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Their Status, National Need and Future Direction

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QUATERNARY GEOSCIENCES IN CANADA

Their Status, National Need and Future Direction

By the

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QUATERNARY GEOSCIENCES IN CANADA

Their Status, National Need and Future Directions

1 Introduction

The Quaternary Geosciences have experienced accelerated, almost explosive, expansion in the past quarter century. At the International Geological and Geographical Congresses that were held in Montreal in 1972 the presentation of Quaternary research formed a significant element of the proceedings. Even so, few who were present could have anticipated that in the next fifteen years further developments in Quaternary science would be so revolutionary that their effect in the earth sciences can only be compared with the impact of plate tectonic theory a decade earlier. We have come to realize that the variability of Quaternary and late Cenozoic environments has been far greater than had been recognized. There has been a multiplicity of glaciations in high latitudes and corresponding climatic and vegetation changes elsewhere on Earth; and throughout this extended period Man's ancestors have been evolving physically, culturally and socially in an ever-changing world. In Canada, rapid growth of research facilities and numbers of scientists in universities and government institutions during the 1960s, began to slow down in the 1970s due to financial restraints. Thus at the very time when a national and international demand for analyzing and interpreting Quaternary events was increasing, Quaternary scientists were under pressure to curtail growth.

1.1 Terms of Reference

To determine how effectively Canadian scientists and institutions are responding to developments in Quaternary science in the past few years, the Geoscience Council of Canada established in 1983 a committee to examine:

1. The status of Quaternary Research in Canada
2. The national need for Quaternary Research
3. The adequacy of current educational, government and industrial sectors to meet these needs.
4. Future directions for Quaternary Geoscience.

Membership of the committee has been:

Chairman: W.O. Kupsch (Saskatoon): until December 1983
J.B. Bird (Montreal): after December 1983
Secretary: O. Slaymaker (Vancouver)

Members

E.A. Christiansen (Saskatoon)
L. Dredge (Ottawa) replaced D. St-Onge June 1984
C. Hillaire-Marcel (Montreal)
J. Locat (Quebec)
A.V. Morgan (Waterloo)
P.J. Mudie (Dartmouth)
A.M. Stalker (Ottawa)

During the early discussions of the committee it was clear that there was general agreement among Quaternary scientists on the present state and desirable future directions for the subject in Canada. The report has therefore been prepared to inform geoscientists in other fields, the universities and science policy groups, and the international Quaternary research community at the time of the INQUA 1987 meeting, of the nature and status of Canadian Quaternary geoscience.

In the report, the terms Quaternary studies, Quaternary science, and Quaternary geoscience are not used interchangeably. It is recognized that each term is less general, more specific than the preceding one. However, we also recognize that attempts to define subject boundaries precisely present a threat in all interdisciplinary research, and not least in studies of the Quaternary period.

1.2 Survey of Quaternary geoscientists

At its first meeting the committee resolved to use a questionnaire to obtain most of the data that were required. Fifty-nine questions grouped into five sections were asked of respondents (Appendix 1); part 1 sought information on the scientists' own work, part 2 their perception of other research, part 3 the national rationale for Quaternary research, part 4 was directed to scientists in government and industry and part 5 to university workers.

Mailing addresses for the questionnaire were obtained from membership lists supplied by earth science societies and other associations and groups. Many lists contained names of scientists not closely linked with Quaternary research. Rather than exclude potential respondents the final list was made as large as possible. After removing duplications, 984 questionnaires were distributed, of which 17% (164) were returned (Appendix 2). The response from the university and government sectors is considered good and representative. Only 13% of the replies received were from industry and consultants. This is believed to underrepresent that sector and arises from the difficulty in identifying the group through mailing lists and probably because many who were sent the questionnaire failed to recognize themselves as being involved with Quaternary science (e.g. environmental planners).

The Canadian Quaternary Association (CANQUA) had a membership (including foreign members) of about 300 in late 1985. At the same date 231 Canadian scientists had indicated an intention of attending the International Quaternary Association (INQUA) meeting in Ottawa in 1987. These data suggest that there are between 300 and 400 scientists in the country who perceive themselves as scientists in Quaternary studies. The response to the questionnaire is therefore from roughly one-half of the group.

1.3 Acknowledgments

The questionnaire was designed by the committee with the direction of the first chairman. The report has been compiled by the second chairman from statistical analyses and reports prepared, initially on a regional basis by members of the committee (Cordillera (O.S.)) Interior Plains (E.A.C. and A.M.S.) Ontario (A.V.M.) Québec (C.H-M. and J.L.) Atlantic Provinces (P.J.M.), North (L.D.).

We wish to thank all respondents to the questionnaire for their time and interest in replying, often at length, to our many questions.

We also acknowledge valuable contributions from Quaternary scientists who wrote to describe the fields and status of specialties within the subject. Their observations, in several cases with modifications by the committee to meet the general pattern of the report, and for which it is responsible, have been incorporated into the report particularly the section dealing with 'Recent Progress in Quaternary Science': J. Adams (Neotectonics) J.T. Andrews (Pleistocene Geology) J.C. Driver (Paleopedology)

J.D. Jacobs (Paleoclimatology) C.R. Harington (Quaternary Studies in Museums) J.B. Macpherson (Palynology) C.S.L. Ommaney (Glaciology) J.T. Parry (Remote Sensing) J.A. Westgate (Tephrochronology).

Our thanks are also due to colleagues, especially those in the Geological Survey of Canada who read and commented upon drafts of the report as it was being prepared. W. Blake, Jr. (GSC) supplied information for the section (11.2) on Laboratories.

The committee acknowledges financial support provided by the Geoscience Council of Canada, the Department of Indian and Northern Affairs and the contributions of the universities with which several committee members are associated.

The processing of production of drafts and the final report were undertaken by Maria Marcone and Pauline Gyorkos (word processing) and Abal Sen (cartography). Statistical analysis, and compilation of several appendices was undertaken by Thom Gallie (UBC) and Paul MacLean (McGill).

2 Conclusions and recommendations

2.1 Summary and conclusions

1. The landscapes of Canada are a product of the Quaternary period. Most terrestrial surface deposits, all the landforms excluding only the largest units, and the seafloor of adjacent continental shelves and ocean basins were fashioned by events in the Quaternary. The objectives of Quaternary geoscience are to identify, describe and understand the rapidly changing physical environments and associated geoprocesses during the past two million years. Quaternary studies also include a fundamental understanding of contemporary environments, and these offer significant contributions to enhancement of national life and the economic development of the country. With understanding of present conditions and past events comes a measure for predicting future environmental change arising either from natural or from man-induced causes.

2. Spectacular global expansion of Quaternary data collection and broadening of the concepts and purposes of Quaternary studies have occurred in the past fifteen years. Advances have been made in all fields, with three aspects predominating internationally:

   i) Recognition of the duration, number and complexity of climate cycles associated with continental glaciation during the late Cenozoic.

   ii) A marked increase of research into Holocene environments.

   iii) The inclusion of many peripheral scientific specializations in Quaternary science, leading to a holistic approach to environmental change in the Quaternary.

3. The quality and quantity of research being undertaken nationally in Quaternary geoscience is impressive given the size of the country and number of problems to solve.

4. Between 300 and 400 Canadian scientists identify themselves as Quaternary specialists. The research output per scientist compares favorably with other major fields of geoscience. However, the total quantity of research when the area of the country and the range of Quaternary problems are considered, is small.

5. The output of Quaternary research appears to have increased marginally although unevenly in different regions, in the past decade. A decrease in research by government agencies has been matched by an increase in the university sector. Whilst stagnation may be explained in terms of the level of national economic activity and government funding policies, it is an unhappy reflection on the limited acceptance of the Science Council's 1971 study (Blais report) which recommended the development of specific Quaternary fields including glaciology, terrain, muskeg, permafrost and Quaternary studies <u>per se</u>.

6. The largest group of Quaternary specialists, although modest in total number, is engaged in studies of sediments and landforms (regional mapping, stratigraphy, glacial sedimentology and geomorphology). In other fields including glaciology, paleoclimatology **(sensu stricto)**, Quaternary marine sedimentology, some aspects of paleobiology and in paleopermafrost studies, only isolated studies are being made outside the federal government.

7. Two geographical sectors: i) The North ii) The seafloors around Canada (the coastal zones, the continental shelves and the deep ocean basins) are conspicuous for the limited quantity of research. Were it not for research in federal government agencies, particularly the Geological Survey of Canada, Quaternary research would hardly exist in these areas.

8. Collaboration between scientists with different specialities is an essential element of successful Quaternary research. Although individual scientists recognize this, collaboration is hindered by the existing compartmentalization of Quaternary fields in different government agencies and university departments.

9. Applied Quaternary science can make significant contributions to national resource planning and development including the fields of mineral resources, forestry, agricultural soils, hydrogeology, geotechnique, urban development, and environmental planning including hazard control.

10. The largest national group of Quaternary scientists is in the Geological Survey of Canada. This is the only group that has adequate resources and personnel from varied fields to come close to being a 'centre of excellence'.

11. The museums of Canada play an important role in Quaternary research, and in providing Quaternary education for the public.

12. The Quaternary scientific community does not favour professional accreditation and registration.

13. Development of Canadian Quaternary science will be accelerated by a wider acceptance of Quaternary science as a field for teaching and research in universities, and by a wider response to its educational value in the schools by public awareness of the excitement and value of Quaternary studies.

14. Although many universities provide a broad range of specialized Quaternary courses in physical, biological and human sciences, appropriate interdisciplinary courses are rarely developed. Inadequate introduction to the subject is provided at the undergraduate level especially for students in (or entering) professional schools (e.g. engineering, planning and forestry). Insufficient numbers of high calibre undergraduate students are introduced to the challenges of Quaternary science and consequently fail to move into graduate work. Compartmentalization of Quaternary topics in traditional academic departments has hindered the development and effectiveness of the subject.

15. More than 130 graduate theses in Quaternary geoscience were written in Canadian universities in the five year period ending 1984.

16. Employment for recent graduates at the Masters level will probably be found most easily in fields related to Quaternary science such as environmental planning. In some regions, notably Alberta, graduates have difficulty finding appropriate employment. Demand for new PhDs is roughly in balance with the supply.

17. Although Quaternary geoscientists do not favour the creation of a national 'centre of excellence' for teaching and research, the arguments for regional centres are persuasive.

18. There is considerable agreement that the four most significant research needs at the present time are to develop (i) greater understanding of natural and man-made environmental changes in the Holocene; (ii) glaciological aspects of the Pleistocene Continental Ice Sheets (iii) geoprocesses in glacial and periglacial environments, and (iv) understanding of interrelationships between terrestrial and marine Quaternary events.

19. Although a majority of Quaternary geoscientists believe that more and better research would be undertaken if research funding were more readily available, shortage of funds is not a major obstacle to the development of Quaternary science. There are two conspicuous exceptions both of which involve high-cost logistical support. One is the development of large multidisciplinary nongovernment research projects in the North. The evidence from successful university projects is that funding is possible but that exceptionally able scientists have to be prepared to spend long periods securing major funding.

    The second difficult field is marine Quaternary science where costs and inevitable lack of flexibility when government ship-support is offered make this a difficult area for research by independent university research scientists.

20. Specialized laboratories are a requirement for virtually all Quaternary geoscience research. National and regional deficiencies exist for practically every type of laboratory facility.

21. Canadian Quaternary science has lacked an effective national association. Reorganization and expansion of CANQUA and the growth of regional associations (AQQUA) should meet this need, particularly if specialists from peripheral disciplines are attracted to take membership (cf range of specialties in INQUA).

22. Rapid and early dissemination of preliminary research results should be increased by newsletters and other ephemeral publications.

23. Quaternary geoscientists have concentrated on data collection, including mapping, and detailed analyses of specific situations at local and regional scales. There is a requirement for the publication of syntheses of both topical and geographical nature, that is not being met. The forthcoming 'Quaternary Geology of Canada and Greenland' which is being published by the Geological Survey of Canada as part of the Geology of North America Series may meet part of the demand, although there will be a continuing need for more Canadian book-length publications.

24. Canadian goescientists have contributed significantly to the international scientific community through participation in international organizations and through Canadian studies which are broadly applicable to research problems in other countries.

25. Although the national applications of Quaternary science are self-evident to many geoscientists, the Quaternary community has failed to identify the importance of its interface with society and has given little time to communicating with, and explaining to Canadians, the role of Quaternary science in our future development.

2.2 Recommendations

The foregoing contains implications for changes that should be made in Canadian Quaternary geoscience.

The committee recommends that the Canadian earth science community through the efforts of the Canadian Geoscience Council, the separate geoscience associations and societies, and individual scientists, should encourage:

1. Increased Quaternary geoscience research in the North and coastal and offshore areas.
2. Research in Holocene environments for a better analytical understanding of changes in contemporary environments.
3. Quaternary geoscientists involved in university teaching to give increased attention to Holocene events and to the Quaternary marine geological record.
4. Students of contemporary geoprocesses to recognize the Quaternary heritage of the landscape.
5. The establishment of regional centres of excellence with teaching, research, library and laboratory facilities.
6. Cooperation between academic units in universities to produce viable Quaternary interdisciplinary programs and courses.
7. Increased collaboration between onshore and offshore Quaternary geoscientists.
8. The addition and extension of multidisciplinary courses on the history and physical environments of the Quaternary as part of professional training in engineering, forestry, soil science and the many varieties of planning (regional, land-use, resource, environmental, urban).
9. The development of teaching and research in emerging Quaternary fields such as glaciology and paleoclimatology.
10. The expansion of the activities of national (CANQUA) and regional Quaternary geoscience associations.
11. The publication of scientific books and a range of informed, popular literature to describe the many aspects of the Quaternary in Canada.
12. Participation by more Quaternary scientists in international activities including applied Quaternary studies in the Third World.
13. Development of Quaternary collections and displays in research and public museums.

3. The Nature of Quaternary Science

The Quaternary, the fourth, shortest and final time unit of the earth as defined by nineteenth century geologists was recognized by them as having unusual characteristics. Most striking were major and rapid changes of climate associated with extensive glaciation in high and middle latitudes. The period was also recognized as unique because it was the time when the world's biota came to resemble contemporary assemblages; above all, during the Quaternary the human family evolved on earth, culminating in the appearance of Man (**Homo sapiens**).

The magnitude of changes in the earth's natural environments during the Quaternary was first appreciated from the scale of oscillations of European Alpine glaciers. Recognition of the extent of continental glaciation during 'The Ice Age', and the significance to Man and the biological world of rapid and dramatic changes in Pleistocene environments followed quickly. More than a century ago J. Geikie, the Scottish geologist, published 'The Great Ice Age' in which he focussed on 'its relation to the antiquity of man'. Since then, the description and explanation of the physical characteristics, dimensions, and chronology of the Pleistocene environments have been the main theme of numerous encyclopedic books by Quaternary scientists. As the response of the biota and Man to changing glacial and nonglacial environments became clearer, the interdependence of the studies of three groups of scientists – the geoscientists, the paleobiologists and the archeologists, became strikingly evident.

The Quaternary, consists of two epochs, the Pleistocene and the Holocene (Recent). It is unique amongst geological periods in its brevity and the extent and complexity of the preserved sediments associated with it. The base of the Pleistocene may be placed between 1.5 and 2 million years ago but it is apparent that the latest global 'refrigeration' in the earth's history had started earlier and the period of most recent ice ages is no longer considered synonymous with the Quaternary. There are also problems in defining the duration of the Holocene, for only locally does it coincide with 'postglacial'; this report follows international convention in recognizing the Holocene as the final 10 thousand years of earth history.

The chronology of Quaternary events has been a central topic for more than a century. From the beginning stratigraphic, lithological and morphological studies have allowed scientists to determine sequences of geological events and environmental changes. However, the preserved sedimentary/morphological record, and thus the sequence of events, was always incomplete and furthermore could only be dated on a relative time scale. Interregional correlations, and even more, intercontinental correlations proved unreliable and in many cases impossible. The duration and number of major glacial events in northern latitudes for long remained uncertain although most scientists accepted that there were four glaciations. It is now clear that the land record indicates many more and the ocean record, gathered during the last fifteen years, suggests there may have been more than twenty glacial, or at least, cold episodes.

After 1945 the development of radiometric dating methods for the Quaternary Period supplied 'absolute' time scales and although not equally suitable for all phases of the Quaternary nor appropriate for all materials, has revolutionized Quaternary chronology. Additional Quaternary geochronometric dating techniques, including the uranium/thorium series, amino acid diagenesis and thermoluminescence, are today extending the time for which absolute dating is possible. Quaternary science is concerned predominantly with the dynamic processes that modify the earth's surface through <u>time</u> and with their response to cyclical changes in the environment. The whole field of Quaternary dating is so important and has become so complex that it is now a recognized subdiscipline in Quaternary sciences. Today all Quaternary scientists require access to geochemistry and radiochemistry laboratories and need to have knowledge of the availability and limitations of geochronometric methods.

The study of landforms and the associated sedimentary and morphological processes has also become more sophisticated. Problems in glaciology, especially the recognition of the importance of different thermal regimes in ice caps and their inherent instability and susceptibility to catastrophic disintegration, demand considerable theoretical geophysical knowledge, as do recent investigations of the earth's crust (particularly related to glacio-isostatic and sea level changes).

Analyses of the chronological, sedimentary, and biological characteristics of ocean floor deposits have extended knowledge of Quaternary events onto continental shelves and to the deep oceans where they have provided a record of the changing global atmospheric climate during the Quaternary, a record that is complemented by studies of ice cores in major ice sheets and certain continental deposits such as loess. For the first time detailed climatic data are available for analyzing the changing environments of the Quaternary and determining the degree to which these changes have been influenced by orbital forcing, topographic modification, carbon dioxide variation and volcanic dust. As a consequence, paleoclimatology has become in the past few years an important Quaternary subdiscipline.

At the same time that the number of Quaternary subdisciplines has been increasing the emphasis of Quaternary science has also begun to change. In Canada, Quaternary geoscience historically has been concerned principally with the Pleistocene epoch; studies of the Holocene received less attention. Since it has been recognized that environmental changes in the Holocene, both of natural and man-induced origin, are important to studies of contemporary ecology and Man, Holocene environments attracted increasing attention.[1] The significance of modern sea level changes to shoreline erosion and deposition, the range of geohazards from flooding to landslides, permafrost modification and analyses of contemporary physical environmental systems are but a few of the Holocene phenomena of interest. Equally clearly, studies of environmental change in the recent past provide a means of predicting possible future environments.

Quaternary geoscience has never been isolated from other Quaternary sciences. Today it contributes to our understanding of the surface of the globe during Man's existence; perhaps even more important it provides a guide for means of retaining the earth as a habitable place for our children.

The broad range of scientific disciplines concerned with Quaternary events cuts across the traditional lines of scientific enquiry. The need for scientific contact between the disciplines led to the establishment in 1928 of the International Association (Union in 1932) for Quaternary Research (INQUA), with international cooperation in the multidisciplinary facets of the Quaternary as its principal objective. Initially INQUA was strongly focussed on European events but in its most recent congresses has become global in its activities with as many as fifty countries represented.

4. <u>Quaternary Geosciences in Canada - the early years</u>

Quaternary research was established in Canada during the second half of the nineteenth century by the Geological Survey of Canada and at the universities of Toronto and McGill. Officers of the Survey undertook widespread exploratory geological reconnaissances, which included mapping Quaternary landforms and sediments; already by 1863 it had been possible to produce a map of the surficial deposits of 'Canada'. The extension of observations beyond the settled regions followed quickly, notably by the journeys of J.B. Tyrrell west of Hudson Bay, which laid the foundation for all subsequent studies of the Laurentide Ice Sheet. This phase continued to 1914; emphasis was on the glacial sediments but with some theoretical interest in the extent and dynamics of the Pleistocene ice caps. Studies of nonglacial episodes concentrated on the extent of late Quaternary lakes, particularly in southern Ontario and Manitoba where the research was basically an extension of work in the adjacent United States. Interglacial and/or interstadial beds in southern Ontario were analyzed to

[1] The introduction of radiocarbon dating has been a major factor in the emergence of a recognizable field of Holocene studies: Increased interest in the Holocene is evident from the fact that in the recent (1984) 2-volume 'Late Quaternary Environments of the United States', Wright, H.E. Jr. (ed.), the second volume is concerned <u>wholly</u> with the Holocene.

determine their depositional environment and biological content. Farther east the character of late and postglacial marine transgressions in the St. Lawrence estuary and the Maritime provinces attracted attention.

