Think Globally, Learn Locally: Broadening Perspectives of the Earth[1]

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SUMMARY
The call to develop earth system science and the simultaneous spread of professional registration of geoscientists in Canada have created perceived conflicts in university earth science curricula. This paper is an abridged version of a report commissioned by the Canadian Geoscience Council to suggest possible avenues of resolution. It is concluded that there are no essential conflicts between the two programs, but all earth science resources in the universities will have to be concerted to present a sufficiently broad curriculum. To effect the changes implied here, the first requirements are for much increased mutual respect and much increased communication among all earth science disciplines.

RÉSUMÉ
L'existence d'un mouvement qui vise à définir une «science des systèmes terrestres» alors même que les inscriptions des professionnels en sciences de la Terre sont en pleine croissance donne une impression d'incohérence dans la planification des cursus universitaires en sciences de la Terre. Le présent article se veut une version abrégée d'une étude commandée par le Conseil géoscientifique canadien pour dégager quelques avenues de solution. On y conclue qu'aucune contradiction majeure n'existe entre ces deux programmes de formation, mais que toutes les ressources en sciences de la Terre des universités devront être mises à contribution si l'on veut pouvoir offrir un programme couvrant tous les aspects requis. Pour y arriver, il faudra qu'il y ait beaucoup plus de respect mutuel de part et d'autre et, que de bien meilleures communications existent entre les diverses disciplines des sciences de la Terre.

INTRODUCTION
The context for the earth sciences in Canada is changing rapidly. Emerging global environmental, economic and social problems, an increasingly concerned public (see Lubchenco, 1998, for an international perspective; Fyfe, 1993, for a perspective from an earth scientist), and dramatically changing information technologies are reshaping research priorities. Meanwhile, the move to regulate the profession of geoscience in Canada appears to have the potential to reshape advanced training in the earth sciences. There have also been significant changes in our universities, driven by changing resources and by changing public perceptions of what the universities should be doing. These trends have created both remarkable opportunities to redirect research and teaching toward contemporary problems (see, for example, Eyles, 1997), and the possibility for conflict and confusion (*e.g.*, Howard, 1997). Leaders of the earth sciences in Canada need clear and coherent advice about appropriate responses in order to ensure a strong and effective earth science enterprise in the future.

This paper is an abridgment of a report commissioned by the Canadian Geoscience Council (CGC) to seek such advice. Specifically, the report was to "attempt to recognize, and respond to, the different pressures of curriculum reform in universities to meet the needs of Earth system sciences, and those of professional registration..." (letter of

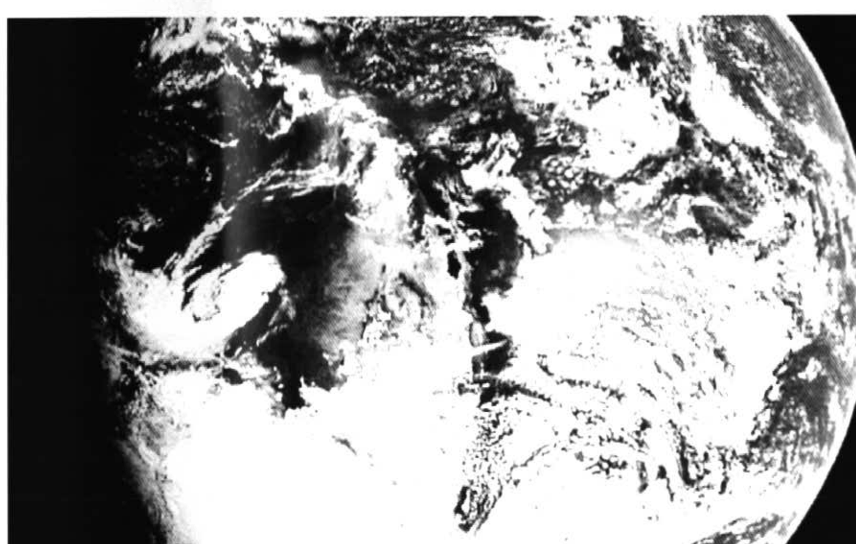

Figure 1 View of partly cloud-covered Earth from space, taken during the Apollo lunar missions of the 1970s. Baha Peninsula of southwestern North America is located near the centre of the view (courtesy of the National Aeronautics and Space Administration).

[1]Sub-titled: "Implications for university curricula, and for the requirements of professional registration and accreditation." Regular readers of *Geoscience Canada* will have noted that earth system science, professional registration of earth scientists, and the nature of university earth science curricula are topics of considerable interest at present. We are pleased to publish Professor Michael Church's thoughtful and incisive paper, an abridged version of a full report by the same title prepared by Professor Church for the Canadian Geoscience Council in May 1998. Although the full report is now available on the World Wide Web at: http://www.science.uwaterloo.ca/earth/cgc/church2.html, and in paper copy from A.V. Morgan, Executive Director, Canadian Geoscience Council, Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, N2L 3G1 (avmorgan@uwaterloo.ca), the nature and substance of Michael Church's argument deserve the widest possible distribution. Issues centred on thinking globally and learning locally affect all of us, as well as our future and that of our science. R.W. Macqueen, editor.

commission, D.A. St-Onge, President, CGC, 3 March 1997).

Specified antecedents of this report are the report "Future Challenges and Trends in the Geosciences in Canada" (Barnes *et al.*, 1995), and the move since 1990 to implement licensure in most provinces (see Williams, 1997, for a status report).

