Academic Program Review
Self-study Report

Department of Earth Sciences
Memorial University of Newfoundland

August 1, 2003

1. INTRODUCTION

1.1 Departmental History

The Department of Earth Sciences ("the Department") is one of nine academic units within the Faculty of Science. It was formed in 1982 through the amalgamation of the Department of Geology with the Geophysics Group, which was then within the Department of Physics. Following this amalgamation, the Department embarked upon a major expansion.

The faculty complement increased from 22 full-time faculty members in 1982 to a maximum of 30 over the next decade. In addition to these regular faculty members, there were 3 University-paid contractual faculty members associated with the Centre for Earth Resources Research (CERR). This unit of the Department was established in 1985 to expedite interaction between the expanded Department and the resource industry, which was anticipated to nucleate around the discovery of the Hibernia offshore oil field. The purpose-built Alexander Murray Building, where the Department and CERR are now housed, opened in 1990 with financial support from the Canada-Newfoundland Offshore Development Fund.

The faculty complement now stands at 25.5 full-time faculty members. Predictable retirements within the next 5 to 10 years will remove upwards of 10 faculty members, with disproportionate impact on some areas of the Department, most noticeably geophysics. Four new faculty appointments are being advertised in connection with a University-level initiative in petroleum development. In addition, the Department has been allocated two Canada Research Chairs (Tier II); one in organic aqueous geochemistry (application before the CRC panel for September 2003) and one in Petroleum Geosciences (a replacement for the CRC held by Andrew Pulham before his resignation in June 2003). The Department will also host the initial Husky Energy Chair as a fully endowed chair in reservoir imaging.

1.2 Departmental Objectives

The Department assumes responsibility for providing high-quality undergraduate and graduate education, and for advancing the state of knowledge through basic and applied research. In keeping with the University's mandate, the Department recognizes a special responsibility to address the needs of our province, particularly in areas of hydrocarbon, mineral and water resources, and the environment.

In order to meet these objectives, the Department strives to maintain a broad spectrum of research and teaching competence. This poses a difficult challenge in an area such as the geosciences where discipline boundaries, which have always been broad, are becoming increasingly so with the recognition of intricate dynamic interactions between the solid Earth, the oceans, the atmosphere and the biosphere. The Department faces some hard choices as our areas of research expertise fluctuate through faculty retirement and loss of technical support, as our discipline expands into new areas of research, as our immediate opportunities for faculty renewal become increasingly tied to specific strategic initiatives rather than maintenance of core

competencies, as our research and teaching infrastructure ages, and as Memorial's traditional student base becomes eroded through a decline in the high school age population of the province.

1.3 Preparation of the Self-study Document

Preparation of this self-study document has provided an incentive to take a collective look at the Department, and to set goals for ourselves over the next few years. This document is one of three similar documents we have prepared over the last decade. One was prepared at the request of the then-Dean of Science shortly after his arrival at Memorial, and another was prepared in connection with an external review of CERR. This current document updates those previous studies and should form a basis for the Department and university administrators to collegially shape the future of Earth Sciences at Memorial.

The self-study document began as draft sections written by three sub-committees of faculty members, was refined by the Head and three individual faculty members (Drs. Hall, Quinlan and Wadleigh), and was finalized at a faculty retreat. It is organized into three major sections dealing with, respectively, our undergraduate program, our graduate program, and our research activities. Conclusions flowing from these three sections are used to formulate a plan for the future direction for the Department, to define the resources needed to achieve this plan, and to identify measures by which attainment of the objectives can be assessed. Supporting data are presented in a series of eight appendices.

2. UNDERGRADUATE PROGRAM

2.1 Degrees Awarded

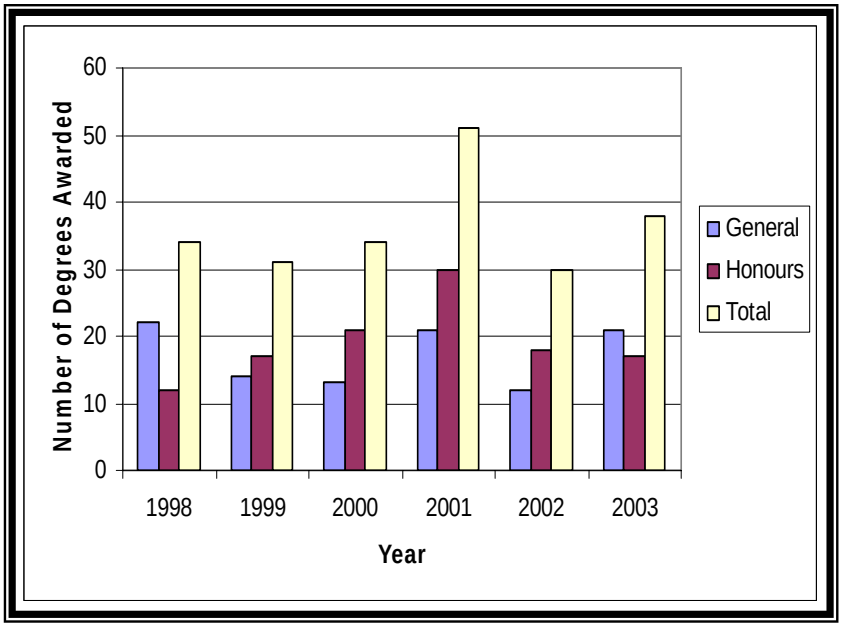
The Department offers Honours and General BSc degrees in Earth Sciences, as well as a Minor program in Earth Sciences. Collaboration exists with other departments in the Faculty of Science by which students can choose from 1 Joint Major and 5 Joint Honours BSc degrees. The details may be found in Appendix 4.

2.1.1 University Degree Requirements

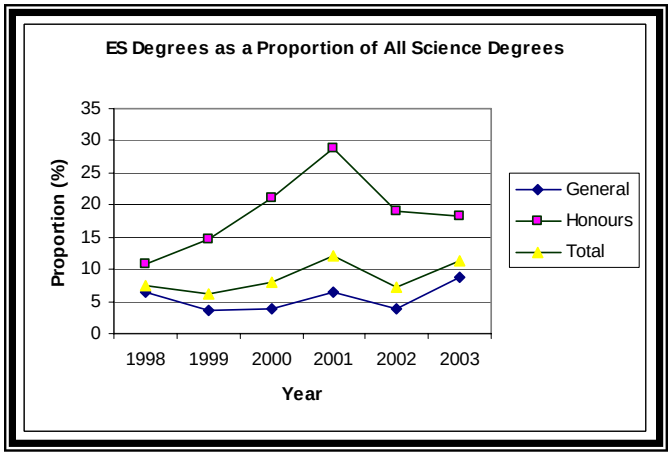
The University requires students to complete 120 course credit hours for either an Honours or a General BSc degree. Most one-semester courses are worth 3 credit hours, and so this requirement effectively amounts to 40 one-semester courses. It is possible, however, to offer courses worth fewer than 3 credit hours. At the moment the Department offers two such courses, both of which are field schools. EASC 2905 is worth 2 credit hours and EASC 3905 is worth 1 credit hour.

2.1.2 Honours BSc vs. General BSc

The number of Honours and General degrees awarded varies from year to year but has totalled 30 or more in each of the last 5 years. The Honours degree requires completion of a greater number of Earth Sciences courses than does the General degree, and also requires a higher academic standing. Many of our General BSc students opt to complete the same Earth Sciences course load as Honours BSc students rather than selecting optional electives from other disciplines. As a result the main difference between our Honours and General BSc degrees is often limited to grades achieved rather than courses completed.



The Honours BSc degree curriculum is the standard used for professional registration as a geoscientist across Canada. For this reason, the Honours BSc degree is generally more desirable to our students than is the General BSc degree.



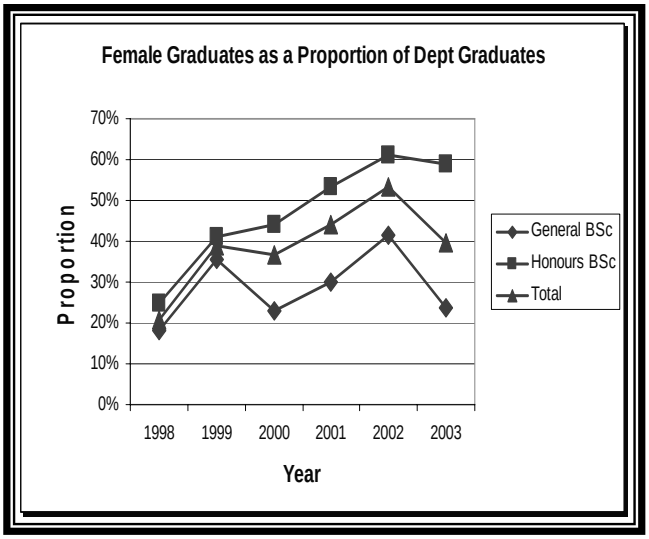
In contrast to other departments in the Faculty of Science, the Earth Sciences Department typically has more students graduating with an Honours BSc degree than with a General BSc degree. In fact, the number of Honours BSc degrees awarded in Earth Sciences is approaching 30% of all Honours BSc degrees awarded in the Faculty of Science. The Department as a whole contributes about 12% of all BSc degrees awarded in the Faculty of Science.

The Faculty of Science stipulates that an Honours degree program must include at least 60 credit hours of courses from the department of Major. Different departments allow their students varying amounts of freedom in selecting courses to meet this requirement. The Earth Sciences Department is at the liberal end of the spectrum, specifying only 17 of the required 54 (excluding 2 first year courses) credit hours (ES2030, 2031, 2502, 2905, 499A, 499B). Students are allowed to select which Earth Sciences courses they will use to complete the remaining 37 credit hours. Students must receive a minimum grade of B (65%) in the 17 specified credit hours, and an overall GPA of 2.75 in the 120 credit hours required for the BSc degree.