Major developments in the following quarter century were disappointingly few, emphasizing the vast size of the country, the complexity of the problems and the small number of scientists working on them. Quaternary mapping continued in the Geological Survey and significant contributions were made by scientists from the United States and Europe, but it was not until the mid-1930s that the direction was indicated for further advances. Growing awareness of the applications of Quaternary geoscience had led to the support by the Ontario Research Foundation from 1934 onwards for the production of a physiography of southern Ontario by L.J. Chapman and D.F. Putnam which concentrated largely on glacial sediments and landforms.

Problems associated with the size and difficult access of much of the country were slowly overcome using the airplane, and by 1939, J.T. Wilson had shown the potential of airphoto landform interpretation for Quaternary research. The war and its immediate aftermath delayed further advances until the 1950s, when the broad generalizations of glacial events made at the beginning of the century finally were subjected to critical analysis. However, for a time, progress continued to be slow.

Quaternary studies were however finding a research and teaching base in the universities, especially in southern Ontario; in the North, helicopter-based reconnaissance surveys by the Geological Survey were about to start and detailed mapping in all parts of the country was gaining momentum. In 1958 the first 'Glacial Map of Canada' was published under the guidance of J.T. Wilson; Canadian Quaternary geoscience was entering an era of expansion. The Geoscience community as a whole however was slow to appreciate these developments. A special publication of the Royal Society of Canada, 'The Earth Sciences in Canada', has only a passing reference to Quaternary deposits and scarcely mentions geomorphology.[1] Lack of recognition of Quaternary geoscience was not allowed to continue. Three years later, in a background study for the Science Council of Canada, the Blais commission in 'Earth Sciences Serving the Nation' identified seven fields in the Earth Science for special developments. They included Studies of the Quaternary and northern terrain.[2]

5. The Components of Quaternary Science: Progress and Status

For almost a century Quaternary geoscience concentrated on litho-stratigraphic and landform studies. The rapid extension of research in recent years has been marked by the inclusion of numerous other specialties as an increasingly holistic view of environmental events has come to dominate the science. Today, collaboration between scientists with different specialties is at the heart of successful Quaternary research. The need for active cooperation between many disciplines and the close integration of theoretical modelling and field observations has been demonstrated clearly in recent analyses of the Laurentide Ice Sheet. Controversy about the morphology and dynamics of this, the largest of the northern hemisphere Pleistocene ice sheets, has continued for more than a century. Successive hypotheses have been abandoned as new field evidence was obtained. It is now clear that only through the active and close interaction between glacial geologists examining terrestrial and marine stratigraphy, geophysicists studying the effects of crustal and sea level changes, and theoretical modelling by glaciologists and paleoclimatologists will satisfactory solutions be developed.

The branches of Quaternary science supply inputs for an integrated characterization of environmental events, the dynamics of change in the environment and their chronology. Although the various fields draw on different techniques and methodologies, the boundaries of the disciplines as perceived by research scientists are rarely clear cut. Increasingly the historical divisions of geoscience and related fields have become less meaningful and in the teaching and training of Quaternary scientists, the traditional university disciplines often seem an obstacle rather than an aid to excellence.

In the following pages the scope and status of the component parts of the core group of Quaternary Geoscience are described, followed by the disciplines and techniques that help characterize and date the Quaternary environments (Fig. 5.1).

5.1 Quaternary stratigraphy

One of the major themes of Quaternary studies is the effect of climatic change (the process) on the geological record (the response). Although it may be argued that the methodology of Quaternary geology is no different from that used in the geology of other periods responses on shorter time scales can be detected in the more nearly complete and less diagnetically modified record. While in the Quaternary responses of the order of 10^2 to 10^4 a can be detected, Pre-Quaternary geology typically examines changes in the geological environment on time-scales driven by internal tectonic forcing at resolutions of 10^5 a and usually 10^6 a.

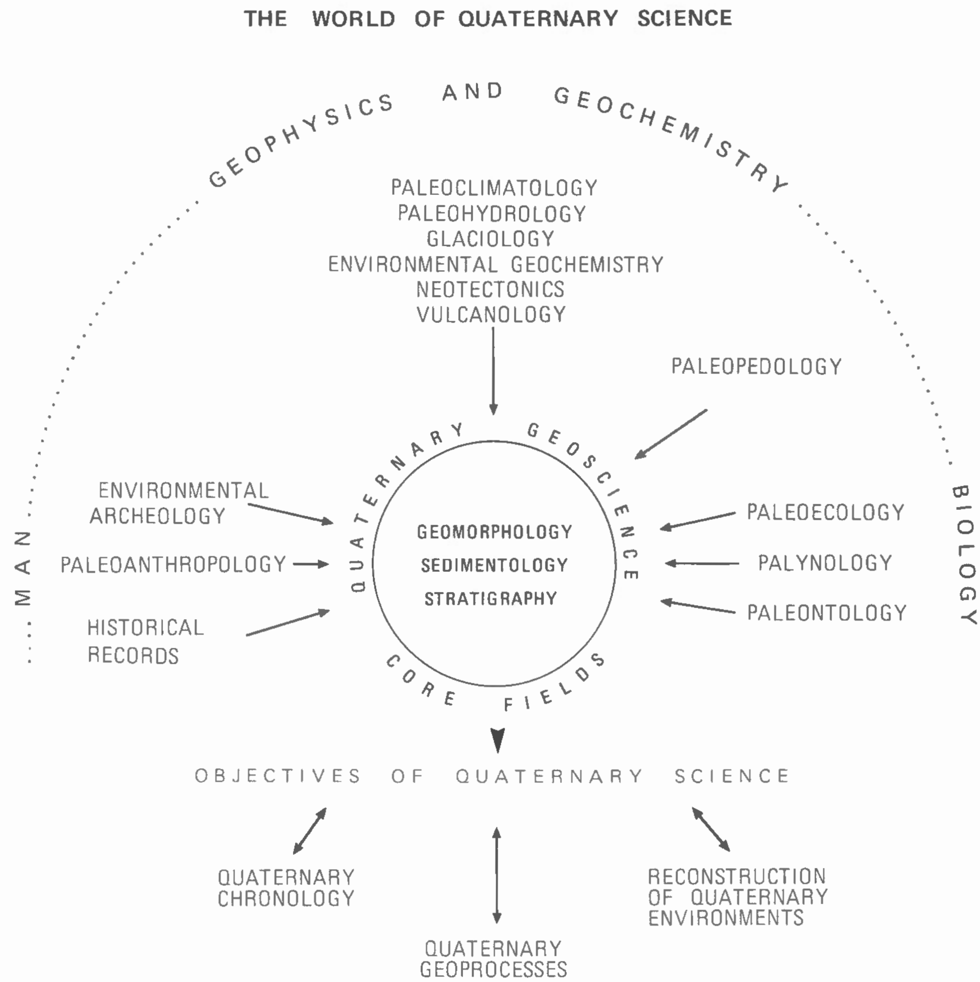
Canadian Quaternary geology has been dominated by attempts to describe and interpret the glacial sequences that contribute so much to the contemporary Canadian landscape and surficial deposits. Tremendous advances have been made,and these are readily apparent from summaries, such as Craig and Fyles (1960), Prest (1970) and Fulton (ed) (1984). There are few areas within Canada's borders that have not been covered by former ice sheets or glaciers and Canadian Quaternary geologists have concentrated their efforts to a considerable extent on interpreting stratigraphy and chronology of Quaternary glaciations. As the Laurentide Ice Sheet probably contained about 70 percent of the global water extracted during Quaternary glaciations, the history of this ice sheet is far from being of simply national interest and Canadian work on the chronology of glaciation clearly has global consequences.

Advances in Canadian Quaternary stratigraphy over the last 25 years have been impressive. Knowledge of the Quaternary of the Canadian northlands has increased dramatically. Most Quaternary scientists now understand that the Laurentide Ice Sheet had a northern border! Canadian Quaternary stratigraphy has also benefitted by the development of a wide variety of dating and correlation techniques that reflect general scientific advances in physics and chemistry and their applications to geological problems. The last 25 years has seen a fundamental change from a glacial chronology which was relative in nature to a more absolute one based on physical or chemical laws. Canadian scientists have also, in a sense rather slowly, expanded their interests in different sets of sediment records. In particular, the development of the Atlantic and Pacific Geoscience Centres, in Dartmouth and near Victoria, has been an important element in Quaternary stratigraphic studies as it

[1] Neale, E.W.R. (ed) The Earth Sciences in Canada. Royal Society Canada Special Publication no. 11, 1968, p.
[2] Blais, R.A. Earth Sciences Serving the Nation, Special Study, no. 13, Science Council of Canada, 1971.

Figure 5.1

The components of Quaternary geoscience and related fields.



has given Canada a group which works in the bays, shelves, and deep-sea basins of Canadian and international waters. In the Canadian context the most important techniques for Quaternary time stratigraphy have been ^{14}C dating, U-series dating (both of speleothems and of organic carbonaceous materials), tephrochronology, magnetochronology, oxygen isotope chronology and fission-track dating, and amino acid racemization studies. One of the techniques with a high potential is thermoluminescence (T/L) which theoretically works with lacustrine, marine, glacial marine, and fluvial sediments. A fundamental change in the last 25 years has been the realization that many Canadian Quaternary records span a considerable length of time and there has been a tendency for specific units to be assigned a greater age as knowledge and dating techniques improve. A case in point is the recent suggestion that the Bécancour Till of the St. Lawrence Lowlands is pre- last interglacial. On Baffin Island, foraminiferal biostratigraphy, amino acid racemization, and paleomagnetic studies have all supported a conclusion that the lowermost sediments exposed in wave-cut sections along the east coast are Pliocene. On Banks Island, in the Western Arctic, a combination of amino acid, stratigraphic and paleomagnetism data also show that some deposits date from at least 0.7 Ma; similarly a long record of glaciations and interglaciations is preserved in the Hudson Bay Lowlands and the Prairies. Deep sea sediments in the Labrador Sea and Arctic Ocean provide continuous records covering 3.5-4 Ma.

5.2 Geoprocesses and landforms

The physical landscape contains a complex assemblage of landforms produced through time by processes of erosion and deposition acting on earlier land surfaces. Probably all surficial sediments and meso- and micro-scale landforms in Canada developed their dominant characteristics during the Quaternary, for the great part in the Late Quaternary, including the Holocene.

Analyses of sediments and landforms enable contemporary weathering and erosion rates to be determined. These determinators are of immediate value to the agricultural scientist, forester, environmental planner and engineer, and from their present characteristics, past chronological and environmental information may be deduced.

Four major geoprocess environments have existed in Canada during the Quaternary: glacial, periglacial, fluvial (mid-latitude) and, in coastal areas, marine. The complexity of present landscapes results from the repeated displacement of one environmental system by another, many times over, in Quaternary.

The study of landforms in Canada has progressed rapidly in the past 40 years and there are numerous geomorphologists in the universities, principally in departments of geography. Throughout the period landform mapping has dominated the field in government agencies but not in the universities where historical and process studies have attracted greatest attention. In applied geomorphology, geological interpretation from landform expression has been important. In the Questionnaire responses, the greatest amount of Quaternary research in a single field was concentrated in geomorphology. Confirmation that the study of landforms is a Quaternary field in which there is particular national interest is found in an examination of NSERC grants (Table 10-2).

International comparisons are not easy but two observations may be pertinent. At the First International Conference on Geomorphology held in 1985, Canadian participants formed the fourth largest national delegation. Twenty-five papers out of a total of 550 (including poster sessions) originated in Canada and 15 were on glacial and periglacial topics. When the number of Canadian major geomorphological publications is compared with the output from Australia, a country with only half the population, Canadian productivity is smaller (for list of monographs published in last decade see Appendix 6).

5.2.1 Geoprocesses and landforms: glacial and proglacial

The processes of erosion and sedimentation associated with glaciers have attracted comparatively little attention in Canada. It is remarkable how little is known about such topics as: rates of glacial denudation; sediment fluxes from the land to offshore; glacier/marine (and lacustrine) interaction; and all aspects of high latitude, polar, glacial processes. Interpretation of much Quaternary stratigraphy will remain ambiguous until knowledge of the environments of glacial deposition is improved.

Cooperation between glaciologists, glacial geomorphologists and sedimentologists is not well-developed in Canada and the introduction of new developments in glaciology has been principally by foreign scientists. The recent transfer of glaciologists to the Geological Survey of Canada from the Polar Continental Shelf Project econd chairman from statistical analyses and reports prepared, initially on a regional basis by members of the committee (Cordillera (O.S.)) Interior Plains (E.A.C. and A.M.S.) Ontario (A.V.M.) Québec (C.H-M. and J.L.) Atlantic Provinces (P.J.M.), North (L.D.)

We wish to thank all respondents to the questionnaire for their time and interest in replying, often at length, to our many questions.

We also acknowledge valuable contributions from Quaternary scientists who wrote to should improve this situation.

The application of geomorphological and sedimentological processes to evaluation of glacial terrains through a Landsystems approach[1] shows considerable promise of further development.

5.2.2 Geoprocesses and landforms: periglacial (including permafrost)

In the early years of the century it was recognized that rock weathering and mass wasting in arctic (and alpine) areas were characterized by processes associated with ice in the ground. Periglacial geomorphic processes are conspicuous and often dominant when permafrost is present, although individual processes may operate in warmer environments. In the presence of permafrost and suitable surficial sediments, ground moisture migrates extensively: excessive soil water collects near the surface and ground ice accumulates beneath. In consequence, surficial sediments in the shallow-active layer above the permafrost table are often highly mobile and geometric sorting of surface material is widespread.

Permafrost is present in nearly 60 percent of the land area of Canada. Since the last interglacial, probably all parts of the country excluding only some narrow coastal zones have, at one time or another, experienced a permafrost regime and relict (or paleo-) permafrost has survived from the past in many northern areas. The thickness of permafrost may frequently be inversely correlated with the distribution of late Pleistocene glacier ice and marine transgressions. In the Northwest, glacially deformed ground ice at least 40 000 years old survives, ground ice is found beneath the Beaufort Sea and, in southern Canada, periglacial microlandforms are preserved from the past. Elsewhere, particularly in the Prairie Provinces, Wisconsinan glaciers advanced into unconsolidated and semiconsolidated sediments in which permafrost was present, and thrust the material into conspicuous landforms which survive to the present.

The role of permafrost in modelling the landscape, today in the North and practically everywhere in Canada in the late Quaternary, makes it an important subfield in Quaternary geoscience. It was therefore disturbing to find that only 8 respondents (5%) listed permafrost as a research field of prime interest and none (in replying to question 33) consider that permafrost research is a sector demanding increased attention.

The problems associated with developing permafrost research are like those of Quaternary geoscience in which there are theoretical and applied inputs from a broad range of disciplines. Permafrost studies developed in Canada after 1945 with active participation by the National Research Council in mapping, theoretical analysis and applied studies. Subsequently research has become more distributed across the country. In spite of the small number of scientists involved in permafrost research the case can be made that Canada is a world leader, largely through the efforts of a few individuals.

Permafrost and periglacial landform studies are frequently linked in the same research program. In the latter, major investigations began on Victoria Island in the early 1940s with work by A.L. Washburn. They were extended to many parts of arctic Canada by field parties of the federal Geographical Branch in the 1950s. The most intensive research has been in the western Arctic, where scientists from the Universities of British Columbia and Ottawa have studied the role of ground ice in the development of landforms, including pingos. Other periglacial studies of weathering, mass movement, and lake and sea ice processes have been made at many centres and particularly in the federal departments of Energy, Mines and Resources and Environment, and in the universities of Alberta, Carleton, McGill, Montreal and Ottawa.

Research into periglacial processes and permafrost has been widely applied to developmental problems especially in the Mackenzie-Beaufort sector. However, fundamental explanations of many problems associated with weathering, solifluction (and other forms of mass movement) and patterned ground have not been forthcoming. Nor have descriptive accounts of the presence of tors and unique periglacial (altiplanation) slopes in the eastern and high Arctic led to detailed studies of these phenomena.

[1] Eyles, N. (ed.) Glacial Geology, Oxford, 1983, 409 p.

In recent years some geomorphologists have recognized that, even when periglacial conditions failed to develop after the withdrawal of an ice sheet, a transient set of unusual boundary conditions prevailed (paraglacial regime) for a period before the reestablishment of a 'normal' regime.

5.2.3 Geoprocesses and landforms: slope and erosion studies southern Canada

Studies of the geomorphic processes that dominate contemporary landform evolution in the southern parts of Canada are less numerous, although most of the major subfields (e.g. fluvial, eolian, karst) have attracted small numbers of geomorphologists. Research into slope evolution is in progress at several universities. Analysis of the stability of slopes in Champlain Sea and other post glacial sediments and of the mechanism of slope failure have led to a number of important papers with applied significance. In the Cordillera, estimates of weathering rates and slope evolution in alpine environments have been made for many years. Karst studies have been largely in the Cordillera and have led to interesting estimates of Quaternary alpine environments and the age of the mountain/valley relief. Given the wide variety of environmental impact assessments required in southern Canada in the last few years, the shortage of competent Quaternary geoscientists in these fields has had a serious effect.

5.2.4 Geoprocesses and landforms: marine, coastal

Littoral geomorphic research has been concentrated on the East Coast and some Great Lakes shorelines with scattered research projects on the West Coast and in the Arctic. Sediment transport budgets with associated morphology, including multiple cliff forms and shore platforms formed during the late Quaternary, have attracted most attention. Paleo-coastal elements, including multiple cliff profiles and elevated platforms of interglacial origin and, in the North, the distribution of strandflats have been described, but their origins and significance to Quaternary events await further research. The special case of sedimentation in the tidal zone of estuaries around the Bay of Fundy and elsewhere in the Maritime Provinces, continues to be a significant field for research.

Theoretical research is distributed between a number of universities, especially Dalhousie and McMaster, federal departments, with work by the Geological Survey of Canada on both Atlantic and Pacific coasts, and provincial agencies. Other groups developing west coast research are at the University of British Columbia and the Institute of Ocean Sciences at Patricia Bay. Only little applied research is found in engineering faculties, but much is done by consulting groups that draw on university scientists.

5.3 Sea levels

5.3.1 Quaternary sea levels

Sea level has fluctuated widely in Canadian coastal areas since the withdrawal of the late Wisconsinan ice sheets. The changes in any one locality are a complex function of global, regional and local influences. Some of the changes of sea level result in part from diastrophism, as around the Beaufort Sea, but the majority are due to variables dependent on the glaciations including ice volume changes, glacial isostasy and hydro-isostatic loading. Where long-term postglacial records cover many millenia, conclusions as to the age and form of the final glacier retreat, the thickness of the ice sheet, and tectonic changes may be inferred. In addition, geophysical crustal models can be tested.

Today, sea level is rising in most of the outer coastal zones of Canada, including the continental shelves. Off Nova Scotia and in the Beaufort Sea, coastal plains have been submerged by more than 100 m in the past 20-30 thousand years and the morphological effects of this submergence is conspicuous particularly around the western islands of the High Arctic. The degree of postglacial submergence decreases away from the ocean and in the Atlantic Provinces the zero isobase intersects the west of pensinsular and northern Nova Scotia, central Edward Island and southern Newfoundland. On the continental side of the isobase the overall effect is one of emergence, with contemporary sea level lower than maximum postglacial transgression.

5.3.2 Postglacial (Holocene) sea levels

Field observations on Holocene sea levels were begun in the late nineteenth century and at first concentrated on mapping the marine limit in areas rebounding from glacio-isostatic depression. A map of eastern Canada, (including Labrador-Quebec and part of northeastern United States) showing marine limit isolines was published by de Geer in 1892. It has been followed by numerous, and increasingly more detailed maps. In the past two decades, intensive field research and radiocarbon dating of material in littoral sediments has led to maps showing emergence between specified dates and relative changes over selected time intervals, as well as diagrams of rates of change of sea level at individual sites, and maps of crustal tilt.

Holocene sea level curves have been published from dozens of localities in eastern and northeastern Canada, including Hudson Bay, but few are available from the West Coast. Most curves from sites in the north, northeast and interior of the continent (i.e. away from the open ocean coasts, and formerly beneath the inner zone of the Laurentide ice caps) reveal rapid uplift at deglaciation with exponential decrease to the present. On the outer side of this sector is a zone where initial rapid uplift has been followed by submergence in the past few millenia, typified by many British Columbia localities. The areas of a third possibility, continuing but not necessarily uniform submergence in the Holocene, are limited to the Mackenzie delta and possibly the outer Baffin Island coast.