"Future Challenges" presents earth science as earth system science, the study of Earth as an integrated, dynamic system characterized by exchanges of material and energy from the core to the outermost atmosphere, and creating conditions at the planetary surface for the development and sustenance of life (Figs. 1, 2). The report prominently emphasizes the ability of life, principally now humans, to modify those conditions. We are well on the way to realize that capacity. To respond to it, the education and activities of earth scientists must become much broader than they have been in the past. This development presents the appearance of an emerging conflict with the requirements for licensure. The latter include academic training requirements understandably more narrowly focussed upon assuring competency for the practice of applied geoscience, interpreted in a more traditional sense. But, in the years ahead, research, practice and education will find common themes in the set of problems presented by human stewardship of Earth. It is the purpose of this report to explore this and related threads in the attempt to initiate a constructive dialogue about the question of what constitutes a suitable curriculum for education in earth science in Canada today.

In this report **earth science** denotes the study of Earth and the application of technical knowledge about Earth, in any context. In principle, this definition is the same as that given by the United States National Research Council (USNRC) (1993, p.1) and adopted in "Future Challenges." The term **geoscience** is reserved to refer to the definitions presented in the charters of the professional bodies. This distinction, not made in "Future Challenges," is useful because the specification of educational requirements by the professional bodies is guided by those definitions. The term **discipline** refers to a constituent discipline of earth science (which could be called a **superdiscipline**) or to a defined specialty within geoscience. The term **curriculum** is used consistently to refer to a university program of study, while the term **syllabus** refers to specified educational requirements for professional registration.

CONTEXT: EARTH SCIENCE AT A CROSSROADS

Future Challenges

"Future Challenges" (Barnes *et al.*, 1995) was commissioned by the Canadian Geoscience Council to discuss the future development of the earth sciences in Canada. Of its 10 summary recommendations, the ones of principal relevance to a discussion of earth science curricula are (numbered as in "Future Challenges," p. 2; see also Chapter 11 therein):

(2) That the geoscience community advocates and accomodates to the concept of earth system science, which has produced a paradigm shift within the discipline.

(3) That the academic community reforms curricula to provide a quantitative earth systems foundation and, with programs in other sectors, promotes systematic lifelong learning opportunities to sustain a highly qualified creative workforce.

(6) That future changes in policy and funding within and among the government, academic, and industrial sectors ensure a balanced continuum of basic to applied earth science in the nation.

(9) That all sectors aggressively support programs to promote the public awareness of the earth sciences.

(10) That all sectors commit to a new

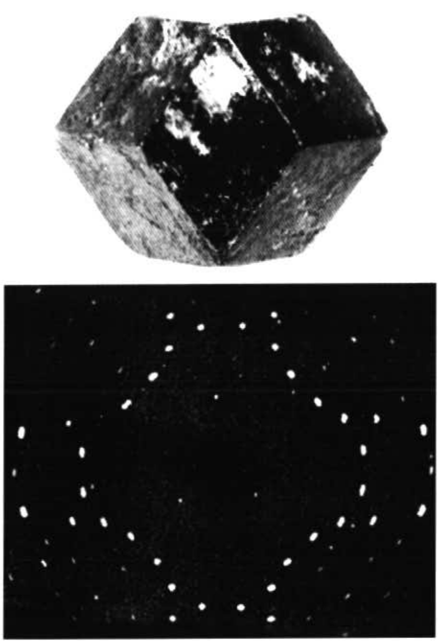

Figure 2 Earth science research encompasses very different scales, from planetary-sized studies as seen in Figure 1, through the macro scale of field studies, to the atomic level of this garnet and its X-ray diffraction pattern (A.V. Morgan).

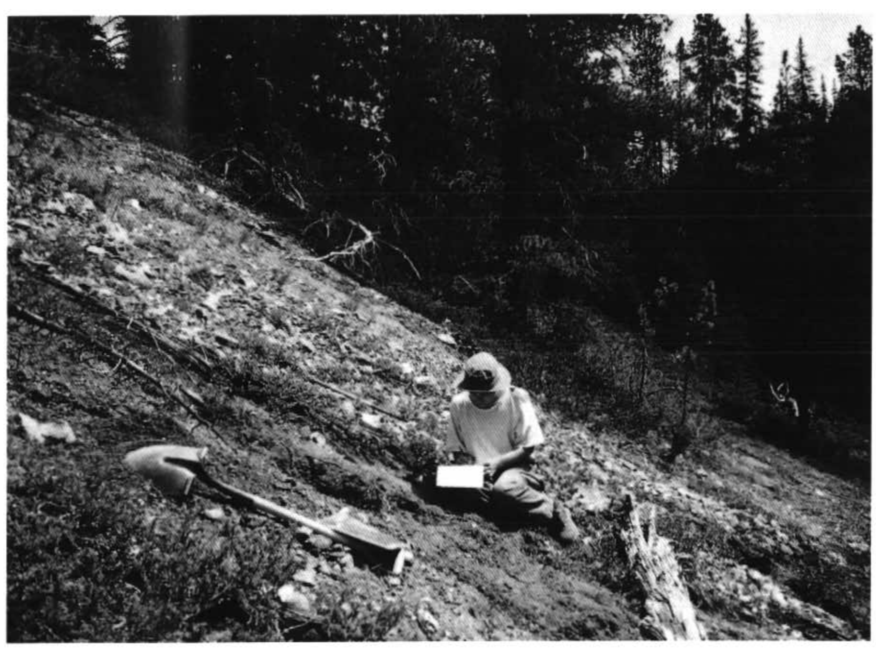

Figure 3 Logging slope stability information. Terrain analysis is a recently emerged environmental earth science discipline that responds to the need for dramatically improved information about land surface conditions to support resource development planning, major engineering projects, and geological hazard identification and remediation (M. Church).

era of changed attitude, behaviour, and leadership, with a shared concept of earth system science, a recognition of the severe future global environmental and resource issues, and a responsibility to make Canada more efficient, productive, and sustainable, thereby turning crisis into opportunity.

