelor's degree	
Canadian	26
U.S.A.	13
U.K.	10
Elsewhere	8
Doctorate degree	
	14
	27
	9
	7

3. The great majority of professors hired from outside of Canada are now Canadian citizens.

4. To demonstrate the cosmopolitan training of our staffs, contrast with the 7 campuses of the University of California with an academic staff of 187, only 25 obtained their doctorates outside the U.S.A.

APPENDIX 2 B

MAJOR EQUIPMENT IN THREE DEPARTMENTS

ALBERTA, 1979

a) Research Equipment

Mass spectrometers MS10, MM6, MM30B and home-built 6-inch machine. Access to 7 other mass spectrometers which are used on a shared basis.
Argon fusion system
Rb, Sr, U and Pb SMD laboratories.

ARL EMX Microprobe
ARL SEMQ Microprobe
Various electronic testing equipment

2 X-ray diffraction units
2 Manual XRF units
1 Philips Pailred single crystal diffractometer
2 Gamma ray spectrometers

1 Sieve shaker and ultrasonic sieve
1 Rock splitter
4 Rock saws
2 Jaw crushers
4 Rock grinders
2 Thin section grinders
4 Rock polishers
3 Swing mills
1 Wilfley table
2 Frantz separators

1 30 kilobar press
1 5 kilobar internally heated pressure vessels
6 cold seal bonds
Several 1 atomosphere furances and all appropriate pressure controlled equipment

Fully equipped chemical analytical laboratory capable of doing ultra-clean analytical work
2 Beckman ASS units
2 Perkin Elmer ASS units
1 Perkin Elmer flame photometer

93 Stereo microscopes
66 Reflective light microscopes
57 Polaroid microscopes
Microscopes include 3 Zeiss Universal Vickers hardness testing equipment, heating and freezing fluid inclusion stages with television screen

5 Drafting tables
1 Theodolite light
2 Stereo plotters
2 Microfilm readers
10 Electric typewriters
Numerous programmable calculators
5 Terminals including graphics display unit
10 Cameras
3 Polaroid cameras
1 16 mm camera
2 Enlargers
1 Photographic dryer
Floodlight unit
Magnetometer
1 Soil moisture meter
1 Water current meter
1 Water level recorder
2 Seismometers
1 Mobile auger
1 GSC sample drill
3 Trail bikes
3 Inflatable boats
2 Canoes
4 Outboard motors
1 Trailer

Question

(b) Do you charge time on any of this equipment against research grants? No.

Question

(c) Do you charge outsiders for the use of it? Yes.

Institute of Earth and Planetary Physics
University of Alberta, November, 1978

1. Mass spectrometers

Unit	Manufacturer	Funding	Replacement Cost	Status	Use
M.S 1	In Dept of Physics	U. of A.	*$75,000	Under construction	C,O
M.S 2	"	$25,000 NRC CAP (Cumming)	*$75,000	Recently upgraded	Rb (Sr)
M.S 3	"	NRC $25,000 (Krouse)	*$75,000	Obsolete	C,O
M.S 4	"	NRC CAP (Cumming) $25K	*$75,000	Being rebuilt	U,Pb
MM30	V.G. Micromass	NRC CAP (Lambert) $142K	$142,000	2 yr. old	U,Pb Sr
MM602D	"	$32K	$32K	2 yr. old	H/D

*In-house rebuilding costs.

2. Seismology

(1) SEISMIC DATA LINK (Funding U. of A.)

This is situated in the Edmonton (EDM) Observatory (U. of A. property) and contains Energy, Mines and Resources Seismic Analog Earthquake recording system with 3 long period and 3 short period instruments. The telemetry and digital recording system is University capital equipment. This includes Analog to Digital converter, multiplexer, amplifiers, 2 radio repeaters (RCA-54A), 6 helicorders, a PDP 11/20 computer with 28,000 word memory, 2 magnetic tape formats, 5 tape driver. Mixed age but all parts good for about 3 years.

Value ~$200,000

(2) TRIPARTITE SEISMIC ARRAY SYSTEM (Funding NRC-negotiated development grant)
(Earthquake recording)
9 Systems - Recording system 5-7 years old, nearly obsolete; seismometers and trailers still useful.
New Value ~45,000
(but now obsolete except seismo-meters etc. ($15,000)

(3) PEACE RIVER SEISMIC ARRAY SYSTEM (NRC Funding)
Obsolete Value when new ~20,000
Above items (2) and (3) being replaced by

(4) SEISMIC TELEMETRY SYSTEM - 3 stations (Earthquakes)
(Funding NRC and U. of A.) ~30,000

(5) EVENT DETECTING SYSTEM - 20 stations
(Funding NRCO ~30,000
(Items (3) and (4) have been purchased and are being built now.

(6) SEISMIC CRUSTAL REFLECTION RECORDERS
(Funding U.S. Air Force)
(Obsolete but can be used with much maintenance).
Parts of this are 7 to 15 year sold. (Part of U.S. Air Force grant for crustal studies).
Old Cost ~50,000

(7) TEST EQUIPMENT (Funding U. of A.)
Tectronix oscilloscopes, function generators, meters, etc. Value (fairly new) 15,000

(8) FIVE TERMINALS for access to University computer and playback of field tapes
Value (fairly new) 15,000
(Funding U. of A. and NRC)

(9) GEODETIC SURVEY EQUIPMENT
Value (new) 12,000
(Funding U. of A.)

3. Magnetometer arrays

No.	Unit	Manufacturer	Funding	Replacement Cost	Status	Use
25	Gough-Reitzel magneto-meter	In Dept. of Physics	U. of A. + NRC operating + $6,000 capital	$75,000	Serviceable, being upgraded	Magnetometer arrays
8	As above	As above NRC operating	U. of A. +	$24,000	Under construc-tion	As above

4. Paleomagnetism and Rock Magnetism

No.	Unit	Manufacturer	Funding	Replacement Cost	Status	Use
	Magneti-cally shielded room	In Dept of Physics	NRC capital + U. of A.	$30,000	Operational	Thermal demagnetiza-tion of paleomagnetic specimens; field-free storage
	Crygenic magneto-meter	Superconducting Technology Inc. California	Alberta/Canada ERRF	$33,000	On order	Cretaceous magneto-stratigraphy
	Spinner magneto-meter 1	Digico, England	NRC capital +U. of A.	$35,000	Operational	General paleomagnetic measurements; low and high temperature investigations
	Spinner magneto-meter 2	Schonstedt	U. of A.	$20,000	Operational	General purpose; good for fragile specimens
	Spinner magneto-meter 3	P.A.R.	$9,000 in 1966 U. of A.	—	Operational (but tends to be held in reserve)	General purpose measurements
	Aniso-tropy of suscep-tibility magneto-meter	Dept. of Physics	U. of a. + NRC opetating	$25,000	Operational	rock fabric studies
	High tem-perature vibrating sample magneto-meter	Dept. of Physics	U. of A. + NRC operating	$40,000	Operational	Room and high temperature measure-ments of magnetiza-tion

Major Equipment, Department of Geological Sciences, U.B.C.

Equipment	Purpose type of research	How financed	Date purchased	Replacement value	Maintenance cost per year	Life expectancy	Breakdown time per year
Microprobe		Special grant	1975	$200,000	$4,000	20 yr?	20 weeks
Mass Spectrometer	Isotope	Special grant	1973	$200,000	$800	20 yr	1 week
X-ray Fluorescence		Special grant	1976	$80,000	$800	20 yr	2 weeks
X-ray Diffractometer		Department funds and special grant		$90,000	$800	20 yr	2 weeks
X-ray Spectrometer		Grant	1976	$80,000	$800	20 yr	2 weeks
Ultraphot	Optical	Department funds and grant	1968	$25,000	$300	15 yr	5-10 days
Ultraphot	Optical	Grant	1969	$20,000	$50	15 yr	--
Lathe	Research equip. manufacture	Department funds	1978	$18,000	$100	30 yr	2-10 days
Maho Milling Machine	Research equip. manufacture	Department funds and grants	1970	$22,000	$100	25 yr	1 week
Truck	Field Trips/Field Work/ Runabout	Department funds	1978	$13,000	$500	10 yr	1 week
Press (HJG)	Experimental petrology	NRC	1976-8	$15,000	$1000	10 yr	2 weeks
Press (JVR)	Experimental deformation	NRC	1970	$15,000	$1000	10 yr	2 weeks

1. Charging of operating costs of microprobe, XRF, XRD equipment to users inside and outside the University.

Discussion centred around the need to defray operating and maintenance costs, and the need to charge outside users enough so as not to compete unfairly with any available commercial supplier of the same or similar service. After considerable discussion, the following rates were agreed upon.

XRD	Departmental users	$ 3.00 per hour, diffractometer $ 5.00 per run, powder cameras
	Non-U.B.C. users (contracts, etc)	$20.00 per hour, or $10.00 per diffractometer chart plus film costs
XRF	Departmental users	$ 3.00 per hour
	Non-U.B.C. users	$20.00 per hour, user supplies materials and manpower
SEMO		Departmental users
	Normal working hours	$20.00 per hour (help available)
	Weekends, nights	$10.00 per hour (permission required)
	Undergrad theses	3 hours free, with supervisor's permission
	Non-U.B.C. users	$50.00 per hour, plus film costs

Definition: A non-U.B.C. user is any person, including students, staff, and faculty of U.B.C. who uses instruments to provide results for a person or group outside of the University.

Billing: The user will be billed by the Department for the time used at the above rates. if the user is acting as agent for someone else then that user can collect the amount due privately but it is the user who is financially responsible for the bill.

Under present arrangements, Mary Malcolm will handle invoicing, collecting, and deposit of payment in the proper account.

Cheques may be made payable to the University of British Columbia, and mailed or given to Mary Malcolm.

Accounting of chargeable time used will be attended to by G. Georgakopalous.

2. Charging rates for Departmental services (E. Montgomery)

Trucks - 20¢ per mile
Thin sections - $3.75

APPENDIX 3A

VARIETY OF FIRST DEGREES IN GEOLOGY AND GEOPHYSICS
GRANTED AT CANADIAN UNIVERSITIES

	University and Departments	Undergraduate Degrees in Geology and Geophysics	Duration (in years)
(1)	Acadia:		
	Wolfville, N.S.	B.Sc. (pass) and B.A. (pass) in geology	4
	Geology	B.Sc. and B.A. honours in geology	4
		B.Sc. (specialized) in geology	4
(2)	Alberta:		
	Geology, Physics,	B.Sc. honours and specialization in geology	4
	and Zoology	B.Sc. honours and specialization in geophysics	4
		B.Sc. concentration in geology	3
		B.Sc. honours and specialization in geology and geophysical	4
		B.Sc. honours and specialization in geophysics in geophysics	4
(3)	Brandon:		
	Brandon, Manitoba	B.Sc. major in geology	3
	Geology	B.Sc. specialist in geology	4
(4)	British Columbia:		
	Vancouver, B.C.	B.Sc. major in geology	4
	Geological Sciences,	B.Sc. major in geophysics	4
	Geophysics and Astronomy	B.Sc. honours in geology	4
	Geography	B.Sc. honours in geology and geography	4
		B.Sc. honours in physics and geophysics	4
		B.Sc. honours in physics and geophysics	4
		B.Sc. honours in geology and geophysics	4
(6)	Calgary:		
	Calgary, Alberta	B.Sc. major in geology	4
	Geology	B.Sc. honours in geology	4
	and Geophysics	B.Sc. major in geophysics	4
		B.Sc. honours in geophysics	4
(7)	Carleton:		
	Ottawa, Ont.	B.Sc. major in geology	4
	Geology, Chemistry	B.Sc. honours in geology	4
	and Physics	B.Sc. honours in biology and geology	4
		B.Sc. honours in chemistry and geology	4
		B.Sc. honours in geology and physics	4
(8)	Concordia:		
	Montréal, Québec	B.Sc. major in geology	3
	Geology	B.Sc. honours in geology	3
	(Note: admission to all Quebec universities for Québec students follows graduation from CEGEP. The CEGEP's have replaced the old first year university programs.)		
(9)	Dalhousie:		
	Halifax, N.S.	B.Sc. major in geology	4
	Geology	B.Sc. honours in geology	4
(10)	École, Polytechnique:		
	Montréal, Québec		
	Dept. de Génie Minéral	B.Sc. A. en genie geologique	4
(11)	Guelph:		
	Guelph, Ontario	B.Sc. general program in earth science	3
	Land Resource Science	B.Sc. honours program in earth science	4
(12)	Lakehead:		
	Thunder Bay, Ontario	B.Sc. general program in geology	4
	Geology	B.Sc. honours program in geology	4
(13)	Laurentian:		
	Sudbury, Ontario	B.Sc. general program in geology	3
	Geology, Chemistry and	B.Sc. honours program in geology	4
	Physics	B.Sc. honours in chemistry and geology	4
		B.Sc. honours in physics and geology	4