Because of the wide range of inferences that can be made from sea level records, they will continue to be derived for all coastal areas where Quaternary research is in progress. Particular attention should be given to 'anomalous' coasts (e.g. northeast Ellesmere Island, Queen Charlotte Islands) where the general pattern of emergence is not followed, and to increasing the number of points and decreasing the time-spacing for situations where smooth exponential decrease appears to be broken.

Changes of sea level in the past few centuries may be deduced from the uplift curves, from historical data and from tide gauges. Unfortunately only a small number of gauges are operative, especially in the northern parts of Canada, and Canadian gauges are noticeably absent from the coordinated global tide gauge network recently discussed in Eos (v. 65, 1985, p. 754-756). Nevertheless it is important to note that two of the seven committee members are Canadian geoscientists.

5.3.3 Late Pleistocene changes of sea level

Evidence for sea level changes prior to the Holocene is limited. Coasts on the extreme outer rim of the country and the adjacent continental shelf experienced fluctuations of sea level throughout the late Wisconsinan glaciation. Data are available from the Beaufort Sea sector, outer Baffin Island and the continental shelf off the Atlantic provinces, although much has still to be determined from these areas.

Sea level changes during and prior to the Sangamonian interglacial are even less well-known and are essentially limited to observations of rock (wave cut?) platforms around the Gulf of St. Lawrence, in Nova Scotia where they are associated with sediments, and from isolated localities farther north, notably on Baffin Island.

5.4 Associated scientific disciplines contributing to Quaternary geoscience.

The committee identified a group of Quaternary subjects that form the core of Quaternary Geoscience. These are Quaternary geomorphology, glacial geology, sedimentology and stratigraphy. Numerous associated disciplines contribute to an understanding of the core subjects (e.g. glaciology) and an even larger group of subjects provides information for determining the chronology of the Quaternary and the history and geography of Quaternary environmental events.

The report examines the status of some of these associated fields in the following pages.

5.4.1 Glaciology

The field of glaciology covers the study of ice in its terrestrial and marine forms. Glaciology is essentially an interdisciplinary subject and consequently has teaching and research problems not unlike those found in the Quaternary geosciences. The training of a Quaternary geoscientist requires some knowledge of glaciology for consideration of the processes associated with glacial denudation, debris entrainment, transportation and deposition. Research scientists seeking to reconstruct past glaciations benefit from close collaboration with glaciologists, particularly those working in ice physics, for their theoretical studies of modelling of spatial, dynamic and thermal characteristics of ice caps, the geophysical regimes of surging and waning ice sheets and the mechanics and properties of floating ice shelves.

Canada has the second largest area of contemporary glaciers in the northern hemisphere (after Greenland), the second largest area of permafrost and ground ice (after USSR) and the largest area that was covered by Pleistocene ice caps. It is therefore remarkable to find that there is little ongoing theoretical glaciology in the country and not much more applied glaciology (such as mass balance studies).

In several universities (Alberta, Memorial, Ottawa, Trent and Waterloo) there is research on glaciers, primarily directed to analysing recent climatic change, but extended research and graduate programs are limited to the Department of Geophysics and Astronomy, University of British Columbia. Glaciological studies are found in the federal government, where the projects of the National Hydrology Research Institute are principally directed to contemporary glaciers. The glacier studies of the Polar Continental Shelf Project include ice-core drilling, with particular attention to long-term climatic change.

Drilling that began at Camp Century on the Greenland ice cap in the 1950s led to the recovery of long ice cores. Subsequently, cores have been obtained from other ice caps in the northern hemisphere and Antarctica. Analysis of ice layering and the contained oxygen and hydrogen isotopes and particulate and chemical pollutants have provided a unique record of Quaternary climatic change for continental sites. Although the interpretation of the chronology can be ambiguous, particularly for the basal ice, data extending to the last interglacial have been established. In Canada deep cores have been obtained from the Devon, Meighen and Agassiz (north Ellesmere Island) ice caps and shorter-period cores from the Barnes and Penny ice caps, Baffin Island. If resources are available within the next decade, it will be possible to determine in detail, from ice caps around Baffin Bay, climatic change in northeastern Canada for the past 10 000 years that will include the final stages of the Laurentide ice sheet and the post glacial interval.

The Committee was told repeatedly during interviews that the national training and research situation in glaciology are deteriorating. The glaciologists who made significant international contributions from Canada in the 1960s and 1970s are now retired or have returned to their own countries; rarely are they being replaced. Of all the disciplines that contribute to Canadian Quaternary geoscience, glaciology appears to be in the weakest state.

5.4.2 The ocean record

Quaternary paleoceanography began in the 1950s when the invention of Kullenberg piston corer allowed systematic sampling of long (10 m) sediment cores from the world's oceans, and Cesare Emiliani showed that changes in the stable isotopic ratios ($^{18}O/^{16}O$) of foraminifera in these cores correspond to cyclical variations in sea surface temperature (SST) and are directly related to glacial cycles. During the next 20 years it was established that: (1) ocean records revealed climatic fluctuations as sequences of biogenic sediments which represent interglacials that alternate with muddy or gravelly glaciogenic sediments deposited by melting icebergs or by gravity flows from continental margins during glacial intervals of sea level lowering; (2) lithological cycles and isotope stratigraphies from individual cores can be correlated precisely over long distances within an ocean basin and from one ocean to another; (3) marine sediment cycles can be mapped from ships by means of high resolution seismic profiling systems.

In the 1970s, through the development of the international Deep Sea Drilling Program, a global marine isotope chronology was firmly established for the past 0.7 million years[1], and it was shown that smaller scale cyclical variations reflect major climatic cooling events at least as early as the Middle Miocene in the Northern Hemisphere and the Late Oligocene in the Southern Hemisphere.

The apparent reliability (reproducibility) of the results from the paleoceanographic studies led to re-evaluation of the duration and timing of the classical Quaternary records onshore, so that increasingly European, North American and East Asian Quaternary chronostratigraphies use the deep sea biostratigraphic and paleomagnetic record as a foundation for dating the major glacial cycles recorded in terrestrial deposits.

During the past five years, several major scientific developments have continued to open up new perspectives in Quaternary geology. They included the following advances: (1) very high resolution seismic systems for mapping the top 100 m of sediment on continental shelves and the linking of these marine records to coastal Quaternary deposits; (2) submersibles for mapping submarine topography, study of marine sediment stability and sediment transport processes; (3) continuous coring systems for deep sea drilling and the commissioning of a Canadian-built vessel, the JOIDES Resolution which permits drilling to depths of 2 km in Arctic waters south of 78°N; (4) piston coring in the Arctic Ocean from 80-89°N, using ice islands or ice flows as a camp base; and (5) development of a marine biochronology based on diatoms, benthic foraminifera and marine palynomorphs (dinoflagellate cysts) which allows the extension of the global biochronology into high latitude regions where temperature conditions prohibit growth and/or preservation of calcareous microfossils and radiolarians.

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[1] Shackleton, N.J. and Opdyke, N.D. Oxygen-isotope and paleomagnetic stratigraphy of Pacific core V28-239, Late Pliocene to Latest Pleistocene, Geol. Soc. Amer. Mem. 145, 1976, p. 449-64.

Canadian contributions to modern Quaternary paleoceanography have been substantial in the following areas: (1) development of the HUNTEC high resolution seismic system and its use for regional mapping of continental shelf sediments; (2) piston coring of glaciated shelf margins and high latitude oceans, including Labrador Sea, Baffin Bay and Scotian Shelf; (3) seismic mapping and sedimentological study of major submarine ocean channels; (4) correlation of onshore and offshore Quaternary deposits using palynology, benthic foraminifera or a combination of both palynology and marine microfossils; (5) coring from FRAM, LOREX and CESAR ice camps in the Arctic Ocean; (6) development of a high latitude biochronology for Miocene to recent sediments recovered from the Norwegian Sea and Baffin Bay – Labrador Sea; (7) acoustic recognition and study of geotechnical effects of submarine permafrost in the Beaufort Sea; (8) sea ice and iceberg scour processes; (9) sediment transport processes in arctic fiords; and (10) joint industry – government – university projects to study Quaternary deposits in exploratory drillholes from the Eastern Canadian margin and Beaufort Sea.

Major problems hindering further development of Canadian Quaternary paleoceanography are the limited number of training centres for marine geologists (only Dalhousie University, and Memorial University of Newfoundland have formal marine geology programs); (2) the limited number of dedicated marine research vessels (two at Bedford Institute of Oceanography, two at the Institute of Ocean Sciences near Victoria) and the restricted sea time available per year for research from these vessels; (3) outdated coring equipment, shipboard laboratories and the absence of a global navigation system for the Canadian arctic regions; (4) total lack of Canadian expertise in siliceous marine microfossils; and (5) very restricted opportunity and capability for quantitative processing of very large marine geology data bases such as those used by CLIMAP and its successor, SPECMP. International collaboration is seen as an essential means for Canada to keep abreast with developments in Quaternary marine geology and paleoceanography.

5.4.3 Quaternary geomagnetism

Paleomagnetism is the record of the direction, sense, and intensity of the earth's magnetic field during geologic time. Its study is based on the fact that those features were continually changing, and that the record of the field becomes preserved in many types of sediments during deposition. The study of paleomagnetism has developed largely during the past 20 years and, though not in general use in Canadian Quaternary work, it will doubtless become more widely used as a valuable means of correlation and of determining both ages and rates of deposition.

Paleomagnetism has extreme value because the effects are worldwide and many types of material can be used for analyses. Thus, in the Quaternary, geomagnetic marker horizons can be used to correlate between loess in China, glacial lake deposits on the Canadian Prairies, sediments laid down on the floor of the Atlantic Ocean, and lava flows in Hawaii. Further, once the age of a magnetic event has been established, a worldwide method of absolute dating is available. Indeed, it is probable that, in time, many of the Quaternary boundaries will be defined at certain absolutely dated paleomagnetic events.

Fine grain materials, such as lake or marine silts and clays, give best results in analysis, for their slow settlement in water allows time for the grains to become aligned parallel to the earth's field. Work has been done on till, but commonly the results are considered unreliable. This is mainly because, even if a till consists mostly of clay and silt particles, one or two larger grains can completely distort the results.

For dating and correlation purposes, magnetostratigraphy makes use of both major and lesser reversals during which, for reasons not fully understood, the north and south magnetic poles exchanged positions. It also uses the periods of high and low magnetic intensity (magnetic remanence) and the periods of fairly stable and extremely unstable remanence. Periodic secular variations in the magnetic field give a means of determining rates of deposition of sediments. The easiest features to use, and the ones that have attracted most attention, are the reversals. The present position of the poles is defined as normal, the opposite as reversed. The only major reversal in the Quaternary, at the Matuyama-Brunhes boundary of about 730 000 years ago, has already proven valuable in indicating a great age for some surficial deposits on Banks Island and in southern Alberta and Saskatchewan. Lesser reversals have also proven valuable as markers, in particular the Mungo Lake and Mono Lake events of some 30 000 to 25 000 years ago and the Olduvai Polarity Event that lasted from 187 to 167 million years B.P.

Though it can probably be stated that, nowadays, no description of an important section can be considered complete unless it includes the magnetostratigraphy, paleomagnetic studies are still in their infancy in Canada. Some offshore work has been done by both the Atlantic and Pacific Geoscience Centres, mainly through piston coring. However, the rate of sedimentation is so high in many areas that few cores reach the Matuyama-Brunhes boundary, and so work has concentrated more, and with considerable success, on the recognition of the lesser polarity events. However, the same rapid accumulation of sediment has allowed recognition of periodic secular variations during the Holocene on a scale of a few hundreds of years. On land, most of the work has been carried out at the universities of Windsor and Lethbridge, with much of the latter being for the Geological Survey of Canada, and at Sidney, British Columbia. The Lethbridge studies have used laboratory and computer facilities in the United states.

Due mainly to the newness of the study, both the number of workers and laboratory facilities, including computer and computer program facilities, can probably be considered inadequate for the needs of Canada. Further, most of the work done here is applied, rather than theoretical and more attention should be given to theoretical studies. In particular, more study needs to be given to the paleomagnetism of tills. This is a matter of importance in Canada, where tills are so widespread and so abundant in the Quaternary deposits.

5.4.4 Paleoclimatology

Reconstruction of past atmospheric circulation patterns and the associated climates is the principal objective of Quaternary paleoclimatology. Many types of proxy data for paleoclimatic reconstruction are available, and the establishment of past climates, the rates and processes of climatic change and the testing of theoretical models form the basis of the subject.

Recent Canadian paleoclimatological research has generally had a regional focus and much of it consists of paleoclimatic inferences drawn from Quaternary geoscience, exemplified by the work of the Quaternary group of the Geological Survey of Canada. Ice core research in Canada is also yielding significant results (5.4.1).

Progress in paleoclimatic reconstruction continues to come from paleobotanical studies. An example is recent work in northern Yukon which has added greatly to our knowledge of conditions on the northwestern fringe of the Laurentide ice sheet and of the relatively early thermal maximum and subsequent decline which occurred there. Considerable information about late glacial and Holocene climates has also been accumulated for the eastern Arctic;

this collaborative work based at the University of Colorado includes much palynological work on terrestrial and marine sediments. It indicates a deterioration in climate there since 2000 BP.

There has been some success in establishing relationships between climatic variations and synoptic and hemispheric circulation patterns, but the nature of glacial and interglacial circulation regimes and the transitions between them are still uncertain. The most promising approaches in this area involve the use of numerical models and the integration of terrestrial and marine records, as has been done in the United States CLIMAP program. A qualitative model has been obtained for the northern Labrador Sea by collaborative Canadian government-university projects.

There are no large multidisciplinary programs concerned with paleoclimate in Canada, although a start has been made with The Climate Change Program of the National Museum of Natural Sciences. It has produced a series of review papers and a bibliography[1] and, with the Canadian Climate Program of the Atmospheric Environment Service, sponsored symposia and new research, including studies of historical and early instrumental climate records. These initiatives, of value to all the Quaternary scientific community and spurred by concern about the consequences of future climate change, will result in a strengthened, coordinated effort and further progress in paleoclimatology in Canada.

5.4.5 Paleoecology

Terrestrial sectors of northern latitudes during the Quaternary experienced two fundamentally different environments according to whether or not the land was covered by glacier ice. Environmental and chronological interpretations of glacial episodes depend largely on stratigraphic evidence from lithostratigraphy and other physical observations. Plants and animals reoccupied these glaciated zones during interstadials and interglacials. Through identification of the remains and analyses of the distribution and density of species and, by inference of the climate and ecosystems in which the species lived, the paleobiologist provides a major contribution to interpretation of Quaternary chronology and nonglacial environments.

Some paleobiologists are concerned primarily with taxonomic and genetic questions, but the major contribution to Quaternary geoscience is by paleoecologists who reconstruct past ecosystems from fossil evidence guided by contemporary experience.

Historically, Quaternary paleoecology began with the recognition of plant macrofossils. Subsequently it has been dominated by stratigraphic pollen analysis from which past vegetations at a specific time, principally during the Holocene have been inferred. Climatic conditions are estimated from the vegetation.

Other forms of paleobotanical evidence have not been used extensively in Canada. The measurement of annual tree ring widths, cross-dating between samples, and the reconstruction of past climates (dendroclimatology) have not been developed as successfully in Canada as in some other countries although it has been used around James Bay, and in the Canadian Rockies, the Yukon and the Mackenzie Delta.

Contemporary distribution of species (plant and microfauna) in formerly glaciated areas is normally explained by postglacial dispersal from unglaciated regions to the south. However it is possible that species survived in refugia within the ice sheets or along their coastal margins. In Canada the possibility of refugia on the Queen Charlotte Islands, in the northern arctic islands, on Baffin Island and along the Labrador-Newfoundland rim, as well as the complex case of the Yukon-Alberta ice-free corridor, provide interesting, if controversial, biological perspectives on problems of the completeness of Quaternary glacier coverage.

Fossil animal remains are also valuable in reconstructing Quaternary environments. Within the invertebrates the largest class is represented by the arthropods, and the exoskeletal remains of many organisms are well preserved in a variety of deposits. Insects are one of the most important terrestrial groups, and environmental inferences from their occurrences have been widely developed in Britain and Europe during the past three decades. Studies in Canada have principally involved Coleoptera (beetles), but new research areas are being developed utilising Trichoptera (caddisflies), and the Chironomidae (non-biting midges). Many families of the forementioned insect classes have aquatic representative or are entirely aquatic in some, or both, stages of their life histories. The remains of these individuals, together with Ostracoda (and freshwater diatoms), can provide much information in the reconstruction of paleohydrologic regimes. Many species, particularly within the Coleoptera, show strong preferences for specialised environments and have considerable value in paleoenvironmental and paleoclimatic studies. Work on fossil beetle assemblages has been concentrated mainly in southwestern Ontario, the Yukon and N.W.T., but with siolated studies elsewhere in the country. Canadian workers have also been responsible for many studies in Alaska, and in the northern part of the continental United States.

Paleoentomological research, and studies involving other micro-organisms are extremely time consuming. Often they require the washing and sorting of tens of hundreds of kilograms of sediment, laborious picking and mounting of specimens, and considerable research time in identification. It is not unreasonable to assume a productivity rate of one site per year. The problem here is not equipment, but technical support and ready access to reference collections of modern comparative materials. An understanding of these problems by grant-awarding agencies is essential for the continued growth of these research fields.

Vertebrate fossils, especially of mammals, are rarely sufficient in numbers to be used for precise environmental reconstruction, although the stratigraphic position of specific fossil bone assemblages in southeastern Alberta and southwestern Saskatchewan has been significant in determining chronology and correlation between sections.

Marine microfossils, including foraminifera, coccoliths, diatoms, radiolarians and dinoflagellates, form the basis of paleoecological interpretation of changes in ocean circulation and water temperature. In Canada, there is adequate expertise in the knowledge of foraminifera and dinoflagellates, but there is no expertise in Quaternary coccoliths or siliceous marine microfossils.

5.4.6 Palynology

Among the varieties of proxy data available for reconstructing Quaternary paleoenvironments pollen is one of the most valuable. Environmental interpretation of fossil plant assemblages requires a knowledge of present distributions and assumes that there has been no change in the ecological tolerances of species. Since the evidence is normally contained in nonglacial sediments, the terrestrial record in Canada is most complete for the postglacial and is only fragmentary for previous interglacials.

[1] Harington, C.R. and G. Rice (eds.), 1984.

Climatic Change in Canada 4. Annotated Bibliography of Quaternary Climatic Change in Canada; National Museums of Canada, National Museums of Natural Sciences, Syllogeus No. 51, 368 p.

The detail of paleoenvironmental reconstruction depends both on the nature of the evidence and on the methods employed. Plant macrofossils (roots, stems, leaves and reproductive structures) occur only sporadically but normally testify to the former presence of a plant species at or near a site. Among the most significant of these remains are those of trees beyond the present treeline.

Plant microfossils (pollen grains, spores, diatoms and certain algae) form the basis for most paleoenvironmental reconstructions. They are produced in great abundance and can be incorporated into many types of sediment, although they are most frequently studied in lake muds, peat, and, to a lesser extent, in marine sediments. Microfossil concentrations frequently exceed 100 000 per ml in lake sediment, permitting a variety of statistical analyses and a time resolution as fine as one year for varved sediment, although most analyses employ a resolution of a century or more. Pollen grains and spores of terrestrial plants generally fall to the surface within a short distance of the source, but their small size (10-100 microns) can permit dispersal by wind for several thousand kilometres, or their flushing down a river system. Since, in addition, the production, dispersal and preservation of pollen grains differ between species, the relationship between a microfossil assemblage and the contemporary vegetation at the site is complex. Pollen grains in marine sediments are an important means of correlating onshore and offshore marine sediments. Statistical analyses of pollen in surface marine sediments from Baffin Bay to Nova Scotia show there is a strong correlation between contemporary vegetation and marine pollen assemblages.

Since 1975, regional syntheses of postglacial vegetational sequences, with climatic and some edaphic inferences, have been published for much of mainland Canada; reconstructions are in progress for the remainder of the country except the arctic archipelago. The syntheses for southern Quebec[1] and the far northwest[2], each based on a decade or more of work, exemplify the quality of interpretation possible.

Specific postglacial problems that have been investigated include modern pollen distributions, both terrestrial and marine, treeline movements in the Rocky Mountains and the Northwest Territories, the effects of paludification, climatic trends in the Arctic Islands and environments of early Man in Labrador.