This policy is consistent with the Department's view that students should be given choices in their selection of courses. However, there are indications that a minority of students complete an Honours BSc degree without attaining appropriately high grades in courses that most faculty members would consider "core" for the degree. We plan to introduce changes that will increase from 17 to 41 the number of specified Earth Sciences credit hours required for an Honours BSc degree. The additional 24 stipulated credit hours will be at the 3000-and 4000-levels, and will be selected from a list of courses totalling 36 credit hours. The specifics of which courses will be included in these 36 credit hours remain to be decided but will be consistent with national standards as embodied in the Earth science degree regulations of other Canadian universities and the criteria for registration as a Professional Geoscientist.

2.1.3 Gender Balance among Graduates

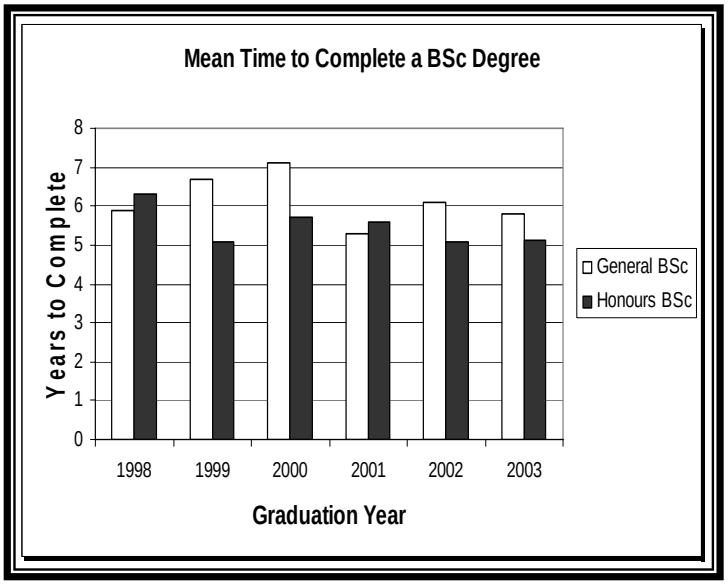
Our graduates are fairly evenly divided between male and female. The proportion of female graduates has increased to somewhat more than 50% over the last few years, particularly among students graduating with the Honours BSc degree.



2.1.4 Time to Complete a Program

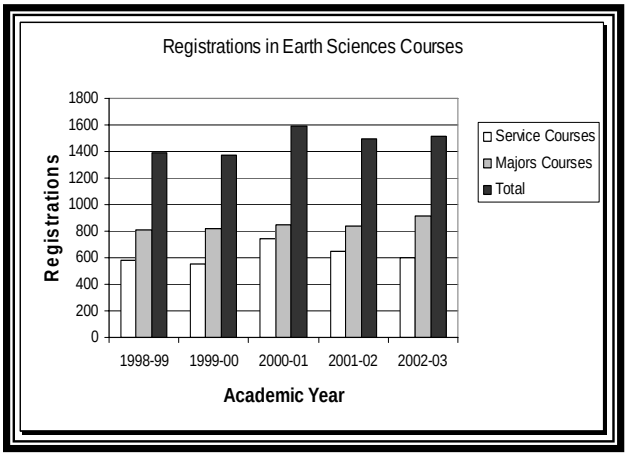
The average time a student spends in the program can be estimated by comparing the year of graduation with the student number, the first two digits of which indicate the year the student first enrolled at Memorial. This method does not establish the exact number of semesters spent in the program because there are two convocations in each calendar year, and a student may enrol at Memorial in any of the 3 semesters.

Recognising the limitations of this method, the mean time Earth Sciences graduates take to complete a General BSc is 6.4 years, averaged over the last 6 years. The mean time to complete an Honours BSc is 5.4 years, averaged over the same interval. There was only one year in this 6-year interval that any General BSc students graduated after spending the minimum 4 years in the program. In this same interval, there have never been more than 40% of the Honours BSc students graduating after the minimum 4 years.



2.2 Courses Offered

The Department lists approximately 50 undergraduate courses in the University Calendar. Of these 50 courses, 4 are service courses at the 1000- and 2000-level, which are taken primarily by students from a general academic background. These 4 service courses typically account for 40% or slightly more of our undergraduate course registrations. In any academic year the Department handles between 1350 and 1550 undergraduate registrations, spread over 3 semesters. Only 1000-level courses are offered in the 3rd academic semester (May - June).



In addition to Earth Sciences courses, our faculty members routinely teach two courses in the Faculty of Engineering (ENGI 3610 and ENGI 7601), 2 or 3 courses in the Department of Physics and Physical Oceanography (PHYS 1020, PHYS 1021, PHYS 3500), and 2 courses in palaeontology, which are cross-listed with the Biology Department (EASC 3811/BIOL 3811 and EASC 4800/BIOL 4800).

2.3 Thematic Structure of the Undergraduate Program

Courses intended for students pursuing a Major program in Earth Sciences cover a wide range of specialities. Our undergraduate programs for Majors are designed around thematic streams, which allow students to combine courses in ways that most effectively support their interests and career goals. There are currently five such streams (Geophysics, Mineral Resources, Sedimentary Basins, Environmental & Engineering Geoscience, and a Comprehensive Stream). The actual degree awarded is a General or an Honours BSc in Earth Sciences; no designation of a specific stream appears on the degree.

Each stream has a list of recommended courses (see Appendix 2). All of the streams satisfy national standards for professional registration, and all streams are broad enough to lay a solid foundation for students pursuing graduate studies in most aspects of geology or geophysics.

The differences between these five streams become most apparent in the selection of 4000-level courses associated with each of them. In earlier years there is sufficient overlap between the four non-geophysics streams that students can relatively easily move between any of these four streams. The geophysics stream is different in that it requires courses in Mathematics and Physics that would not normally be taken by students in the other streams.

Unfortunately, the 4000-level courses that differentiate the streams are not all offered on a regular basis with many only being offered every second year or on sufficient student demand. The significant overlap between the various streams makes it difficult to determine sufficiently far in advance which senior level courses will be in demand in any given year. Students must sometimes substitute for their preferred course in a particular stream because a relevant faculty member is not available that year or because early enrolments are low and the class is cancelled. Only the Geophysics stream, with its specialized quantitative courses, allows easy recognition of its students and planning for its 4000-level course offerings. Scheduling of 4000-level courses in a way that supports our thematic streams is a significant challenge that will become more difficult as faculty members with specialized skills retire.

2.4 Teaching Practical Skills

One of the main strengths of our undergraduate program lies in the opportunities that it offers for practical exercises based in the field, and in the laboratory using modern equipment. Without such an emphasis on practical skills, material covered in lectures can easily become theory detached from reality. In many areas of our undergraduate curriculum the field and laboratory component is at least as important as the lecture component.

2.4.1 Our Approach

We have four field schools of 5 to 14 days duration offered either immediately before the fall semester or immediately after the winter semester. Many of our 2000-level and higher courses include some full-day field based exercises distributed throughout the fall semester when weather permits such activities. Practical exercises in mapping, measurement, and collection of sections for structure, stratigraphy, palaeontology and geophysics take advantage of both our proximity to a variety of geologically interesting features and of the range of equipment we have available for instruction in field technique. Dedicated student laboratories with microscopes, computers, core layout tables, seismic and other geophysical interpretation facilities, and laboratories for geochemistry and palaeontology bring together the theoretical and practical aspects of our science.

Technological developments such as GIS are changing how geoscientists approach a range of issues from map-making to data analysis. Training in such technologically emerging areas is directly incorporated into laboratory components of many of our undergraduate courses. As a result, our students become familiar with these technologies without our having to dedicate specific courses to these topics.

A course in oral and written communications (EASC 2311) gives our students specific guidance in these important skills at an early stage of their undergraduate program.

2.4.2 The Challenges

Equipment

Microscopes and computers are the items of equipment most widely used in undergraduate instruction. There is a finite lifetime of perhaps 10 years for a microscope and 3 to 4 years for a computer. If even a small capital budget is regularly available, a few new microscopes and a few new computers can be purchased regularly. This allows gradual replacement of the oldest and least serviceable instruments, keeping the facilities operational and always at least partially up to date. With no capital budget, as has been the case for the last several years, we will eventually face a major capital expense associated with complete replacement of these facilities.

In the case of the computer laboratory, eventually is now. At the moment more than half of this facility is essentially non-functional. The Department secured a $100K donation in 1999 from Mobil Oil of Canada, which we used to equip expanded computer laboratories for teaching. Were it not for this donation, we would now have too few functioning computers to deliver our undergraduate program. Of course these new computers are themselves becoming outdated and non-functioning, with no clear path available for their replacement. Although general-purpose computer facilities are available for the entire Faculty of Science, these are inadequate as many of our undergraduate needs dictate the use of specialised licensed software (e.g. seismic analysis) and / or hardware (e.g. digitising tablets) that are not available in the university general purpose facilities.

Personnel

In addition to problems created by an aging equipment base, we also experience difficulties with the allocation of personnel to our undergraduate teaching program. Although this issue is most noticeable with technical personnel, it has started to involve faculty members.