University and Departments		Undergraduate Degrees in Geology and Geophysics	Duration (in years)
(14)	Laval:		
	Québec City, Québec	B.Sc. en géologie	3
	Géologie	B.Sc. A. en genie géologique	4
(15)	Manitoba:		
	Winnipeg, Manitoba	B.Sc. general earth sciences	3
	Earth	B.Sc. earth sciences major	4
	Sciences	B.Sc. honours geology option	4
		B.Sc. honours research option	
		B.Sc. honours geophysics option includes geophysics exploration earth physics options	4
		B.Sc. in engineering geological engineering	4
(16)	McGill:		
	Montréal, Québec	B.Sc. major in geological sciences	3
	Geological Sciences and	B.Sc. honours in geological sciences	3
	Mining Engineering	B.Sc. honours in solid earth geophysics	3
(17)	McMaster:		
	Hamilton, Ontario	B.Sc. pass geology	3
	Geology, Chemistry	B.Sc. major geology	4
	and Geography	B.Sc. honours geology	4
		B.Sc. honours chemistry and geology	4
		B.Sc. honours geography and geology	4
(18)	Memorial:		
	St. John's, Nfld.	B.Sc. general in geology	4
	Geology, Physics	B.Sc. honours in geology	5
	and Biology	B.Sc. major in geology and geophysics	5
		B.Sc. honours in geology and geophysics	5
		B.Sc. honours in geology and biology	5
		B.Sc. major in geophysics	4
		B.Sc. honours in geophysics	5
(19)	Université de Montreal:		
	Montréal, Québec		
	Géologie	B.Sc. specialisé en géologie	3
(20)	Mount Allison:		
	Sackville, N.B.	B.Sc. major in geology	3 or 4
	Geology	B.Sc. honours in geology	4
(21)	New Brunswick:		
	Geology	B.Sc. major in geology	4
		B.Sc. honours in geology	4
(22)	Ottawa:		
	Ottawa, Ontario	B.Sc. major in geology	4
	Geology	B.Sc. honours in geology	4 or 5
(23)	Université de Québec:		
	Chicoutimi, Québec		
	Chicoutime	B.Sc. A. en genie géologique	4
	Sc. appliquees, Module des Sciences de la terre		
(24)	Universite de Québec:		
	Montréal, Québec	B.Sc. en géologie	3
	Sciences de la terre		
(25)	Queen's:		
	Kingston, Ontario	B.Sc. major in geological science	3
	Geological Sciences,	B.Sc. honours in geological sciences	4
	Chemistry and Physics	B.Sc. honours in geological sciences	4
		B.Sc. honours in geological sciences	4

University and Departments		Undergraduate Degrees in Geology and Geophysics	Duration (in years)
		B.Sc. honours, major concentration in geological sciences	4
		B.Sc. honours, major concentration in geological sciences and chemistry	4
		B.Sc. in geological engineering	4
		option 1 mineral resources exploration	
		option 2 engineering geology, environmental engineering	
		option 3 applied geophysics	
(26)	Regina:		
	Regina, Saskatchewan	B.A. major in geology	3
	Geological Sciences,	B.Sc. major in geology	3
	Chemistry and Physics	B.A. honours in geology	4
		B.Sc. honours in geology	4
		B.Sc. major in applied geophysics	4
		B.Sc. major in chemical geology	3
		B.Sc. honours in chemical geology	4
(27)	Royal Roads Military College:		
	Esquimalt, B.C.	B.Sc. honours in marine geophysics	4
	Physics	B.Sc. general program in marine geophysics	4
(28)	Saskatchewan:		
	Saskatoon, Saskatchewan	B.Sc. general major in geology	3
	Geological Sciences	B.Sc. advanced major in geology	4
		B.Sc. honours in geology	4
		B.Sc. honours in geophysics	4
		B.Sc. advanced major in geophysics	4
		B.E. geological engineering	4
		B.E. geological engineering (geophysics option)	4
		B.E. = bachelor of science in engineering)	
(29)	St. Francis Xavier:		
	Antigonish, N.S.	B.Sc. general in geology	4
	Geology	B.Sc. major in geology	4
		B.Sc. honours in geology	4
(30)	St. Mary's:		
	Halifax, N.S.	B.Sc. major (pass) in geology	4
	Geology	B.Sc. honours in geology	4
(31)	Toronto:		
	Geology	B.Sc. general major in geology	3
	Biology	B.Sc. specialist major in geology	4
	Chemistry and Physics	B.Sc. specialist major in palaeontology	4
	Physics	B.Sc. specialist major in chemistry and geology	4
	Civil Engineering,	B.Sc. specialist major in geology and physics	4
	Metallurgy, and Material Science	B.A.Sc. geological engineering and applied science	4
		(a) mineral exploration option.	
		(b) mineral engineering option.	
		(c) geotechnical engineering option.	
(32)	Victoria:		
	Victoria, B.C.	B.Sc. general program in physics	4
		B.Sc. major in physics	4
		B.Sc. honours in physics	4
		Co-op program available	4
		All above have electives in geophysics	
(33)	Waterloo:		
	Waterloo, Ontario	B.Sc. honours in earth sciences	4
	Earth sciences	B.Sc. honours in earth sciences Co-op program	5
		B.Sc. honours in science, earth sciences major	4
		B.Sc. major in earth sciences	3 or 4
		The Co-op program has two options namely geology option and geotechnical option	

	University and Departments	Undergraduate Degrees in Geology and Geophysics	Duration (in years)
(34)	Western:		
	London, Ontario	B.A. concentration in geology	3
	Geology, Geophysics and	B.Sc. general program in geology	3
	Chemistry	B.Sc. general program in chemistry and geology	3
		B.Sc. honours in geology	4
		B.Sc. general program in geophysics	3
		B.Sc. honours in geophysics	4
		(a) physical option	
		(b) geological option	
(35)	Windsor:		
	Windsor, Ontario	B.Sc. general program in geology	3
	Geology, Biology and	B.Sc. honours in geology	4
	Geography	B.Sc. honours in geology and biology	4
		B.Sc. honours in geology and geography	4
		B.A.Sc. in geological engineering	4
(36)	York:		
	Downsview, Ontario	B.Sc. specialized honours in earth sciences	4
	Earth and Environmental	B.Sc. honours in earth science and	
	Science Program	environmental science	4
		B.Sc. honours in physics and earth science	4
		B.Sc. honours in applied computational and	
		mathematical science and earth science	4

APPENDIX 3 B

TYPICAL CURRICULA FOR TWO UNDERGRADUATE ENGINEERING OPTIONS

Queen's University Mineral Resources Option	University of British Columbia Mineral Exploration (Mining Option)
2nd year	
Physical Chemistry Analytical Chemistry Strength of Materials Descriptive Geometry Crystallography Mineralogy & Petrology Earth History, Time & Stratigraphy Physics of the Earth Chemistry of the Earth Differential Equations Probability & Applied Statistics	Technology and Scoeity Mechanics of Solids Materials Science Fluid Mechanics Plane Surveying Introd. to Computers and Programming Introd. to Mineralogy and Petrology Stratigraphy and Structure Sedimentology Elem. Statistics Differential Equations ii Series and approximation Methods
3rd year	
Principles of Economics Applied Plane Surveying Soil Mechanics Field Methods Structural Geology 1 Opticla Mineralogy and Petrology Groundwater Hydrology Fossil Fuels Rock Properties 1 Elements of Mineral Engineering	Engineering Communication Effective Technical Reporting Structural Geology Sedimentation Introductory Field School Mineral Resources & Exploration Energy & Water Resources Introduction to Petrology Terrain Analysis Ore Petrology
INTRODUCTION TO GEOLOGY AND GEOPHYSICS	
3rd year	
	Hydrogeology Introduction to Mining
4th year	
Professional Engineering Practice Thesis Mineral Deposits Sulfide Mineralogy and Mineralography Petrology Field Geology Applied Physics of the Earth Introduction to Valuation Introduction to Rock Mechanics and electives	Senior Field School Geological Engineering Thesis Introduction to Applied Geophysics Metallogeny and Mineral Exploration Geochemistry of Ore Deposits and Mineral Exploration Exploration Geochemistry Mine Valuation and Finance Economics of the Mineral Industry and electives

APPENDIX 3C

QUESTIONNAIRE AND SUMMARY OF RESPONSES TO A QUESTIONNAIRE SENT TO MINERAL EXPLORATION AND MINING COMPANIES

Questionnaire

Dear Sir,

The Canadian Geoscience Council has set up a committee under the chairmanship of Dr. John E. Armstrong to do a study of the Status of Geoscience in Canadian Universities. Important aspects of that study include an assessment of career preparedness of recent and current graduates, an assessment of whether appropriate numbers of students are graduating in various subdisciplines, and a review of research emphasis and the degree of research collaboration between individual faculty members and others. The enclosed questionnaire is intended to obtain opinions on these and related topics from people in industry who employ and supervise geoscientists. I would much appreciate it if you would return it to me after completion by the member or member of your staff most directly concerned with the hiring and evaluating of geoscientists and with industry – university research and research co-operation. Additional copies of the questionnaire are available on request.

Yours truly,

P.L. Money
Chief Geologist
Canadian Exploration,
Texasgulf Inc.

CANADIAN GEOSCIENCE COUNCIL
STUDY OF THE STATUS OF GEOSCIENCE IN CANADIAN UNIVERSITIES
QUESTIONNAIRE FOR INDUSTRY (EXCLUSIVE OF OIL AND GAS)

1. Company

2. Division and/or Department

3. Names(s) and title(s) of staff members completing questionnaire

4. Main function(s) of geoscientists in division and/or department

   Mine geology – metals
   – non-metallic except coal
   – coal
   Exploration – metals
   – non-metallic except coal
   – coal
   Other(s) (specify)

5. Commodities and/or deposit types of major interest

6. Number of geoscientists on permanent staff with university or equivalent training

Academic Level

	B.A.Sc. or other Engineering degree	B.Sc or other Non-engineering degree	M.A.Sc.	M.Sc.	Ph.D.	"Equivalent Training"
Geology						
Geophysics						
Geochemistry						
Other (Specify)						

7. (a) At what academic level(s) do you currently prefer to hire geoscientists?
   (b) Has this changed recently? If so, when and in what way?
   (c) If you have hired at levels other than those you prefer within the past 5 years please list and explain why (e.g. exceptional individual(s), nobody available at preferred level, etc.).

8. (a) Have you found it necessary to hire geoscientists educated outside of Canada because people with suitable qualifications educated in Canada were not available?
   (b) If yes, in what field(s) of specialization and at what academic level?

9. In which subdisciplines are Canadian universities producing too many graduates (specify academic levels)?

10. In which subdisciplines are Canadian universities producing too few graduates (specify academic levels)?

11. Judging from staff members and temporary employees hired within the past 5 years what aspects of training generally require improvement (specify academic level and subdiscipline)?

12. If in the previous question you have recommended additional training what adjustments in university programs would you recommend to accomodate such training.

13. List Canadian universities you are familiar with which in your opinion currently offer outstanding/superior/adequate/poor training of geoscientists. Specify academic level and subdiscipline.

14. (a) Have any of your staff carried out joint research projects with university staff within the past 5 years?
    (b) If yes, with whom and at what university?

15. Has your company recently sponsored research projects or studies at any Canadian universities? If so, where and of what type?

16. In the past 5 years has your company helped to provide thesis topics at Canadian universities? If yes, at what academic level(s) and university(s).

17. What areas or topics of geoscience research require more work or work of better quality at Canadian universities?

18. What should be the balance in Canadian university research in geosciences amongst field-oriented, laboratory-oriented, the theoretical studies?

19. In your opinion is this balance usually achieved? If not, what is overemphasized?

20. Comments

Summary of responses from Mineral Exploration and Mining companies

Dr. P.L. Money, a member of the Geoscience Council of Canada Committee established to study the Status of Geoscience in Canadian Universities sent a detailed questionnaire to more than 150 mineral exploration, mining, and mineral consulting companies seeking their views on the education of geoscientists by Canadian universities. The questionnaire and the accompanying letter are attached to this summary. Twenty questions were asked. 150 companies replied and all answered questions 1 to 6. The names of the companies replying are attached to this summary.

Synopsis of answers to questions 4 to 6.

(a) Total number of employers — 150

(b) Total number of geoscientists employed — 1210

(c) Type of employer

- 1) Mineral exploration companies — 61
- 2) Mining companies with large exploration program centred at mine — 6
- 3) Mining companies with a small local exploration program — 17
- 4) Mining companies without exploration program — 55
- 5) Consulting geoscientist firms — 11

(d) Education level of employees in above 5 groups

	%	%	%	%	%	%
1.	384(45.3)	124(14.4)	163(19.2)	35(4.1)	103(12.1)	42(4.9)
2.	59(63.5)	17(18.2)	6(6.4)	1(1.1)	4(4.4)	6(6.4)
3.	33(36.3)	25(27.5)	9(9.9)	3(3.3)	3(3.3)	18(19.7)
4.	55(49.5)	32(28.3)	8(7.3)	3(2.9)	2(1.8)	11(9.9)
5.	19(29.7)	18(29.1)	6(9.4)	2(3.1)	18(29.1)	1.(1.5)
Total	550(45.5)	216(17.8)	192(15.9)	44(3.6)	130(10.7)	78(6.4)

(e) Categories of employees

Geologists	1122
Geophysicists	54
Geochemists	14
Others	20

Summary of answers made to questions 7 to 20 employers in categories 1,2, and 5, who are mainly concerned with mineral exploration.