For the late-glacial, work in the Atlantic Provinces has provided evidence of a climatic oscillation comparable to and synchronous with the Allerød-Younger Dryas oscillation of northwestern Europe. Evidence of late-glacial ice-free conditions has also been found on parts of the Queen Charlotte Islands. On a longer time-scale, cores of marine sediment from East Coast shelves have permitted correlation of data from marine and terrestrial microfossils for more than one glacial cycle, providing evidence of the oceanic conditions which were a major control on the onset and waning of glaciation.

For much of the country the reconnaissance of postglacial paleoenvironments is drawing to a close, and future work will likely be directed toward specific problems. Increased knowledge of modern pollen deposition, together with the use of influx values (numbers of grains deposited annually on a given area), is eliminating some of the problems of interpretation of fossil assemblages. A major remaining problem is that of climate-vegetation equilibrium. Any significant lags in vegetational response to climatic change leads to errors of interpretation. For earlier interstadials and interglacials, fossil assemblages are increasingly likely to differ from modern ones and paleoenvironmental reconstruction becomes decreasingly exact.

A recent compilation for the International Commission for Palynology lists more than 40 Canadian specialists working on Quaternary and modern microfossils.

Much of the work in the eastern Canadian Arctic and in Labrador has been done by workers from the United States. In addition, a number of broad regional syntheses have necessarily included data from both countries, but have generally been published in the United States.

The facilities required for palynological studies are far less expensive and complex than for many other fields of enquiry, but funding for properly trained research assistants is less easily acquired. Many institutions and individual workers have stored samples awaiting analysis, but lack the necessary assistance. Microfossil analysis is notoriously time-consuming if done properly, and in a funding system where publication is a prime criterion of ability, those engaged in paleoenvironmental reconstruction are at a disadvantage.

5.4.7 Tephrochronology

Tephrochronology is a recent addition to Quaternary geoscience; serious studies in North America commenced only in the late 1950s. They may be grouped into those of a fundamental nature and those that are derivative. The former involves method development and original definition of the tephra record; the latter uses these results to help solve particular Quaternary problems, such as age and correlation of sediments and geomorphic surfaces, chronology of environmental change, rates of weathering, age of fossil vertebrate assemblages and of archeological sites, recent history of the Earth's magnetic field and reconstruction of Quaternary orogenic tectonics.

A major accomplishment has been the establishment in southwestern Canada of a late Pleistocene-Holocene tephra record. This has led to the common use of tephra beds in studies related to late Quaternary environmental history, geomorphology, pedology and archeology. Middle Pleistocene glacial sediments have been reliably recognized at several localities in the Western Interior Plains based on their contained tephra. For example, the Wascana Creek tephra (about 0.6 Ma) in southern Saskatchewan permits correlation with well-studied Quaternary sequences in the northern U.S.A., including areas affected by Laurentide and Cordilleran glaciers, and illustrates well the exciting stratigraphical returns to be derived from tephra. More recent work in the Yukon and Alaska has led to recognition of many widespread Quaternary tephra beds, but detailed descriptions and dating studies have been carried out on only a few, one of which covers most of Alaska and the western Yukon.

In Canada, fundamental tephra research is carried out only at the University of Toronto. However, it appears that a group is evolving at Dalhousie University-Bedford Institute, where the focus is on late Cenozoic deep-sea cores from the North Atlantic-Baffin Bay-Arctic Ocean region.

Derivative studies have been made by scientists from western Canadian universities and governmental agencies (earth sciences, soil surveys). In eastern Canada, research associated with tephra is being undertaken by personnel from the Terrain Sciences Division of the Geological Survey of Canada (environmental history, paleoclimatology), University of Western Ontario (late Quaternary environmental history, pedology), and Ottawa University (erosional processes).

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[1] Richard, P. 1977: Histoire post-wisconsinienne de la végétation du Québec méredional par l'analyse pollinique. Service de la recherche, Direction général des forèts, Ministêre des Terres et Forèts du Québec.

[2] Ritchie, J.C. 1984: Past and present vegetation of the far northwest of Canada, Toronto, 251 p.

No purely tephra doctoral studies have started in Canada and research is limited to faculty and post-doctoral (non-Canadian) scientists.

It is clear that the tephra studies can significantly improve our understanding of the Quaternary stratigraphy of the western half of Canada. Because this framework is the foundation of so many Quaternary studies, it follows that more research in Quaternary tephrochronology would be an overall benefit to Canadian Quaternary Science.

5.4.8 Paleopedology

Soil development involves climate and organisms, as conditioned by relief and hence water regime, acting through time on geological materials and thus modifying them. It is relatively simple to identify surface material as soil. However, following burial, the factors of soil formation no longer operate. The aims of paleopedology are, therefore, to establish and interpret the relict pedological characteristics that escaped obliteration after burial.

Paleopedology is somewhat of a stepchild within the soil science community, particularly since most members are trained within the bias of faculties of agriculture. However, paleosols can provide valuable information to Quaternary scientists. Since soil scientists generally have only limited involvement with the study of paleosols, it is now more and more being undertaken by scientists from a wide range of other disciplines, often with limited knowledge of soil science. Yet, failure to critically appraise horizons that may represent paleosols will most certainly lead to misjudgments.

After paleosols have been identified and classified, they are of interest as stratigraphic markers, particularly when they are extensive and recognizable over large areas, and as keys to past environments. For this, it is assumed, of course, that the present surface soils were formed under climatic conditions similar to the present. Valid paleoenvironmental interpretations thus require a complete understanding of soil properties and soil-forming processes.

Many of the chemical analyses normally used to identify a soil are often meaningless for establishing the original chemical nature of a paleosol due to diagenetic changes of the soil's organic matter following burial, and to secondary enrichment with bases, carbonates, and iron oxide by solutions percolating downward, moving laterally, or moving upward by capillary action or changing groundwater levels. Although the study of micromorphology has often been extremely useful, it requires special laboratory facilities. As a result, chemical differentiations are commonly used to establish the genesis and dynamics of paleosols prior to burial.

Probably the most distinct and initial indicators of paleosols are dark-coloured horizons. These are usually due to the presence of organic matter. However, since degradation of organic matter continues after burial, it is desirable, for the classification of these buried soils and the possible reconstruction of the paleoclimate, to establish the properties of the original organic matter. Much research has lately been carried out to determine the presence of original organic molecules in surface soils and their fate in buried soils. Amino acid levels, enzyme activities, polysaccharides, infrared spectra of humic acids, aliphatic carboxylic acids, and alkaline-extractable Fe and Al have all been used to study the organic matter of buried soils. These techniques, however, have yet to be tried on a wide range of soils.

Almost 240 published papers refer, directly or indirectly, to paleosols in Canada, but only about 15 percent treat paleosols as worthy of study per se. Of all Canadian soil scientists, only about a dozen are consciously aware of the usefulness of paleosols as a means of describing landscapes of the past, and actually consider paleosols worth studying. Indeed, almost all paleosol studies reported have been carried out by graduate students or represent curiosity sites. Yet, in Alberta, for example, a distinct buried profile, often up to 50-cm thick, underneath a layer of tephra is present in numerous locations and often contains significant evidence of human presence. However, in spite of one thesis and several other publications, full understanding is still wanting.

Two of the most pressing needs in the study of paleosols are:

1. Identification of the stable, fundamental properties of the original inorganic and organic matter to establish a 'paleosol' as a true pedogenic profile rather than the result of subsurface weathering or sediment stratification;
2. Development of appropriate analytical techniques to qualify and quantify these stable fundamental properties.

5.4.9 Paleohydrology

The science of hydrology, which is concerned with the occurrence, circulation and properties of water on, and close to the earth's surface, studies a major element of the natural environment. Developments in the past several decades have centred on detailed instrumentation and modelling of drainage basins and analysis of the processes acting within the hydrological cycle. Theoretical models derived from these investigations may be applied to examination of drainage basins before instrumental records were kept; these studies form the basis of paleohydrology.

Paleohydrological research may be developed for any period in the earth's history. Quaternary paleohydrology has proved particularly rewarding in determining the physical parameters of Quaternary environments. Since runoff and sediment yield are functions of climate (precipitation and temperature/evaporation), vegetation (which is partially dependent on climate) and surface sediments, paleohydrology has become an interdisciplinary subject with major contributions from climatology, ecology, geomorphology, geology and hydrology. When a hydrological system is analyzed for a drainage basin in a past environment it is usually possible to estimate some of the elements through field studies and obtain other data from suitable models. For example, sediment characteristics and load may be determined from: limnological studies of lakes in the basin, floodplain deposits and from river terraces: and steam discharge can be estimated by changes in meander belts in relationship to valley sides.

Several major themes have been evident in international Quaternary paleohydrology. They include studies of abrupt changes in the hydrological system associated with Man's intervention with the vegetation, especially the clearing of forests and the introduction of agriculture; the hydrological pattern in paleoperiglacial areas often in the presence of permafrost; and the evolution of drainage systems and associated valley forms in early Holocene and interglacial periods. Other topics have included the origin and age of paleogroundwaters in artesian basins and the identification of stream channels subsequently buried beneath fluvial and glacial sediments which may provide potential sources of groundwater. Karst paleohydrology is concerned with the origin and development of surface and underground karstic features in past periods, and with the surface environments that are associated with sediments preserved underground.

Paleohydrology has attracted considerable attention in the USSR and Europe and an International Geological Correlation Programme Project (IGCP 158) is concerned with the paleohydrology of the temperate zone in the last 15 000 years, but apart from some significant karst studies and a few individual research projects, paleohydrology is developing slowly in Canada.

5.4.10 Neotectonics

Crustal uplift and depression, tilting and warping have occurred in many parts of Canada in the Quaternary. Some changes have been associated with tectonic processes; many are more directly or indirectly associated with crustal loading and recovery from glaciation.

Western Canada, associated with the active western margin of the North American plate, remains the most critical region for neotectonics study in Canada because of its implications for natural (chiefly earthquake) hazards. Research has included description of a few active fault traces in the Yukon and in the Kootenay district, British Columbia, and the as-yet-unsuccessful search for active faulting related to the 1946, 1918 and other large British Columbia earthquakes. Above the Juan de Fuca subduction zone, levelling, triangulation, tide gauge analyses, and microgravity surveys on Vancouver Island, together with similar measurements in Washington and Oregon, confirm active subduction and imply a potential for a great thrust earthquake on the plate boundary. Data on Holocene sea level changes are important for placing these historical measurements in perspective. As no great earthquake occurred in the past 150-180 years, evidence for previous earthquakes must be sought in the Holocene geological record, both directly through rapid facies changes due to coseismic uplift or subsidence, and indirectly from periodic deposits that might represent slope failures during strong earthquake shaking. In this context, mapping of landslides and very large rockslides may contribute to new assessments of earthquake hazard.

By comparison with the West, eastern and arctic Canada are tectonically inactive although earthquakes (magnitude 7) in the Gulf of St Lawrence-Grand Banks region are known to cause massive slumping on the continental margin and displacement of sediments over 1200 km south in the Atlantic Ocean. Research into nonglacial neotectonics is hampered both by the slow deformation rates and the fact that much of the pre-Holocene evidence was destroyed during the last glaciation. Nevertheless, areas of relatively high earthquake activity imply secular crustal deformation and studies on interglacial shorelines in the Maritimes demonstrate a nonglacial component of vertical movement. Crustal stress orientation data have confirmed that Canada east of the Cordillera is being compressed from the northeast or east-northeast, most likely in response to ridge-push from the Mid-Atlantic spreading centre or drag on the base of the North American Plate as it drifts southwest. Although there are local anomalies to be explained, the recognition of this continent-wide stress field indicates a plate tectonic control for most contemporary neotectonic deformation excluding the residual glacial uplift.

Vertical deformation due to deglacial unloading dominates secular neotectonics in the east where continuing research will lead to refined crustal rheology models and constrain the mode of deglaciation - details necesssary for understanding Canadian and worldwide sea level and climate changes in the Holocene. In some places (e.g. Great Lakes) the rates are sufficiently high to affect human activities; for example, historical uplift of the outlet to Lake Ontario has raised average water levels at the southwest end of the lake enough to significantly increase shoreline erosion.

5.4.11 Environmental Archeology

Environmental archeology is concerned with the analysis and interpretation of material ultimately derived from Quaternary natural environments, yet recovered from archeological sites. Such sites often contain a wealth of materials which, under other circumstances, would be studied by geoscientists. These materials include remains of plants (e.g. charcoal, carbonized seeds, pollen) and animals (e.g. bone, shell, chitin), as well as sediments and soils. Their presence in an archeological site may be due to direct human intervention (e.g. forest clearance produces a change in the local pollen sequence). Even if there is no human factor involved (e.g. deposition of volcanic ash), such materials may reflect the nature of the environment in which humans lived.

In the past, archeologists tended to ask specialists from other disciplines (zoology, botany, etc.) to analyze such material. However, during the last 20 to 30 years environmental archeologists have increasingly taken on these tasks. This is for three reasons: (a) archeological material is often less well preserved than the 'specialists' are used to; (b) there was often a lack of interest in analysis of archaeological material unless it also helped solve a problem of another discipline; (c) archeologists have a better understanding of what questions to ask of the data in order to solve archeological questions.

An environmental archeologist may be defined as committed to the study of past human societies, but approaching this study through the analysis of materials produced in the natural environment. In Canada, the pre-eminent area of environmental archeology is zooarcheology – the study of animal remains from archeological sites. This is because animal remains are commonly found on sites and are easy to recover, because comparative collections are relatively easy to establish, and because there are relatively few technical skills required for basic analysis. Zooarcheology is the most common environmental specialty listed for departments of Anthropology and Archeology.[1]

Less common areas of environmental archeology are geoarcheology (the study of plant remains, usually seeds and charcoal), and the archeological application of palynology (this is usually separated from paleoethnobotany). The National Museum Guide lists only seven faculty positions in these three areas, while listing seven zooarcheologists.

In many university departments which offer some degree of archeological specialization, there is probably inadequate exposure to the methods, aims and potential of environmental archeology. When one considers that environmental finds often outweigh the number of artifacts recovered, and the considerable emphasis on ecology in North American archeology, this is somewhat disturbing.

At the graduate level, the situation is better. Many graduates are attracted to departments because of an environmental specialty. These departments include Simon Fraser University (Archeology) where zoo-archeology, geo-archeology and archeometry are taught; University of Alberta (Anthropology) which teaches zoo-archeology and palynology; and University of Toronto (Anthropology) which teaches zoo-archeology and paleoethnobotany. Many departments maintain contacts with other departments of biology, geography, geology, physics and chemistry, and graduate students often benefit from these contacts and develop good interdisciplinary research projects.

Research in environmental archeology also takes place away from universities. Federal and provincial agencies (e.g. National and provincial museums, Parks Canada, provincial archeological officers) undertake excavations and report on results. In addition, contract archeology by private consultants has produced hundreds of excavation reports in some areas of Canada. Unfortunately, the quality of environmental archeology is extremely variable.

The major ongoing research goals of Canadian environmental archeology are analysis of prehistoric environments in which human societies and establishing the nature of the human/environment interaction. Because Canada is so large and archeologists so few, basic exploratory

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[1] National Museum of Man, 1982; Guide to Departments of Anthropology and Archaeology.

research is still required in many areas. Also, research problems tend to change as the overall academic climate changes. For example, there is currently a great deal of interest in site formation processes, including the study of how organic remains become preserved on sites and the geomorphological conditions under which sites are destroyed or preserved. There is also a general interest in the development of better methods of analysis (e.g. microscopic analysis of bone surfaces, stable isotope analysis, better recovery techniques). Good examples of recent work in environmental archeology which have received international prominence include the work by the National Museum and the University of Toronto in the Old Crow Basin, the development of stable isotope studies at Simon Fraser and McMaster Universities, and the analysis of blood residues at the British Columbia Provincial Museum.

Funding sources are probably adequate for most university research programs. However, what does appear to be lacking are funds to establish major facilities. The two major vertebrate comparative collections in Canada are in Toronto and Ottawa. Anyone wishing to do serious zooarcheological research has to travel to these collections. Many archeologists are currently attempting to build good regional collections for use by students and faculty, but cannot obtain funding for a technician or for physical facilities (e.g. a specially built laboratory storage area, etc.).

Good environmental archeology is being undertaken in Canada, but the value of the subdiscipline is often not appreciated by those who hold positions of responsibility for the supervision of archeological work, especially at the provincial level.

5.5 Reconstruction of Quaternary Environments

Although the natural environment provides a focus for Quaternary science, the rapid growth of specialized subdisciplines always presents a threat to the unity of the subject because of the possibility of a breakdown of communication. Nowhere is this danger more evident than in the separation between terrestrial and marine research activities in coastal zones.

Although one of the principal objectives of Quaternary science is the description and analysis of the natural environment, the methodology for achieving this depends on the spatial scale. At the micro-level, as for example in studying sedimentation in a river channel, identification of the fluvial processes involved, enables realistic predictions of channel changes to be made. In contrast at the macro-level, as for example an examination of the environment of the Prairies in the middle of the last interglacial, studies frequently became a series of weakly-linked analyses of discrete phenomena.

A unifying methodology for Quaternary science that will enable it to provide a synthetic view of past environments may be a systems approach that traces the flow of energy and matter through the landscape. It would be an extension of analytical methods already applied to the examination of contemporary environmental systems and is being used increasingly in disciplines related to Quaternary science including geochemistry, geomorphology, pedology, and ecology.

5.6 Collaboration

This survey of specialities that contribute to Quaternary geoscience emphasizes the broad range of skills required from physical, biological and human disciplines to solve problems in Quaternary science. Only a few specialities may be relevant to a specific problem, but the Quaternary scientist should be sufficiently familiar with all the fields to enable a comprehensive judgement to be made of the potential value of collaboration with other disciplines.

Respondents to the questionnaire stressed repeatedly the importance of collaboration.

> 'We have to understand with the highest possible reliability the complexity of pre- historic environments: a multidisciplinary approach is essential' (archeologist)

> 'Cette collaboration est essentielle et doit être réciproque. D'abord le chercheur spécialisé dans une de ces disciplines a souvent besoin de la géomorphologie et

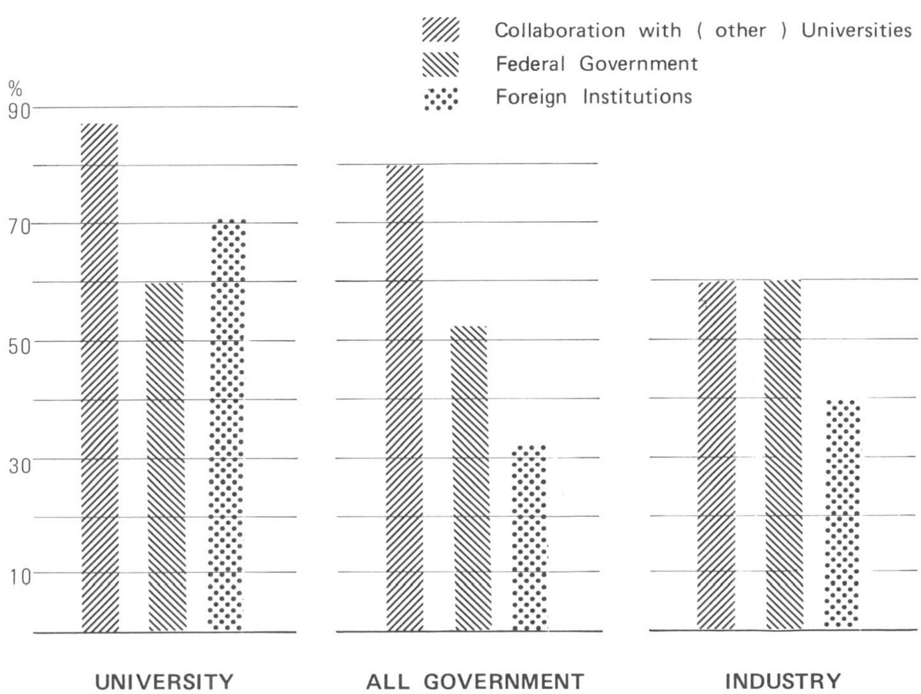


Figure 5.2

Collaboration between scientists is better developed in some sectors than others.

de la géologie glaciaire pour comprendre certains détails ou la vue d'ensemble qui lui échappent. Réciproquement, la possession des connaissances sur les processus actuel ou subactuel doit s'appuyer sur les données de disciplines plus spécialisées telles que l'hydrologie et l'hydraulique'. (géomorphologue)

'The problems are too complex for single- discipline solutions'. (geologist)

'The nature of the problems is inter- disciplinary. Keys to unlock past climate necessitate methodologies from many disciplines'. (climatologist)

'Collaboration is the way to obtain information and ideas more quickly than is possible through publications'. (biologist)

It will be evident from the summaries of the Quaternary subdisciplines that for many, Canadian activity is inadequate to support interdisciplinary studies of Quaternary science, in addition to promoting advances in the separate fields. Glaciology and paleoclimatology are conspicuously weak. While it is clear that productive scientists are working in all of the subdisciplines in virtually every field, there are few scientists, and they are scattered too widely.