Maintenance of the teaching collections in petrology, mineralogy, palaeontology and sedimentology is essential. Without proper maintenance, these collections quickly deteriorate to the point that appropriate teaching material either doesn't exist or cannot be easily located when needed. At the moment this maintenance is done in an *ad hoc* manner. There is a critical need for a new Instructional Assistant position to curate these collections, add new material where there are important gaps in the collections, prepare materials for laboratories, and assist in the conduct of these teaching laboratories. Collectively, the numbers of students in 2000- and higher-level courses that utilise these collections is similar to those doing 1000-level courses. Although the 1000-level courses have one permanent and one sessional support staff member, courses at higher levels have no such support.

Our faculty members have traditionally been actively involved in the delivery of laboratory exercises and field schools. Recently there has been discussion at the Faculty of Science level regarding the necessity of such involvement. The issue seems to be driven by financial pressures stemming from the Faculty Association Collective Agreement, which stipulates the maximum teaching load that can be assigned to a faculty member. Courses having a laboratory component carry more weight than courses without a laboratory component. Hence a single faculty member can be assigned more courses if there is no responsibility for laboratory teaching. This policy has already been implemented at the 1st year level. The Department strongly opposes this policy, especially if applied beyond 1st year. If implemented in senior years, it will have significant, negative impacts on the quality of the educational experience we provide to our students. We believe that some courses lend themselves to an alternative style of teaching. For these courses, we would prefer to abandon the lecture component and concentrate on laboratory- and field-based instruction than to do the opposite. Laboratories typically are three hours long, in contrast to the three 50-minute slots per week allocated to lectures. This new format would lead naturally into an evaluation of the benefits of teaching in uninterrupted blocks of time. This approach should be considered whether or not the Faculty of Science goes ahead with plans to remove faculty members from the teaching laboratories.

2.5 Measuring Quality of the Undergraduate Program

2.5.1 Subsequent Success of Our Graduates

The success our graduates have in pursuing their careers is perhaps the most tangible indicator of the quality of our undergraduate programs.

Recruiters from major companies in the oil & gas sector and the mineral sector visit the Department annually and hire many of our students for summer and permanent employment. Our students are equally successful in finding positions in graduate schools across Canada and

internationally. From these graduate degrees they go on to responsible positions in government, industry and academia. A listing of many of our recent graduates and their initial employment is included in Appendix 8.

2.5.2 Feed-back From Our Current Students

Since the late 1980s the Department has actively promoted student evaluations of our courses. Course evaluations are submitted in confidence near the end of the semester, and examine issues ranging from course material and delivery, to integration with other courses, to utility of textbooks and laboratory exercises. Faculty can use the responses to the formal written reviews presented at the end of the semester to refine and revise courses. A less formal mid-semester meeting between the different year classes and the Head has been successfully used to see that the scheduling of diverse course assignments and tests is adequately managed.

Within the last two years the University has instituted a campus-wide system of course evaluations, which has replaced our own Departmental course evaluations. These new evaluations, which produce a generic picture of the campus, are augmented by questions of specific importance to the Department.

2.6 New Initiatives

2.6.1 Interdisciplinary Studies

The geosciences share common interests with many other disciplines. Recognizing these interdisciplinary linkages, the Department has joint programs with the departments of Biology, Chemistry, Geography, and Physics & Physical Oceanography. Unfortunately, students rarely complete these joint programs. Participating departments commonly require such a large number of their own courses that these programs become difficult to schedule and unattractive to students.

Interdisciplinary programs at the graduate level, such as the Masters in Environmental Science, have attracted large numbers of students in recent years. Such programs are both scientifically justified by the expanding boundaries of our discipline, and practically justified by the high level of student interest. As there is likely to be a similar level of interest at the undergraduate level, our collaborative degree offerings with other departments at Memorial need to be re-evaluated. Although the way forward through the current problems of overloaded programs is not clear, the underlying interest and student employment prospects in these areas justify renewed effort.

The growth in offshore oil exploration and the importance of mineral developments such as Voisey's Bay suggest applied interdisciplinary programs involving the Faculty of Engineering and/or the Department of Geography. An Engineering Geology program could focus on reservoir evaluation and development, as well as surficial processes involved in site development and remediation.

The Department of Physics & Physical Oceanography has recently introduced a program in Environmental Physics, which has some required Earth Sciences courses included in its curriculum. The Department will investigate the possibility of developing an interdisciplinary Physical Environmental Science program, involving collaboration with the Departments of Physics & Physical Oceanography and Chemistry, and the Faculty of Engineering. This program would not duplicate the existing Environmental Science undergraduate program at Sir Wilfred Grenfell College (Memorial's campus in Corner Brook), which focuses mainly on biological and chemical aspects of environmental science.

We see such interdisciplinary programs as being distinct from the joint programs that are currently offered but rarely taken. These interdisciplinary programs would lead to specific degrees, for example BSc (Engineering Geology) or BSc (Applied Environmental Science).

2.6.2 Service Courses

Service courses broaden students' education, and distribute the teaching responsibilities more equitably across all units within the University. Although high-enrolment service courses improve a department's overall faculty-to-student ratio, service courses cannot be a major focus for any department. The University awards degrees for completion of specific Majors, and not for completion of a collection of service courses. Keeping these issues in mind, the Department recognizes a responsibility to offer service courses, and recognizes a practical necessity to maximize the enrolment in such courses.

The Department now offers four courses specifically designed for a diverse student base: EASC 1001 (Earth History); EASC 2150 (The Solar System); EASC 2914 & 2915 (Human utilization of resources). EASC 1000 (Earth Systems), although taken mostly by non-specialists, is also the entry-level course for Earth Sciences majors. EASC 2914 and 2915 each attract 100 or more students, whereas EASC 1001 and EASC 2150 attract only 25 to 50 students each. It is reasonable to ask why there is such a difference in student interest. As a general characterization, the more popular EASC 2914 & 2915 offer science credits without the usual trappings of a traditional science course. They have no prerequisite science courses, few quantitative aspects, and no laboratory requirements. Such issues need to be considered in designing syllabi for any new service courses.

2.6.3 Co-operative or Experiential Education

The Department has considered the idea of offering a co-op undergraduate program, such as is offered in Memorial's Faculty of Engineering and Applied Science and School of Business. When such programs are widely supported by employers they offer students valuable work experience, and can significantly reduce student debt load at graduation. When the economy is weak and demand for co-op students is low, these programs can be a major burden for students who need to complete work term placements in order to graduate.

The main advantage to the Department in having a co-op program is the potential for an increased number of Majors. At the moment, many of our core undergraduate courses have enrolments that tax our physical resources. However, if the overall enrolment at the University were to decline as many predict will happen, such programs could be a useful recruitment tool. The main disadvantage is the requirement to offer a full range of undergraduate courses in all 3 semesters, including the summer months when many faculty members would normally be involved in fieldwork.

As an alternative to co-operative education, the Department has experimented (in our field courses) with experiential learning through the use of the laboratory courses (field or laboratory based) that are full time for short durations. As an example, the Department recently offered a highly successful petroleum / sedimentology course (EASC 4915) in Ireland as a full-time 3 credit hour course in compressed format. In order to achieve some industry-focus, several members from a major petroleum company also attended the course and acted, along with the instructors, as mentors to the students. This proved to be a highly effective means of delivering this part of the curriculum and the students rated this course experience as among their best at Memorial. It is also an efficient means of using faculty time for instruction. In essence, a course load, normally spread over 13 weeks, was completed in 3 weeks (including examination and marking time). For many faculty members, this scheme would allow a far greater effort to be concentrated on research without adversely impacting the quality of undergraduate experience. This could be used more widely in the Department to achieve some of the benefits of co-operative education without the overheads and constraints.

We would welcome the advice of the Review Committee as to relative value of implementing different types of program delivery than those currently used in the Department.

2.6.4 Continuing Professional Development

Continuing Professional Development courses are a special form of service courses that the Department needs to consider, particularly in the light of requirements for professional registration of geoscientists in the province. Such courses are prohibitively expensive to develop unless they can be offered on a regular basis. It may be possible to design courses that meet the needs of professionals yet also serve the needs of our senior undergraduate and/or graduate students for specialized courses in their thematic areas of concentration. Such modular courses would take advantage of the possibility for courses worth fewer than the standard 3 credit hours.

There are many questions related to content and delivery when such an approach is used. For instance, when and how to offer courses; how to charge external participants and students; measuring modular courses as a part of a professor's teaching load; determining an appropriate evaluation format for awarding credit, integration with web-based learning, and how to evaluate a credit level (e.g., 3000 or 4000) for regular students and external participants. Nevertheless, these problems are largely of a logistical nature and the time appears ripe to explore alternative delivery methods in an open-minded way to see if there are workable new ways of teaching that we can utilise to the advantage of both faculty and students.

3. GRADUATE PROGRAM

3.1 Degree Programs Offered

The Department offers MSc and PhD degrees in Earth Sciences (Geology) and Earth Sciences (Geophysics) by either full time or part time study. A research thesis is a major component of each of these degrees. In addition, the Department participates with other departments in interdisciplinary graduate programs, most notably the Graduate Program in Environmental Science and the newly established Master of Oil and Gas Studies (MOGS). The former offers both a thesis-based MSc (Environmental Science) degree and a course-based Master in Environmental Science degree; the latter offers only a course-based Master of Oil and Gas Studies degree.

3.2 Supervision of Graduate Students

According to University regulations each PhD student must have a Supervisory Committee consisting of at least three faculty members including a designated Supervisor or Co-supervisors. Although MSc students must have only a designated Supervisor, most MSc students in the Department also have a Supervisory Committee consisting of the Supervisor and one additional faculty member. Funding for the student's research program is the responsibility of the Supervisor or Co-supervisors. The Supervisory Committee provides academic and administrative guidance.