These 3 categories total 78 employers and employ 1008 of the geoscientists.

Question 7: At what academic level(s) do you currently prefer to hire geoscientists.

(a) B.Sc.	15
(b) B.A.Sc.	7
(c) M.Sc.-M.A.Sc.	8
(d) B.Sc.-B.A.Sc.-M.Sc.-M.A.Sc.	25
(e) Ph.D.	4
(f) All levels	9
(g) No answers	10
	78

Question 8: Have you found it necessary to hire geoscientists educated outside of Canada

Very few yes answers were received to this questions. The great majority of companies prefer to employ Canadians. Several stated that they thought British and European geoscientists were better trained. About a dozen companies said: occasionally they had to seek specialists from outside Canada. Three companies stated they hired non-North American geoscientists because they were willing to work for lower salaries.

Question 9: In which subdisciplines are Canadian universities producing too many graduates (includes multiple answers)

(a) B.Sc. geology, without specialities	5
(b) B.Sc. geology, laboratory and theoretically oriented	3
(c) B.Sc. economic geology	2
(d) B.Sc. geology and geophysics, overspecialized	2
(e) B.A.Sc. geological engineer	1
(f) B.Sc. environmental studies	3
(g) B.Sc. geochemistry	2
(h) Ph.D.'s most subdiscipliies	3
(i) No answers	60

In contrast to question 10, these answers seem to indicate many of those who replied are out of touch with the job opportunities for geoscientists.

Question 10: In which subdisciplines are Canadian universities producing too few graduates (includes multiple answers)

(a) B.Sc. to Ph.D. exploration geophysicists	9
(b) M.Sc. to Ph.D. exploration geochemists	4
(c) B.Sc. to M.Sc. coal geologists	3
(d) B.Sc. to M.Sc. economic geologists	4
(e) B.Sc. to M.Sc. field, mining, and exploration geologists	5
(f) B.A.Sc. and B.Sc. mining engineers and geological engineers	9
(g) B.Sc. to Ph.D. pleistocene geologists	5
(h) No answers	46

Question 11: What aspects of university training in the geosciences require improvements (includes multiple answers)

(a) Improvement needed in ability to express oneself in basic and technical english, both in report writing and orally. Several francophone companies had the same complaint regarding french.	23
(b) Most graduates at all levels have no understanding of business and finance, particularly mining economics. For example few know what 'ore' is.	18
(c) Many graduates need more preparation in field geology, included here is basic geological mapping, surveying, drafting, and presentation of data.	16
(d) Practical or applied goephysics, especially the geological interpretation of geophysical data.	12
(e) Practical application of most course work to exploration and mining geology, particulary true of many courses in economic geology.	9
(f) Exploration and theoretical geochemistry.	8
(g) More petrography and identification of rocks and minerals in the field.	7
(h) Glacial (Pleistocene geology).	6
(i) Structural geology especially in the field.	6
(j) Computer processing and geostatistics.	3
(k) Basic sciences.	3
(l) No answers.	14

Question 12: If in question 11 you have recommended improvement in university geoscience programs what adjustments would you recommend to accomodate such changes. (includes multiple answers)

(a) Improve english with special courses in technical writing. If this is not possible give more essay type exams and exercises and grade them at least 50% on their English (included would be organization and writing style, spelling and in particular grammar). Also include in some courses oral dissertations by students with professor and fellow students acting as critics. 14

(b) Include at least one course in business and finance and if possible it should be a special course slanted towards the development of nonrenewable resources. B.W. Mackenzie of Queen's department of Geological Sciences gives such a course. Outside speakers from industry and finance could be an integral part of such a course. 8

(c) More emphasis could be placed on field-oriented geology by reducing some laboratory-oriented courses. Also by employing more staff members whose major interest is in field geology. Another suggestion is that field schools could be extended to 4 weeks or more and should include instrumentation, geochemistry, and geophysics. Still other suggestions include the following: (1) make 3-6 months field work with government surveys or industry compulsory before graduation, this would include a summer essay based on field work. (2) encourage the Geological Survey of Canada and Provincial Surveys to step up their student employment programs. 11

(d) At least one course should be compulsory in exploration geophysics. 4

(e) Economic and mining geology. Staff should be hired on a full time basis only after they have had 5+ years experience in industry. Another possibility would be to arrange an exchange system in which industry or government geologists could teach at a university and university geologists could spend up to a year in industry or government. If neither the above suggestions is feasible industry and government geologists could be employed on a part-time basis. Medical and law schools do this on a major scale with their own professionals. Some samples of this in geology already exist to name a very few: Holmes at Toronto, Patton at U.B.C., Toth at Calgary and Brown at Victoria.

(f) At least one course in exploration geochemistry should be compulsory. 2

(g) Descriptive mineralogy and petrography should be re-emphasized. 4

(h) At least one course in Pleistocene (glacial) geology should be compulsory in a country at least 95% glaciated. 4

(i) Field structural geology should be a compulsory part of all training. 3

(j,k) These are minor complaints and no solutions were proposed.

(l) General statements concerning solutions to improve the geology programs include the following: 10

(1) Screen out unqualified students and add course load to remainder.

(2) Increase number of compulsory courses and decrease the options.

(3) Eliminate the exotic courses and substitute basic courses and field-oriented courses.

(4) Add one year to undergraduate program as is now done in Waterloo, the extra year for practical training.

(5) Increase work load of faculty by cutting back on their research and consulting.

(6) As will be seen in question 18 most companies believe: there is too much emphasis placed on laboratory and theoretical- oriented courses and not enough emphasis on basic geology and field-oriented courses. This is especially true with graduate students where many of them overspecialize and become carbon copies of their professors.

(7) Students should be taught to think geologically and not to regurgitate their textbooks and professors only. Could be done with much wider use of seminars.

(m) No answers. 34

Footnote to Questions 11 and 12 (J.E.A.):

Most departments that offer degrees in geological engineering either are oriented towards the mining industry, or have options that are mining oriented. In these cases many of the inadequacies referred to in questions 11 do no apply. To a large extent, although not entirely, the criticism concern B.Sc. degrees offered by Science and Arts and Science faculties. In particular they apply to the major and general programs and to a much lesser extent to the honours programs. They reflect a general trend across Canada in which the compulsory course contact has been reduced and the optional course program increased. Some of the mining exploration and mining companies refer to this as the buffet or smorgasbord system of university education Some of our departments have eliminated the honours program and others have eliminated the honours thesis or made it optional, many companies consider this retrogressive.

The writer has studied the curricula at the 6 anglophone universities that grant degrees in geological engineering, which are British Columbia, Saskatchewan, Manitoba, Toronto, Queen's, and Windsor. He has noted the following compulsory courses in these 6 schools.

(a) Technical writing and reporting	3
(b) Surveying	5
(c) Computer programming	5
(d) Mining economics, business, finance	6
(e) Statistics	3
(f) Mineral deposits and economic geology	6
(g) Mineral exploration	2
(h) Exploration geophysics	2
(i) Exploration geochemistry	2
(j) Drafting and graphics	5
(k) Field courses and trips	6
(l) Introduction to mining	2

Where they are not compulsory most are normally available, as electives, the exceptions are (a), (g), (i), and (l).

In the course of the writer's travels he had the opportunity to talk to many undergraduate students, many of them mentioned several areas in need of improvement that I have catalogued for mining and mining exploration companies, although I am sorry to say none mentioned the need to improve their english. The engineering students as a group were less critical of their curricula. I also obtained the impression that the majority of undergraduates in geoscience are prepared to accept a heavier course load and tougher grading. To bear this out the enrolment in engineering geology is increasing faster than in science. The compulsory course load is much heavier in engineering than in science.

Question 13: List Canadian universities you are familiar with which in your opinion currently offer outstanding/ superior/ adequate/ poor training of geoscientists. Specify academic level and subdisciplines.

The replies are summarized below.

41 companies answered this question, 37 did not answer the question

	University Geology Department only	No. of Ratings Does not include departments with less than 5 ratings	Point Average
1.	Western Ontario	18	3.0
2.	Memorial	10	2.8
	Waterloo	6	2.8
3.	Toronto	20	2.7
	McGill	15	2.7
4.	Queen's	30	2.6
	Carleton	6	2.6
5.	Ecole Polytech	5	2.4
	Laval	7	2.4
	Manitoba	5	2.4
6.	Saskatchewan	5	2.2
	British Columbia	27	2.2
	McMaster	5	2.2
	Chicoutimi	5	2.2
7.	Alberta	5	2.0
	Calgary	5	2.0
	University of New Brunswick	5	2.0

outstanding - 4 points
superior - 3 points
adequate - 2 points
poor - 1 point

These ratings are primarily for B.Sc. degrees in Science departments with no distinction between honours and general degree. Graduates with engineering degrees were generally rated higher. Master degrees normally rated about 0.3 points higher and doctorate degrees about 0.8 points higher.

Question 14: Have any of your staff carried out joint research projects with university staffs in the past 5 years.

Twenty-two companies replied yes and 56 no. The following universities were named: Alberta (1), British Columbia (3), Carleton (1), École Polytechnique (2), Laurentian (1), Laval (1), McGill (2), Memorial (1), New Brunswick (2), Quebec-Chicoutimi (1), Queen's (2), Saskatchewan (1), Toronto (5), Waterloo (1), Western (1), Imperial College (1), Pennslyvania State (2), Michigan Tech. (1), Univ. of California in Los Angeles (1), and Australian National University (1).

Question 15: Has your company recently sponsored research projects or studies at any Canadian universities?

Twenty three companies replied yes and 55 no, however several of the latter indicated a willingness to do so. The following universities were named as beneficiaries of grants: British Columbia (4), Calgary (1), Carleton (1), École Polytechnique (1), Laurentian (1), McGill (2), Memorial (1), Queen's (5), Saskatchewan (1). Toronto (5), Waterloo (1),Western (5), Royal School of Mines (1) and unnamed (4).

Grants were made in the following subdisciplines

(a)	Economic Geology	14
(b)	Geophysics	4
(c)	Geochemistry	3
(d)	Mineralogy and Petrology	2
(e)	Geostatistics	1
(f)	Unnamed	14

Question 16: In the past 5 years has your company helped to provide thesis topics at Canadian universities?

Forty seven companies indicated they had helped to provide 137 thesis topics as listed below. Twenty one companies replied they had not helped to provide thesis topics.

	B.Sc. or B.A.Sc.	M.Sc. or M.A.Sc.	Ph.D.	Total
Alberta	1	2	1	(4)
British Columbia	8	3	3	(14)
Calgary	-	1	-	(1)
Carleton	2	3	4	(9)
Dalhousie	1	-	-	(1)
École Polytechnique	-	2	-	(2)
Laurentian	1	2	-	(3)
Laval	-	1	1	(2)
Manitoba	1	2	2	(5)
McGill	1	3	1	(5)
McMaster	-	1	1	(2)
Memorial	-	2	2	(4)
New Brunswick	-	1	1	(2)
Ottawa	1	-	-	(1)
Québec à Chicoutimi	-	2	-	(2)
Queen's	4	12	6	(22)
Saskatchewan	1	1	-	(2)
Toronto	3	7	3	(13)
Waterloo	3	-	-	(3)
Western Ontario	6	11	4	(21)
Unnamed Canadian Universities	3	7	5	(15)
Universities outside Canada	-	2	2	(4)
	36	65	36	137

Question 17: What areas or topics of geoscience require more work or work of better quality at Canadian universitites.

Thirty five companies made suggestions 43 did not. The topics are summarized below, many multiple answers were received.

(a) Mineral and ore deposits including metallogeny.	11
(b) Exploration techniques including applications of geophysics and geochemistry as applied to search for ore deposits.	9
(c) Field geology, particulary structural and petrographic studies	8
(d) Applied research, no enlargement on this statement.	8
(e) Coal geology.	3
(f) Quaternary geology, especially application to mineral search.	3
(g) Miscellaneous suggestions.	5

Some of the more interesting suggestions and comments on research are quoted below.

1. "Studies in which the graduate students have greater involvement with field aspects on projects, and do not spend a number of years as technicians producing much data of little or no practical use. In many universities, the graduate students do not even become involved in the operation of the equipment from which these data are obtained."

2. (a) "Much more emphasis needs to be placed on the distribution of ore and alteration minerals in rocks of ore deposits where they are treated and studied in the petrologic context of the whole rock."
   (b) "There is a crying need for solution geochemistry research not only related to processes of ore formation but also rock diagenesis, metamorphism, etc. Work in this area could revolutionize our understanding of geology, and it has been almost totally ignored in Canadian universities."

3. 1) "Geochemistry-secondary dispersion in variety of media throughout different climate/topography zones of Canada."
   2) "Weathering of rocks-formation of gossans - rates, controls, again across Canada."
   3) "Pleistocene-integration of Pleistocene history and stratigraphy and dispersion trains of mineralization, etc."
   4) "Age dating of rock sequences and ore bodies in volcanic, plutonic, metamorphic terrains."

4. "Less arm-waving, big picture research. Recognition that geology research requires time for good and meaningful work by funding organizations and so remove publish or perish panic requirement. We are being swamped by trivial, repetitious or just plain speculative articles in supposedly learned journals."