These are visionary recommendations, but some practical implications of them are clear. Increasing attention should be given in curricula to quantitative foundations (mathematics, statistics, numerical methods) and technique (computing, GIS, remote sensing, modern analytical methods); the curriculum should introduce a broad view of earth science in all programs, and substantial attention should be given to introducing contemporary environmental and resource issues (Fig. 3). All this implies a substantial reduction in time committed, in undergraduate curricula, to classical earth science disciplines. The commitments to lifelong learning and to promoting public awareness imply that the universities, the learned societies, and private sector educators become increasingly involved in programs variously termed educational extension, professional development, and awareness promotion.

The movement toward professional licensure intersects these educational recommendations. It provides a compelling motivation for lifelong learning since both industrial methods and the focus of practical problems are constantly changing, while registration and regulation introduce both performance norms and ethical standards for practice which require continual education.

"Future Challenges" identifies the emergence of global studies of earth phenomena on a quantitative basis and the perceived urgency to deal with problems of deteriorating environmental quality, shrinking resource endowments, and global environmental change as the major driving forces in the contemporary reshaping of earth science. There are three important things to be said about these developments.

First, they have served to increase the relative prominence of what are called the environmental earth sciences in comparison with solid earth science. But it would be a serious mistake to suppose that the study of the solid earth is not entrained or that it has become somehow a less important part of earth science (Fig. 4). ("Future Challenges" underlines the point: its substantive emphasis falls clearly upon solid earth science.) This situation implies that curricula must become more diverse, or more crowded, or both.

A second point is to dispute the notion that earth system science is new. "Future Challenges" suggests that the paradigm has become accepted within the last decade. But it is as old as the modern study of Earth. The pioneer of earth system science arguably was Alexander von Humboldt (1769-1859; Fig. 5) whose *Cosmos* (1845) contains the first attempt at a comprehensive, synthetic description of Earth based on measurements. His program was reflected in broad syntheses of earth science presented by many 19th century geologists and geographers. By the beginning of the 20th century, an essentially standard prescription was arrived at that is still preserved in the teaching of introductory physical geography. It remains a useful model for thinking about a curriculum for earth science that is broad as well as deep.

Third, to understand the connection between earth system science and the megaproblems of environmental change and resource endowment, it is necessary to understand how human actions modify Earth's environment. "Future Challenges" does not engage this issue. There is, however, a long tradition of study (see Marsh, 1874; Thomas, 1955; Turner *et al.*, 1990, for major syntheses). What is important in the present discussion is that, while consequences of human activities are easily detected at global scale, the activities themselves are compounded of individual and community actions carried out within diverse regional societies through the setting of social and economic policies. A good example is the welter of laws, programs and regulations surrounding mineral resource development in Canada. The management of Earth's environment is

Figure 4 Geologist studying quartz monzonite tor in southern British Columbia, Lakeview Mountain, East Cascades, near the British Columbia-Washington border (M. Church).

Figure 5 Alexander von Humboldt, founder of earth system science, *circa* 1845. From the engraved frontispiece in *Cosmos*, the first attempt at a comprehensive, synthetic description of Earth based on measurements, published by von Humboldt in 1845 (M. Church).

not purely, nor even primarily, a scientific issue, but a social and economic one. While we can conduct scientific research and think globally about such issues, we must learn to manage them locally and regionally through the analysis of social and economic policies and programs. The practical contributions of earth science to this endeavour are delivered mainly by professional geoscientists working within regional resource and environmental management projects. The professional practice of geoscience is almost entirely concentrated within the local to regional socio-economic context. This matter introduces an important question of **scale**.

Scale pervades all earth science problems (Fig. 1, 2), and it underlies some of the distinctiveness that might remain between the training emphases for research and for professional practice. Research ranges freely across all the scales of earth science, incorporating whatever approximations appear to make a problem tractable while preserving the essence of the matter. Professional work is largely defined at topographic scales between, say, 10 m (the scale of a small engineering site) and 10^6 m (the regional scale of mineral and hydrocarbon exploration). Within these scales analysts characteristically retain the most complex feasible representation of the boundary conditions in order to display the full detail of the problem. As a result, professional education emphasizes practical solution methods for typical problems met by society, often at the expense of global perspective and conceptual elegance.

Earth science curricula must recognize and deal with this dichotomy. One beginning point is to realize that the same technological innovations that have promoted progress in earth system science are used to deal with complex topographical problems. Another is to recognize and exploit the connections between regional processes and the global effects that earth system science studies. An important question, then, is how to construct a curriculum that reveals connections across the full range of scales that earth science considers.

Professionalization: Who? Why?

Licensure has largely burst upon earth science in Canada since about 1990, but that is by no means the beginning of the story. The regulation of recognized professions in Canada is a provincial prerogative, an aspect of the regulation of labour. The professions of geology and geophysics have been recognized in Alberta since 1920, although the designations P.Geol. and P.Geoph. were adopted only in 1960. Professional status was next achieved in Newfoundland (1989) and in British Columbia (1990). These provinces followed the lead given by Alberta in many aspects of its legislation, including the decision to combine geoscience with engineering under a common regulatory body. The licensure issue has since been taken up in most other provinces, following some variant of the established models.