3.3 Graduate Courses

The Department currently requires MSc students to complete 6 credit hours of graduate courses, a thesis proposal examination, and a thesis. PhD students must complete an additional 6 credit hours of graduate courses, a comprehensive examination, a thesis proposal examination, and a thesis defence. At both the MSc and PhD levels, a student's Supervisory Committee may require additional courses where there is perceived weakness in the student's background preparation.

The Department lists 26 graduate courses in the University Calendar, each worth 3 credit hours. Some of these courses deal with relatively specialized topics, and others deal with broader issues in Earth Sciences. Few of these courses are offered on a regular basis, and rarely in a lecture format. This situation has its roots in two issues: the workload value assigned to graduate teaching in the Faculty Collective Agreement; and the wide spectrum of views within the Department regarding the function of graduate coursework.

Under the present Collective Agreement workload formula, graduate teaching may be considered either part of a faculty member's overall teaching workload or part of a faculty member's supervisory responsibilities. The deciding factor is the number of students enrolled in the graduate course; the cut-off point is 4 or 5 students at the discretion of the Head.

In order to get this minimum number of students in a course, the course would either have to be mandated by the Department or deal with a topic of broad applicability. Without teaching credit, there is little incentive to teach a course to other than one's own graduate students. These courses usually take the form of directed reading specifically related to the thesis topic. Although such courses foster student-motivated, individual exploration, they don't provide the group environment that encourages collegial interaction between graduate students, and do nothing to broaden a student's background knowledge.

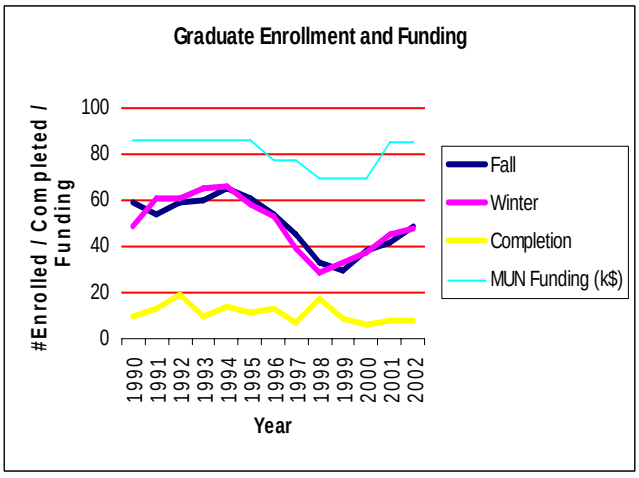
Some faculty members in the Department feel that graduate students need more formal course requirements in order to develop a broader, perhaps cross-disciplinary, perspective. Others feel that such courses simply divert students' attention away from their thesis research, and so increase graduate residence times. Hence, there is no agreement in the Department about whether we have a problem, let alone how to deal with it.

There is little empirical evidence to support the view that more required courses means longer residence times. The Department used to require all MSc students to complete four 3-credit hour graduate courses. The reduction to the present two courses has not produced a noticeable reduction in the time taken to complete the MSc degree.

We would value the Review Committee's views on an appropriate number of graduate courses required for a degree.

3.4 Graduate Enrolment and Funding

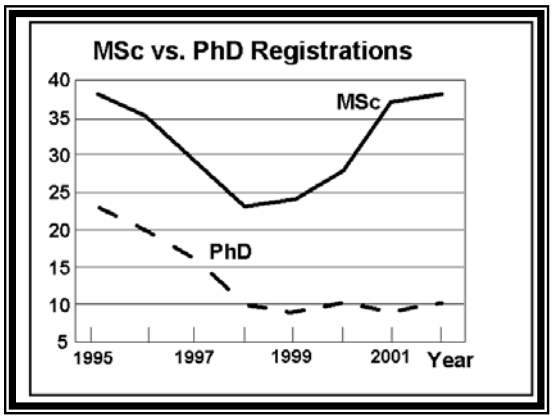
There is a consensus in the Department that one of our major strengths lies in the depth and breadth of our teaching and research profile, and that the graduate population should reflect that strength. Sources of funding for research and graduate students, which have traditionally been dominated by NSERC, are changing to include an increasing contribution from other public sources and the private sector. The Department needs to adopt strategies that create an appropriate balance in our research efforts, and insure that this balance and funding attendant with it reflect the breadth of the Department.



The minimum levels of support for graduate students eligible for fellowship (nominally 75% average in Earth Sciences undergraduate courses) are $15,000 per annum for MSc student and $16,500 per annum for PhD students (supervisors may, and often do, top this up). These include a Teaching Assistantship of $1500 per annum (two laboratory sections @ $750) and a supervisor's grant of $6,000 per annum. The balance is provided from the School of Graduate Studies (SGS) allocation to the Department. The level of funding provided by the SGS is presently at a level comparable to the

early 1990s. However, because the Department has raised the value of graduate fellowships since 1995 by 25% - 30% in an effort to enhance recruitment, the actual number of graduate fellowships partially funded by the SGS has decreased to about 65% of early 1990's levels.

Under current practice, the Department awards graduate fellowships from the SGS baseline allocation on the basis of GPA, with two lists formed: one of Canadian and landed applicants and the second of international student applicants. Both lists are considered from the top rank GPA downwards until the entire SGS baseline is committed. THERE NEEDS TO BE SOME MENTION OF HOW A BALANCE IS STRUCK BETWEEN CANADIAN AND FOREIGN APPLICANTS. Often, this results in applicants with an average of 80% still not being awarded any SGS baseline. This process could be modified to continue to award SGS support on the basis of GPA, but with additional consideration being given to applicants whose field of study is not as likely to attract industrial support. This would assist in balancing the number of graduate students receiving support from the SGS.



In the early 1990s graduate enrolment was around 60 but decreased starting in 1996 and fell to 30 in 1998-99. In the past three years graduate enrolment has increased and presently stands at 48. It is noteworthy that although the number of M.Sc. candidates has risen to 38 from the 1998-99 low of 23, the number of Ph.D. candidates has remained steady at about 10 over this same interval. The increase in graduate enrolments since 1998-99 is, therefore, entirely due to increased numbers of M.Sc. candidates.

These enrolment numbers include only those students registered for Earth Sciences degrees and does not include those students in interdisciplinary programs that are supervised, partially funded and housed in this department. At the present time, there are five such M.Sc. students.

The average residence time for M.Sc. candidates is 13.5 semesters (4.5 years) and for PhD candidates is 17.9 semesters (6 years). There is no way in the system to determine if a student is on campus as long as they are continuously registered. These averages include time taken out for employment, and more importantly, the time in which a thesis is undergoing examination and revision. We would suggest that 2 to 3 semesters is a typical duration for the examination and revision period. Even with this modification, the average time to complete a M.Sc. degree exceeds 3.5 years, and the average time to complete the PhD degree exceeds 5 years.

Although the trend across Canada has been towards longer times to complete graduate degrees, these residence times are cause for concern. The extra time increases the demand on supervisory time, office and laboratory space and infrastructure and cost. The latter is especially acute in the light of the fact that normally University funding is available only for the first 2 years of the M.Sc. program, with a further 3 years of fellowship available for the Ph.D. program.

The Department plans to aggressively investigate methods to reduce the length of time in program for each of the degrees. It may be that we are requiring too much of our students, especially M.Sc. students. It is recommended that Supervisory Committees need to be more vigilant in keeping the thesis "on track" and that within bounds the thesis timeline in the thesis proposal should be a guide.

Over the last several years, various Departmental committees have identified a set of issues some of which have been the focal points of Departmental attempts to aid recruitment and increase graduate enrolment. In order of perceived importance these issues are; 1) funding, 2) raising the level of awareness of the department within Canada and internationally, 3) streamlining the response to graduate inquiries and admissions procedures, 4) cultural perceptions of Memorial in mainland Canada. Modest increases in the number of fellowships have occurred through externally funded chairs within the Department and by including teaching assistantships, funded by the Faculty of Science, as part of the Graduate Fellowship. The Departmental web site has become increasing friendly for potential graduate students looking for opportunities, and the graduate assessment and admissions procedure has been streamlined through an internal Departmental webpage.

The Department has set a goal of having at least 75 graduate students in the department by the end of 2006 (an average of three graduate students per faculty member). If this is to be achieved, both the effectiveness of the graduate research must be improved and additional mechanisms for graduate fellowship support must be identified.

The complement of graduate students has benefited significantly from the two externally funded chairs (Petro-Canada Chair in Applied Seismology and VBN Paterson Chair in Mineral Deposits) in the Department. These chairs have been successful in attracting a number of high quality graduate students that function as research groups and provide a core of enthusiasm that is very healthy for the graduate environment. The Department also participates in two interdisciplinary programs (Environmental Science and Computational Science) that provide access to other sources of graduate funding and broadens the potential graduate experience in the Department. With the filling of the two Canada Research Chairs (Petroleum Geosciences and Aqueous Organic Geochemistry) and the Husky Energy Chair and their associated research budgets, it is anticipated that similar centres of graduate activity will grow in the Department.

3.5 Issues in the Graduate Environment

The Department offers graduate students the opportunity to participate in a broad range of high quality research programs in an active and diverse environment. The range of research projects available provides preparation for entrance into either the academic or industrial environment. The Department houses a large range of high-end analytical facilities in support of geochemical, petrological, geophysical and environmental studies. The Department also houses a complete computational facility for seismic data processing and interpretation and will shortly house an immersive visualization facility. Two new industrially based programs will come on stream over the next year (the PanAtlantic Petroleum Systems Consortium (PPSC) and Inco Innovation

Centre (IIC)) that will operate as centers of applied research and will carry funding for graduate students.

The research facilities in the Department are operated by user groups (see Section 4.6.2) that charge a user fee designed to cover operational costs of the facility. Costs for the support of graduate research are born by the student's supervisor from external grants. To support the graduate student research, the University provides office space, laboratory space and technical support.