We shall suggest in the section on universities and Quaternary Science training that at the doctoral level graduate students should have ready access to advanced workers in all the subdisciplines. The range of specialized skills in the main Quaternary centres of the United States and Europe show that this objective is feasible, but it is not easy to achieve in Canada at present.

In view of the importance to Quaternary research of inputs from different specialities, collaboration between scientists is clearly essential. In some cases large, multi-disciplinary projects are feasible, in others a single scientist may be working alone but seeks specialized support elsewhere. In response to the question (no. 19) of whether interdisciplinary collaboration is essential, 83 percent of the respondents believed it to be so to attain their research objectives, although occasionally adding warnings of expecting too much:

'Collaboration is useful but not essential. University and government Quaternary scientists look mainly back into the past. We work in the present and towards the future' (Geomorphologist in private sector).

Analysis of replies to question 17 (Do you regularly collaborate with researchers in other areas of the expertize?) revealed an existing high degree of collaboration. It is, however, distributed unevenly between the main sectors. Most collaboration is between scientists in different universities, and between universities and the private sector with the federal government. University scientists have twice as much collaboration with foreign Quaternary scientists as do the government and private sector groups (Fig. 5.2).

6 Applied Quaternary Geoscience

Applications of the methods, conclusions and observations of Quaternary geoscience for the benefit of society are as numerous as they are varied. The central objectives of Quaternary science, the description and chronology of past environments, rarely has immediate and direct application, but the surficial sediments and landforms associated with these events form the physical stage on which the life of the country is acted out. The soils, considered both from agricultural and engineering viewpoints, surficial resources of aggregate, peat, placer deposits, the morphology of the surface, hydrology, and geophysical environmental hazards are all closely linked to geoscience events through the Quaternary. A complete understanding of the properties of these fundamental resources demands a knowledge of the Quaternary.

6.1 Geotechnical studies

Following the formation of a surficial sedimentary sequence during a glacial episode, changes induced in the soil environment during the subsequent phases, such as later glacial advances, lacustrine and marine submergence, together with modifications introduced by later geomorphic and climatic changes, determine the mechanical and behavioral properties of a surficial material. Awareness of the Quaternary geological history is consequently essential in specific civil engineering site location analyses and in geotechnical studies of engineering soils in general. The application of Quaternary geoscience to geotechnical studies is not restricted to glacial, proglacial, paraglacial and periglacial sediments but also includes the modification of earth materials by glaciers, and, during nonglacial episodes, by ground ice when permafrost is present. Geomorphological and soil mechanics studies of the stability of natural and of many artificial slopes clearly involve the properties of Quaternary sediments and their environmental history.

Geotechnical studies of Quaternary surficial sediments are assuming an increasingly important role in environmental studies of the disposal of industrial wastes and the effects of acid precipitation.

6.2 Terrain studies

Terrain studies are based on the recognition that physical landscapes may be classified into units (at different scales) throughout which there is a degree of uniformity of slope, relief, surficial sediments, soil moisture and ground ice. Initial studies may concentrate on areal mapping and description; subsequent analyses of the dynamics of terrain evolution in the Holocene provide a fuller understanding of the surface properties and have a predictive role for terrains in areas not fully explored. Indeed the value of terrain studies is highest in frontier regions when they provide the basic information for many planning processes.

6.3 Geochemical mineral exploration

A major applied field of geochemistry is the exploration for mineral deposits through drift prospecting. Till is the normal medium for identifying distinctive mineral

Table 6.1 Environmental Hazards (Geophysical/ geomorphic origin)

Earthquake	
Tsunamis	
Volcanic eruption	
Storm surges (marine)	
Glacier surges	
Dust storms	
Blowing sand	
Fluvial (floods, erosion, meander shifts etc.)	
Marine coastal changes	
Iceberg drift and scour	
Submarine pingo formation	
Rapid mass movement:	rockfalls
	snow/debris avalanche
	rock slides
	earth/mud/debris flows
	submarine slumps and turbidites
Slow mass movement:	surface creep
	rock creep
	solifluction

components that were dispersed from a source outcrop in a train down ice during glaciation. Complications are introduced when the till has been recycled in subsequent glaciations. Stream and lake sediments derived from glacial drift may also be used.

This exploration method has been applied with success in several parts of the country during the past thirty years and is currently being tested, refined and applied by federal and all provincial government geoscience agencies and by an increasing number of private companies.

6.4 Quaternary nonmetallic mineral resources

Quaternary deposits are the main sources of sand and gravel aggregrate in the country. The aggregate is derived principally from materials of glaciofluvial, fluvial (terraces, floodplains) and glaciodeltaic origin. Annual production is in excess of $500 M. Although there are large potential sources of aggregate, it is being depleted locally, particularly near large cities and new sources have continually to be sought.

Peat covers about 15 percent (1.5×10^6 km^2) of Canada. Virtually all peat deposits have formed during the changing environments of the Holocene. They provide agricultural soils (280 x 10>ha), horticultural peat and a theoretical energy source comparable to the oil and coal resources of the country.

Other Quaternary nonmetallic mineral resources include clay, marl and sodium sulphate.

6.5 Placer deposits

Placer gold deposits of Quaternary (and late Cenozoic) age are found in many parts of the country. Principally alluvial in origin, many are located in areas that were never glaciated (e.g. parts of the Yukon), where glaciation was ineffective in removing preglacial alluvial deposits (as in interior British Columbia) or where there has been Holocene alluvial concentration of detrital gold.

6.6 Agricultural soils

Soils provide the basis of the agricultural and forest industries. Canadian soils are derived from Pleistocene and Holocene sediments modified at the surface naturally by climatic, hydrologic and biologic processes and artifically by human activities. As soils evolve over time intervals of centuries to millenia, Quaternary environmental history contributes to an understanding of the parent material from which soils are derived and the changing dynamics during their formation.

6.7 Environmental planning (Hazards)

Human catastrophes induced by geophysical events including floods, earthquakes, landslides and volcanic eruptions have been viewed historically by mankind as calamities over which they had no control. Whilst the degree of control often remains low, geoscience can provide statistical probabilities of their occurrence, their geographical distribution over the earth's surface, and an understanding of the processes involved. Studies of environmental hazards have become increasingly relevant as settlement and development have moved into regions where historical experience of hazards is limited. In Canada this is particularly true of the Western Cordillera, although environmental hazards occur in all parts of the country.

Environmental hazards involve recognition of departure from normal or stable situations and include the concept of magnitude and frequency of such deviations. For geomorphic events at a site, knowledge may be required for millenia (i.e. through the Holocene) and, for waste disposal over even longer periods.

The relevance of Quaternary geoscience is evident. Hazard and long-term site stability studies are, or should be an integral part of all land planning.

6.8 Quaternary scientists in an applied role

The foregoing sections (6.2-6.6) describe the many facets of Canadian life to which Quaternary science makes a contribution. It is evident that the degree of contribution will vary from essentially total, for example in developing methods of drift prospecting where highly skilled Quaternary geoscientists are mandatory, to many cases where non-Quaternary specialists need some knowledge of Quaternary events. We find it extraordinary that the university training of environmental, resource, regional and urban planners rarely provides an introduction to Quaternary science.

In spite of the numerous applications of Quaternary geoscience, only 13 percent of the respondents to the questionnaire reported they were principally involved in the private sector. These figures minimize the contribution of Quaternary geoscience to Canadian economic development. Engineers and planners frequently fail to recognize that all persons in the private and government sectors who are engaged in the development of the land and the natural environment to some degree, draw on the experience of Quaternary research.

6.9 Recommendation: Applied Geoscience:

Universities and other institutions providing professional training in civil engineering, soil science, forestry and the many aspects of land planning (regional, resource, environmental, urban) should provide multidisciplinary courses in the history and physical events of the Quaternary in addition to specialized Quaternary courses such as geotechniques.

7 Quaternary Scientists: the Profession

We believe that there are between 300 and 400 identifiable Quaternary scientists in Canada. A more precise figure is difficult to achieve because of the broad range of specialization in Quaternary subjects. A federal employee engaged full-time in research in Quaternary stratigraphy is unquestionably a Quaternary geoscientist and a professional engineer employed as a consultant in environmental management of coastal zones may be working wholly in applied Quaternary science. Responses to the questionnaire were strongly biased towards the former group and we often failed to identify members of the latter group in our mailing.

The questionnaire did not ask how respondents would describe themselves professionally, but comments in the replies suggest that in the government sector the term Quaternary would appear in a job description (e.g. Quaternary geologist), that in universities the title would correspond to a major discipline (e.g. archeologist) and in the private sector a more general title would be chosen (e.g. environmental engineer). The varying perception in the several sectors of the significance of Quaternary in an employment label is one of the factors that contributes to the restricted interest in professional registration (see 7.11.1).

A high proportion (70%) of the respondents practising Quaternary science hold a doctoral degree. This result is not unexpected considering the large number employed in universities (55%: of which 95% hold a doctoral degree) and as federal government scientists (19%); in both cases a doctoral degree is commonly a prerequisite for employment. The highest proportion of respondents (from all sectors) with a doctorate was from British Columbia and the lowest from the Atlantic Provinces and Ontario; in the latter many private sector respondents hold masters and bachelors degrees (Fig. 7.1).

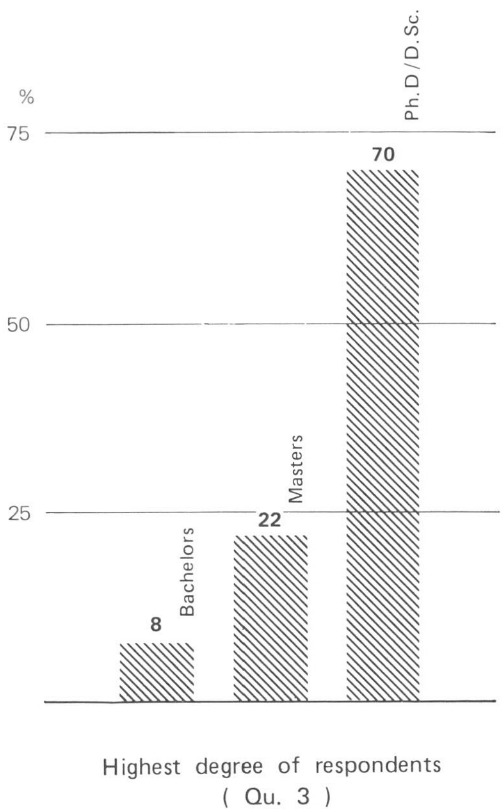


Figure 7.1. A majority of responding Quaternary scientists have doctoral degrees.

7.1 Age distribution and work experience of Quaternary geoscientists

The questionnaire did not enquire the age of respondents but did gather information on the years of work experience from which some general conclusions may be reached (Fig. 7.2). Analyzed nationally, the Quaternary work force increased slowly in the 1950s, increased more rapidly in late 1960s and has continued to increase but more slowly after the mid-1970s. The numbers in Ontario appear to have increased proportionately earlier than elsewhere, and if Ontario is removed from the data, the increase in the other provinces has been essentially constant to the present.

In view of the significance of vacancies created by retirement for new employment, it is apparent that the number of Quaternary scientists approaching retirement age is disturbingly low -8 percent of the workforce has more than 34 years experience – the majority of whom are presumably in their sixties. If the figure is valid for the whole group of Canadian Quaternary geoscientists and not only for those who replied to the questionnaire three may leave the work force on an average each year and this number will not increase for at least another decade.

7.2 Geographical location

Analysis of mailing lists of base location (not to be confused with field research areas) of Canadian geoscientists with actual or potential interests in Quaternary topics is shown in Table 7.1 and Fig. 7. and confirms a concentration in the vicinity of the major metropolital areas.

The mailing lists failed to identify consultants working in the (Quaternary) environmental management fields but it is believed that their addition to Table 7 would increase appreciably the numbers in the Halifax, Montreal, Toronto and Victoria/Vancouver areas.

Table 7.1 Location of Geoscientists with actual and potential Quaternary interests

West		Central	
Victoria and Vancouver Island	27	Toronto	104
Vancouver	64	National Capital area	106
Remainder of British Columbia	16	Southwest Ontario	67
Yukon Territory	4	(Hamilton-Windsor, including	
Northwest Territories	24	Kitchener and Waterloo)	
Calgary	56	Remainder of Ontario	39
Edmonton	60	Montreal	98
Remainder of Alberta	19	Quebec	37
Regina	10	Sherbrooke	18
Saskatoon	63	Remainder of Quebec	32
Remainder of Saskatchewan	12		
Winnipeg	27		
Remainder of Manitoba	8		

East	
Fredericton	10
Remainder of N.B.	2
Prince Edward Island	3
Dartmouth - Halifax	48
Remainder of Nova Scotia	3
St. John's, Newfoundland	24
Remainder of Nfld-Labrador	3

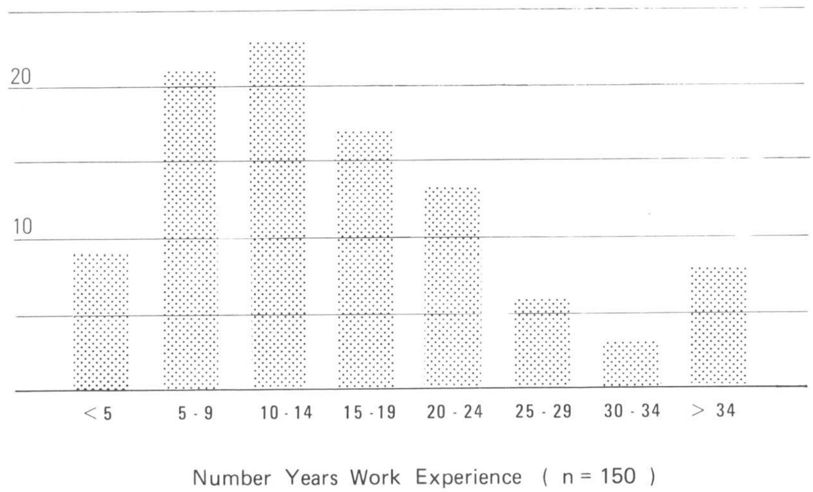


Figure 7.2 Professional entry into Quaternary Science has declined in the past decade.

7.3 Specialization by field

One of the objectives of the questionnaire was to discover the numbers of Quaternary scientists working in various subjects and so to determine the subfields that should be examined. The objectives of Quaternary geoscience (Fig. 5.1) are attained through the investigation of Quaternary morphology and sediments; these fields are therefore assumed to form the core of the subject. Two-fifths (43%) of the respondents gave one of the core topics as their principal field of research and more than half of the replies showed a core topic as first or second choice.

The two major groupings of the core of Quaternary geoscience, studies of the surface of the land (morphology) and the surficial sediments (Quaternary geology, sedimentology, stratigraphy) were nearly equally divided as principal research fields (sediments 23%: morphology 20%). An important finding was that relatively few (27%) respondents reported that they concentrated in a single field (70% research time or more). Whilst this was particularly evident in the core category it shows that the broader, peripheral groupings are not mutually exclusive and many respondents believe they make significant contributions in several major fields.

7.4 Specialization by environment investigated

A different perspective on the specialization was obtained from question 12 which asked which physical environments were the principal concern of the Quaternary geoscientist. A concentration of interest in glacial phases of the Quaternary (44%) is pronounced. Responses also clustered around two other environments: marine which included contemporary as well as postglacial marine transgressive environments (29% nationally, reaching 57% in the Atlantic Provinces) and 'near-glacial' environments including periglacial, paraglacial and tundra conditions (25%). It is evident that 5% of Quaternary geoscientists are primarily concerned with low and middle latitude environments that support forest and grassland associations either during the Pleistocene or today. This further confirms a conclusion that interglacial intervals receive little attention from the Quaternary community.

Table 7.2. Replies to Question 7 – Principal Research Field (percentage)

Geoscience core:	geomorphology glacial geology sedimentology stratigraphy	43
Archeology		15
Physical Environment:	Climatology Pedology Permafrost Physical Geography	13
Applied Geoscience	Economic geology Engineering geology Environmental geochemistry Geotechnique Hydrogeology	12
Paleobiology:	Paleoecology Paleontology Palynology	10
Marine geoscience:	Marine geology Oceanography	5
Geophysics:	Geophysics Glaciology Tectonics Vulcanology	2

7.5 Specialization by geographical area of research

The questionnaire returns showed an even distribution of scientists in terms of their principal research areas in the major regions of the country. (Fig. 7.3)

7.6 Research outside North America

A small number of Quaternary scientists reported that they had undertaken major research overseas; nearly half of these activities were in Western Europe generally whilst the respondent was registered as a doctoral student at a European university.

In view of the large area of Canada, the range of Quaternary problems and the small number of research scientists it might seem unnecessary for research to be directed outside the country. Some researchers believe that funding agencies do not look favorably, perhaps for these reasons, on grants for overseas work. Enquiries of NSERC fail to confirm that, at least in the Earth Sciences group, this is policy and respondents indicated they had received grants from NSERC and SSHRC (for archeology) for research outside North America. Even when allowance is made that Table 7.3 under-reports the number of Quaternary scientists who have overseas experience, the total number is disturbingly small. The limited first-hand knowledge of Antarctica (where the West Antarctic Ice Sheet may be the closest contemporary analogue to the Pleistocene Laurentide Ice Sheet) and to tropical Quaternary environments is apparent. In the applied field the large and growing Canadian external assistance to studies of changing natural environments in the Third World by consultant groups and national organisations (i.e. CIDA:IDRC) suggests a need for increased experience of Quaternary events in other parts of the world. In its absence, the value of obtaining 'secondary' field experience by participation in international conferences that include field symposia and by involvement with the commissions and working parties of the International Quaternary Association (INQUA), the International Union of Geological Sciences (IUGS), the International Geographical Union (IGU) and the International Union of Geodesy and Geophysics (IUGG) must be emphasized.

7.7 Quaternary goescientists and their work

Four major types of work were identified: administration, teaching, research and consulting. Scientists in all three sectors, university, government and industry participated in the four areas (Fig. 5.2). In universities teaching and research occupied roughly the same percentage of time whilst in government over two-thirds of the time is spent in research.

7.8 Quaternary Studies in the Federal Government:

7.8.1 Geological Survey of Canada

The largest national group of Quaternary scientists is in the Geological Survey of Canada. In addition to a specialist Quaternary staff of about 100, it hires 40-50 university students a year, providing them with much of their field experience. It also provides fellowships and facilities to post-doctoral fellows and to university faculty. Inevitably the policies and actions of the Geological Survey have strong influence on Quaternary studies in the universities and to a lesser degree, on the number of students specializing in Quaternary studies.

Quaternary work in the Geological Survey is concentrated in the Terrain Sciences Division and the Atlantic Geoscience Centre at Dartmouth, Nova Scotia. The first handles land-based studies and its main function is mapping, glacial history, stratigraphy, paleontology, paleoclimate studies, glaciology and geophysics; mineral tracing studies are also important. Holocene, climate, urban geology, and groundwater research receive less attention. In recent years there has been emphasis on work in northern regions, partly because of the opening up of those areas, but also because several provinces handle much of their own Quaternary work, and the Division took over some of the functions of the former Geographical Branch which had concentrated on the North.

To carry out its mandate, the Terrain Sciences Division has a complement (1986) of about 80, including 50 geologists and physical geographers, 7 geophysicists and 6 biologists. The biologists work mostly on plant and insect fossils. Two professional staff are based in Calgary, two in Vancouver, and the rest in Ottawa. The other 17 members of the Division consist mainly of support staff, including secretarial staff, laboratory technicians, editors and financial officers.