5. 1) "Physical and chemical models of ore forming systems - continue the work going on and expand it."
   2) "Studies related to migration and evolution of basinal connate brines."
   3) "Research into improving "metallurgical" recovery of base metal ores."
   4) "Research into the physiochemical effects and ramifications of metamorphism on various sulfide-related equilbrium systems viz: fluid inclusions, solid solution geothermometers, etc."
   5) "Experimental investigations into water/rock reactions aimed at:
      i) whole rock alteration studies and subsequent problems with protolith designation, etc., from samples altered early in their history.
      ii) evolution of ore-forming fluids."

6. "More emphasis on practical means of locating economic and viable ore deposits. Much current research has no economic significance."

<u>Question 18:</u> <u>What should be the balance in Canadian university research amongst field-oriented, laboratory-oriented, and theoretical studies.</u>

No. of Companies	Field	Laboratory	Theoretical
17	50%	25-30%	20-25%
10	60%	20-25%	15-20%
9	30-35%	30-35%	30-35%
2	40%	30%	30%
1	20%	20%	60%
1	80%	10%	10%
40			

<u>Question 19:</u> <u>In your opinion is this balance usually achieved, if not what is overemphasized.</u>

Thirty eight companies replied to this question and the answers are summarized below. 40 companies did not reply.

	No. of replies
Too much laboratory-oriented research	12
Too much laboratory and theoretical oriented research	10
Too much theoretical-oriented research	10
Balance at present about right	4
Too much field-oriented research	2

<u>Question 20:</u> <u>Comments.</u>

A representative sample of comments are listed below to show the range, the contradictions, and thought that went into them.

1. " - too much number gathering
   - too much number crunching
   - too little field time
   - too little problem definition
   - too little geology."

2. " - There appears to be a serious shortage of geoscientists who have any real appreciation of the fundamental aspects of mineral exploration. At the B.Sc. level, I realize time is limited and not all topics can be covered. However, at the higher degree level, some training in these areas, beyond those currently generally available, would be a good idea. I do not mean purely practical field experience such as the use of specific instruments and sampling methods, but rather a fundamental knowledge of Em, IP, etc., the movement of metals under different conditions, effect of different conditions, effect of different overburden on geochemistry, etc., and a knowledge of the genesis of different classes of ore deposits. in a country where mineral export is so important, this gets very minor attention at virtually all universities."

3. "Without wishing to be regressive or particularly small "c" conservative."
"Recent graduates in Geology lack:"

(i) "Any ability to identify rocks in the field/in drill core or to have some reasoned approach to naming rocks."

(ii) "Any confidence in their ability to map, and construct a geological map or to draw a cross-section of their own gelogical map."

(iii) "Very few Canadian graduate geologists have any feel, or interest in the Pleistocene -especially "hard rock" geologists and yet 90% of their field areas are "unexposed" e.g. Pleistocene."

(iv) "Few recent graduates have any real feel for constraints on the paragensis of rocks; they do not seemed to have grasped the fundamentals of element distribution in nature."

(v) "Whatever geophysics has been taught at B.Sc. (or even M.Sc. course) level seems to be "independent" of the rocks; there seems to be no "feel" that geophysics, and measuring physical properties of rocks, helps to construct geological maps/cross-sections, etc."

(vi) "Basic principles of geochemical dispersion at N.T.P. seems to be wholly lacking; recent graduates seem to have no "feel" as to why a rock should chemically weather, what processes are involved, or at what rates reactions proceed, what products are produced, what is left behind, what is in solution and when, what and how these solutions would precipitate. Recent graduates radiate a feeling that the present earth's surface is geochemically completely static or in complete equilibrium."

(vii) "90% of recent graduates cannot construct a histogram or contour a geochemical or geophysical plan."

(viii) "90% of recent graduates cannot write, even a simple, descriptive account of what they achieved on a geological/exploration project, let alone analyse, integrate, and synthesize their data.

"Virtually all these criticisms are directed at University teaching staffs not the graduates, who, almost without exception, are delight to learn: how to map; how to interpret their maps; how to write about their maps; how to recognize rocks; Pleistocene features; and to interpret geophysical/geochemical anomalies, etc., etc."

"One sometimes wonders exactly what they do in four years of geology at university."

4. "University of Waterloo's Co-op program seems like one of the best concepts for actually training people to do something useful or economically beneficial."
"More educational programs involving university/industry cooperation are necessary."
"I don't think people can afford and I don't think business or society can afford to have people spend 4 years or more straight at university. This is particularly true when the average B.Sc. or B. Eng. is now becoming obsolete in 7 years. The "only" solution to this problem is to have people "being educated" and "working" simultaneously. i.e. integration of universities with business."

(Oh dear - the academics won't like that')

5. "Historically, universities in the 1960's and 1970's have tended to stress theoretical studies more than field studies. This is a logical consequence of striving for some originality in research (it is easier to perform original lab work than field research). To a point, this "box of rocks" philosophy has been over-emphasized in some sub-disciplines and sectors leading to competition and duplication of effort. Because of ever-tightening financial belts on research funding, many universities have turned increasingly to industry for research problems and funding. This is a healthy balance and should be encouraged. At no time, however, should the value of "pure research" be equated in temporal dollars and cents. Pure research must be funded on its own, longterm merits with federal governments usually the "patron saints". Applied research and co-operation between universities and industry is a dynamic equilibrium. Hopefully, the free energy of reaction is tending toward increased rather than decreased interaction."

6. a) "There appears to be too much emphasis on training undergrads to become a grad student. Many of the basic skills are lacking upon graduation."
"Perhaps more professors (advisors) should take a more active role in communicating with their students and acting as a liason to industry, particularly by following up experience their students receive before, during, and after summer employment (which I consider a critical part of any student's training)."

b) "The treatment of ore deposits and economic geology is superficial at most universities, or in some instances, focused entirely on one aspect or type of ore deposit."

7. "On the whole I believe Canadian universities are producing a lot of very keep people at the M.Sc. level and Ph.D. level, but with some tendency to forget that in some way their knowledge and work has to make a contribution to the national economy as well as pure knowledge."

8. "Universities are not fulfilling the role that they should play. They are putting most of their eggs in theoretical research, without any regard for the priorities of society."

9. "While I may be labelled a materialistic person, the obvious fact is that viable mineral deposits in large numbers will have to be located and utilized within the next 50 years if our world economy is to survive. Emphasis should therefore be placed on the location and methods of utilization of such deposits with decreased emphasis on what is in many cases minor ecological impact. Theoretical considerations are important only where they may lead to significant discoveries."

10. "We note that university graduates with honors degrees have a distinctly better knowledge of petrology, sedimentology etc."

    "Many technical colleges produce well-trained and motivated geological technicians, etc. to fill less demanding positions. This places a responsibility on universities to provide a distinctly higher level of training and knowledge."

11. "Question 17 was the most important. I would like to have had more time to consider the question, but certainly if CGC can bring any improvement in that area especially the area referred to in 17 (b), this will be of great significance to Canadian geosciences education."
    "In undergraduate level programs, little consideration is evident of the fact that the majority of these people will be placed on the job market with very few skills obtained from the university program. Consideration is not apparent, on the university's part, of this fact."
    "Many undergraduate courses tend to ignore the basic building blocks of knowledge, which are necessary for understanding any subject. The impression one gets is that many professors find the basic knowledge required in many subjects to be too mundane to teach."
    "Shortcomings in the undergraduate training may directly lie in the fact there has been an alarming decrease in professors with significant practical or industrial experience."

12. " - An M.Sc. should be able to participate in feasibility market studies (Mineral economics).
    " - A B.Sc. should know the principles of reserve estimates, grade control and mining."
    " - University of Waterloo Co-operative Education system, which sees students alternate between campus and related "work term jobs" seems to be a very good experiment in which we participate and which we recommend."

13. "I believe that some non-practical i.e. academic studies are being emphasized in universities that used to be known for their economic-exploration oriented geological engineers because of a trend by some graduates toward non-field jobs. Perhaps it is therefore not the universities fault but industries fault for not making the exploration geological positions of a more attractive nature to future geological graduates."

14. "I think the major weaknesses are:

    1) "Lack of Fundamental Geology in Bachelor's Program. The esoteric stuff should be at the graduate level."

    2) "Lack of Economic Geology - Mineral Economics - Mining Geology courses at Bachelor's level."

    3) "Lack of Applied Geophysics courses at all levels - lack of Applied Geophysics research."

    4) "Dismal State of Research in Economic Geology at most Universities."

    5) "Lack of interdisciplinary approaches to problems of economic geology."

15. Several employees stated that they were primarily interested in employing bright motivated young geologists and that they would train them for the job.

Mining Companies

72 mining companies included in categories 3 and 4 replied to Money's questionnaire. 6 of them do not employ a geologist, the remaining 66 employ 202 geologists or equivalent. More than 80% of these employees have a bachelors degree or less and normally new employees are hired at this level. Many state a preference for engineering graduates in geology. Their answers to questions 11, 12, 17, 18, and 19 are similar to those from exploration companies with even more emphasis on practical courses. Only 20 of the companies rated the universities and these ratings applied to 12 universities, none being referred to more than 3 times.

The most interesting part of these questionnaires was the comments and reproduced below are samplings of them.

1) "From a practical and economic viewpoint one should strive for application of theory to field-oriented projects. lab-oriented studies are necessary for determining and planning economic feasibility of projects. Emphasis must be placed on application of geology for practical conditions. It is my opinion that some universities are leaning too heavily towards theory and in many instances undertaking irrelevant research, possibly with an aim to prepare undergrades for postgrad studies. Research and theory are acceptable as long as the end result will aid in ore search, (coal and oil included), and economic development of ore. It seems that some students are studying or researching a finite topic that will never have any application, to ore search and therefore little or no contribution, to the mineral industry."

2) "I think overall geoscience programs in Canadian Universities are in a fairly good balance. However slightly more time could be spent training students in the practical aspects of exploration and mining, e.g. mapping, geophysics, diamond drilling, core logging, mining methods, economics. It could be argued that these subjects should be learned at technical schools but university graduates should at least have some exposure."

3) "Very little exposure to industry is made during the school year. Guest speakers are usually of the professor or sabbatical type or with G.S.A. or G.A.C. working on pet projects, why can't guest speakers include: (i.e.) the chief geologist of (i.e.) Campbell Red Lake Mines; exploration manager of any natural resource company (i.e.) mining analyst with a financial institution, etc."

4. "University studies do no benefit as much as they should from the practical side and experiences of industry (mining) because of an over-emphasis on theoretical geology and hypothetical models rather than real-life models and practical geology and geophysics."

5. "In our slope stability and mine geology work we frequently uncover mistakes, (often very costly ones) which can be directly attributed to false, or unrealistic, geological concepts. It has been obvious that the observation of geological phenomena and the conceptualization of these observations into useful models has been the "weak link" in the chain of events leading to some economic decision; that is, the transformation of a geogical concept into numbers and its eventual computorization is generally well done but unfortunately, since the foundation is weak, the results fall short of expected. The basic problem here is that geologists have not identified and stressed the geological reality of the situation - in most cases, it appears that the geologist couldn't recognize the geological phenomena before him."

"If this same process is occuring in other geoscience fields, where perfect mathematical, physical or chemical models are being applied to false geological concepts, then the results are akin to that structurally perfect skyscraper built on a foundation of bentonite. This is why we stress, first and foremost, the development of fundamental recongition skills in whatever field the geologist claims to have expertise."

6) "The majority of graduates B.Sc. and M.Sc. today can tell you a great deal about theories of origin etc., but could not go underground and differentiate between ore and waste. They also seem to lack the ability to think in three dimensions."

"A graduate of a technical school has been taught generally in all phases of the mining operation (milling, assaying, surveying, etc.) and has a better overall understanding of what is required in each place."

7) "For a mine geologist,s job, the universities should put more emphasis on practical training in an operating mine. Each year of university training, the B.Sc. student should acquire 2 months of practical training in an operating mine or in an exploration camp. Subjects like surveying, elementary mining methods, structural geology and ore genesis along with other basics of gelogy will be quite useful for a practicing mine geologist. Above all, a mine geologist should have a strong 3 dimensional concept."

8) "I am a geologist with 11 years experience both underground and open pit. It would seem that the new graduate is very soundly trained but for what. Here, geologists are treated as second class to an engineer of equivalent training and undergraduate studies are very similar. I am involved in Grade Control but in order to do it my company classification was changed to Mining Engineer. Production needs have hit all-time highs while I've been in charge of scheduling ore and waste movements. It is disallusioning to think a "geologist" couldn't achieve the same results."

9. "A reluctance on the part of some recent (minimal experienced) graduates to "get their hands dirty" in mining or related fields such as diamond drilling or rock mechanics."