There are concerns related to graduate studies that surround the cut backs in university-paid technical support. This issue is discussed at greater length in the Research section (Section 4.6.1). At present, we have limited technical support for all of the major analytical facilities but minor facilities lack any support. With respect to graduate students, one of the major issues in using research facilities is the shortage of tutorial style technical support for training in the operations of expensive, delicate analytical equipment and complex computer software. Graduate students sometimes suffer discouraging delays in research due to prioritization of the duties of a thinly spread Departmental technical support staff. If the graduate student population in the Department grows significantly, as we expect it will with the addition of the new CRC Chairs and the initiation of the PPSC and the IIC initiatives, lack of sufficient technical support will become a critical issue for the quality of the graduate experience.

Although the Department embraces the role of the University and the Department in training highly qualified personnel, there is an ongoing debate in the Department concerning the cost effectiveness of graduate students (particularly MSc. candidates) in research programs. A number of faculty members have gone through the experience of investing significant amounts of time and money in graduate students that do not complete the graduate program and leave no legacy that aids faculty in seeking further research funding. The Department has also experienced situations in which graduate students leave the graduate program and destroy or carry away data acquired as part of their research projects. While these situations represent a minority experience, they have had enough of an effect on faculty perceptions that some faculty have elected to hire well-qualified, part-time research assistants in place of graduate students.

The Department and the SGS have made an effort to address these issues by clarifying the respective responsibilities of the supervisor, the supervisory committee and the graduate student. The Department and the SGS have also worked together to define an option to allow manuscript-based Ph.D. theses. The manuscript-based format puts the student farther down the route of timely, peer reviewed, reporting of research work, which is advantageous to both the student and the supervisor.

The Department, in collaboration with the SGS, must put in place mechanisms that ensure that the faculty member's investment in a graduate student program is protected.

In the near future the Department will house two new industrially based research initiatives and presently houses two industrially based research chairs and two CRCs. These chairs and initiatives are important to the Department because they provide the means to increase research

that is of direct relevance to the resource sector in the Province and they directly fund graduate student fellowships and research. However, there is debate in the Department about how these programs of applied research will affect the broader mandate of more curiosity-driven research and specifically individual faculty members who, for a variety of reasons, are unlikely to participate in the applied initiatives. There is a concern that individual researchers operating on modest NSERC or other grants will be marginalized in the department due to very stiff competition for graduate funding.

The Department must put in place a policy that ensures that all research is valued in the Department. We must be very clear that in all aspects of university research, the excellence of the personnel and of the work is paramount. This is essential for both faculty and graduate student morale. Some instruments to encourage this are distribution of the SGS funding (see previous), insuring that priority for use of equipment is equitable (not first for those who can pay a premium or who "need" to meet a contractual deadline).

Because of the breadth of research programs in the Department there is an increasing desire to draw graduate students from other disciplines (mathematics, physics, chemistry, biology and engineering) into graduate programs in Earth Science. The majority of faculty agree that a graduate degree within the Department must contain some components from the Earth Science program. The problem is to provide the Earth Sciences component without setting out hurdles that unnecessarily increase program length and make graduate work in the Department less attractive for "non-traditional" applicants. This might be an area where the overview courses could be valuable. Another approach to this issue might be to require the student to attend one or several undergraduate courses. This approach meets with mixed success because first and second year courses are generally below the sophistication level of the graduate student and third and fourth year courses tend to be too specialized.

Current and proposed overview graduate courses can play a role in attracting and integrating students whose undergraduate experience is not that of an earth scientist to view the Department as an attractive graduate locale.

3.6 Summary of Goals for the Graduate Program

The primary goal for the graduate program is to maintain the breadth and depth of research possibilities available to graduate students and to train a broad spectrum of highly qualified personnel. This goal is well supported by the physical, analytical and computational facilities in the Department. However, the shortage of technical support staff is at a critical level and will restrict the quality of graduate student experience as new programs come on-line and indeedeven the ability of the Department to attract additional students. Maintenance of a broad program also requires that the Department find an appropriate balance between academically and industrially oriented research, and actively foster research in both realms. Funding for graduate fellowships is the major impediment to maintaining a broad base of graduate students. The Department recognizes that significant additional funds will likely not be forthcoming from the SGS. New, industrially based research initiatives will provide graduate funding in specific focus areas but unless these initiatives free funding for other areas of the Department, the graduate student

population could become increasingly narrow in focus. Innovative approaches at a variety of levels will be required to provide the funding to maintain or increase the breadth of graduate opportunities.

Several examples of programs that we are presently implementing or are under consideration provide a flavour of the range of possible approaches. The first example is the new program for Crustal Evolution Studies. This program is designed to bring together faculty and student researchers from across a range of disciplines including geochemistry, petrology and geophysics to study a range of issues focused on the evolution of the Earth's crust. The Department is ideally suited to host the program as several of the faculty are internationally recognized workers in various aspects of crustal evolution and the analytical and computational facilities support state-of-the-art research. Parallel examples exist in the Basins and Reservoir components of the PPSC in which researchers from a wide range of sub-disciplines are cooperating on a thematic study. It is expected that the IIC will provide exactly this venue for a comprehensive research study of the genesis and evolution of the Voisey's Bay and other similar base metal deposits.

Another possibility for building the graduate program strength is that of a course and / or project-based graduate program focused on providing high-level and focused education in specific fields. This type of program would operate under a fee-schedule that would enable it to be self-sustaining, and would focus on attracting students seeking specific technical training and professionals interested in professional development in specific areas. The attraction of this type of program to the Department and the University is that it could help maintain the breadth of faculty in the Department. This type of program also has the potential to provide the Department with renewal of aging teaching equipment such as computers and microscopes that are increasingly difficult to replace through the base academic budget.

The Department will actively consider the goals, program requirements and the resources required to offer course-based graduate programs in targeted areas.

4. RESEARCH

4.1 Current Status

The Department aims to maintain a broad research program that balances an understanding of fundamental Earth processes with applications of geoscience to resource and environmental issues. The range of Departmental research is reflected in the faculty curricula vitae (Appendix 1) and in the summaries of research activity of various groups within the Department (following sections).

Historically, Memorial's reputation in Earth sciences was built on geological mapping of the Appalachian mountain belt, later supported by palaeontology and analytical studies in geochemistry and petrology that demonstrated the applicability of modern plate concepts to this orogen. Paleomagnetic studies confirmed the major continental movements involved. The development of laboratory studies was extended to new techniques in geochemistry (e.g., inductively-coupled laser-ablation mass spectrometry) and geochronology (e.g., U-Pb dating of zircons). The reducing costs of computer cycles assisted in the Department's enhancement of capabilities in geodynamics and in seismological imaging. Marine geological studies, especially of sedimentary basins, were enhanced by high resolution single- and multi-channel seismic reflection acquisition systems, backed up by new facilities for examination of drill-core. The Department has also made significant investments in environmental geochemistry and engineering geology. The balance of field- and lab-based research has been improved by the emphasis on field mapping of Archean and Proterozoic geology brought by the Voisey's Bay Nickel Paterson Chair.

So what has the Department of Earth Sciences contributed recently in research? Details are listed elsewhere, but achievements in a variety of areas might be summarised as follows.

The national Lithoprobe research program figures prominently in research accomplishments in the Department. Quinlan, Hall and others have shown that the deep structure of the Appalachians in Newfoundland is compatible with geodynamic models of collision, but that for Newfoundland the collision was 'soft' with modest crustal thickening especially in the north-east. Hall and others found that Proterozoic crust in the NE Canadian shield is variable in thickness and seismic velocity, it is readily distinguishable from local Archean in having prominent internal whole-crustal reflectivity, it retains early Proterozoic crustal roots (below the Torngats), and is quite susceptible to overprinting by younger events. Indares has made major contributions to our understanding of spectacular high-pressure rocks in the Manicouagan area of Quebec. With Indares, Hurich has shown how the variation of seismic velocities in those high-pressure rocks can be linked to deep crustal reflectivity patterns. These Grenville rocks are part of a newly-recognized high-pressure belt in the Grenville orogen, and Rivers has shown that this belt implies rapid exhumation of lower crustal rocks in a manner similar to tectonic models of the Himalaya: this process may be a general feature of wide, hot orogens.

Burden and Calon have remapped part of the Humber zone in western Newfoundland to show quite different associations of formations with tectonic slices thrust onto the Appalachian

foreland. From U-Pb zircon geochronology, Dunning has continued to make critical contributions to understanding of various geological provinces in Canada, including a surprising demonstration that the largest gold deposit in the Canadian Appalachians at Hopebrook (NL) is Precambrian. Wilton has discovered early Proterozoic organic material (oldest in eastern N. America, and amongst the oldest known) in the Mugford Mountains of Labrador. He is also examining the geochemistry of chert artefacts from northern Labrador and New England in an attempt to link 10,000 year-old arrowheads from Vermont to northern Labrador: the results have implications for concepts on the peopling of North America. In a transatlantic collaboration, Miller has discovered trends orthogonal to the Appalachian subsurface geology on both continental margins.

Sylvester and co-workers demonstrated that in-situ U-Pb dating of zircon grains by laser ablation ICP-MS can yield precision and accuracy similar to TIMS dating. With others, he has rekindled interest in the big-bang model for early formation of most of the continental crust. With Hodych and Cox, he has also proven the value of apatite fission track by ICP-MS, rather than the traditional irradiation techniques.

Leitch and collaborators have shown that pervasive mesoscale flow is a mathematically-viable mechanism for granite intrusion, alongside dyking and diapirism. This mechanism could have significant impact on the temperature history and composition of the continental crust. She continues to evaluate her mathematical models with laboratory analogs.