The desirability of licensure remains controversial, both within the earth sciences community and outside it. The main interest claimed is protection of the public from incompetent, unethical, or improperly prepared persons representing themselves as experts in earth science. The underlying assumption is that the knowledge and skills of earth scientists are sufficiently arcane to be beyond general public appraisal, hence an oversight body is required. Within the community, protection of the good reputation of earth science and earth scientists by discriminating who is qualified to practise — a closely allied purpose — is prominently forwarded as a reason for licensure. Virtually everyone who accepts these purposes agrees that the appropriate way to achieve them is to review and adjudicate the formal education and the experience of individual earth scientists. This matter lands professional bodies squarely in university curriculum issues.

But there is no consensus in the earth sciences community about the desirability to have a professional qualification procedure along these lines. Many practitioners of geoscience, particularly in the exploration community, have developed their expertise by means other than formal academic qualification. More significantly, in the present discussion, the definition of modern earth system science has brought within its purview a considerable number of people — for example, within fields such as atmospheric physics, environmental chemistry, geophysics, and oceanography (Fig. 6) — whose formal education might not have involved traditional earth science. This situation has generated substantial concern over the purview of professional bodies and the definitions of geoscience which, in turn, determine professional syllabi.

Figure 6 Deploying a sample cluster in oceanographic work (S.E. Calvert).

Some Canadian University History

The organization of Canadian universities impinges upon the teaching of earth science subjects. The dominant model is Victorian. That period marked the full flowering of modern disciplinary natural science. Accordingly, our universities all possess strong faculties of science within which earth science has traditionally been taught in departments of geology.

Canadians have also found academic precedents in either European or American customs. This has had significant curricular implications for earth science in Canadian universities. European traditions usually define the subject in terms of what we have come to call solid earth science. The science of Earth's surface (Fig. 7) has been largely consigned to geography. In the United States, however, surface earth science was swept up into geology. Canadian geography departments have adopted European traditions — hence physical geography remains a relatively prominent subject — whereas Canadian geology departments have largely followed the American tradition. Consequently, they also pursue surface earth science (which, in a landscape dominated by the effects of glaciation, largely meant glacial geology until relatively recently). So there have been wasteful turf wars between the two kinds of department.

There are some other historical accidents. Soil science in Canada has been associated almost entirely with agriculture, not surprisingly in a newly settled country (Fig. 8). Accordingly, it has been largely overlooked in the councils and curricula of earth science in Canada. Hydrology has remained substantially the preserve of engineers preoccupied with water resource development. Until

Figure 7 Peyto Lake delta, Rocky Mountain Main Ranges north of Banff, Alberta, in September, 1965. Hydrology is an important aspect of Earth sciences. The Peyto delta illustrates the braided nature of debris-choked montane streams picked out by an early snowfall. The stream is flowing from the nearby Peyto Glacier, located just off the photograph at the top (A.V. Morgan).

Figure 8 Brunisol developed on loess over Pleistocene-aged lacustrine silts, Peace River Valley, British Columbia. Abundant salt efflorescence is present on the surface. Pedology is very much a part of the larger picture of the earth sciences. Sections such as this reveal much about the nature of climates under which the soils have been formed (M. Church).

fairly recently, we have mainly respected European tradition in atmospheric and marine science by isolating them in graduate institutes, with considerable interest from relatively influential federal technical bureaucracies.

Earth science has by no means a coherent or unified academic tradition or representation in Canada. This matter impinges upon attempts to define curricula for both earth science and geoscience, and to establish an earth system science perspective in most universities.

STAKEHOLDERS

Professional Bodies

Professional bodies, in the sense intended here, are groups of individuals with special skills or capabilities, recognized by society as able to govern their professional activities in the best interest of society. In Canada, they are chartered to do so by provincial governments. The medical, legal and engineering professions are prominent examples. The focus is upon the individual members who practise the skills of the profession. Among other responsibilities, the professional body must ensure that skills are maintained and improved by the members. This entails determining and examining in some manner the body of special knowledge and technique which members must possess, and inventing ways to sustain and enhance it.

The learned professions have come to recognize university education as the necessary first step for an individual to acquire the special knowledge. The professors are the effective mediators of what the special knowledge should be, but not without continual negotiation with the professional body. This has become a formal procedure. The universities have organized for it without appearing to compromise their own academic independence by segregating professional training into special faculties that parallel the organization of the learned professions. Hence, we find faculties of medicine, of law, and of applied science or engineering.

This pattern has been coming under substantial pressure. Technical problems appear in the interstices between traditional disciplines, or range across several of them. Individuals are appearing whose knowledge and experience, although plainly sophisticated, does not easily fit any recognized professional disciplines. This is creating a need to rethink the mechanisms for qualification and examination used by professional bodies. These problems appear to characterize geoscience to an extreme degree within the context of earth system science.

Learned Societies

Learned societies exist for the promotion of interest in specialized bodies of knowledge. For the present discussion, one can include a range of craft and even trade organizations among them. The focus of these organizations is on the promotion of the discipline rather than the individuals who represent it. The criterion for membership usually is professed interest in the discipline, although some societies maintain grades of membership which may entail technical qualifications.

Individual members or groups of members sometimes attempt to use a learned society as an avenue to forward professional ambitions or agendas by urging it to take on the activities of a professional body. This role has in the past been urged upon the Geological Association of Canada, in the absence of formal professional licensure. But learned societies lack any socially conferred authority to act officially, hence lack any mechanism to ensure the compliance of members with technical and ethical standards. It is fairly clear that the core activities of professional bodies and learned societies do not mix very well.

Learned societies nevertheless serve significant functions in professional development and education. They have been the main repositories of the record of technical experience and knowledge through their management of the main learned journals and conduct of the major technical meetings of learned disciplines. These activities help to define the discipline, hence to sway what are appropriate curricula for professional and research training.