These types want to be able to sit in an office and work at everything on paper.

a) "Industry should be given tax incentives to hire students; this would insure field/lab training."

b) "Perhaps necessary to expand co-op system to other universities seems to work well at University of Waterloo."

or

"establish a 5th year of "on-the-job" training-funded jointly by industry and government. This would insure that young students who did not acquire summer jobs obtain the necessary training to secure a permanent job."

c) "Computer Science should be made a prerequisite to graduation (i.e. do away with Arts & Science courses i.e.) Philos-etc."

d) "Universities should provide more "Short Courses" for past graduates to update their knowledge. These short courses might equally be extended to field trips. People who take such courses should be given a certificate to that effect."

e) "If possible "mobile" - lectures should be made available for remote communities, i.e. - often individuals cannot attend out of the way courses etc."

i.e. courses could be of 1 to 2 weeks duration.

f) "A "report writing" course should also be made mandatory at all universities."

g) "Economic geology courses should include geophysical techniques etc."

10. "The following is a reflection of the need of the industry I am currently associated with and based on my personal contacts with geoscientists from the aforementioned universities."

"It appears that the balance of field/laboratory theory in any of the subdisciplines of geochemistry mining and geotechnology has not been suffieient."

"The geochemists are well trained in laboratory and statistical analysis tools, however deficient in field and occasionally theoretical applications."

"The mining geologists are rare and frequently their training is insufficient in either engineering or scientific fields."

"The science of geotechnology and structural geology are rarely offered as research topics to the mining industries."

"Though a happy balance of all training is not practical for each individual. The quality of a team abilities, rather than individual ability, must be considered as the main compensation force behind the successful application of any geoscience."

APPENDIX 4A

MAJOR FIELDS OF GRADUATE STUDIES IN CANADIAN GEOLOGY AND GEOPHYSICS DEPARTMENTS*

Name of University and Department	Major Fields and Special Aspects	Degrees
*Acadia (Geology):	Appalachian geology, economic geology, petrology, sedimentology, stratigraphy, and structural geology	M.Sc. and M.A.
*Alberta (Geology):	Mineral deposits, petrology, vertebrate and invertebrate paleontology, palynology, sedimentology, biostratigraphy, physical stratigraphy, structural geology, tectonics, Quaternary research, hydrogeology, coal geology, geochronology, isotope geochemistry, inorganic geochemistry	M.Sc. and Ph.D.
*Alberta (Geophysics):	Seismology, geodynamics, electromagnetic and magneto-telluric studies, geophysical instrumentation, paleomagnetism, mass spectrometry and isotope studies, gravity and magnetic interpretation, numerical modelling, heat flow, and geothermal resources	M.Sc. and Ph.D.
*British Columbia (Geological Sciences):	Cordilleran geology, mineral deposits, coal geology, marine geology, Quaternary, groundwater and engineering geology, mathematical modelling, theoretical geochemistry, experimental petrology, structure, tectonics, geochronology, applied geochemistry, paleontology.	M.Sc., M.A.Sc. and Ph.D.
(Geophysics and Astronomy):	Aeronomy, applied geophysics, communication theory, geo-dynamics, geomagnetism, geo-physical instrumentation, glaciology, inversion theory, isotopic studies and mass spectrometry, seismology, tectonophysics.	M.Sc. and Ph.D.
Brock (Geological Sciences):	Quaternary studies, particulary geochronology, stratigraphy, palynology, glacial geology, limnogeology, geomorphology and hydrology. Studies of mobile regions, particulary petrology, volcanolgy, structural geology, tectonics, sedimentology, economic geology and paleontology.	M.Sc.
Calgary (Geology and Geophysics):	Sedimentology, stratigraphy, structure, petrology, geochemistry, economic geology, mineralogy, paleontology, palynology, geophysics, surficial geology.	M.Sc. and Ph.D.

*Except the departments marked with an asterik all the information in this table was obtained from Geoscience Canada, V. 6, no. 3, p. 167-170 (1979).

Name of University and Department	Major Fields and Special Aspects	Degrees
Carleton (Geology):	Precambrian studies, resource geology, structure and geodynamics. Collaboration with scientists at the Geological Survey of Canada, Earth Physics Branch, and University of Ottawa.	M.Sc. and Ph.D. in geology and geophysics
Dalhousie (Geology):	Marine geology and geophysics, oceanic crust. Appalachian geology; sedimentology, petrology; geochemistry, including REE, oxygen isotopes; geochronology; metallogeny; Quarternary studies. Joint programs with Oceanography Department. Close association with Bedford Institute of Oceanography and International Program of Ocean Drilling.	M.Sc. and Ph.D.
*École Polytechnique (Genie Geologigue):	Economic geology, engineering geology, mineralogy, petrology, mathematical geology, and exploration geophysics and geochemistry. Associated with Mineral Exploration Research Institute.	M.Sc.A. and Ph.D.
Guelph (Land Resource Science):	Soil physics, soil chemistry, soil genesis, clay mineralogy, soil-plant relations, weathering geochemistry, applied sedimentology, agrometerology. Associated with Centre for Resources Development and Interdepartmental Program of Hydrology.	M.Sc. and Ph.D.
Lakehead (Geology):	Structural and metamorphic geology, petrology and geochemistry, mineralogy, sedimentology, and stratigraphy. Strategically located for Archean, Proterozoic, and Quaternary Studies.	M.Sc.
Laurentian (Geology):	Regional and economic geology of the Precambrian Shield (eastern Superior, Southern, northern Grenville, and Sudbury Basin), Precambrian and Ordovician-Silurian stratigraphy, sedimentation, paleoecology.	M.Sc.
*Laval (Geologie):	Engineering geology, economic geology, mineralogy, petrology, stratigraphy and structural geology, geochemistry, and exploration geophysics.	M.Sc., M.Sc. and Ph.D.

Name of University and Department	Major Fields and Special Aspects	Degrees
Manitoba (Earth Sciences):	Ore deposits and metallogeny; volcanology; mineralogy and crystallorgraphy; structural and metamorphic petrology, tectonics and geochronology of Precambrian provinces; carbonate sedimentology; Quaternary sedimentology; exploration geophysics; seismology; crustal studies, paleonagmetism, remote sensing. Associated with the Centre for Precambrian Studies.	M.Sc. and Ph.D in geology and geophysics
McGill (Geological Sciences):	Petrology, sedimentary geology, economic geology, structural geology, geophysics, geochemistry crystallography, geochronology, geomorphology, paleontology. Associated with Marine Sciences Institute and Mineral Exploration Research Institute.	M.Sc. Ph.D. and non-thesis M.Sc. program in Mineral Exploration and in Engineering Geology
McMaster (Geology):	Elemental, isotopic geochemistry; precious metal studies; petrology of alkaline rocks; silicate crystallography; volcanology. Clastic sedimentology; palaeocology; Mesozoic biostratigraphy; palaeotemperature studies; structural geology. Pollutants in atmosphere and lakes.	M.Sc. Ph.D. (Geology) Ph.D (Geochemistry)
Memorial (Geology):	Igneous, metamorphic petrology, petrochemistry, structure; Lower Paleozoic biostratigraphy; clastic, carbonate sedimentology.	M.Sc. and Ph.D.
Memorial (Geophysics in Department of Physics):	Rock magnetism, paleomagnetism; crustal/mantle investigations of electromagnetism, gravity, and heat flow; seismology; theoretical studies in global geophysics and planetary physics. Geomagnetic Research Laboratory is a major facility.	M.Sc. and Ph.D. (Geophysics) M.Sc. and Ph.D. (Physics)
*Montreal (Geologie):	Stratigraphy, paleontology, structural geology, sedimentology petrology, geochemistry, and geochronology.	M.Sc. and Ph.D.
*New Brunswick (Geology):	Economic geology, mineralogy, mineralogy, petrology, structure, rock mechanics, geophysics and biostratigraphy.	M.Sc. and Ph.D.
Ottawa (Geology):	Precambrian studies (petrology, structue, ore deposits); Arctic geology (biostratigraphy, sedimentology, paleontology); Geochemistry (granites, magmatites, rare earth elements); Quaternary geology (sedimentology, permafrost).	M.Sc. and Ph.D.

Name of University and Department	Major Fields and Special Aspects	Degrees
Ottawa (Geology): cont'd–	Collaboration with scientists at the Geological Survey of Canada, Earth-Physics Branch, and Carleton University (cooperative graduate program) and with other departments in the University of Ottawa.	M.Sc. and Ph.D.
*Universite de Québec à Chicoutimi Sciences de la Terre:	Precambrian exploration and mining geology, mineral deposits, sedimentology, volcanology, petrology, geochemistry, exploration geophysics, rock mechanics, and physical properties of rocks and minerals.	M.Sc. A.
*Universite de Québec à Montréal Sciences de la Terre:	Quaternary research, environmental geology, radiocarbon dating, and petrology.	M.Sc.
Queen's (Geological Sciences):	Exploration geochemistry, exploration geophysics, economic geology, engineering geology, environmental geology, geochemistry, geochronometry, hydrogeology, marine geology, mineralogy, paleontology, igneous and metamorphic petrology, stratigraphy, sedimentology, structural geology, tectonics. Non-research M.Sc. in mineral exploration; association with Centre for Resource Studies	M.Sc. and Ph.D.
*Regina (Geological Sciences):	Precambrian geology, petroleum, and coal geology, geothermal energy, economic geology, petrology, structural geology, and geochemistry. Associated with Energy Research Unit.	M.Sc.
Saskatchewan (Geological Sciences):	Palaeontology (particulary micropalaeontology, palynology); petrology, geochemistry, mineral deposits; sedimentology; stratigraphy; structural geology; geophysics (including seismology); engineering geology (including rock mechanics). Associated with interdisciplinary divisions within university and with geological sections of governmental institutions.	M.Sc. and Ph.D. Post-graduate Diploma
Toronto: Geology and other departments listed under major fields	A comprehensive array of programmes covering most aspects of the earth and planetary sciences, many of which are unavailable elsewhere in Canada, are offered by the Department of Geology and in co-operation with Geophysics, Geography, Metallurgy and materials Science, Geotechnical Engineering, Institute for Environmental Studies, and Royal Ontario Museum.	M.Sc., M.A.Sc. and Ph.D.
*Victoria (Geophysics in the Physics Department):	Electromagnetic induction in the earth and ocean, analogue models and theoretical studies, geomagnetism, theory of plasma waves, upper atmosphere physics.	M.Sc. and Ph.D. in physics (geophysics option)

Name of University and Department	Major Fields and Special Aspects	Degrees
Waterloo (Earth Sciences):	Environmental geology with special emphasis on hydrogeology, isotope hydrology, geochemistry, mathematical geology, shallow geophysics and engineering geology; Paleozoic stratigraphy and micropaleontology palynology; Precambrian geology (structural, metasomatic, economic); Quaternary geology; sedimentology (carbonates, clastics). Non-thesis M.Sc. in Environmental Geology; interdisciplinary programs available; excellent geochemical, geophysical, engineering, stable isotope, age-dating, computing and drilling facilities.	M.Sc. in geology and Ph.D. in all aspects of environmental geology and engineering geology.
Western Ontario (Geology):	Quarternary geology, environmental geology (with engineering), geochemistry, biogeochemistry, isotope geochemistry, economic geology, fluid dynamics, global tectonics, x-ray crystallography, petrology, structural geology, mathematical geology. Joint projects with Chemistry, Engineering and Bacteriology.	M.Sc. and Ph.D.
(Geophysics):	Age determinations, laboratory Measurements of physical properties under mantle conditions, paleomagnetism, seismology, terrestrial heat flow.	M.Sc. and Ph.D.
Windsor (Geology):	Sedimentology emphasizing applied stratigraphy and petroleum geology; Economic geology emphasizing industrial mineral deposits; Engineering geology emphasizing rockfluid interactions; Analytic geochemistry; igneous petrology; terrain geology, tectonophysics.	M.Sc. and M.A. Sc.
*York (Earth and Environmental Science Programme):	Earth dynamics, long baseline interframetry (precision geodosy), rotating fluids (applications to core dynamics), and gravity studies	M.Sc. and Ph.D.

*Except the departments marked with an asterik all the information in this table was obtained from Geoscience Canada, V. 6, no. 3, p. 167-170 (1979).

APPENDIX 5A

SPECIALITIES OF CANADIAN ACADEMIC GEOLOGISTS AND GEOPHYSICISTS AND KEY TO SCIENCE COUNCIL CODING

The specialities are those recognized by the Science Council of Canada and modified by the authors.