The Atlantic Geoscience Centre concentrates on oceanographic work off the east coast of Canada. It does not have a separate Quaternary unit, but about 21 members of its staff, including three geochemists, three geotechnical engineers and two paleontologists, specialize in Quaternary studies associated with topics such as seabed processes,

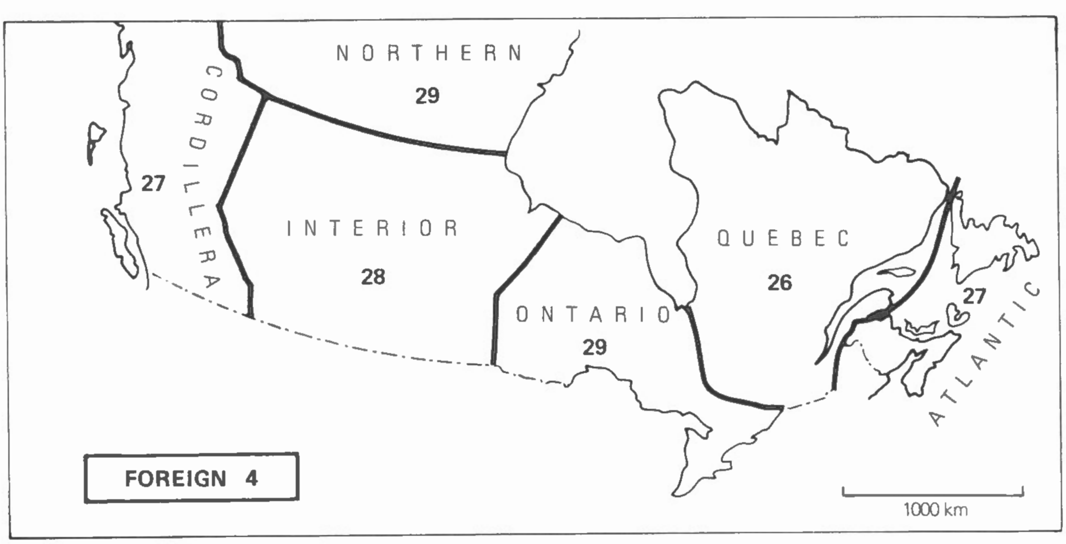


Figure 7.3. Principal research regions and numbers of respondents.

Table 7.3. Physical environment (past and/or present) of strong research interest (percentage)[1]

Glacial	44
Marine	29
'World-climate' (periglacial etc)	25

[1] Some replies listed more than one environment

bottom sampling and stratigraphy of the bottom deposits, geophysics, and paleoclimate studies. General support to these professionals is supplied by the Atlantic Geoscience Centre as a whole.

Thirty-four of the Geological Survey Quaternary specialists have doctorates; of these, 21 were in Quaternary topics, the remaining scientists having concentrated in Quaternary fields after commencing their careers. Nearly a half (48%) of the Quaternary doctorates are from Canadian universities with a majority of the rest from the United States (40%).

The number of Quaternary scientists in the Geological Survey has been fairly stable for a number of years, and is unlikely to change much in the foreseeable future. Undoubtedly the Survey will continue to concentrate on geological and geographical studies, both basic and applied. Mapping of Quaternary deposits, both on land and the seafloor, will continue to be its major concern, with mineral tracing, stratigraphic and paleoclimatic and permafrost studies also being given emphasis. Interest in natural hazards is increasing, and there is a growing emphasis on federal-provincial co-operative programs.

7.8.2 Quaternary studies in other federal departments

Although federal government activity in Quaternary geoscience is concentrated in the Department of Energy, Mines and Resources, several other federal departments are involved either directly with in-house research, or through external contracts. These include Environment Canada where there is research into paleoclimate, particularly in the historical period, and groundwater, by the Atmospheric Environment Service and studies at the National Hydrology Research Institute that include snow hydrology, glaciology and geomorphic research into the evolution of fluvial channels. The Department of Fisheries and Oceans are using satellite image data to monitor ocean currents and sediment transport and the Atlantic Oceanographic Laboratory is participating in international programs to monitor long-term changes in ocean-atmosphere interactions in the North Atlantic Ocean.

The Department of Indian and Northern Affairs has a continuing interest in Quaternary science and undertakes some mapping through its Geology Office. The National Research Council with its Division of Building Research (DBR) is concerned with some aspects of the evolution of permafrost in the Quaternary and with géotechnique of Quaternary sediments and ground ice.

A large block of Quaternary research with emphasis on paleobiology is based in the National Museums of Canada (sec 7.10).

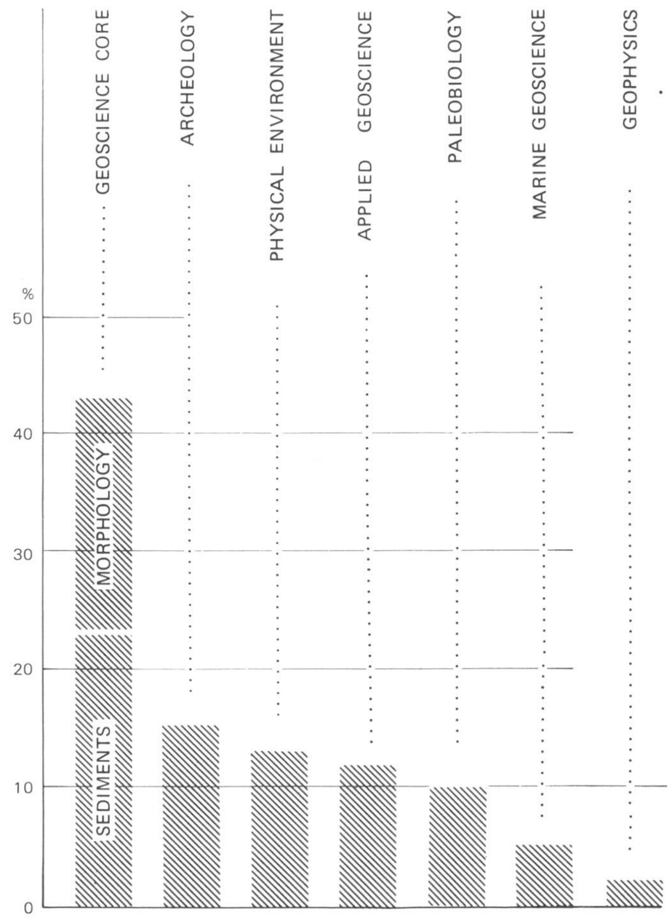


Figure 7.4. The principal research fields of Quaternary scientists responding to the questionnaire.

7.9 Quaternary studies in provincial governments

All provincial governments with the exception of Prince Edward Island have one or more units engaged in Quaternary mapping, stratigraphy, and related research. The pattern is similar in each province with one or more scientists engaged in mapping with emphasis on resource development. Geochemical programs concentrating on trace element analysis of glacial, stream and lake sediments are common. Although they are principally directed to the discovery of ore bodies some theoretical studies of methods and of the direction of Pleistocene glacier flow have been made. Between 1977 and 1982 the Engineering and Terrain Geology Section of the Ontario Geological Survey commissioned the preparation of maps (scale 1:100 000) and reports on terrain conditions in over 400 000 km^2 of the province, mainly north of 44°. One hundred and twenty-seven reports have been published to date. The Prairie Provinces also undertake research in paleohydrology. Organic terrain studies linked with the exploitation of peat for energy and industrial uses are being made in several provinces.

7.10 The contribution of museums to Quaternary geoscience research

The major Canadian natural history museums have a long record of contributions to Quaternary geoscience, despite the small number of permanent, full-time scientists.

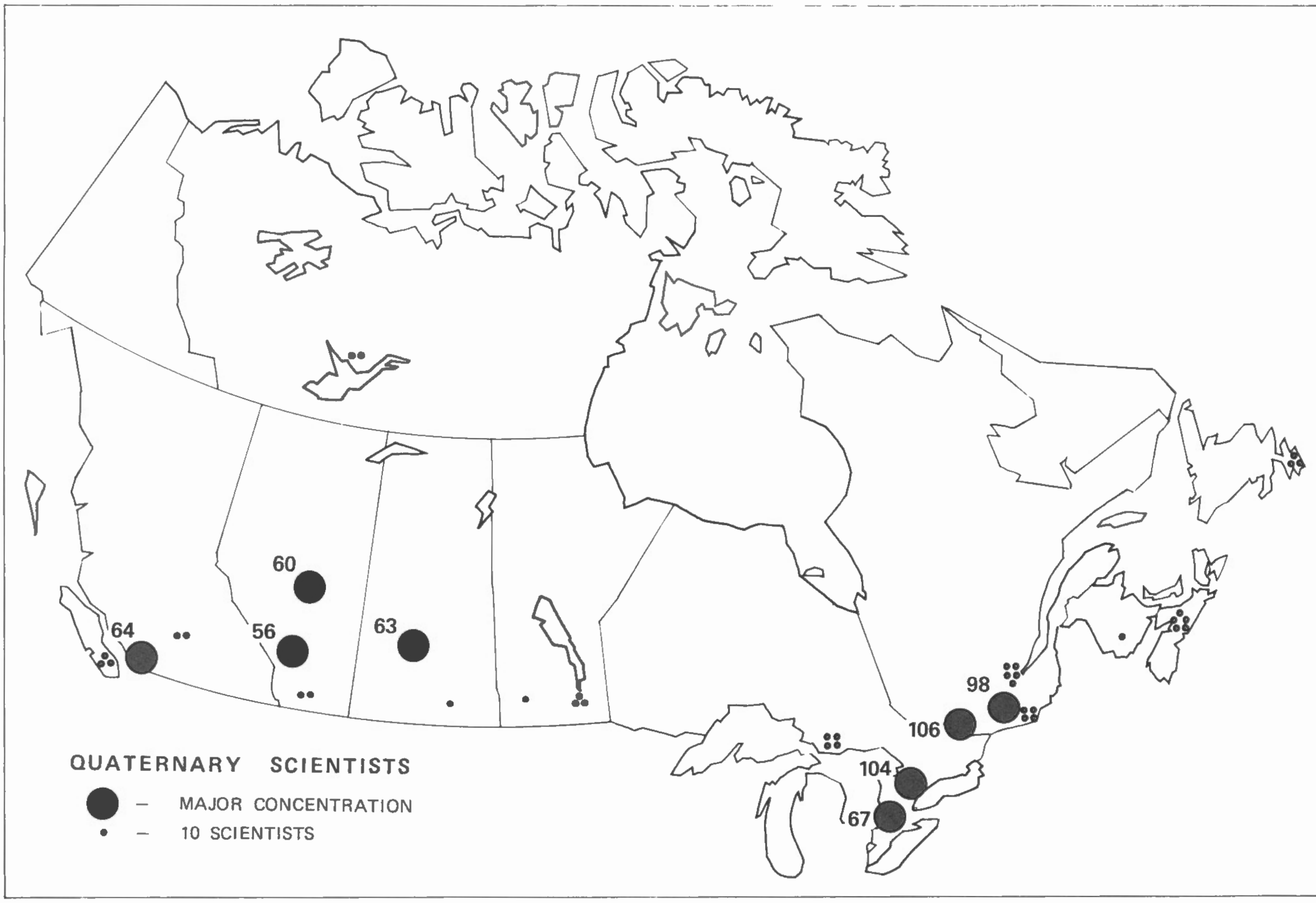


Figure 7.5. Regional distribution of geoscientists with Quaternary interests. 'Ten scientist' dots are positioned by province.

There is considerable regional variation of size and number of museums. The situation is relatively strong in Ontario (at the National Museums of Canada in Ottawa and the Royal Ontario Museum in Toronto) and proportionately weak in British Columbia, Saskatchewan and Québec.

The National Museums contain the largest number of Quaternary scientists in museums who are involved in research. The Paleobiology Division has three scientists in the Quaternary Zoology Section; research is principally centred on Quaternary vertebrates with occasional support for Quaternary palynology and paleomycological problems. Unfortunately, a scientist in the Invertebrate Zoology Division, who provided an important national service by identifying mollusc remains from Quaternary deposits, retired recently and has not been replaced. In addition, museum scientists are actively engaged in supporting provincial and local museums in their efforts to develop Quaternary field work and in preparing displays. They have developed travelling displays and a long-term display (about one-third of the 'Life Through the Ages' Hall) as well as producing about fifty scientific and popular papers on Canadian Quaternary life.

A National Museum of Natural Science 'Climatic Change Project' initiated in 1977 has resulted in financial support for researchers across Canada who are studying Quaternary climatic change and variation, in several national and one international meetings, five volumes of multidisciplinary papers and a travelling display which deals in part with the paleobiological evidence for Quaternary climatic change in Canada.

The Royal Ontario Museum, in close association with the University of Toronto has made extensive and important collections of Quaternary vertebrates for southeast Alberta for southwest Saskatchewan. Collections have also been made abroad, particularly in Florida, and elsewhere in the United States and in Africa.

7.11 The future

7.11.1 Professional registration for Quaternary Geoscientists?

There is considerable discussion at present on the advisability of developing professional accreditation for geoscientists either independently or within an existing organization. In order to clarify the reaction of Quaternary geoscientists to professional registration the questionnaire (no. 53) asked of government and private sector respondents:

'Is there a pressing need for professional registration, standards and testing of Quaternary researchers on a national or provincial level? If so, why?

A majority of respondents chose not to answer the question or gave ambivalent replies which suggests either that it is perceived to be an unimportant question or is unusually complex. The definitive replies are tabulated in Table 7.4 (Fig. 7.6).

Table 7.4. In favor of professional registration:

Yes	16
No	33

Positive reasons given for securing professional registration include the general argument that it would provide standards and inform members of common matters of interest. It is claimed that accreditation would allow Quaternary geoscientists to participate in projects involving waste disposal, slope stability in surficial sediments, hydrology and site planning. At present only accredited engineers can compete for such contracts. Accreditation of Quaternary geoscientists is seen as an appropriate solution to this problem.

The two-thirds of the respondents who were opposed to registration cited most frequently the complexity of Quaternary geoscience and the varied nature of the background of Quaternary scientists. It was also pointed out that registration and accreditation were not a guarantee of professional excellence.

Clearly a majority of the Quaternary scientists in government and private sectors do not favor professional registration. They are supported by the national scientific organization (CANQUA) which, at its 1985 annual meeting, determined to monitor the reasons and trends towards registration but also resolved that:

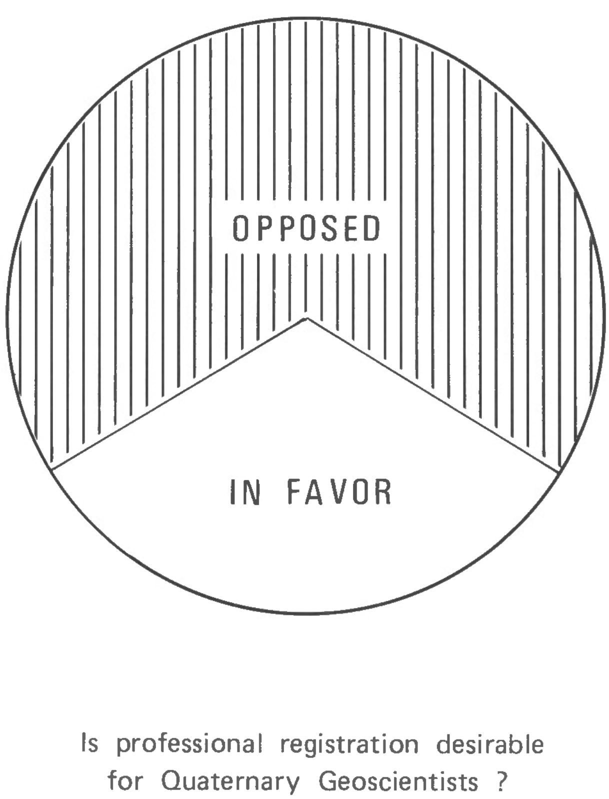


Figure 7.6. Quaternary geoscientists are not in favor of professional accreditation – registration.

Table 7.4. Scientists reporting Quaternary research outside North America[1]

(Canada and USA)	
Europe	13
Africa	6
Australasia	5
Antarctica	3
Latin America	2
Caribbean	1
Other regions	3

[1] Number of respondents: question 16. 'In which areas of the world has most of your Quaternary research been conducted?'

'CANQUA, an interdisciplinary association of earth scientists affiliated with the Geological Association of Canada, is extremely concerned about the proposal to place further restrictions on professional accreditation for earth scientists, urges that demonstrated competence be the sole criterion and opposes the setting up of a national accreditation committee whose mandate will include definition of acceptable university curricula.

If individual university programmes are evaluated with a view to defining acceptability, CANQUA will insist that all disciplines which it represents be given the opportunity to propose alternate approved programmes for accreditation of Quaternary geoscientists.'

Annual Meeting, Lethbridge, 1985.

7.11.2 Employment for Quaternary science graduates

The committee received a wide range of views on employment prospects for positions that demand Quaternary research skills (Question 58 plus interviews). The experience of 40% (27/66) of the University respondents is that students graduating in Quaternary science obtain employment that uses their special skills. The poorest experience at the present time is in the Prairie Provinces, particularly Alberta. In part this appears to reflect general employment possibilities in the area and a lack of appreciation by potential employers in industry of the special skills of Quaternary scientists. We note also the high production of Quaternary scientists with a Masters' degree by the Alberta universities (Table 8.1).

The majority of replies confirm that students at the level of a first degree are not sufficiently trained in Quaternary sciences for many types of employment that use these skills. At the Masters' level the main opportunities were commonly in applied fields, including environmental impact assessment and terrain studies. With the possible exception of the Prairie Region it appears that the great majority of Quaternary master's graduates secure employment in related, applied fields rather than directly in Quaternary sciences.

Although individual cases of underemployment of recent doctoral graduates in Quaternary science are known to the committee, it is noted that there have been few Quaternary geoscientists in the NSERC University Research Fellowship 'holding pool'. Any upturn in university faculty recruitment by the early 1990s will lead to a visible shortage of Quaternary scientists at this level.

8 Education and training in Quaternary science

8.1 Introduction

The committee was instructed to determine improved ways for Quaternary geoscience to meet national needs. In the short term this will be achieved by contemporary scientists developing and implementing new research applications. In the long term it will be met by increasing the awareness throughout society of the contribution that Quaternary science can make to national development and by training an increased number of scientists to meet the demand for their skills.

A major, long-term objective must be the improvement of the quality and quantity of Quaternary science offered in the education system all the way from the secondary schools to university graduate programs.

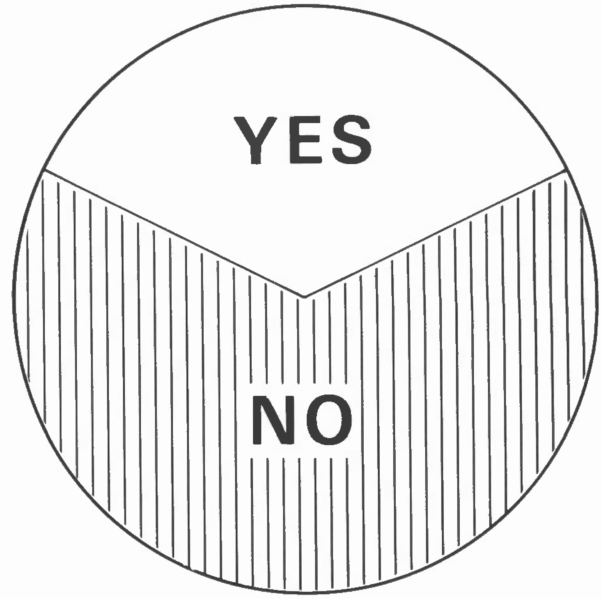
The 1971 Special Study (No. 13) of the Science Council of Canada on 'Earth Sciences Serving the Nation' described the poverty of earth science teaching in the schools and submitted that its most important conclusion was that 'provincial departments of education should encourage and promote the teaching of earth science in secondary schools ... (and) that the fundamental principles of science be taught within the frame of reference of man's environment' (p. 143). There have been improvements in some provinces in the subsequent 15 years but it remains an objective that has still to be realized. It is of little importance whether Quaternary science is treated in schools as part of programs in earth science, or physical geography or environmental studies but it is essential that students receive instruction in the origins, evolution and characteristics of the natural environment in which they live. We are reminded that an eminent Canadian Quaternary specialist, on being interviewed recently about the development of his professional career, identified 'Most importantly, the charismatic teaching of my high school....teacher'. It would not be easy to make a similar statement for teaching of Quaternary topics in many parts of Canada.

We had hoped to find that the situation in colleges and universities is better, but our analysis of undergraduate courses and enrolments suggests that courses of both the component fields of Quaternary geoscience (e.g. Pleistocene geology, geomorphology etc.) or of the rare interdisciplinary Quaternary science courses do not attract large enrolments and are rarely designed to stimulate the most promising students to follow graduate work in the field.