Another key function of the learned societies is the conduct of short courses and symposia designed to provide continuing education to members, and to explore new developments in a discipline. Among these activities is one that the learned societies undoubtedly do best and that is of surpassing importance in earth science: conducting field trips and field courses. For earth scientists, this provides reference to the primary data of interest. It is an essential part of training, of professional continuing education, and of critical review of the results of research.

The Universities

The interest of the universities in disciplinary education is plain. However, forces in the contemporary universities are prompting a fundamental rethinking of the Victorian disciplinary organization for learning.

Superficially, budget pressures are forcing amalgamation of certain programs and departments. Important criteria in these rationalizations are administrative unit size and student/teacher ratios. Earth science has not escaped rationalizing tendencies. In some Canadian universities, comprehensive earth science departments have been created out of former geology, geophysics and other departments. In some cases, couplings of geography and geology — common in the early academic evolution of these subjects — have been re-established.

Administrative efficiency is by no means the entire story, however. Universities traditionally have been elite institutions. In Canada, fewer than 10% of young adults proceeded to post-secondary education before the 1970s. But with increasing emphasis on education as the key to both individual and collective economic and social success, the proportion of young people expected to proceed to post-secondary education has escalated into the range 30% to 40%. The costs attendant upon this effort have also moved society to demand that the education received be in some sense useful, meaning, usually, directly responsive to economic and social trends.

Neoconservative political agendas have emphasized the trend toward "more relevant" education in the universities. In these agendas, environmental studies are not perceived to be of high priority and earth science does not have a prominent place. There appears, here, a discrepancy between the perceptions of an environmentally concerned public and those of its economically preoccupied governments. One guesses, as well, that, in all but perhaps two or three provinces, the mineral sector is no longer considered to be an economic growth area either.

None of the foregoing trends augurs well for traditional honours courses in earth science disciplines. Professionalization of the discipline might change that. At the very least, it will provide an easy measure of the economic (meaning job-creating) role of the earth sciences in Canada. This could plug earth science into the agenda of the "relevant university." It could also present some considerable dangers for the research disciplines.

The Public

There are several publics with an interest in the earth sciences. In this report, the most obvious one is students. Many among the substantial proportion of all young people who enter university today do not have a clear view of a career path when they arrive. Many do not know what subject will become their major focus of study. This situation holds a significant implication for earth science. It is important to offer general interest courses and to participate in programs of environmental studies and general science; these are likely sources of recruits, especially as earth science is not prominent in secondary school curricula.

A second important issue respecting students arises directly from the move to licensure. As the result of knowledge and contacts gained in the university, many students eventually seek a degree that leads to a secure post-university career path. Professional qualification appears to hold the promise of that security. Hence, many students attracted to earth or environmental science for diverse reasons wish to assure themselves of eligibility for registration at the end of their program. In short, most students today form ideas about career paths during their university program. This complicates the educational pathway. Curricula must be flexible in order to accommodate a range of student pathways through undergraduate years.

Another important public is the corporate public. Companies seek appropriately trained recruits in the earth science sector, and this means technically trained earth scientists. Now it means recruits who are academically qualified for eventual registration. Traditionally, it has meant honours graduates, mainly in geology, to serve the mineral sector, and both geologists and geophysicists for the oil and gas industry. A recently expanding industrial sector is the consulting sector in environmental geology. Environmental chemistry, ground water hydrology, remote sensing, and terrain analysis constitute significant growth areas. Much of the rhetoric associated with attempts to make university curricula more "useful" emphasizes the need to serve the requirements of business. Both student and corporate perspectives, then, suggest that the universities must find means to accommodate professional education requirements within their curricula, and flexible ways to lead students to complete these requirements.

There is abundant evidence that the general public is seriously interested in environmental matters, including earth science aspects. This presents a significant opportunity and an important obligation for educators, learned societies, and professional bodies in earth science. The opportunity is to reinforce the research and general educational activities in the discipline by capitalizing on this interest. The obligations are to monitor the public debate about the earth environment, to intercede with authoritative information when necessary to assure the soundness of the debate, and to ensure that technically educated advisors and investigators are available for all groups that contribute to the public debate.

The requirements of these publics substantially reinforce the need for university earth scientists to develop modern curricula that ensure both breadth and depth of learning: that achieve the vision of earth system science without sacrificing traditional earth science skills.

THE PROBLEMS FACING EARTH SCIENCE EDUCATION

Serving Professional Ends

An important objective of professional licensure of geoscientists is to ensure the technical competence of practitioners. The means chosen is to prescribe formal university education requirements followed by supervised professional experience. This effectively imposes a prescriptive and potentially relatively narrow curriculum on the universities. A prescriptive curriculum is one in which the student is told what courses must be taken. It looks a lot like a traditional honours course. It is also, in the context of modern earth science, a rather conservative curriculum. The obligation of professional bodies is to ensure that their trainees understand the current principles of the discipline very well, so that they can apply established methods to the solution of practical problems. Research frontiers are important, but they are addressed somewhere else.

How is this a problem? Prescriptive curricula have been accepted in engineering schools — to draw the obvious parallel — for a long time. It is a problem because, unlike the major professional subjects, earth science does not occupy a separate faculty dedicated to serving the needs of professional education. Earth science departments form part of the science faculties of Canadian universities, and, along with arts faculties, make up the core of the university. The arts and sciences are dedicated to education and to research without any external intellectual constraints. It would be stultifying to the role of earth science departments to accept the constraint of an externally set, conservative curriculum. The establishment of a professional syllabus for geoscience appears to represent a direct challenge to the intellectual freedom of earth science departments.