Slawinski has developed many new contributions through his industry-sponsored geomechanics project. Included among these are rigorous proofs of Fermat's principle of stationary traveltime for general elastic media; the use of the ray parameter in modelling anisotropic and inhomogeneous media; and the application of the Finsler metric to differential geometry in ray theory.

Wadleigh has used sulphur and oxygen isotopes in tracing sources of atmospheric sulphur, developing new techniques using lichens as detectors, with applications to distinguishing local anthropogenic point sources from long-range transported anthropogenic sulphate and sea spray.

Aksu, Hiscott and co-workers have found non-catastrophic variations in sea-level to refute the Ryan and Pitman hypothesis of the biblical Noah's Flood, which they attributed to sudden opening of connection between the Mediterranean and the Black Sea. From marine reflection seismic in the eastern Mediterranean, Aksu, Calon and Hall have discovered how strain partitions from oblique slip zones into separate thrust and strike-slip faults as the angle of plate convergence relative to strike changes around the associated arc. Hiscott with others have discovered abundant sheet sands in (ODP) drilling the deep-water Amazon Submarine Fan. This surprise is likely to lead to reappraisal of the petroleum potential of deep-water fans.

The Department's research inventory (Appendix 6) reflects most of the funding won from external agencies, together with a few internal awards, over the last five years. In this period, annual cash contributions to the research inventory vary from $1 million to $3 million dollars, with over $1 million per year coming from NSERC, which supplies some funding to 18 out of 25

departmental full-time faculty members. Up to $600 thousand comes from private companies, $300 thousand comes from other public sources, with one exceptional contribution of $1.5 million from CFI for the visualization system. Software donations constitute up to $3 million per year of in-kind contributions (notably from Landmark Graphics Corporation).

This level of research funding is moderately good for a science department at Memorial University, the total annual research inventory of which is just short of $50 million, and is quite good, but not exceptional, for a Canadian department of Earth Sciences of its size. The average annual inventory for the Department has decreased somewhat in actual dollar terms over the last ten years, but initiatives currently being pursued have potential to raise our research profile to new levels.

Over the last 20+ years, the Department of Earth Sciences has established a widely-recognised reputation for its research. The current research profile reflects some of the problems, especially budgetary, in maintaining and extending this reputation. The Department recognizes a need to enhance its research profile, and is taking initiatives to do this.

4.2 Large-scale Multi-institutional Collaborative Research Programs

Modern geoscience research involves projects at various scales, from those of individual researchers, to national and international programs. The Department continues to play leadership and collaborative roles in those larger projects.

The Department has housed the Canadian secretariat of the *Ocean Drilling Program* (ODP). Hiscott is chair of the Canada ODP Council, and Hall is a member. Aksu, Awadallah, Hiscott and Jenner and have been involved in ODP drilling legs. Canada's efforts to join the new Integrated Ocean Drilling Program (IODP), which will replace ODP over the next couple of years, is being spearheaded by Memorial with Dalhousie University and the Universities of Toronto and Victoria. Canada is now a subscriber to the *International Continental Scientific Drilling Program* (ICDP), which participated in drilling gas hydrates in the Mackenzie river delta. Hall chairs a Canadian Geoscience Council standing committee to develop Canada's participation in ICDP,.

LITHOPROBE has been the largest and longest national geoscience program, with its ten transects providing new insights into the evolution of Canada's lithosphere over 4 billion years. Quinlan led the Lithoprobe East transect (focused on the Appalachians) and Hall was co-leader of the ECSOOT transect (on the Archean and Proterozoic of the NE Canadian Shield). Rivers has chaired the Supporting Geoscience committee and is a member of the Pan-Lithoprobe synthesis committee. Jenner was a member of the Geology subcommittee and Wright was a member of the EMOG subcommittee. Calon, Dunning, Hurich, Indares, Miller, Williams, and Wilton have also made significant contributions to this project.

MARIPROBE is a new project focused on the development and use of seismological and allied techniques to the understanding and exploitation of Canada's continental margins. Hall, Hurich and Deemer are participants in Phase 1, which has completed wide-angle and normal incidence

seismic profiles in three corridors across the Newfoundland basin margin of the Atlantic. This conjugate to the Iberian margin will be the target of the last ODP drilling leg, this summer, and the MARIPROBE data are part of the site survey background. The data acquired in Phase 1 were obtained through international collaboration among Canadian groups (Dalhousie, GSC, Memorial), Americans (Woods Hole Oceanographic Institution, University of Wyoming), and Danes (Danish Lithosphere Centre).

Coasts under Stress is a multi-disciplinary project, funded principally by SSHRC and NSERC to Memorial and University of Victoria, to analyze the long- and short-term impacts of socio-environmental restructuring on the health of people, their communities and the environment, from case studies on Canada's east and west coasts. Wilton co-leads a project on the impacts of mining, with an analysis of the history of Tilt Cove, Baie Verte.

Canadian SOLAS (Surface Ocean Lower Atmosphere Study) is a multi-disciplinary NSERC Network examining physical and biogeochemical processes affecting uptake and emission of climatically active gases in the Atlantic and Pacific Oceans. Wadleigh leads a project investigating the sources of sulphate aerosols in the marine environment.

COMERN (Collaborative Mercury Research Network) is an NSERC Network using an ecosystem approach to examine mercury in the environment. Wadleigh is collaborating with Dr. R. Anderson at DFO to investigate the relationship among N and S isotopes and Hg in freshwater foodwebs.

CWN (Canadian Water Network) is a Network of Centres of Excellence focused on the management and sustainable use of water resources, preservation of access to clean water, protection of the health of Canadians and their aquatic ecosystems, and support of the Canadian economy. Gale is a project leader.

4.3 Research Chairs

The Department has been able to develop its research profile by accessing external funds to support chairs. *PetroCanada* has supported a Chair in imaging seismology that has varied its focus through three holders since 1987: Hall (crustal seismology), Lines (applied seismology with a focus on reservoir characterization) and Slawinski (current chair, wave propagation). NSERC co-supported the Chair during the ten years eligible under its Industrial Research Chair program. Both Lines and Slawinski built industrially-supported research consortia from a wider spectrum of companies to support specific series of projects.

INCO, through its *Voisey's Bay Nickel Company*, supports the Voisey's Bay/Paterson Chair of Tectonics and Mineral Exploration Research, occupied by Myers. NSERC also provides leveraged support for this project. The Chair studies tectonic evolution of continental crust and applications to mineral exploration, with particular emphasis on the Precambrian geology of Archean cratons and Proterozoic orogens. The focus field areas are Labrador, Greenland, Australia and the Andes.

The program of Canada Research Chairs (CRC) has brought three new positions to the Department. We are currently seeking to fill a Tier II CRC in Petroleum Geosciences, to replace Pulham. A Tier I CRC in Petroleum Reservoir Engineering and Characterization, recently taken up by Johansen, is shared by Earth Sciences and Engineering. These appointments are part of Memorial's new *Oil and Gas Development Partnership* described in the next section of this document. Recently, Memorial has concluded negotiations to fill a Tier II CRC in Aqueous Organic Geochemistry, housed in the Department and in support of the Graduate Program in Environmental Science. The nomination for an appointee in this department will be complete and sent to the CRC panel in September 2003.

In June 2003, Husky Energy endowed the Husky Energy Chair in Oil and Gas Research at Memorial. In the first instance, this fully endowed chair will be in the area of reservoir imaging using seismic methods. This will complement the team already being built jointly between the Faculty of Engineering and the Department in the area of reservoir management. It is expected that the Chair will be filled by 2004.

4.4 New Research Initiatives

Recent and anticipated funding from the Atlantic Innovation Fund, the Canada Research Chairs Program, the Canadian Foundation for Innovation, and the INCO Innovation Centre will balance and extend work in fundamental areas of geoscience with more applied, oil and gas and mineral-related research. New infrastructure such as the CFI-funded computer visualization centre and anticipated state-of-the-art instruments for analytical geochemistry in the INCO Centre will push both basic and applied research in novel directions. New faculty positions associated with the PPSC, as part of Memorial's Oil and Gas Development Partnership, and activities associated with the INCO Innovation Centre can be expected to generate significant new funding and research avenues, particularly in applied geoscience over the next few years.

These exciting new initiatives strengthen further the Department's strategic role in providing a research resource relevant to the economic development of the Province of Newfoundland and Labrador. With the economic benefits of the East Coast oil already being realized in the province and the promise of an economic windfall through the development of Voisey's Bay soon to be upon us, Memorial's Earth Sciences Department occupies a central role in provincial activities. The Department is now, more clearly than ever, meeting the mandate of its Centre for Earth Resources Research.

4.4.1 Oil and Gas Development Partnership (OGDP)

This initiative is to develop partnerships between Memorial, the oil and gas industry, associated service companies, and all levels of government. It has its own administrative structure, housed in the Alexander Murray Building, but operates with existing groups like Earth Sciences in building its partnerships. Various initiatives are part of the OGDP strategy. Two of the three

CRCs mentioned above are an integral part, as is the PanAtlantic Petroleum Systems Consortium described next.

4.4.2 The PanAtlantic Petroleum Systems Consortium (PPSC)

This consortium involves Memorial , Dalhousie University, and the University of New Brunswick. It has won major funding from the Atlantic Innovation Fund (AIF) to build a multi-disciplinary, distributed but collaborative, research and development network across the Atlantic area. The aim is to capitalise on the growth of the petroleum industry in the region, especially offshore, and to develop an Atlantic-based research capacity for petroleum research.