	Number of Academics (see footnotes)	
	Prinicpal speciality	Secondary and tertiary specialities
1. Coal geology	3	2
2a. Economic geology - metals	40	17
2b. Economic geology - nonmetals	3	2
3. Engineering geology	16	3
4. Environmental geology	3	6
5. General and regional geology	14	10
6. Geomorphology (see also 49a)	7	5
7. Historical geology	1	6
8. Hydrogeology	10	6
9. Marine geology	6	4
10. Mineralogy	22	2
10a. Crystallography	13	1
10b. Clay mineralogy	-	4
10c. Soil mineralogy	1	2
11. Mining geology	-	3
12. Paleobotany	2	3
13. Paleontology	22	14
13a. Micropaleontology	13	-
13b. Vertebrate paleontology	6	-
14. Palynology	7	2
15. Soil Science (Pedology), general (footnote 3)	13	-
15a. Soil chemistry and biochemistry	12	-
15b. Soil physics	7	1
15c. Soil biology	6	-
15d. Soil genesis, classification, and land evaluation	12	3
15e. Soil fertility	9	5
15f. Soil management	5	1
15g. Soil hydrology	2	2
15h. Agrometeorology and biometeorology	5	2
16. Petrology (general)	-	10
16a. Igneous petrology	30	9
16b. Metamorphic petrology	16	4
16c. Sedimentary petrology	-	2
17. Petroleum geology	6	6
18. Photogeology	-	7
19. Quarternary geology and Quarternary research	19	20
20. Rock mechanics (see footnote 2)	16	9
21. Sedimentology	37	14
22. Soil mechanics (see footnote 2)	46	2
23a. Physical stratigraphy	8	11
23b. Biostratigraphy	9	16
24. Structural geology, Tectonics and geotectonics	35	19

	Number of Academics (see footnotes)	
	Prinicpal speciality	Secondary and tertiary specialities
25. Volcanology	5	9
26. Other fields in geological sciences	1	3
27. Exploration geophysics	23	9
28. Geodesy	1	3
29. Geomagnetism and paleomagnetism	21	11
30. Geophysical instrumentation	-	8
31. Gravity	2	1
32. Heat flow	1	3
33. Magneto-telluric studies	4	4
34. Marine geophysics	4	4
35. Physical properties of rocks and minerals	2	
36. Remote sensing	7	5
37. Seismology	8	4
38. Tectonophysics	1	6
39. Other fields in geophysics	13	7
40. Biogeochemistry	1	8
41. Exploration geochemistry	13	1
42. Inorganic geochemistry	7	1
43. Isotope geochemistry and geochronology	27	7
44. Physical geochemistry	7	8
45. Organic geochemistry	1	5
46. Other fields in geochemistry	5	2
47. Mathematical geology	1	3
48. Computer applications to earth sciences	2	7
49. Physical geography		8
49a. Geomorphology, includes fluvial coastal, glacial, alpine, arctic, karst, and arid land (see also 6)	60	
49b. Hydrology, water resources, limnology, and groundwater	7	7
49c. Climatology, and meteorology	12	12
49d. Natural hazards, slope stability and mass wasting	5	2
49e. Energy budget and heat balance	5	7
49f. Biogeography	5	3
49g. Terrain evaluation	2	0
49h. Permafrost, periglacial, ice, snow, and glaciology	5	1
49i. Physical environment	3	4
49j. Pedology (see 15 also)	8	0
50. History of earth sciences	-	3
51. Oceanography, mainly physical	15	0
52. Geotechnical engineering (includes 20 and 22)	83	1
53. Mining research (funded by NSERC)	4	1

Footnotes:

(1) Listed here are the prime specialities as indicated by the various departments. A majority of the academics listed indicate more than one speciality as shown in the faculty index.

(2) The cataloguing of soil science departments has not been completed. Information missing from, McGill, and Laval.

(3) Six geography departments have been missed, 28 are included.

APPENDIX 5B

1979 FACULTY INDEX OF
GEOLOGISTS, GEOPHYSICISTS AND PHYSICAL GEOGRAPHERS

Following each name are the research specialities of faculty members as indicated by the individual faculty members or if this information was not available, the information was taken from the A.G.I. 1978-79 (17th) edition of directory of geoscience departments. In a few cases where the faculty members are not involved in research the teaching disciplines are listed. Where more than one discipline is indicated the most important one is listed first. The specialities are catalogued according to the list of Solid-Earth Science Disciplines recognized by the Science Council of Canada. The authors have made a few modifications as indicated.

Faculty Index

Abbot, R.N., Geol., Dalhousie, (16a)
Achab, A., INRS-Pétrole, Québec - a - St. Foy (17)
Acton, C.J., Land Resource, Sci., Guelph
Adams, W.P. Geog., Trent, (49h,49c,49b)
Aldridge, K., Earth Environ. Sci., York, (39)
Allen, C.M., Geol., Mount Allison, (16a,25)
Allen, J.M., Geol., Toronto, (10,44)
Anderson, D.D., Earth Sci., Manitoba, (27,29)
Anderson, D.T., Earth Sci., Manitoba, (36,2a)
Anderson, G.M., Geol., Toronto, (44,2a)
Anderson, M.M., Geol., Memorial, (13,23b)
Appleyard, E.C., Earth Sci., Waterloo, (16b,24)
Archibald, O.W., Geog. McMaster, (49f,49k)
Armbrust, G.A., Geol., Ottawa, (2a)
Armon, J.A. Geog., McMaster, (49a)
Armstrong, R.L., Geol., U.B.C. (43,24)
Arndt, N.A., Geol. Sci., Saskatchewan, (16a,2a)
Assad, N.A., Geol., Laval, (2a)
Atkinson-Keen, S., Geol., St. Mary's, (24)
Aumento, F., Geol., Dalhousie, (10)
Ayres, L.D., Earth Sci., Manitoba, (25,2a)
Azzaria, L.M. Geol., Laval, (41,42,4)

Baadsgaard, H., Geol., Alberta, (41,43)
Bachinski, D., Geol., U.N.B., (16b)
Bachinski, S., Geol., U.N.B., (16a)
Baer, A.J., Geol., Ottawa, (24,5,16)
Bailey, R.C., Geophys., Toronto, (29,33,48)
Baracos, A., Geol. Eng., Manitoba, (3,20)
Barker, J.F., Earth Sci., Waterloo, (43)
Barnes, C.R., Earth Sci., Waterloo, (13a)
Barnes, M.A., Geol. Sci., U.B.C. (45)
Barnes, W.C., Geol. Sci., U.B.C. (21,45)
Barr, S.M., Geol., Acadia, (16a)
Barr, W., Geog., Saskatchewan, (49a)
Bartlett, G.A., Geol. Sci., Queen's, (13,9)
Bates, T.E., Land Resource Sci., Guelph, (15e)
Bayliss, P., Geol. Geophys., Calgary, (10a)
Beales, F.W., Geol., Toronto, (23,2a,21)
Beaty, C.B., Geog., Lethbridge, (49a,6)
Beauchamp, E.G., Land Resource Sci., Guelph, (15c,15e)
Beaumont, C., Oceanogra. Geol., Dalhousie, (27,28)
Beck, A.E.,Geophys., Western Ontario, (32,27)
Becker, A., Génie Minéral, École Polytechnique, (27)
Beland, J., Géol., Montreal (24)
Belisle, J.M., Génie Minéral, École Polytechnique, (2a)
Bell, K., Geol., Carleton, (43)
Benoit, P., Sciences de la Terre, Québec a Montréal, (5)
Berard, J., Génie Minéral, École Polytechnique, (36)
Berger, A.R., Geol., Memorial, (16a, 24)
Berry, L., Geol. Sci., Queen's (10)
Berube, M.A., Géol., Laval, (10,2a)
Best, R.W., Geol. Sci., U.B.C. (13, 13b)
Bettany, J.R., Soil Sci., Saskatchewan, (15a)
Beswick, A.E., Geol., Laurentian, (44,16,25)
Bird, J.B., McGill (49a)
Bilodeau, M.L., Min. Metall., McGill (53)
Black, T.A., Soil Sci., U.B.C. (15h)
Bomke, A.A., Soil Sci., Manitoba, (15e)
Bonn, F., Geog., Sherbrooke, (49e)
Borradaile, G.J., Geol., Lakehead, (24)
Bouchard, M., Géol., Montréal, (6,19)
Bourne, J.H., Sciences de la Terre, Montréal a Québec, (16b)
Bourque, P.A., Geol., Laval (21,23a)
Bovis, M.V., U.B.C., (49a,49d)
Bowen, A.J., Oceanog., Dalhousie, (51)
Boyer, L., Génie Minéral, École Polytechnique, (3)
Braun, W.K., Geol. Sci., Saskatchewan (23b,13)
Brisbin, W.C., Earth Sci., Manitoba, (24,5)
Bristol, C.C., Geol., Brandon, (10,2a)
Brooke, M.M., Geol. Sci., Saskatchewan, (13a)
Brookes, I., Geog, York, (49a, 19)
Brookfield, M.E., Land Resource Sci., Guelph, (23a, 13, 24)
Brooks, C., Géol., Montréal, (25,43)
Brown, A.C., Génie Minéral, École Polytechnique, (2a)
Brown, D.M., Land Resource Sci., Guelph, (15h)
Brown, M.C., Geog., Alberta, (49a, 49b)
Brown, R.L., Geol., Carleton, (24)
Brown, T.H., Geol. U.B.C. (44,20,47)
Bryan, R., Geog., Toronto, (49a, 49d, 49i)
Bunting, B.T., Geog., McMaster, (49j)
Burke, K., Geol., U.N.B. (31)
Burley, B.J., Geol., McMaster, (10,16)
Burling, R.W., Oceanog., U.B.C., (51)
Burwash, R.A., Geol., Alberta, (16b,24,42)
Busten, R.M., Geol. Sci., U.B.C., (1)

Caldwell, W.G.E., Geol. Sci., Saskatchewan, (23b,13)
Calon, T.J., Geol., Memorial, (24)
Cameron, R.A., Geol., Laurentian, (27)
Campbell, F.A., Geol. Geophy., Calgary, (2a)
Campbell, I.A., Geography, Alberta (49a)
Cannon, Earth Environ. Prog., York, (28)
Carbonneau, C., Géol., Laval, (2b)
Carmichael, C.M., Geophys., Western Ontario, (29)
Carmichael, D.M., Geol. Sci., Queen's, (16b)
Carroll, R.L., Redpath Museum, McGill, (13b)
Carson, M.A., Geog., McGill, (49a,49d)
Carter, A., Soil Sci., U.B.C., (15c)
Casteel, R.W., Archeology, Simon Fraser, (19)
Caty, J.L., Sciences de la Terre, Québec à Chicoutimi, (21)
Caviedes, C.N., Geog., Regina, (49a)
Cawker, K.B., Geog., Western Ontario, (49f,14)
Cerny, P., Earth Sci., Manitoba, (10,16a)
Chagnon, L.Y., Géol., Laval, (3,4)
Chakravarti, A.K., Geog., Saskatchewan, (49c)
Chao, G.Y., Geol., Carleton, (10)
Chapman, C.H., Phys. Geophys., Toronto, (37)
Charbonneau, J.M., Sci. de la Terre, Québec à Montréal, (24)
Charlesworth, H.A., Geol., Alberta, (24)
Chase, R.L., Geol. Sci., U.B.C. (9,24)
Chatterton, B.D., Geol., Alberta, (13)
Cherry, J.A., Earth Sci., Waterloo, (8)
Cheseworth, W.A., Land Resource Sci., Guelph, (46)
Cho, C.M., Soil Sci., Manitoba, (15a)
Church, M.A., Geol., U.B.C., (49a)

Church, W.R., Geol., Western Ontario (16a)
Churcher, C.S., Zoology, Toronto, (13b)
Chou, C.L., Geol., Toronto, (42,26)
Chown, E.H., Sciences de la Terre, Québec à Chicoutimi, (16b)
Clark, A.H., Geol. Sci., Queen's (2a)
Clark, D.B., Geol., Dalhousie, (16a)
Clark, G.S., Earth Sci., Manitoba, (43)
Clarke, G.K., Geophys., Astronomy, U.B.C., (39)
Clarke, W.B., Phys., McMaster, (43)
Clement, P.M.J., Géog., Sherbrooke, (49a)
Clifford, P.M., Geol., McMaster, (24)
Clowes, R.M., Geophys and Astronomy, U.B.C., (37,34)
Cogley, J.G., Geog., Trent, (49a, 49b)
Collerson, K.D., Geol., Memorial, (16b,24)
Coleman, L.C., Geol. Sci., Saskatchewan, (10,16)
Colwell, J.A., Geol., Acadia, (41,2a)
Cooke, H.B., Geol., Dalhousie, (19,12,23a)
Cooke, R.C., Oceanog., Dalhousie, (51)
Cooper, P., Geol., Laurentian, (13)
Corlett, M.I., Geol. Sci., Queen's (10,44)
Cormier, R.F., Geol., St. Francis Xavier, (43)
Cossa, D.J., INRS-Océanology, Québec à Ste-Foy, (51)
Crampton, C.B., Geog., Simon Fraser, (49f,49h)
Crocket, J.H., Geol., McMaster, (2a,43)
Crossley, D.J., Min. Metall., mcGill, (27,37)
Cruden, D.M., Geol., Alberta, (3,20)
Cumming, G.L., Physics, Alberta, (43,29,37)
Cunningham, F.J., Geog., Simon Fraser, (49a,50)
Currie, J.B., Geol., Toronto, (24,17)