Serving Research

In the universities, earth science is a basic research discipline. The essence of research is to be open to new ideas, to the recognition of new problems, to new ways of formulating old problems, and to new methods for solution. This requires a constant interchange of ideas between disciplines, and a continual readiness to learn and to teach new material as focal problems and effective techniques shift (Fig. 9). These circumstances require an open curriculum, one quickly able to adopt new material and to form new disciplinary alliances by adopting new courses.

The undergraduate curriculum that is implied by these considerations emphasizes basic science; it requires an introduction to earth system science in order to emphasize the connections among phenomena across a wide range of scales; and it requires students to make considerable progress toward mastery of some discipline within earth science.

The need for openness is not consistent with the adoption of a narrowly prescriptive curriculum, particularly not an externally imposed one. However, it is entirely consistent with the maintenance of honours courses, the discipline and quality of which form the appropriate basis for teaching about a research discipline.

Serving Liberal Education

Earth science, as part of the university core, also has a responsibility to serve liberal education. Earth science may be studied by students as an avenue to explore environmental issues or to learn about the planet with no professional ends in view. Liberal education requires a permissive curriculum to allow students to explore various cross-disciplinary themes. To permit this sort of program, the hierarchies of courses typical of prescriptive curricula cannot be allowed to dominate students' options. The major curricular element for earth science is a sequence of integrative courses which emphasize aspects of earth system science, often with a problem analysis perspective. Reference to social and policy studies is important, and the courses must remain accessible to a range of students not all of whom have a strong grounding in basic science.

Taken altogether, the competing educational styles described in this section present a severe challenge to the teaching resources of even the largest university departments.

Figure 9 This schematic view of Canada's highly successful LITHOPROBE program illustrates the roles of multiple disciplines. See, for example, Clowes, 1996 (diagram courtesy of R.M. Clowes).

ELEMENTS OF A SOLUTION

Broadening University Curricula

On balance, the most significant need in the undergraduate earth science curriculum in Canadian universities today is to broaden the curriculum. There are several reasons for this.

- The re-emergence of earth system science requires that a much broader range of earth science topics be recognized within the curriculum in order to give students the opportunity to understand and appreciate the implications of this vision of the discipline.
- The need to give appropriate emphasis to newly emerged topics in environmental earth science, without de-emphasizing traditional topics, requires a broader construction of the discipline.
- The need to respond to rapidly moving and diversifying research frontiers requires a range of foundation courses at the base of an open curriculum, and the timely establishment of new advanced courses to introduce emerging research perspectives.
- The need to contribute to an effective program of liberal education requires the offer of a range of mainly nontraditional courses to present perspectives based in earth science of the workings of the planet and of the human impact

Figure 10 Elizabeth Clark and Kris Vasudevan examining deep seismic data acquired in the LITHOPROBE program, at the LITHOPROBE Seismic Processing Facility (LSPF), University of Calgary (courtesy of R.M. Clowes).

upon it.

At the same time, it is vital to recognize that technical depth cannot be ignored if earth science is to remain a viable research discipline and a foundation for professional work (Fig. 10). Therefore,

• The need to provide strong technical training for the industrial sector and for advanced research requires that appropriately structured honours courses be maintained within earth science curricula, including courses that emphasize phenomena over a wide range of scales.

There are some obvious problems associated with implementing broader curricula while maintaining and even developing technical depth. From where are the necessary resources to be drawn in universities preoccupied with rationalization, and under strong external pressures to do more with less? I suggest that the solution of this problem lies within the universities, and that the necessary elements are present. Earth system science is a superdiscipline. It sweeps up the elements of a number of traditional university subjects, each with its own department (or program) and resources. It is time to recognize the common elements and to forge a program that reconnects atmospheric and oceanographic sciences with geology and geophysics, re-incorporates physical geography, and recognizes soil science, hydrology and geomatics as significant elements of earth system science. By this route, university earth scientists might gather together the resources necessary to maintain honours curricula within which several specializations are available, while still being able to offer the breadth that earth system science and liberal studies demand.

How the reintegration of the earth sciences could be achieved in individual universities depends upon local circumstances and histories. There is no general prescription. In most cases, there will be considerable reluctance on the part of individuals to countenance reorganization of established departments. A staged procedure may be best, beginning with the establishment of joint courses and programs, and only much later proceeding, perhaps through program management councils, to departmental mergers.

There are substantial additional rewards for proceeding along this path. Many of the most exciting areas in contemporary earth system science fall into the gray zones between the traditional disciplines. Disciplinary mergers can create powerful new research teams.

How broad a curriculum can become while still retaining adequate rigour will depend — other factors remaining equal — on the size of the earth science enterprise in a particular institution. A desirable end will be, first, to maintain honours courses that offer a sound scientific foundation and a number of special disciplines at the senior level (because this is the basis for both research and professional viability), and next, to be able to offer a suite of integrative courses for a wider audience. Within the honours program, the courses offered in the lower years should not pre-empt the disciplinary orientation that students may adopt in their upper years, but these courses should provide an introduction to earth system science. Programs should be constructed to assure that appropriate attention is given to the study of Earth across the entire range of relevant scales.

Only the largest institutions will manage all of this. At the least, however, it appears important to strive to maintain credible curricula for solid earth science and for environmental earth science, both relatively broadly construed. This recommendation will still be impossible to meet in small institutions. Earth scientists there simply do not have the numbers to offer a curriculum that is both broad and deep. A different kind of solution is necessary. To provide students with an entry into a modern superdiscipline, or the possibility to embark on professional preparation, such institutions need first to ensure that introductory and foundation courses are in place, and then to form inter-institutional networks of co-operating partners to secure more advanced work. The establishment of mechanisms for students to obtain credit for courses taken in neighbouring institutions (and the design of schedules to permit them to do it), the incorporation of distance-learning modules into the program, and the possibility to arrange convenient transfer mechanisms for students to complete their degrees in a larger institution all need to be explored. Smaller institutions need special consideration that might eventually lead to some innovations in inter-institutional relations, but earth science is not alone in requiring such developments.