Components are spread across engineering, geoscience, transportation, refining, petrochemicals, safety, and environment. Details of the award from AIF are now finalized, and there is a strong expectation that the AIF awards will leverage further funding from other agencies, public and private. The budgetary scope of the PPSC proposal is on the order of $40 million over 5 years. The implications for the Earth Sciences Department are considerable. New faculty positions for Earth Sciences in geomechanics (wave propagation), regional basin analysis, and both geological and geological aspects of reservoir characterization will be funded by AIF for 5 years. The total of new funding from AIF to the Earth Sciences component of PPSC for specific research in hydrocarbon exploration and production, involving new and current faculty, will amount to over $4 million over five years.

4.4.3 INCO Innovation Centre (IIC)

INCO is investing $20 million in the INCO Innovation Centre to be housed in the former Thomson Student Centre, now being refurbished. The IIC will build on the University's existing research strengths in Earth Sciences and Engineering and help develop innovative research in a number of areas. Half of the investment will be used to support operations over 10 years, and it is anticipated that the INCO investment will leverage additional resources from public sources such as AIF. Discussions are ongoing with sponsors so we are unable to detail what research and equipment will be funded in the Department. Field geophysical projects, and new analytical equipment, including a multi-collector ICP-MS and SEM, are anticipated. The objective of the Earth Sciences component will be to develop commercial technologies for advanced exploration, ore delineation and mine planning. Particular goals will be to develop seismic methods for detection and imaging of deep ore deposits, and geochemical methods to infer mineralogical variations and ore distribution within the magmatic system.

4.4.4 Geoarchaeology

The history of human settlement of Newfoundland and Labrador is one of the most dynamic in Canada. Discovering and sharing this history with the public is at the core of the province’s burgeoning tourism industry. Sylvester and Wilton are joining with archaeologists at Memorial to develop a Microanalysis Centre for North Atlantic Studies. Its goal will be to characterize and chemically fingerprint the source of lithic and metal artifacts used by aboriginal peoples in the region. These include cherts chipped to make knives, projectile points and harpoon endblades,

soapstone (talc) carved into cooking pots, lamps and carvings, and iron obtained from Asia and various sources in Greenland. Such a resource base has tremendous potential for elucidating the fine details of ancient exchange and interaction systems, networks of communication, and patterns of movement. It will bring together a unique combination of existing research strengths at Memorial: the Archaeology Unit, which is one of the most active and highly regarded in Canada, the physical geography group, whose research on Holocene environmental change is both active and innovative, and members of the Earth Sciences Department, who are leaders in geochemistry and field geology. This initiative has the potential to make Memorial the leading research and student training centre in Canada for this type of geoarchaeological research.

4.4.5 Crustal Evolution Studies

Crustal evolution studies include a multidisciplinary group that has joined together to enhance and promote collaborative research on the structure, growth and evolution of the continental crust. A steering committee (Hurich, Indares, Leitch, Sylvester) is developing a program of discussion venues and joint graduate student recruitment and supervision. The approach taken depends on the background of the researcher. Hurich (geophysics) uses reflection seismology and physical properties studies to characterize crustal structure and heterogeneity and the tectonic evolution of orogenic belts. Indares (metamorphic petrology & tectonics) investigates the tectonothermal evolution of deep crust in Proterozoic continental collision settings with studies mainly focused on the Grenville province. Leitch (geophysics) studies mantle melting using large-scale numerical simulations; crustal magma transport mathematically and numerically; and magma chamber dynamics using analog laboratory experiments. Sylvester (geochemistry) seeks to understand the nature and origin of mantle and crustal magmatic events through the Precambrian through the trace element and radiogenic isotopic geochemistry of rocks and minerals. Crustal evolution has been a traditional strength of Memorial since the pioneering work on Appalachian geology by its faculty in the 1970s and 80s, and the subsequent Lithoprobe project. This initiative seeks to find new relevance for crustal evolution studies in the context of exciting opportunities in Arctic bedrock studies and sample returns from Mars expected over the next decade.

4.5 Longer-term Strategy

The Department is committed to taking advantage of the opportunities presented by the OGDP, PPSC, and IIC. Nevertheless, their longer-term implications for the Department's development are less clear. For example, it is unclear what consequences the new faculty positions associated with these programs will have for the disciplinary profile of our faculty a few years hence.

The Department can anticipate the retirement of at least six faculty members within the next ten years. Within this same period, however, the several new faculty members now being recruited into externally-funded positions will fall back on the University's base budget. The University appears to have intentions to downsize the Faculty of Science, in response to anticipated declining student enrolment and a preference for building professional schools. If so, the

replacement of retiring faculty members and the rejuvenation of research directions may be difficult.

The research profile of the Department needs both reinforcement in some traditional areas and development into new areas. The Department has determined that a substantial part of its research focus should be in areas related to natural resources (oil, minerals, water, sustainability) and environmental geoscience. Will the Department be able to be involved in these and other emerging areas? Our future directions as a department may already been determined by making the new externally-funded faculty appointments, supported by current initiatives. The Department may need to be creative in seeking alternative funding for support of new areas. Potential appointments in emerging areas of geoscience research would maintain a forward-looking vision for the Departmental research profile, and are discussed further in section 5.2.

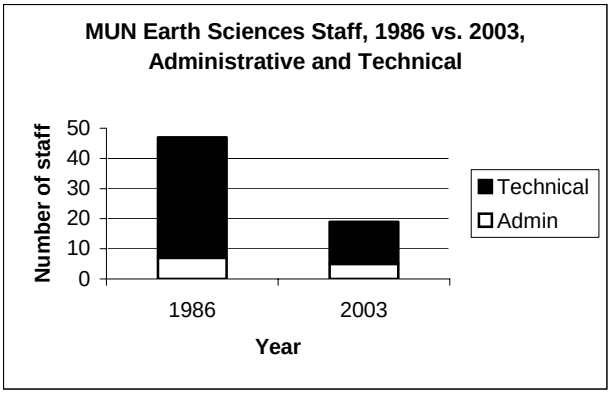
4.6 Research Resources

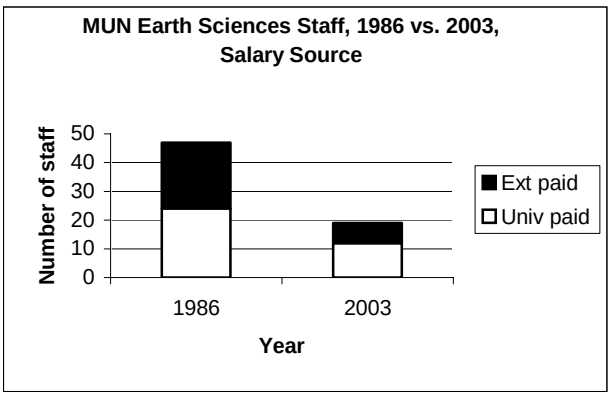
4.6.1 Technical Support

The quality and quantity of technical support has been one of the strengths of the research function in the Department that has helped in recruitment of new, energetic faculty members. Although some of this support was provided from research grants and contracts, there were a number of technical positions supported directly by the University. The charts below show how much technical (and administrative) support has been eroded over the last 17 years (the number of faculty members is the same to within one or two). All administrative staff members are University-paid.

In the difficult budget years that began in the mid-90s and are still with us, the University would not replace departing technical staff members who were not engaged primarily in support of the undergraduate teaching function. Currently, the Department has 7 University-paid technical support staff, including instructional and teaching-lab computing assistants. Such staff members have become increasingly vulnerable to lay-offs resulting from cost-cutting measures, and others have had their function shifted more toward teaching support. As a result, the burden of finding salaries for research technicians has shifted onto faculty members' research budgets. The cost of paying for technical support has increased relative to research budgets over the last ten years. These factors have led to an insidious decline in the quantity of technical support available to faculty members, and a corresponding impact on research productivity. The Department is not alone in this regard, either within Memorial, or within the Canadian earth science departments. However, a problem is still a problem no matter how many people experience it.

As the federal government pays lip service to enhancing Canada's R&D capacity through, for example, its Innovation Strategy, we do not see sufficient resources being added to reinstate the situation of 16 years ago, never mind enhancing our performance to new levels. New funds, recently provided by the federal government, to support the indirect costs of research might help, if we could compete for them.





The University is considering an umbrella scheme, Research Equipment Support and Training Services (RESTS), of operating expensive research infrastructure, so that economies of scale might be applied to the total human and physical resource complement. We are quite unsure as to whether this is in the long-term interests of researchers. Our Department's experience suggests that wider access to facilities (e.g., to other units at Memorial or outside) can be profitable in some circumstances, but quite negative in others, especially where the external client has come to expect free services. If new money in support of indirect research costs is used only to support pan-campus technical facilities based on service provision, we suspect that this will not be successful in building the Department's research profile. It may be appropriate for the Department to request a modest block fund to be used for half support of a handful of Departmental research staff, as an alternative to accessing RESTS.

4.6.2 User Groups

Each Departmental research facility is managed, operated and maintained by a User Group made up of faculty members and research staff most directly interested in this facility. The User Groups are responsible for scheduling work, setting user fees, and arranging for the maintenance and upgrading of equipment. Each facility charges fees to all users, whether they are in the Department, elsewhere at Memorial, or outside the University. These fees are reviewed regularly and are set at levels sufficient to operate the facility and to provide money for most levels of equipment upgrade. The User Groups have been successful in maintaining and building the

Department's research facilities with minimal call on financial support from the University's base budget. This will become increasingly difficult as the equipment base becomes older and the cost of technical support is increasingly borne by the user groups.