Dalrymple, R.W., Geol. Aci., Brock, (21,9,19)
d'Anglejan, B.F., Marine Sci. Centre, McGill, (9)
Danner, W.R., Geol. Sci., U.B.C., (23b,13,5)
Darling, R., Génie Minéral, École Polytechnique, (10)
David, P.P., Géol., Montréal, (19,21,23a)
Davidson-Arnott, R., Geog., Guelph, (49a)
Davies, J.F., Geol., Laurentian, (2a,24)
Davis, M.W.D., Génie Minéral, École Polytechnique, (2a)
Davis, T.L., Geol. Geophy., Calgary, (27,37,3)
Day, J.C., Geog., Waterloo, (49b,49d)
De Albuquerque, Geol., St. Mary's (10)
Dean, W.G., Geog., Toronto, (49a,19)
De Boutray, B.U., Sci. de la Terre, Québec à Montréal, (16a,10)
De Jong, E., Soil Sci., Saskatchewan, (15b)
Deland, A.N., Geol., Concordia, (16a,10)
Denner, W.W., Phys., Memorial (39)
De Romer, H.A., Geol., Concordia, (5,24,18)
Deutsch, E.R., Phys. (Geophysics), Memorial, (2a)
De Vries, J., Soil Sci., U.B.C., (15b, 15g)
Dimroth, E.V., Sci. de la Terre, Québec a Chicoutimi (25)
Dixon, J.M., Geol. Sci., Queen's, (24)
Dixon, O.A., Geol., Ottawa, (13,23b)
Doig, R., Geol. Sci., McGill, (43)
Donaldson, J.A., Geol., Carleton, (21,5)
Donnay, G.H., Geol. Sci., McGill, (10a)
Dosso, H.S., Phys., Victoria, (27,29,39)
Dostal, J., Geol., St. Mary's, (44,2a)
Drake, J.J., Geog., McMaster, (49c,49a)
Dreimanis, A., Geol., Western Ontairo, 919)
Duffus, H.J., Phys., Royal Roads, (29)
Duberger, R.U., Sci. de la Terre, Québec à Chicoutimi, (27,37)
Duckworth, K., Geol. Geophys., Calgary (27,33)
Dunlop, D.J., Geophys., Toronto, (29)
Durand, M., Sci., de la Terre, Québec à Montréal, (3)

Eakins, P.R., Geol. Sci., McGill, (24,2)
Edgar, A.D., Geol., Western Ontario, (16a,44)
Edmund, A.G., Geol., Toronto, (13b)
Edwards, R.M., Geophys., Toronto, (33,30)

Ek, C.M., Géog., Montreal (49a,19)
Elbrond, J., Génie Minéral, École Polytechnique, (53)
Elias, R.J., Earth Sci., Manitoba, (13)
Ellis, R.M., Geophys. Astronomy, U.B.C. (37)
Elrich, D.E., Land Resource Sci., Guelph, (15b)
El Sabh, M., Québec à Rimouski (51)
Elson, J.A., Geol. Sci., McGill, (19,18)
Emery, W.J., Oceanog., U.B.C., (51)
England, J.H., Geog., Alberta, (19,49a)
Erb, D.K., Geog., Waterloo, (49a,49g,36)
Ervine, W.B., Geol. Dalhousie, (42)
Evans, L.J., Land Resource Sci., Guelph, (10d,15b)
Evans, M.E., Phys., Alberta, (29)
Everall, M.D., Mines Métall., Laval, (53)

Faessler, W.C., Génie Minéral, École Polytechnique, (27)
Fahey, B.D., Geog., Guelph, (49h)
Fahraeus, L.E., Geol., Memorial, (13a, 23b)
Falconer, R.K., Geol., Dalhousie (34)
Farquhar, R.M., Phys. Geophys., Toronto, (43)
Farrar, E., Geol. Sci., Queen's, (43)
Farvolden, R.N., Earth Sci., Waterloo, (8)
Fawcett, J.J., Geol., Toronto, (16b,25)
Ferguson, L., Geol., Mount Allison, (13)
Ferguson, R.B., Earth Sci., Manitoba, (10a)
Fitzgibbon, J.E., Geog., Saskatchewan, (49a,49b)
Fleet, M.E., Geol., Western Ontario, (10a)
Fletcher, R.J., Geog., Lethbridge, (15)
Fletcher, W.K., Geol. Sci., U.B.C. (41)
Flint, J.J., Geol. Sci., Brock, (6,8)
Ford, D.C., Geog., McMaster, (49a, 49b,46,6,19)
Foster, H.D., Geog., Victoria, (49a,49d)
Fox, R.C., Geol., Alberta, (13b)
Francis, D., Geol. Sci., McGill, (10,16a)
Fransham, P., Earth Sci., Waterloo, (3,22)
Freeze, R.A., Geol. Sci., U.B.C., (8,48,47)
French, H.M., Geol. Geog., Ottawa, (6,49h)
Frind, E.A., Earth Sci., Waterloo, (47)
Fritz, P., Earth Sci., Waterloo, (43)
Fryer, B.J., Geol., Memorial, (43)
Fyfe, W.S., Geol., Western Ontario, (44)
Fyson, W.K., Geol., Ottawa, (24)

Gagnon, H., Géog., Ottawa, (49d,18)
Gale, J.E., Earth Sci., Waterloo, (3,20)
Gangloff, P., Géog., Montréal, (49a)
Gardner, J.S., Geog., Waterloo, (49a,49d)
Garland, G.D., Phys. Geophys., Toronto, (33,32)
Garneir, B.J., Geog., McGill, (49c)
Garrett, C.J., Oceanog., Dalhousie, (34)
Gautier, C.H., INRS-Pétrole, Québec à Ste. Foy, (51)
Gelinas, L., Génie Minéral, École Polytechnique, (16a)
Geninas, P.J., Géol., Laval, (8,19)
Gendzwill, D.J., Geol. Sci., Saskatchewan, (27)
Generst, C., Sciences Humaines, Québec à Trois Riveres, (6)
Geurts, M.A., Géog., Ottawa, (49f)
Ghent, E.D., Geol. Geophys., Calgary, (16b)
Gibson, I.L., Earth Sci., Waterloo, (16a)
Gilbert, R., Geog., Queen's, (51)
Giles, P.S., Geol., Dalhousie, (21)
Gill, D.E., Génie Minéral, École Polytechnique, (3,20)
Gillham, R.W., Earth Sci., Waterloo, (15b,8)
Gillespie, T.J., Land REsource Sci., Guelph, (15h)
Gilliland, J., Phys., Royal Roads, (29,39)
Giovanella, C.A., Geol. Sci., U.B.C. (5)
Gittins, J., Geol., Toronto, (16a, b)
Godwin, C.I., Geol. Sci., U.B.C., (2a,43)
Goodchild, M.F., Geog., Western, (49a)
Goodwin, A.M., Geol., Toronto, (6)
Gordon, W.A., Geol. Sci., Regina, (13,7)
Gorman, D.H., Geol., Toronto, (10)
Gorman, W.A., Geol. Sci., Queen's, (5,19)

Gorton, M.P., Geol., Toronto, (43)
Gough, D.I., Phys., Alberta, (29,28,27)
Goulet, N., Sci. de la Terre, Québec à Montréal, (24)
Grant, B., Geol. Sci., Brock, (5)
Grant, R.H., Geol, U.N.B., (32a)
Gravenor, C.P., Geol., Windsor (19)
Gray, J., Physics, Alberta, (43)
Gray, J.T., Géog., Montréal, (49h)
Greenhouse, J.P., Earth Sci., Waterloo, (27,29)
Greenwood, B., Geog., Toronto, (49a)
Greenwood, H.J., Geol. Sci., U.B.C.,(44,16)
Greggs, R.G., Geol.Sci., Queen's, (13,23b,7)
Gretner, P.E., Geol. Geophys., Calgary, (3,27,35,20,24)
Grice, H.R., Geol. Sci., McGill, (3,8)
Grill, E.V., Oceanog., U.B.C., (51)
Grundy, H.D., Geol., McMaster, (10a)
Gwyn, Q.H.J., Géog., Sherbrooke, (49a,19)

Hajnal, L., Geol. Sci., Saskatchewan, (27)
Hale, W.E., Geol., U.N.B., (2a)
Hall, D.H., Earth Sci., Manitoba, (29)
Hall, J.M., Geol., Dalhousie, (29,34)
Hall, R.D., Geol., St. Francis Xavier, (16b)
Hall, R.L., Geol. Geophys., Calgary, (13a)
Halls, H.C., Geol., Toronto, (29)
Halstead, E.H., Soil Sci., Saskatchewan, (15a,15e)
Hanley, T.O., Phys., Saskatchewan, (39)
Haq, A-U., Land Resource Sci., Guelph, (15)
Harding, N.E., Geog., Toronto, (36)
Harris, S.A., Geog., Calgary, (49a,19)
Harrison, R.S., Earth Sci., Manitoba, (21,16c,17)
Hay, J.E., Geog., U.B.C., (49c)
Hayatsu, A., Geophys., Western Ontario, (43)
Haynes, S.J., Geol. Sci., Brock, (2a,11)
Hebda, R., Biology, Waterloo, (14)
Hedlin, R.A., Soil Sci., Manitoba, (15e)
Hemstaedt, H., Geol. Sci., Queen's, (24,16)
Hendry, H.E., Geol. Sci., Saskatchewan (21)
Hennigar, T., Geol., Dalhousie, (9)
Henry, J.L., Soil Sci., Saskatchewan, (15e)
Heroux, Y., INRS-Pétrole, Québec à Ste. Foy, (17)
Hesse, R., Geol. Sci., McGill (5,21)
Hickin, E.J., Geog., Simon Fraser, (49a)
Hill, A.R., Geog., York, (49b,8)
Hill, P.A., Geol., Carleton, (4)
Hillaire-Marcel, C., Sci. de la Terre, Québec à Montréal, (19)
Hills, L.V., Geol. Geophys., Calgary, (14,12,19,21)
Hiscott, R.N., Geol., Memorial, (21)
Hodder, R.W., Geol., Western Ontario, (2a)
Hodgins, L.E., Geog., York, (19,49a,49b)
Hodgson, C.J., Geol. Sci., Queen's, (2a)
Hodych, J.P., Geol. Phys., Memorial (27,33)
Hoffman, D.W., Land Resource Sci., Guelph, (15)
Hoffman, H., Géol., Montreal, (13,23b)
Hogarth, D.D., Geol., Ottawa, (10)
Holmes, J.W., Geol., Toronto, (2a,11)
Hooper, K., Geol., Carleton, (13a, 23b)
Hope-Simpson, D., Geol., St. Mary's, (5,7,23a,25)
Hopkins, J.C., Geol. Geophys., Calgary, (15,23b)
Horita, R.E., Physics, Victoria, (39)
Howarth, P.J., Geog., McMaster, (36,49a,49b)
Howatson, C.H., Geog., Victoria, (5,18)
Hron, F., Physics, Alberta, (37)
Huagn, C-h, Geol., Windsor, (42)
Huang, P.M., Soil Sci., Saskatchewan, (15a,10b)
Hubert, C., Geol., Montreal, (23a,24)
Hudec, P.J., Geol., Windsor, (3,20,2b)
Hughes, C.J., Geol., Memorial, (16a)
Hunting, B.T., Geog., McMaster, (49j)
Huntley, D.A., Oceanog., Dalhousie, (51)
Hutcheon, I., Geol. Geophys., Calgary, (42,21)
Hutchinson, I., Geog., Simon Fraser, (49f)
Hutchingson, R.W., Geol., Western Ontario, (2a)
Hynes, A.J., Geol. Sci., McGill (24)

Ingram, R.G., Marine Sci., McGill, (51)

Jackson, E.L. Geog., Alberta (49d)
Jacobs, J., Geog., Windsor, (49c,49a,36)
James, N.P., Geol., Memorial, (21)
James, R., Geol., Lakehead, (16b)
Jansa, L.F. Geol., Dalhousie, (21).
Jaouich, A., Sci. de la Terre, Québec à Montreéal, (8)
Jenking, J.T. Geol., Concordia, (10,16)
Jensen, O.G., Min. Metall., McGill, (37)
Jeremic, J., Min. Eng., Alberta, (53,20)
Johnson, J., Geol. Sci., Regina, (1,13)
Johnson, J.P., Geog., Carleton, (49a,49h)
Johnson, P.G., Geog., Ottawa, (49a,49d)
Jolly, W.T., Geol. Sci., Brock, (25,16a)
Jones, B., Geol., Alberta, (13,23,21)
Jones, F.W., Physics, Alberta, (27,32,39)
Jones, R.W., Land Resource Sci., Guelph, (15)
Jopling, A.V., Geog., Toronto, (49a)

Kanasewich, E.R., Physics, Alberta, (37,38)
Karrow, P.W., Earth Sci., Waterloo, (19)
Kay, B.D., Land Resource Sci., Guelph, (15b)
Kehlenback, M.M., Geol., Lakehead, (24,16b)
Kemp, D.D., Geog., Lakehead, (49a,19)
Kennedy, M.J., Geol. Sci., Brock, (24,16)
Kent, D.M., Geol. Sci., Regina, (21,17)
Kerrich, R.W., Geol., Western Ontario, (43)
Kesik, A.B., Geog., Waterloo, (49a,36)
Ketcheson, J.W., Land Resource Sci., Geulph, (15f,15g)
Kimberley, M.M., Geol., Toronto, (2a,21)
King, A.F., Geol., Memorial, (21)
King, K.M., Land Resource Sci., Geulph, (15h)
King, L.H., Geol., Dalhousie, (9)
King, M.S., Geol. Sci., Saskatchewan, (3,20,27)
King, R.H., Geog., Western, (49j)
Kisak, E., de Mathematiques, Montreal, (33)
Kissin, S.A., Geol., Lakehead, (2a,10a)
Klovan, J.E., Geol. Geophys., Calgary, (21,47,48)
Knowles, R., Marine Sci., McGill, (15)
Kobluk, D., Geol., Toronto, (13)
Kontak, D., Geol., St. Francis Xavier, (2b)
Koster, E.H., Geol. Sci., Sasktachewan, (21)
Kramer, J.R., Geol., McMaster, (42)
Kretz, R., Geol., Ottawa, (16b)
Krogh, T.E., Geol., Royal Ont., Museum, Toronto, (43)
Krouse, H.R., Physics, Calgary, (43)
Kubalova-Peck, Geol., Carleton, (13)
Kucera, R.E., Geol. Sci., U.B.C., (6)
Kumarapeli, S., Geol., Concordia, (39)
Kupsch, W.O., Geol. Sci., Saskatchewan, (6,19,50)