University departments and the profession also need to reconsider how complete the formal education of an earth scientist really is at the bachelor level. The industrial world and the professional bodies still regard the honours undergraduate degree as the essential preparation for a career of work. But simultaneous requirements for breadth and depth in the modern discipline mean that one's formal education cannot end at that level. The educational requirements for registration are, after all, the assurance that an adequate level of preparation has been reached to commence supervised practice; they are not the definition of an ideal education. In a broader earth science curriculum, the focus must be on appropriate rigour at each step, not upon formal completeness.

Broadening the Professional Discipline

The university is not alone in facing the implications of earth system science. Geoscience is no longer just the activity associated with mineral resource development (if it ever was). Nor can geoscientists properly specialized in that sector deal with all the range of practical problems confronting earth scientists today. The rapidly evolving role of earth scientists in society, and the proliferation of special techniques in advanced earth science equally require a broadly defined profession. This has two implications.

First, the definition of a geoscientist needs to be drawn in such a way that persons engaged in professional earth science work, who may, in fact, have a broad range of technical educational preparations, can all be licensed. The common elements required of all geoscientists are a sufficient knowledge of earth science principles to assure the ability to communicate effectively with a wide spectrum of peers, and competence in some discipline that is recognized to contribute to the analysis and management of the earth system. The upshot of these desiderata will be:

• the specification of a relatively broad syllabus or group of syllabi to serve the educational requirement for registration; and

• careful specification of foundation courses to define the preparation in basic science and earth science principles so that disciplinary orientation in senior years is not pre-empted.

Both of these proposals parallel desiderata for university curricula, so that the long-range interests of the research disciplines and the profession are not so much at cross purposes as they may appear.

The second implication of the need to arrive at a broad definition of geoscience is that there are limits to what can plausibly be construed as earth science and, well within those, practical limits to what is useful to regulate as geoscientific activity. There may be subjects now integral to earth system science that appear to the framers of professional charters to be essentially research subjects best left outside the net of licensure. At present, atmospheric and ocean sciences appear to fall into this sphere. Moreover, a range of special problems is being defined today which demand the attention of individuals with very special knowledge of the kind not gained in a usual earth science education. Particular problems in the chemistry of the environment, problems in mathematical and statistical interpretation methods, problems that fall into the realm between earth science and ecology, and problems with major human behavioural dimensions come to mind. It is not reasonable to require geoscientists acting alone to tackle such problems, nor does it seem practical to widen the definition of geoscience to include all practitioners with specialized knowledge of relevance for the management of the earth environment.

Relations Between the University and the Profession

A broad university curriculum and a broad construction of geoscience ought to eliminate most of the potential conflict over curricular matters. It is essential that there be a core syllabus common to all geoscience disciplines in order to ensure that geoscientists have a common basis for communication and for contextualizing geoscience problems. Beyond basic physical science and mathematics, the core syllabus might reasonably demand some study of earth materials, an introduction to the geometry and deformation of rock units, a review of Earth history and chronology, including the most recent Epochs, and some study of processes at and near the Earth's surface. The latter might be given within the context of an introduction to earth system science. These topics ought to be found in the curriculum of any university earth science program. Beyond that, a broad construction of geoscience ought to provide a sufficient range of options, to permit some correspondence with the professional syllabi to be found in any university curriculum that includes advanced courses in earth science, without constraining what that curriculum or the individual courses are. There can be no reasonable guarantee that any individual university program is able to satisfy all possible syllabi that a professional body might specify. On the other hand, it is essential that the universities keep firmly in view the academic requirements for qualification to practise in the mainstream geoscience professions in Canada; this much represents a reasonable measure of social relevance for advanced education.

The specification of the professional syllabus should remain separate from the setting of university curricula, and the academic qualifications for registration of applicants should continue to be examined individually. Given the functions of university earth science departments as research units and as units in faculties of liberal education, it would not be appropriate to establish external boards with authority to review the entire program of a department and to recommend that graduates be either accepted or not for registration. This would represent an external tyranny over the curriculum that is not acceptable to research faculties and not reasonable in the context of liberal education.

On the whole, the course sketched here is the one that is emerging in Canada. Provided that professional bodies remain respectful of the concern for academic autonomy of the earth science departments, and provided the universities develop reasonable arrangements to allow students who wish to achieve licensure to work toward their academic qualifications, there is no reason to suppose that there cannot be a mutually supportive co-existence of academic and professional earth science.

A ROLE FOR THE CANADIAN GEOSCIENCE COUNCIL

What Needs to be Done

Promoting the emergence of earth system science curricula and developing professional geoscience in the manner outlined above require that some important contextual conditions be established. The Canadian Geoscience Council, the learned societies, and the professional bodies collectively have the responsibility to see that they are established. The Canadian Geoscience Council ought to assume leadership in this endeavour.

First of all, there is an urgent need to build mutual respect among individuals and among the various disciplines within earth science if the superdiscipline of earth system science and the professionalization of geoscience are to be successfully established. Earth science has remained divided within the universities for too long, and has undoubtedly lost resources because of it. One reason for this has been unproductive competition between traditional departments based, at least in part, on lack of mutual respect. Nor are professional bodies free of similar problems. Potentially damaging is the failure of some in the more traditional earth science community to appreciate the skills and sophistication that are associated with recently emergent earth science disciplines, and consequently, to continue to argue that a narrow construction of geoscience will best serve the community. That is a recipe for professional obsolescence.