The average age of all items of research equipment in the Department having a replacement value of $100,000 or more is 12 years. The total replacement cost of this equipment exceeds $6.9 million. While the acquisition of equipment is usually left in the hands of individual faculty members and user groups, the Department may need to be more deliberate in long-term planning for the upgrading of its equipment base.

Equipment	Age (Years)	Replacement Value ($K)
Geophysics field equipment		
Seismic streamers	3 - 15	335
Seismic streamer (Stealth)	5	750
Seismic Recorders	3 - 15	400
Air gun x 11	10	180
Compressor	20	250
Huntec	30	350
Seismographs (OYO)	1 - 10	230
GPR, magnetometer, e.m.	5 - 10	100
Geophysics computing facilities	2 - 5	200
Marine coring equipment	**1**	100
GCC/IRMS (Optima/Isochrome)	11	250
CF/IRMS (MAT 252)	14	250
XRD (Rigaku)	14	400
Probe (Cameca)	11	1200
XRF (ARL 8420)	12	300
TIMS (MAT 262)	10	500
ICP-MS (HP 4500)	5	300
Laser ablation system (266 nm)	12	150
Laser ablation system (213 nm)	0.5	170
ICP-MS (VG PQII+)	10	500
Microscope (BP donation)	20	250
Microscope (Mobil donation)	30	150
Microscope (Chevron donation)	35	150
Vitrinite reflectance microscope	**??**	200
Petrographic microscope	**??**	100
Sedigraph	**??**	100

4.7 Conclusions

- The Department has played a prominent role in research in the Earth Sciences for at least two decades, but must enhance its current research profile to maintain this reputation;
- We are poised to begin major new externally-funded initiatives in applied R&D in support of the petroleum and mineral economies of the province.
- The Department must determine a longer term research strategy, setting out priorities in which current initiatives are complemented by a broader perspective, especially of inter-disciplinary studies; the University administration must give a clearer signal about the constraints on the realization of such a strategy.
- The Department can help the University drive an innovation agenda that is directed at enhancing Canada's R&D record, but would do this much more effectively with additional support from the University for highly-trained technical staff to carry out its new and ongoing research programs.

5. FUTURE DIRECTIONS

5.1 Undergraduate Program

Memorial University traditionally draws more than 95% of its undergraduate students from within this province, approximately 3% from elsewhere in Canada, and the remaining 1 – 2% from outside Canada. Projections indicate that the population of high school age students in the province is declining, and could be reduced by up to 40% over the next 5 to 10 years. The collapse of the fishery over the last decade, with the consequent migration out of the rural parts of the province, has no doubt been a major factor. Whatever the reasons, such a significant drop in the number of high-school-age students has dire implications for future University enrolment.

Dealing with these implications requires co-ordinated action at all levels of the University. At the Departmental level we need to focus on aspects that set our programs apart from those of other universities, and we need to ensure continued high quality within these programs. In doing so, we enhance Memorial's ability to attract more undergraduate students from inside and outside the province.

We have earlier alluded to the possibilities of introducing a co-operative education option or other variants of experiential learning and of reworking some of our senior undergraduate courses to appeal to the market for Continuing Professional Development courses. We could also take greater advantage of the fact that Department offers a more intensive undergraduate education in some areas of geoscience than is available almost anywhere in Canada, certainly in Atlantic Canada. Among our distinctive current offerings, geophysics is perhaps most notable.

The Atlantic Provinces already co-operate in the delivery of specialized programs in such areas as Nutrition and Forestry. In these areas students complete the first two years of their undergraduate program at their home university and the final part of the program at the university designated to offer the specialized program. The actual degree is awarded from the home university. Similar collaborative approaches might usefully be investigated for specific aspects of Earth Sciences and other expensive and specialized programs. Any such plans require the active support of the University because they entail reciprocal arrangements with other universities.

The significant growth in our undergraduate enrolments in the last few years has led to the doubling of laboratory sessions for many classes. This, in turn, has highlighted the critical need for repair and/or replacement of teaching microscopes, upgrading of computers and software in our microcomputer laboratories, training of faculty and staff in new software applications, and employment of staff to ensure proper maintenance of teaching collections. There is no creative solution that will substitute for an infusion of hard cash into these areas. The only question is whether the cash will arrive in regular and affordable increments, or whether it will need to be found in a large lump sum. Clearly without a viable mechanism for maintaining the teaching equipment base, the Department will be poorly positioned to help recruit new students.

5.2 Graduate Studies and Research

Every geosciences department that has a graduate program is competing for the same pool of qualified students. Although competitive fellowships and smoothly functioning administrative procedures are undoubtedly important, the best graduate students will not go to a department unless opportunities exist for exciting research. For this reason, it is pointless to separate plans for graduate studies from plans for research.

The Department has determined that its strategic research foci should be in areas related to natural resources (oil, minerals, water, sustainability) and environmental geoscience. We consider that our geographic position offers us a particular opportunity to focus on these issues within a broader theme of Northern and Arctic development. Having determined this, it is clear that the research profile of the Department needs both reinforcement in some traditional areas and development into new areas in support of these strategic themes. We suggest that this can be achieved through a combination of externally funded and University-funded faculty appointments.

The Department has done well in securing new externally funded faculty appointments through individual industrial contributions and programs such as the Canada Research Chairs and the Atlantic Innovation Fund. The University can anticipate picking up the salary support for many of these externally funded positions at much the same time as current faculty members are retiring. These externally funded positions could be seen as an ideal way to bridge the Department into the future. However, these externally-funded appointments are intended to be primarily in support of research and graduate education within a rather narrow range of sub-disciplines. It is not clear that the people hired to fill these new roles will also be the best people to replace faculty members retiring over the next 10 years. It is critical that the short-term objectives of building the OGDP, the PPSC and IIC be consistent with the longer-term, more important objective of sustaining a viable, forward-looking and broadly based Earth Sciences program.

We anticipate the retirement of at least six faculty members over the next decade (see Appendix 7). These retirements will not be evenly distributed among discipline expertise, with geophysics being hardest hit and “hard rock” geology being least affected. The impending retirement of several geophysics faculty members offers an opportunity to appoint replacement faculty members in such areas as environmental geophysics. Doing so would both allow continued delivery of the undergraduate geophysics program and support a major research theme in environmental geosciences.

Faculty complements in engineering geology and in structural geology are below critical mass despite being important to several components of our strategic research areas and central to our teaching needs. Faculty members working in these areas can be anticipated to retire within the next 10 years. These are areas in which at least replacement, but preferably reinforcement, is needed.

There are emerging areas of geoscience research that are both scientifically exciting and also highly relevant to our strategic themes. Some of these emerging areas are focused on the nature of, and transportation properties across, the interfaces of Earth's spheres. Biogeochemistry is an obvious example, whether we mean by this the discovery and chemical conditioning of life much deeper in the Earth than had been anticipated, or the use of microbes in mine site remediation. Memorial is in the process of nominating to a Tier II Canada Research Chair in Aquatic Organic Geochemistry. Although the research theme is interdisciplinary in nature, the appointee will be hosted in Earth Sciences and able to support this research theme. High-resolution imaging of the seabed and interpretation of such images in terms of processes acting at the sediment-water interface is another example. Contributions to the development of tourism in the province would be aided by support of new research in geoarcheology.

Will the Department be able to be involved in these and other emerging areas? The Department needs a much clearer indication from the senior University Administration regarding the replacement of retired faculty members and the long-term status of new externally funded faculty appointments in order to understand what the level of support will exist for new appointments from the University base budget.

5.3 Measuring the Success of Our Plans

This document has described our past, our present and our aspirations for the future. These plans will require resources, and resources need to be justified by results.

Our plans for the **undergraduate program** will require:

- Enhanced funding for equipment maintenance and replacement
- A new technical position for maintenance and archiving of teaching collections
- An operating budget adequate to continue delivery of high-quality field schools
- Perhaps a budget for student recruitment, or at least an opportunity to work more closely with other offices within Memorial on recruitment issues

Our success in this area could be measured by the following standards:

- Increased numbers of BSc graduates in Earth Sciences as a proportion of Memorial BSc graduates
- Increased numbers of BSc graduates going on to graduate school and to assume responsible positions related to their education
- Increased numbers of students registered for service courses offered by the Department
- Initiation of a regular schedule of Professional Development Courses that overlap significantly with a revised group of senior undergraduate and graduate course offerings

Our plans for the **graduate program** will require:

- Increased support from the SGS for graduate fellowships
- Adequate recognition of the time required for faculty members to supervise graduate students
- Increased technical support within the Department's research laboratories

Our success in this area could be measured by the following standards:

- An increase to at least 75 graduate students over the next 3 years
- A reduction in the time taken to complete MSc and PhD degrees
- An increase in the number of publications arising from graduate student research
- An increase in the number of externally funded graduate students
- An implementation of specialised course-based professional masters degree programs

Our plans for the **research program** will require:

- Increased technical support within the Department's research laboratories
- Specific recognition of the difference between externally funded faculty appointments made for specific research purposes, and University-paid faculty appointments made to ensure an appropriate breadth to the Department
- Competitive access to Industry Canada infrastructure money transferred to the University to assist in offsetting indirect research costs

Our success in this area could be measured by the following standards:

- Increased externally funded research by 30% over the next 5 years
- Increased peer-reviewed journal publications by 30% over the next 5 years
- Increased peer-adjudicated awards and honours to Departmental personnel

Appendix 1 – Faculty CVs
Appendix 2 – Undergraduate Handbook
Appendix 3 – Graduate Calendar Entry
Appendix 4 – Undergraduate Enrolment and Degrees Awarded
Appendix 5 – Undergraduate Scholarships and Awards
Appendix 6 – Research Funding
Appendix 7 – Faculty Renewal Chart