8.2 Quaternary geoscience education in Canadian colleges and universities

The continuing expansion of Quaternary science in Canada depends to a considerable degree on its development in the universities. There are no university departments or institutes of Quaternary studies except for a recently established institute at Simon Fraser University. To extend, or even retain their present position, Quaternary subdisciplines are in direct competition with other subjects for restricted university funding. Not only are additional finances required in a period of excessively tight budgets, but scientists of the highest ability have to be attracted into the field.

Many university geoscience departments fail to recognize Quaternary research as a distinct area of academic activity. Negative responses to this question (no. 54a) outweighed positive replies in the proportion of 2:1 (Fig. 8.1); and yet the Quaternary scientific community overwhelmingly believes that there is a unifying theme and/or methodology in Quaternary science and that the quality of research is comparable to that in other disciplines (no. 54b). The quality, value and uniqueness of Quaternary science is not always appreciated by university colleagues and university administrators. They may prove more difficult to educate than the students!



Is Quaternary Research recognized as a distinct area of academic activity?

Question 54, n = 70

Figure 8.1. In the universities recognition of Quaternary Research as a distinct field is not widespread.

The causes of the weakness, and frequent absence of broadly-based Quaternary training in Canadian universities are complex. A major reason is the compartmentalization of teaching in traditional academic departments. They safeguard their perceived interests by defending the perimeter sectors of their disciplines. In Quaternary studies this is most obvious in the division between geology and geography. The former has a long history and established position in many universities; although we were told repeatedly that Quaternary geology is the 'poor member' of many departments and the first to be discarded if programs have to be restricted or the number of faculty positions has to be reduced. Geography in the universities is still a relative newcomer with few departments established before 1950. The relationship of the two disciplines is complicated by the example of United States universities where, although physical geography is the branch of geography with highest undergraduate student enrolments, the subdiscipline does not (with some notable exceptions) make significant contributions to Quaternary studies. This is in contrast to the pattern in Great Britain, Scandinavia, USSR and Australia where physical geographers provide strong, and in some fields, notably geomorphology, the total national input to Quaternary geoscience.

One respondent summarized the problem:

'the barriers between departments are the single most important constraint in the development of all (Quaternary) programs'

8.2.1 Undergraduate training

Replies to the questionnaire (no. 56) confirm that the quality of undergraduate training is highly variable between universities. A small proportion of replies provided a clear evaluation and they were grouped equally between good, adequate and poor. Individual responses were conditioned by the type of student being considered. Four main groups are identified.

1. Students enrolled in a general degree, either Arts or Science who are seeking, or in a few cases are advised to take, a course that presents the changes in global physical environments during Man's period on earth.
2. Students already in professional schools (e.g. engineering) or in programs that lead to professsional activities (e.g. planning) who benefit from an overview of Quaternary history treated as an interdisciplinary topic.
3. Students enrolled in specialized programs usually of 'Honours' quality who will probably be continuing in graduate work in the same field or possibly in Quaternary science (e.g. Biology (Ecology), Geology, Environmental Studies, Physical Geography, Archeology); they should be offered an overview Quaternary course and one or more specialized Quaternary courses.
4. Students in a specific undergraduate program in Quaternary studies. While a number of respondents favour the establishment of this type of program in their university, many believe that students should be encouraged to specialize initially in a traditional discipline. However, in those universities in which the degree structure permits, undergraduate minors provide a means of early identification with Quaternary studies.

The establishment of undergraduate courses, and sympathetic advising from faculty counsellors who may not themselves be Quaternary scientists, is clearly a considerable undertaking. In our examination of university undergraduate programs and courses in Quaternary subjects we failed to find any university that met the full program we have outlined above. Implementation presents formidable problems. Too few instructors are qualified and committed to Quaternary science and those that are specialized are frequently required to provide courses in other fields. Above all is the difficulty of establishing appropriate interdisciplinary courses.

Analysis of university courses and programs reveals a richness of course offerings in specialized topics of Quaternary science in some universities and at the same time a virtual absence of interdisciplinary courses that introduce the complex relationships of the Quaternary physical environments, the biological world and early Man. We observe that in all three major centres of excellence in Quaternary studies identified by respondents (University of Colorado, University of Washington and Cambridge University) multidisciplinary courses in the Quaternary are offered.

In many universities, courses in Quaternary Geography provide a broadly-based examination of Quaternary events but even here faculty specialization is not always appropriate and suitable text-books are not available.

'Geomorphology is stressed at the expense of other areas of Quaternary Geography such as paleoclimatology and biogeography'. (Several respondents)

'We need good quality Canadian Books'

Notwithstanding the many difficulties, effective programs of undergraduate courses would provide, in a decade or so, a far wider understanding in society of the value of Quaternary science and an increasing number of high-calibre students to continue into graduate work.

8.2.2 Graduate training

Canadian university Quaternary scientists believe that the quality of graduate training is superior to undergraduate training (Fig. 8.2). Seven universities were specifically named as providing excellent training, although other replies suggested that in most cases excellence in the university is restricted to a single academic department.

Many respondents, including those who considered the standards in their own university to be high, identified weaknesses and offered suggestions to overcome them. The most common handicap is the overall small number of Quaternary scientists in a university and their availability to cover the numerous fields that contribute to Quaternary science. It is not unusual to find that one university department is good but is not supported by others.

'The quality of graduate training inevitably varies across the country. To raise our standards we need to hire more young, dedicated, enthusiastic Quaternary scientists. This is not easy in the present financial climate.'

'Improvements will only come through more faculty appointments. Highly trained and dedicated graduates must be given university positions if we are to expand our teaching/resource base.'

'Many universities lack a desirable mix of Quaternary disciplines, with one department dominating the course offerings.'

'Many faculty are deficient in their understanding of the many facets of Quaternary science.'

The content of graduate programs was also criticized by respondents. The most frequent comment was that the programs did not adequately cover the theoretical concepts of Quaternary science; a second criticism was that they were not rigorous enough.

'Of what I see here the quality of training is good, but it could be more demanding in the theoretical aspects.'

'In general students do not go deeply enough into their subjects. They have a good knowledge for mapping but are weak in theory, process and methodology.'

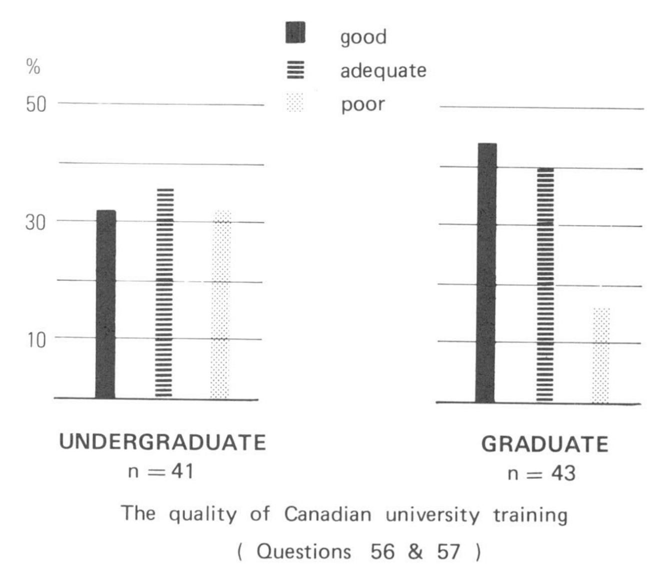


Figure 8.2. Graduate training is perceived to be significantly better than undergraduate.

'There is a serious lack of mathematical and statistical training.'

Some replies, with the future employment of students their concern, stressed the need for training in applied topics. However these were not in the core fields of Quaternary geoscience but rather in peripheral disciplines.

'We should introduce more training in applied topics including géotechnique, geophysics etc.'

'Graduates who have never heard of Quaternary Science leave this university with Master's degrees in Resource Management.'

A measure of the current commitment of a university to graduate training in Quaternary studies is provided by the number of degrees awarded in the past few years. Universities departments were asked to supply titles of accepted theses for the five years, 1979-84 (inclusive – Table 8.1: Appendix 3).

A total of 118 graduate degrees (32 PhD; 104 Masters') were awarded in the Quaternary geoscience core fields including paleobiology, at Canadian universities during the five-year period 1979/80-1983/84. An incomplete survey of United States graduate schools reveals an additional 10 PhD's were awarded in the same period for dissertations on a Canadian Quaternary topic; six of these (i.e. as great as any Canadian department) were from the Institute of Arctic and Alpine Research (INSTAAR - U. of Colorado).

It is only too clear that few universities have been able to overcome the difficulties in their infrastructure of introducing truly interdisciplinary graduate programs and degrees. Although the main arguments for establishing centres (institutes) of Quaternary studies are based on the need to attract research scientists with varied backgrounds, and of developing laboratories, there would also be important academic gains if Centres had the independent status enjoyed by departments.

8.3 Centres of excellence in Quaternary studies

The Blais Commission report discussed at considerable length the rationale for the establishment of centres for special studies (centres of excellence) and named Quaternary Studies as one of seven fields in the earth sciences for which this was desirable. The present committee sought to determine whether one or more Quaternary centres of excellence had evolved in the fifteen years since the Blais report and if not, whether they remained a desirable development and if so, how they could be achieved.

Respondents to the questionnaire (no. 39) were asked to identify worldwide centres of excellence. Most chose to name centres providing a broad coverage of the Quaternary field rather than specialized studies in narrowly defined fields. Two university groups, INSTAAR at University of Colorado and the Quaternary Research Center at the University of Washington, Seattle, were perceived as outstanding in North America. In Europe, the University of Cambridge and Stockholm University were similarly, but to a lesser degree, identified. No Canadian Centre of Excellence was named by more than a single respondent except for the Terrain Sciences Division of the Geological Survey of Canada (5%). Clearly a considerable majority believes that no large, interactive, multi-disciplinary group of Quaternary scientists exists in a formal organization in Canada today.

The extent of the Geological Survey of Canada commitment to Quaternary geoscience may not be fully appreciated by Quaternary scientists across the country, but the principal reason that it was not named by more respondents was probably because 'Centres of Excellence' are considered, by definition, to provide training for future scientists and it is the interaction between research and teaching, and between professional and student scientists that is considered so desirable.

A continuing theme running through this report has been that, whether consideration is being given to a narrowly-defined field of Quaternary geoscience or to a more general study of Quaternary environments, the research scientist concentrating on Quaternary events will only be successful if he has access to the information and stimulus of scientists in cognate fields in the earth sciences, in the biological sciences and in the study of early Man. What is true of research is equally true for the training of the Quaternary scientists. How then is it to be achieved?

Respondents were asked (no. 35) whether the establishment of a single, independent national research centre would be one means of improving the status of Quaternary research. It is clear from the strong negative response (only 10%: (n - 162) favored creating a national centre), that this proposal is not favoured. However, the question did not ask whether a solution would be to develop an existing unit into a national centre for Quaternary sciences with appropriate number and variety of research scientists and laboratory, library and support infrastructure. It is possible that over a long period one may develop, perhaps in or associated with the Geological Survey of Canada, but the Survey does not have training as a primary role.

Given the size of Canada the concept of regional centres of excellence, is at first sight, more attractive. A minority of respondents were in favor of this solution (42%). The strongest support for regional Quaternary centres, probably based in universities although possibly linked to provincial research councils, comes from the East and West coasts and from government scientists.

The success of the several recognized international centres of excellence has encouraged their development in other parts of the world, most recently in North America at the University of Alaska, Fairbanks (1984). The presence of a number of Quaternary scientists in the same institute (or in reasonable physical proximity), an appropriate scientific organizer (and fund raiser?) and a suitable research-oriented environment would favor the success of one or more centres in Canada. The University of Waterloo has taken the first steps in this direction with the creation (1986) of a Quaternary Science Institute.

The committee believes that centres of excellence in Quaternary science should be encouraged in several parts of the country. However it is evident that funding for new ventures in research and higher education is not easily obtained and it is improbable that a centre will develop, however desirable, in a Canadian university within the next decade. As an alternative, in view of the number of

Table 8.1. Graduate degrees in Quaternary Geoscience

PhD		Masters	
Dalhousie	6	Waterloo	12
Western Ont.	5	Sherbrooke	10
McMaster	3	Alberta	9
Other Canadian Univ.	16	Ottawa	9
		Québec à Montréal	9
		Dalhousie	8
		British Columbia	8
		Other Canadian Univ.	42
	30		107

Quaternary scientists with varied specialities that are present in several parts of the country, although scattered in different institutions, we recommend that active encouragement should be given to the development of one or more multi-institutional centres of excellence linking scientists in universities (and, where appropriate, government departments) in the same region. There are sufficient Quaternary scientists in several areas to make this feasible (Halifax-Dartmouth, Montreal, Ottawa, southwest Ontario and possibly Edmonton and Vancouver). Informal contacts in these regions are already strong but attempts should be made to establish more formal groups as the Quaternary Institute is doing at Simon Fraser University. We do not underestimate the difficulties but believe these can be overcome.

9 Directions for Quaternary research in Canada

Quaternary research takes several forms and has many objectives. Fundamentally it aims to fill the gaps in our knowledge of the history of the earth during the Quaternary era. A research scientist has no difficulty in identifying subjects for study; the problem is rather to select topics of exceptional significance and to concentrate on them rather than follow other, fascinating but peripheral questions. Much Canadian research which is of immediate national relevance may also be significant to global problems. The information already available on sea level change, warping of glacial lake shorelines, neotectonics and periodic faulting is not only of national value but permits new models of earth rheology and earthquake prediction on a global scale. The mass of recently produced data on climatic change in Canada in the Quaternary must be incorporated into global models and be available for predictive modelling.

The questionnaire revealed considerable agreement amongst Canadian geoscientists on the important contemporary questions in Quaternary research, but less unanimity on how successfully they are being solved. A section of the questionnaire examined present and future research directions (Nos. 32, 33 and 37). Three principal groups may be identified in the replies.

9.1 Holocene environments

The first, and by far the largest problem is seen as the interaction of the land/ice/sea/atmosphere geosystem during the Holocene. Studies in this most recent geological time interval involve process and change within the subsystems, the response of the total system, and the length of time needed for equilibrium to be restored. Problems are innumerable. Important aims identified by respondents are: improving the accuracy and value to other disciplines of climatic proxy data: applying additional chronological techniques such as greater use of dendrochronology: estimating the impact of people, both aboriginal and 'European' in the system: and recognizing the frequency and role of catastrophic events.

The objectives of Holocene research are viewed as the reconstruction of the natural environment for time-slices at varying geographical scales and to determine environmental change in the past 10 000 years. Attempts at environmental reconstruction are being made for many parts of the country but the results as measured by publications do not approach those in Europe, the USSR or recently, the United States. Indeed this research field is considered by Quaternary scientists as one that has been slow to develop in Canada. We are also disturbed that compartmentalization of disciplines has begun to appear here.

An indication of the relative contribution of the several Quaternary sciences in Canada to the reconstruction of Late Wisconsin and Holocene environments is provided by an analysis of the papers offered on these topics at the CANQUA Symposium, Lethbridge, Alta., August 1985. Of the 54 papers in the program, 28 were in the field of geostratigraphy/morphology but of these only eight examined nonglacial events. Papers in paleobiology (15) and paleoclimatology/hydrology (11) concentrated on Holocene, nonglacial environments. Scientists working in stratigraphic/morphological Quaternary research are able to make significant contributions in the reconstruction of non-glacial, Holocene environments but little is being done in Canada.

Holocene environments, until the past decade, were judged to be largely of theoretical concern, but events in the last few years have emphasized the sensitivity and vulnerability of the natural environment to intervention by Man. The application of this research to contemporary and future environmental planning should be of national concern.

9.2 The Pleistocene continental ice sheets

The second group of topics identified as being of great significance concerns the dynamics of continental ice sheets and, in the Canadian context, the several, dynamically different, Wisconsinan ice masses that covered the eastern and central sectors of the country (the Laurentide and Maritimes), the Queen Elizabeth Islands and the Cordillera. Considerable progress has been made in studies on the Laurentide ice cap, but study of the other ice caps is still at an early stage. Many respondents observed the problems of dating the inception of glaciation, the geophysical characteristics of the ice during waxing phases, the properties of the glacier ice close to the glacier perimeter at its maximum, both on land and sea, the presence and role of shelf ice, the thermal characteristics of the glaciers, and the climates in different phases. Their solution depends on close comparison of theoretical glaciological models with field observations. Unfortunately, as we have shown earlier in this report (section 5), several of the relevant specialities, and particularly glaciology, are not well-developed in Canada.

9.3 Sedimentology

A third group of research topics is associated with sedimentation in glacial environments, both from glacier ice and in the adjacent terrestrial, and marine periglacial sectors. Better knowledge of the processes involved will lead to clearer interpretation of sediments and associated landforms. It will also lead to a better understanding of the properties of the sediments and to subsequent changes, particularly on the seafloor and in permafrost areas in their final characteristics.

9.4 Pleistocene nonglacial intervals

In addition to the three principal groups of research areas, respondents noted others which require extended examination. Most Canadian Pleistocene research has been directed at the glacial episodes. In the future, additional research should be directed to enhance our knowledge of nonglacial phases, including the urgent question of how many there have been. The last interglacial, the Sangamon, and the Wisconsinan interstadials should attract special attention, particularly of their chronology, duration, climate and geoprocesses, along with identification of contemporary analogues.

9.5 Global research problems

It was noted that there are many global Quaternary questions to which Canadian scientists could contribute far more than at present. Probably the biggest of all contemporary problems is the correlation of the deep sea and terrestrial Pleistocene records. There is also an urgent requirement from every subdiscipline for innovations in radiometric dating throughout the Quaternary and especially for the interval 50 ka-150 ka B.P. that immediately preceeds the optimum radiocarbon dating interval. Canadian participation in the international Ocean Drilling Program (ODP) now provides continuous records of Pliocene-Pleistocene deep sea sediments from the Labrador Sea, Baffin Bay and the Norwegian Sea. Paleoecological studies of these records are being carried out at Memorial University of Newfoundland, Université de Montréal, Université de Québec â Montréal and Atlantic Geoscience Centre. Results of these studies will allow quantitative correlation of North American and European land-sea records for the entire Quaternary epoch.

10 Research funding

10.1 Research funding by governments

Canadian Quaternary scientists secure funding from a broad range of sources but a few predominate. Federal funds are allocated directly to units in the Department of Energy, Mines and Resources, principally the Geological Survey of Canada, to the Department of Environment, and to National Museums. Federal funds reach the university research sector through awards from the Natural Science and Engineering Research Council (NSERC), the Department of Indian and Northern Affairs, Department of Energy, Mines and Resources and Environment Canada. Provincial funds are the principal source for general university activities, and consequently support indirectly, research workers and their laboratories. Provincial funding is also available in some parts of the country from provincial agencies, either as grants (eg. FCAR in Québec, Ontario Geological Research Fund) or through research agreements.

10.2 University support

The main support for Quaternary research in the universities comes from a pool of funding available to the earth sciences as a whole and, consequently the Quaternary scientist is in a sense in competition with other earth scientists. The overwhelming amount is from NSERC. In Ontario universities, the NSERC proportion rose from 73% of all direct support for Quaternary research in 1981, to 89% in 1983. It is evident that in periods of acute financial stringency the university sector may have to depend almost entirely on NSERC funding.

In the past five years (1980-84) between 15% and 20% of NSERC awards in the Earth Science sector have been made in Quaternary geoscience topics (Table 10.1); of these roughly two-thirds of the grantees have been in departments of geography and one-third in geology/earth sciences. There were few large grants to Quaternary scientists in the period and the average grant ($18,200 in 1984-85) was about 15% less than to all earth sciences; even so the average figure may be misleadingly high because of a few major grants. It should be recognized that the large, interdisciplinary field programs which we consider as one desirable form that Quaternary research should take, may not be visible in grant lists due to pooling of individual grants for the whole project.

Table 10.1. NSERC Grants in the Earth Science Sector (ESS)[1]

	1983/84 No.	1983/84 Amount	1984/85 No.	1984/85 Amount
Total ESS Grants	495	$9,782,941	481	$10,546,416
Total Quaternary Geoscience	89	$1,424,250	90	$ 1,640,831

[1] Does not include geotechnical studies except where specifically related to Quaternary conditions.