Laidlaw, D.D., Min. Metall., McGill, (20)
Lajoie, J., Géol., Montréal, (21)
Lajtai, E.Z., Geol., U.N.B., (3)
Lambert, R., St. J., Geol.,Alberta, (16a,b,24,38,52,53)
Lancery, J.M., Sci. Humaines, Québec a Trois Riveres, (6)
Lane, T.H., Land Resourve Sci., Guelph, (15f)
Langford, F.F., Geol. Sci., Saskatchewan, (2a)
Langleben, M.P., Physics, McGill, (39)
Laurent, R., Géol, Laval, (16a,25,43)
Lavalle, P.D., Geog., Windsor, (49a)
Lavkulitch, L., Soil sci., U.B.C., (15d,10c)
Lawson, D.E., Earth Sci., Waterloo, (21)
Laycock, A.H., Geog., Alberta, (49b,18)
Laznicka, P., Earth Sci., Manitoba, (2a)
Lebel, J., Océanog., Québec à Riminouski, (51)
LeBlond, P.H., Oceanog., U.B.C. (51)
Ledoux, R., Géol., Laval, (10)

Legault, J.A., Earth Sci., Waterloo, (14)
Leighton, H.G., Meterology, McGill, (49c)
Lenz, A.C., Geol., Western Ontario, (13)
Lerbekmo, J.F., Geol., Alberta, (21,29,17,1,23)
Lespérance, P.J., Géol., Montreéal, (13)
Levinson, A.A., Geol. Geophys., Calgary, (41,42,40)
Lewis, J.E., Geog., Mcgill, (49c,49e)
Lewry, J.F., Geol., Sci., Regina, (24,5,16)
Liberty, B.A., Geol. Sci., Brock, (23a,13)
Loewen-Rudgers, L.a., Soil Sci., Saskatchewan, (15a,15e)
Logan, A., Geol., U.N.B., St. John, (13)
Longerich, H., Geol., Memorial, (48)
Longstaffe, F., Geol., alberta, (43,42)
Lowe, L.E., Soil Sci., U.B.c., (15a)
Luckman, H.B., Geog., Windsro, (49a)
Ludden, J.N., Géol., Montréal, (25,42)
Luk, S.H., Geog., Brock (49d)
Ludvigsen, R., Geol., Toronto, (23b,13)
Lyttle, N.A., Geol., Dalhousie, (5)

Mackay, J.R., Geog., U.B.C. (49h)
Mackenzie, B.W., Geol. Sci., Queen's (2a)
Mackintosh, E.I., Land Resource Sci., Guelph, (15f,10b)
Maclean, W.H., Geol.Sci., McGill, (2a)
Macneill, R., Geol., Acadia, (19,8,18)
Macqueen, R.W., Earth Sci., Waterloo, (23a,21,2a)
Macrae, N.D., Geol., Western Ontario, (16a)
Mahanney, W.C., Geog., York, (49a,49j)
Malpas, J.G., Geol., Memorial, (16a)
Mamet, B.L., Géol., Montréal, (7,13,23b)
Mansinha, L., Geophysics, Western Ontario, (37)
Mark, D., Geog., Western Ontario, (49a,48)
Martignole, J., des Sci. de la Terre, Québec à Montréal, (24)
Martin, R.F., Geol. Sci., McGill, (16a)
Martini, I.P., Land Resource Sci., Guelph, (21,19)
Mathewes, R.J., Biol. Sci., Simon Fraser, (14)
Mathews, W.H., Geol. Sci., U.B.C., (19,5,6,21)
Matthews, B.C., Earth Sci., Waterloo, (15)
May, R.W., Geol., alberta, (19,21,6,47)
Mayr, F., Sci. de la Terre, Québec à Montréal (19)
McAllister, A.L., Geol., U.N.B., (2a)
McCann, S.B., Geog., McMaster, (49a,21)
McCaughey, J.B., Geog., Queen's, (49e)
McDougal, D.J., Geol., Concordia, (10)
McFarlane, W., Physics, Royal Roads, (34)
McGowan, C., Zoology, Toronto, (13b)
McGugan, A., Geol. Geophys, Calgary, (13a)
McKercher, R.B., Soil Sci., Saskatchewan, (15a)
McLellan, A.G., Geog., Waterloo, (49a)
McMurray, J.H., Geog., Wilfred Laurier, (49a)
McNutt, R.H., Geol., McMaster, (43)
McPherson, H.J., Geog., Alberta, (49a,49d)
McTaggart, K.C., Geol. Sci., U.B.C., (16b)
Meagher, E.P., Geol. Sci., U.B.C., (10a)
Medioli, F., Geol., Dalhousie, (13a)
Mellinger, M., Génie Minéral, École Polytechnique, (41)
Menzies, J., Geog., Brock, (49a)
Mercy, E.L., Geol., Lakehead, (42,16a)
Middleton, G.V., Geol., McMaster, 921)
Miller, E.E., Geog., Lethbridge, (49a)
Miller, M.H., Land Resource Sci., Guelph, (15e)
Milligan, G.C., Geol., Dalhousie, (24,2a,11)
Mirynech, E., Geol. Sci., Brock, (19)
Misener, D., Earth Environ. Sci., York, (2a)
Mitchell, R.H., Geol., Lakehead, (43,16a)
Moore, Jr., J.M., Geol., Carleton, (16b)
Moore, J.C.G., Geol., Mount Allison, (2a)
Moore, R.G., Geol., Acadia, (23b,13)
Moore, T.R., Geog., McGill, (49j)
Morency, M., Sci., de la Terre, Québec à Montréal, (46)
Morgan, A.V., Earth Sci., Waterloo, (19)
Morton, R.D., Geol., Alberta, (10,2a)
Mossman, D.J., Geol. Sci., Saskatchewan, (2a)
Mothersill, J.M., Geol., Lakehead, (21)
Mountjoy, E.W., Geol. Sci., McGill, (23a,5,24)
Muecke, G.K., Geol., Dalhousie, (43)
Muehlenbachs, K., Geol., Alberta, (46)
Mukherji, K.K., Geol., Concordia, (21)
Muller, F., Geog., McGill, (49h)
Munroe, D.S., Geog., Toronto, (49c, 49e)
Murray, J.W., Geol. Sci., U.B.C., (9,17,23a)
Murtha, P.A., Soil Sci. Forestry, U.B.C. (36)
Murthy, G.S., Phys (Geophys.), Memorial, (29)

Nagy, A., Sci. de la Terre, Québec à Chicoutimi, (10)
Naldrett, A.J., Geol., Toronto, (2a,16a)
Nance, R.D., Geol., St. Francis Xavier, (24)
Nelson, J.G., Geog., Waterloo, (49i)
Nelson, S.J., Geol. Geophys., Calgary, (23b,13)
Nesbitt, H.W., Geol., Western Ontario, (21)
Nichol, I., Geol. Sci., que en's, (41,2a)
Nicholls, J.W., Geol. Geophys., Calgary, (16a,25)
Nickling, W., Geog., Guelph, (49d)
Nkemdirin, L.C., Geog., Calgary, (49e)
Noble, J.P., Geol., U.N.B., (23b,13)
Norris, G., Geol., Toronto, (14,23b)
North, F.K., Geol., Carleton, (17,24)
North, R.B., Geol. Sci.,Saskatchewan, (13a)
Nyland, E., Physics, Alberta, (38,37)

Oke, T.R., Geog., U.B.C., (49c)
Oldenburg, D.W., Geophys. Astronomy, U.B.C., (33,28,39)
Oldershaw, A.E., Geol. Geophys., Calgary, (21,24,16c)
Oliver, T.A., Geol. Geophys., Calgary, (21)
Ongley, E.D., Geog., Queen's, (49a,49b)
Osborn, G.D., Geol. Geophys., Calgary (6,4, 19)

Packer, R.W., Geog. Western Ontario, (49a)
Pageau, Y., Sci., de la Terre, Québec a Montréal, (13b)
Pajari, Jr., G.E., Geol., U.N.B., (16a)
Palmer, H.C., Geophys., Western Ontario, (29)
Papezik, V.S., Geol., Memorial, (10,5,2b)
Parry, J.T., Geog., McGill, (49g,18)
Parslow, G.R., Geol. Sci., Regina, (41,16a,2a)
Patterson, R.J., Geol. Sci., Queen's, (8,46,4)
Paul, E.A., Soil Sci., Saskatchewan, (15)
Peach, P., Geol. Sci., Brock, (16a,19)
Pearce, G.W., Geol., Toronto, (29,24)
Pearce, T.H., Geol. Sci., Queen's, (16a)
Pearson, D.A.B., Geol. Laurentian, (23b, 13)
Perrault, Guy., Génie Minéral, École Polytechnique, (10)
Peters, H.R., Geol., Memorial (2a)
Peucker, T.K., Geog., simon Fraser, (49g,48)
Phillips, B.A.M., Geog., Lakehead, (49a)
Phipps, M., Geog., Ottawa, (49i)
Pickerill, R.D., Geol., New Brunswick, (23b,13)
Pitblado, J.R., Geog., Laurentian, (49j,49b)
Piper, D.J., Geol., Dalhousie, (21,9)
Platt, R.G., Geol., Lakehead, (16a)
Pond, G.S., Oceanog., U.B.C., (51)
Pouliot, G., Génie Minéral, École Polytechnique, (10)
Pounder, E.R., Marine Sci., McGill, (51)
Price, A., Geog, Toronto, (49b,49c)
Price, R.A., Geol. Sci., Queen's, (24)
Prichonnet, G., Sci.de la Terre, Québec à Montréal, (21)
Pride, C.R., Geol., Ottawa, (16a)
Protz, R.L., Land Resource Sci., Guelph, (15d,10b)

Racz, G.J., Soil Sci., Manitoba, (15a,15e)
Rafek, M., Geol. Sci., Saskatchewan, (13a)
Rains, R.B., Geog., alberta, (49a)
Ranalli, G., Geol., Carleton, (26,24)
Rankin, D., Physics, Alberta, (29,33)
Rasid, H., Geog., Lakehead, (49i,49a)

Walker, R.G., Geol., McMaster, (21)
Wangersky, P.J., Oceanog., Dalhousie, (51)
Wardlaw, N.C., Geol., Geophys., Calgary (17,21)
Warren, H.V., Geol. Sci., U.B.C., (40)
Watanabe, T., Geophys. Astronomy, U.B.C., (39,29)
Watkinson, D.H., Geol., Carleton, (2a)
Watters, B.R., Geol. Sci., (16a,42)
Weaver, D.T., Physics, Vicotia, (27)
Webber, L.R., Land Resource Sci., Guelph, (15)
Webber, R.G., Geol. Sci., McGill, (41)
Webster, G.R.B., Soil Sci., Manitoba, (15)
Welsted, J., Geog., Brandon, (49a)
West, G.F., Phys. Geophys., Toronto, (27,38)
Westgate, J.A., Geol., Toronto, (19)
Whitehead, R.E., Geol., Laurentian, (41,2a)
Wilkinson, T.P., Geog., Carleton, (49a)
Williams, G.D., Geol., Alberta, (17,1,23a,47)
Williams, H., Geol., Memorial, (5,24)
Williams-Jones, A.E., Geol. Sci., McGill, (2a)
Williams, P.J., Geog., Carleton, (49a,49j)
Williamson, D.H., Geol., Laurentian, (10)
Willis, A.L., Land Resource Sci., Guelph, (15)
Wilson, D.W.R., Elementary Education, Alberta, (13,26)
Wilson, H.D., Earth Sci., Manitoba, (2a)
Wilson, M.V.H., Zoology, Alberta, (13b)
Winder, C.G., Geol., Western Ontario, (23a,13,50)
Woo, M.K., Geog., McMaster, (49b)
Woods, D., Geol., Sci., Queen's, (27)
Woussen, G., Sci. de la Terre, Québec Chicoutimi, (16a)
Wright, J.A., Phys. (geophys.), Memorial, (29)

Yole, R.W., Geol. Carleton, (21,23b)
York, D., Phys. Geophys., Toronoto, (43)
Young, G.S., Geol., Lethbridge, (49a)
Young, G.M., Geol., Western Ontario (21)

Zentilli, M., Geol., Dalhousie, (2a)
Zeiber, G.H., Geog., Lethbridge, (49a)
Zodrow, E.L., Geol., St. Francis Xavier, (1)
Zwarich, M.A., Soil Sci., Manitoba, (15d)