Mutual respect may be difficult to establish. It means recognizing and appreciating the abilities and expertise of others without subjecting them to the test of knowing one's own field as well as one does oneself. It means recognizing the points of contact between disciplines, and respecting the legitimacy and value of different disciplinary perspectives on common phenomena. It also carries the requirement to demonstrate that one conducts one's own studies and practice with a high level of rigour and intellectual honesty, so that respect may be earned.

At this juncture, dealing with an excitingly enlarged vision of earth science and with a rapid move to license practice, the development of mutual respect among all those involved is by far the most important priority to assure success. Everything else that needs to be done depends on it. There are, however, some other requirements.

There is still a need to promote earth system science by defining and analysing the essential features of the concept which make it more than the sum of traditional earth science disciplines; that is, to convince both earth scientists and others of the advantageous perspective that it affords, both intellectually and in pursuit of solutions to problems of social interest. A good deal more attention than heretofore will have to be paid to local- and regional-scale considerations, and to scaling arguments in general, if this exercise is to be successful. At the same time, the essential role of specialists, working from more traditional disciplinary constructs, needs to be reaffirmed. These people will continue to be the key individuals who create the building blocks of the science. While the traditional earth science disciplines must look outward much more than has been customary, they must not be neglected or downgraded. This is as true in research as it is in professional practice.

There continues to be a need to encourage those in the universities to foster curriculum developments that will articulate a broadly based earth science, at the same time developing the resources for specialist study. Nearly everyone in the university is a specialist of one species or another (Fig. 11), and it can be as difficult there as anywhere to espouse synthetic themes.

Finally, there is a need to establish a dialogue among university, learned and professional bodies about actions and responsibilities for continuing technical and professional education, about how to translate the commitment to lifelong learning proposed in "Future Challenges" into a practical program, and about how better to inform the public — corporate and general — about what earth system science can offer to the nation.

Figure 11 Geologists examining sheeted pegmatite veins, Emerald Lake, BC. Traditional field work remains a critically important element of modern earth science studies (courtesy of J. Mortenson).

All of these are activities that the Canadian Geoscience Council should consider playing some role in initiating, even though it could not carry through any of them by itself.

How To Do It

This is a genuinely difficult question. No single individual will see all of the effective means. There is no doubt, however, that communication represents the key.

A number of activities would constructively serve the needs outlined above.

Building Respect and Understanding

- Facilitation of regional and national lecture tours by distinguished earth scientists who can discuss both recent research results and practical applications of them, and who can demonstrate a broad earth science perspective, perhaps as CGC lecturers. Such tours should be addressed specifically to joint academic and professional audiences.
- Exploration of the possibility of improving the arrangements for university-academic exchanges, so that university scholars may learn better what really is involved in a contemporary industrial career, and so that senior geoscientists can learn more about the context and conduct of university teaching and research.
- Co-operation with the provincial professional bodies to ensure that there are reports of interesting and practical results from earth system science available at their annual general meetings.
- Promotion of panel discussions on the relation between earth science and professional geoscience: What does geoscience need from earth science? Can geoscience help the development of earth system science awareness? ...of earth system science research?
- Encouragement of special sessions at national scientific meetings, or of joint meetings which engage professional applied earth scientists by providing them with forums for discussion and reports on new results of practical interest.

Facilitating Lifelong Learning

- Promotion of task groups involving all the concerned bodies to study and promote methods of co-ordinated continuing education.
- Promotion of task groups and demonstrations to study electronic and other

distance-learning methods adapted for effectiveness in earth science education.

- Promotion of a joint examination by universities and professional bodies of the systematic use of adjunct teaching appointees from the profession to bring advanced applied earth science into the university classroom.
- Promotion of direct communication to the public about earth system science and geoscience.

The promotion of methods for co-ordinated continuing education is particularly important. This probably is the real key to assuring continuing competence among all professional geoscientists, an objective to which the professional bodies are committed.

Some of these activities are recognizably going on already. In none of them does CGC have any special authority. For most of them, it would have to look to its member societies. It does have the prominence, however, to be a potentially effective co-ordinator of a program designed to achieve the development of a broad earth system science discipline across the country.

A PERSPECTIVE: WHY THE RECOMMENDATIONS ARE NOT VERY SPECIFIC

The advice given in the section headed "A Role for the Canadian Geoscience Council" remains rather general. There are good reasons for that. First, earth science both as a research discipline and as professional geoscience requires sensitive management in a continually shifting context. Good advice is advice which leaves the recipient a good deal of room to tailor specific responses to particular contexts.

Second, the proposal of specific rules or objectives is almost always a mistake when the careers of individuals are involved. And that, in the end, is the essence of the re-organization that is going on, both in earth science and in professional geoscience. There needs to be discussion and reflection among all the individuals who are affected by current developments so that perceptive leaders can define the most satisfactory development for the greatest number of individuals, and for earth science and for society, altogether. That process needs to be continual, because the context and, therefore, the most satisfactory development, continually change. Fixed objectives and rules are decidedly inferior ways to manage the enterprise.

Finally, many readers will be surprised to discover no actual proposals for university curricula or professional syllabi in this paper. These are the prerogative of university curriculum committees and provincial registration committees. This report has rather been about possible means to reconcile potential conflicts that might grow out of the setting of curricula and syllabi.

Mutual respect and ready communication are, in the end, the means to achieve the reconciliation of academic and professional curriculum needs, and to guarantee the success of the more general development of the earth sciences in Canada.

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