10.3 Adequacy of funding

The committee asked scientists responding to the questionnaire about adequacy of funding (no. 21). The reply depends on the type of research and for whom the scientist is working. Respondents from industry find that funds are adequate for specific and narrowly-defined projects. Government scientists in general find funding adequate although this is after policy decisions are made as to which research projects to develop. Since the projects are chosen with a prior knowledge of funds available, a favorable response does not answer the policy question as to whether the projects are the best possible ones.

In contrast, much university-based research, while it normally has definite objectives, also has an open-ended aspect and the response of university scientists was equivocal on whether funding was adequate (varying from 42% affirmative in Ontario to 64% in British Columbia).

Question 35 provided a different approach to the perception of funding when it asked how Quaternary research could be improved. A majority of university respondents (64%) believe that an increase of funds will improve the quality of research. However, a higher proportion believe that greatest improvement would come from new interdisciplinary programs.

There is a nation-wide feeling revealed in replies to the questionnaire which were made in a period when university funds are damagingly short, that more funds would necessarily mean more and better Quaternary research. It is probable that some applicants for grants tailor requests to their perception of available funds. However, we found in general considerable satisfaction with the NSERC granting procedures and the funding that is available.

Environmental archeologists are the one group of Quaternary scientists that only occasionally receives NSERC funds and they normally apply to the Social Sciences and Humanities Research Council (SSHRC).

It is evident that major, multidisciplinary Quaternary research programs, particularly in remote areas including the North and marine environments, entail a scale of financing two or three magnitudes greater than the majority of individual NSERC grants and this presents special problems.

10.4 Funding for multidisciplinary studies in remote areas

The multidisciplinary nature of Quaternary studies encourages field programs manned by several scientists working on the same problem but contributing different skills. This is especially true if there are major logistical problems. In Canada this normally pertains to northern areas where economies of transportation are achieved when several scientists work together. NSERC recognizes the high costs of northern field work by making additional grants to workers in remote areas. Even so, most Quaternary university scientists engaged in northern research (and all who work in the Queen Elizabeth Islands) have depended to a large extent on support they receive from federal agencies, notably the Polar Continental Shelf Project (PCSP) and the Geological Survey of Canada. Funding cuts in the PCSP budget in 1986 now requires that universities pay for transport in the Arctic; this will greatly increase the demand for university funds from NSERC.

The small quantity of Quaternary university research in the North raises the question as to what degree the high cost and related limitations of funding are restricting factors. Individual university scientists working on Ellesmere, Devon, Baffin Island and elsewhere have shown that this type of operation is viable. Large-scale, successful university-based projects on Axel Heiberg Island from McGill University in the 1960s, on Baffin Island from the University of Colorado and on Ellesmere Island from the University of Alberta in the 1970s and 1980s, and in northern Labrador from the Universite de Montreal and Memorial University in the 1980s suggest that funding and other support is procurable, but that a greater problem is the limited number of scientists with the skills, incentive and ambition to organize large undertakings.

Table 10.2 NSERC Quaternary grants by subfields

	1982/83 No.of grants	1983/84 No. of grants	1984/85 No. of grants	Average amount
Historical climatology	10	7	8	17,631
Paleoclimatology	2	2	1	4,000
Paleobiology	10	7	7	22,245
Geomorphic process	35	35	38	16,161
Quaternary stratigraphy	18	21	21	15,832
Quaternary geochronology (isotopes, paleomagnetism, tephra studies)	8	6	7	34,312
Terrain, remote sensing	1	4	4	17,335
Glaciology	1	2	1	44,520
Engineering	-	3	3	13,156

A comparable problem exists in developing offshore Quaternary research. Whilst in detail it is different from northern terrestrial research the problems are, if anything, more severe for the university scientist where national or possibly provincial agencies are likely to possess the required ship, personnel and heavy equipment. The solution appears to be for the university worker to join the larger group or to have access to a stipulated period of ship research time. Neither answer is ideal. A possible alternative of using grouped university resources (e.g. the Bamfield Marine Station on Vancouver Island for biological studies) has proved difficult to organize.

11 Specialized facilities and services

Although the field provides the focus of their activities for most Quaternary geoscientists, a comparable period of their professional life is spent in offices, laboratories and libraries. Responses to the questionnaire did not reveal serious obstacles to research and teaching imposed by limitations of buildings and libraries. However as Quaternary science is scattered between several disciplines, a single university campus frequently displays a wide range of accommodation for the subject. The current tendency for universities to plan new buildings around groups of disciplines (e.g. earth sciences) may lead to greater physical concentration of Quaternary disciplines, but so far it has been unusual for the ancillary Quaternary disciplines to be included in the plans. This problem is only likely to be overcome where identifiable centres for Quaternary research are created.

11.1 Library resources

Quaternary science faces problems common to multidisciplinary fields when library facilities are considered. There are no major library collections of Quaternary material in Canada and consequently they are found within earth science collections that are weak in the biological and archaeological fields or in general collections where the different subdisciplines may be scattered through several floors and commonly, several buildings.

With the exception of the libraries of the Geological Survey of Canada, we failed to recognize a library in Canada containing comprehensive Quaternary materials. The difficulties of building one or more collections within the next few years are immense and it is improbable that others will be developed until recognized Quaternary centres are established. Indeed one of the arguments for developing Quaternary centres is that specialized library collections will be formed.

There are a number of privately-owned Quaternary libraries specialized in selected subfields and rich in offprints. It will be an unnecessary loss if, when the owners dispose of them, an effort is not made to retain the material for major collections.

In the meantime we offer a suggestion that could make some publications more accessible. The largest output of published Quaternary materials in Canada is produced by the Geological Survey of Canada. Many university libraries file all documents produced by the federal government under a single category with the result that Quaternary (and other geoscience material) from the Geological Survey vanishes into 'government documents'. Where this is the practice a strong case can be made for a second set of GSC publications being retained in local (i.e. departmental or groups of departments) collections.

11.2 Laboratories

During the past three decades Quaternary geoscientists have adopted quantitative techniques for solving many problems. Most of them demand relatively expensive laboratory facilities. These exist in Canada but are not always accessible to Quaternary geoscientists. There are several reasons for this anomaly:

1) Most geochemists and geophysicists who actually handle laboratory infrastructures are primarily involved in bedrock studies;
2) Physical geographers and archeologists are frequently located in Arts faculties where equipment budgets are small and often nonexistent;
3) The NSERC funding system is such that there is a straight correlation between operating and equipment grants; as a consequence, Quaternary geoscientists have difficulties obtaining large equipment grants because of their relatively low operating grants.

The only exception to this deficiency concerns simple remote sensing (RS) facilities which are reasonably well spread and accessible throughout the country, both in government agencies and universities. In the latter they are usually operated by physical geographers. However, advanced RS research also has serious laboratory difficulties (sec. 11.3).

Quaternary geoscience relies increasingly on 'absolute' age determinations. 'Relative' dating based on biostratigraphy is of limited support because of the

Table 11.1. Quaternary Chronology Dating Methods

1. Radiometric	Radiocarbon, Uranium-thorium series, etc. Thermoluminescence (TL) Electron Spin Resonance (ESR)
2. Biological	Dendrochronology Lichenometry Paleoentomology Palynology Marine microfossil biochronology
3. Age-equivalence horizons	Paleomagnetism Tephrochronology
4. Chemical	Amino-acid racemization Weathering-rates - pedogenesis - obsidian hydration
5. Incremental	Varve chronology

uniformity of the fauna and flora throughout the time period, especially in the Upper Quaternary, and lithological correlation is handicapped by the lateral and vertical discontinuities which characterize the continental deposits of the period. Most dating methods are, directly or indirectly, linked to the measurement of radioactive isotopes. The equipment used for such analysis may range from relatively cheap α or β counters to expensive Accelerator Mass Spectrometers (AMS). Although some methods are sufficiently well-known to most Quaternary geoscientists (e.g. ^{14}C), others are still 'esoteric'; their use implies collaborative studies in which geochemists have an important role. In such cases, manpower may be a limiting factor.

11.2.1 Radiocarbon dating laboratories

Radiocarbon is still the most used isotope for dating purposes when studying Upper Pleistocene and Holocene periods. Facilities are unevenly distributed in the country. Ontario and Quebec have access to a number of dating units but researchers in the Atlantic and the Western Provinces are deprived of adequate local facilities. As a whole, the production of radiocarbon dates in Canada is still insufficient, despite the productivity of the two most accessible laboratories (G.S.C.-Ottawa: ca. 4000 dates since the early sixties; UQAM: ca. 1300 since 1980). Private laboratories in the United States (including Beta, Analytic, Teledyne Isotopes etc.) regularly provide commercial services for Canadian researchers.

11.2.2 Accelerator mass spectrometry

The development of accelerators (Tendetron, tandem Van de Graaf...) may change the situation and also give access to new dating tools. It permits measurement of ^{14}C abundances in very small samples down to 0.1 g of shell; because sample size has been a limiting factor in various fields of research (archeology, deep sea and lake core studies etc.), this possibility is of great importance. Moreover, other radioactive isotopes with longer half-lives (^{10}Be, ^{36}Cl) become measurable and may provide absolute age determinations at the scale of the whole Quaternary.

The IsoTrace Laboratory, in the University of Toronto, has been set up around a Tendetron, to serve as a national facility. This might well be over-optimistic because the laboratory is not devoted full time to ^{14}C and the maximum number of samples it can process on a yearly basis is

Table 11.2. Conventional Radiocarbon Dating Laboratories

Laval University	University of Waterloo
Université de Québec (UQAM)	Saskatchewan Research Council/
Geological Survey of Canada	National Museum of Canada
Brock University	Alberta Environmental Centre
Inoperative laboratories (1985)	
Dalhousie University	Simon Fraser University

ca. 340[1], and the maximum voltage allowed on the Tendetron (ca. 2.75 MeV)[1] may well be too low for the measurement of some other isotopes (e.g. ^{36}Cl).

For the present, Canadian researchers may have to rely on this infrastructure although at McMaster University (in conjunction with Simon Fraser University), a series of AMS age determinations have been made. In the longer term it is desirable to consider the conversion of other existing accelerators in Canada to the measurement of terrestrial cosmogenic radionuclides. Several advantages should be underlined:

1) several other low-energy, accelerators are available in Canada, including University of Montreal and at Chalk River.

2) Their use in nuclear physics is decreasing drastically.

3) Most of them are supported by NSERC infrastructure grants or by other public funds.

4) Pixie-type research programs on such machines do not justify the financial cost (plasma source and other new mass spectrographs are more efficient for such work).

5) Because of their higher acceleration (5 to 7 MeV), tandem Van de Graaf are more recommendable[2] than Tendetron for the measurement of most radionuclides; moreover, the cost to adapt an existing accelerator (from ca. $300 k to $500 k) is much lower than for a Tendetron installation (from $1.5 M to $2 M).

As soon as such facilities will become available, research on dating potentials of ^{10}Be and ^{36}Cl should be encouraged.

11.2.3 Other dating techniques

In the 50-250 ka range, Th/U isotopes are routinely used for absolute dating purposes. Although the method is more complex than with radiocarbon, it is still of relatively wide interest in terms of applications to various types of geological samples. Two laboratories are routinely operating in the country (McMaster and UQAM); in view of the large number of potential users, this is inadequate.

In some cases, K/Ar dating may be applied to Quaternary studies. Several laboratories are devoted to K/Ar measurements in Canada and are evenly distributed across the country; one, at University of British Columbia, will date material younger than 100 ka.

[1] 1984-Annual Report; Isotrace Laboratory.
[2] 'A strategy for adoption of accelerator mass spectrometry by the earth sciences', Doe et al., U.S. Geol. Surv., Open File Rept. 84-664.

Among other dating techniques, thermoluminescence should be given special attention. Unfortunately there is only one laboratory in the country (Simon Fraser) well-equipped and with enough expertise to respond to the need and this is, at present, not in commercial operation. Material for commercial T/L dating may be sent to the United States (Alpha Analytic) for processing at Cambridge University.

Fission track dating does not require very special equipment (a microscope and access to a reactor). Therefore, such facilities may be easily developed when and where needed and have been used at the University of Toronto for dating tephra layers.

Finally, amino-acid measurements may provide a relative indication of the age of some Quaternary fossils and materials. Here again, laboratories are not sufficient: the University of Alberta runs one well-established unit at Edmonton, partly on a commercial basis; two others are in developing stage (Université de Québec in Montréal, Memorial University of Newfoundland). Many samples collected for Canadian research are sent to Boulder, Colorado and Washington.

11.2.4 Other laboratory facilities

Because the Quaternary is subdivided on climatostratigraphic grounds, stable isotopes (^{18}O, ^{13}C, ^{15}N, ^{34}S) may be useful analytic tools. ^{18}O has been used particularly to establish a reference stratigraphy in deep sea and ice cores. It is also of great help when studying continental paleoenvironments (speleothems and lacustrine deposits). Several Canadian laboratories have a significant role in the international research in this domain. Facilities are available in a majority of the country's universities and in some governmental agencies (Alberta, Manitoba, many Ontario universities: McMaster, Waterloo, Toronto, Western, Ottawa, UQAM in Québec and Dalhousie and Memorial in the Atlantic Provinces). Most of them are relatively well-equipped; it is desirable that they be in a good competitive position with a regular upgrading of equipment.

There is also a demand for less expensive laboratories devoted to micropaleontological studies with special emphasis on the Quaternary period. Palynologists are well-established in the country but other micropaleontologists are rare. A few specialists on Quaternary foraminifera are grouped in the Atlantic Provinces (Atlantic Geoscience Centre, Dalhousie, Memorial) and more researchers are needed in this speciality. Other specialists (on beetles diatoms, dinoflagellates, ostracods) are so few that Canada is unable to undertake any exhaustive study where micropaleontological tools are essential. Again, manpower is the limiting factor.

11.3 Remote sensing

Analysis of landforms and surficial sediments by remote observation from the air has been of considerable interest since the early days of aerial photography. The advent of new remote sensing techniques using both aircraft and spacecraft as platforms has sparked renewed interest in traditional problems of Quaternary geoscience and innovative research on a wide range of topics that could not have been addressed even a decade ago. Photo-interpretation is now combined with evaluation of other kinds of imagery obtained by sensors operating outside the visible spectrum (uv, thermal and microwave), thus the term 'imagery interpretation' is more appropriate than photo- interpretation in referring to the activity of the geoscientist who is applying remote sensing techniques in his work.

Remote sensing can provide data on a variety of physical properties of bedrock, surficial materials, soil, water and ice, such as reflectance, colour, radiance, emissivity, temperature, surface roughness, vegetation cover. These data are presented in quasi-map form in various types of imagery, almost all of which can be digitally corrected to fit a selected graticule at any particular scale. The major advantage of remote sensing in Quaternary geoscience is that continuous data can be rapidly collected over large areas at a fraction of the cost of ground survey. The major disadvantage, particularly with remote sensing from spacecraft, derives from the fact that measurements are made at a relatively great distance, and so there is a loss of signal strength, and reduced resolution causing problems in the detection of the smaller features. However, the improvement in imagery systems over the last decade has allowed the geoscientist to map, measure and study a range of geomorphological features with unprecedented speed and accuracy.

The Quaternary geoscientist has a distinct advantage compared with his bedrock colleague because one of his major objects of interest – the landform – is directly visible in the image. There is generally less deduction involved than in most other types of interpretation and so a high level of reliability can be expected. Examination of the subsurface presents more difficulty because even with microwave sensors, the extent of penetration is limited. The success of the Space Shuttle radar in detecting buried valleys of an earlier pluvial episode in the Sahara cannot be taken as an indication that similar results could be obtained in mapping drift-filled bedrock channels in western Canada because the type of fill and the moisture content are quite different. For problems of this type the best procedure is still that of using surrogate detail provided by vegetation or soil indicators. The same is true of permafrost, and it is clear that many important linkages between the thermal regime of the sub-surface and the microtopography have still to be established. Careful integration of remotely sensed data and environmental data, particularly botanical, is essential when process, morphogenesis and environmental linkages are under scrutiny. The success of the analysis is often more dependent on the professional experience and regional knowledge of the interpreter than the performance of the sensor.

For a nation of its size and financial resources, Canada has a weak record in developing remote sensing techniques appropriate for Quaternary geoscience. Quaternary studies are seen as peripheral to the main concerns of the Canada Centre for Remote Sensing and provincial governments seldom have the expertise necessary to engage in such work. At the universities, remote sensing has not been able to achieve status as a discipline per se and is generally found as an adjunct to geography (as at McGill, Waterloo and Sherbrooke) or forestry (as at the University of British Columbia). The severe financial constraints under which universities have operated have precluded the development of specialised thematic or regional remote sensing courses where Quaternary geoscience applications can be treated in the detail that they merit. It is perhaps no accident that one of the best publications addressing a variety of topics in the field of applied geomorphology and remote sensing in Canada[1] is the product of the field experience of an engineering geologist working without the constraints of the boundaries set by academic disciplines or government mandates.

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[1] Mollard, J.D. and J.R. Janes. Air photo interpretation and the Canadian Landscape. Energy, Mines and Resources, Canada, 1984.

12 Internal relationships within Quaternary science

One theme dominates this report. Without cooperation between scientists of different disciplines, Quaternary geoscience will not flourish. There must be continuing communication and interaction between members of the Quaternary science community. Whilst this is often maintained at the personal level, more formal contacts are fostered through specialized journals and associations and by the organization of symposia frequently held during meetings of broader-based scientific societies.

12.1.1 Scientific publications: journals

Scientific papers describing advances in Canadian Quaternary geoscience appear in a wide range of international and national journals. Authors of Quaternary papers face a decision of whether to submit them to journals specializing in their own discipline or to send them to a journal publishing in a range of Quaternary topics. Journals in the latter category are relatively new amongst scientific publications. Two have a strong international reputation. 'Quaternary Research' first published in 1970 by Academic Press for the Quaternary Research Center, University of Washington and 'Boreas' published since 1971 in English by the Norden countries. In reply to the question (No. 42) of where respondents believe important Canadian papers appear, these two journals were amongst the five most commonly recognized.

In addition to 'Quaternary Research' and 'Boreas', other journals in Table 12.1 include 'Arctic and Alpine Research', a publication of the Institute of Arctic and Alpine Research, University of Colorado. Its editorial policy does not claim that it specializes in Quaternary topics but in practice it does, through being limited geographically to 'cold lands'. 'Géographie physique et Quaternaire' of the Université de Montréal press was known formerly as 'La Revue de Géographie de Montréal', until a change of title and publishing policy in 1970. In its revised format, the majority of papers were at first restricted to the province of Québec but in the last few years there has been a widening of subject matter, authorship and readership, a trend which will be maintained in the future as the publication has become the official journal of CANQUA and Association québecoise pour l'étude du Quaternaire (AQQUA). The editorial board of the journal has recently been restructured. It is hoped that it will become the recognized main vehicle for diffusion of Quaternary information in Canada.

Absent from Table 12.1 and it is assumed from failure to mention it in the responses to Question 42, not widely known in Canada, is 'Quaternary Science Reviews' (Oxford, England). It was first published in 1982 and the quality of the overview papers which form the great part of an issue is high.

The Quaternary Research Association (UK) plans to publish a new biannual journal, 'The Journal of Quaternary Science' which will concentrate on the results of multi-disciplinary and interdisciplinary research, beginning in 1986.

The 'Canadian Journal of Earth Sciences' is considered by respondents to be outstanding amongst journals that are not restricted by editorial policy to Quaternary topics. Nearly a quarter of the papers in the past two years have been in Quaternary subjects and the quality of the papers, the range of topics and the standard of editing identify it as a continuing major outlet for the Quaternary sciences in Canada.

Table 12.1. Five Journals with Significant Contributions for all Canadian Quaternary Geoscientists (Que. 42)

Canadian Journal of Earth Science (Ottawa, Ont.) Quaternary Research (Seattle, Wash.) Arctic and Alpine Research (Boulder, Col.) Geographie physique et Quaternaire (Montréal, Québec) Boreas (Oslo)

12.1.2 Other publications

Both federal and provincial geological surveys publish summaries of current research, papers on topical subjects, and fund comprehensive monographs upon completion of major research projects. Although these publications are, in one sense, a significant contribution to both pure and applied Quaternry geoscience, their usefulness is severely limited by their general inaccessibility, since most libraries catalogue them as miscellaneous government documents (see section 11.1).

Quaternary scientists produce a variety of newsletters and other ephemeral publications that are usually restricted to small subdisciplines of Quaternary science. They provide a rapid and cheap method of dissemination of preliminary observations and conclusions, prior to final publication. They commonly have a limited but international distribution. From Canada the 'Loess Letter' ('La Lettre du Loess'), the newsletter of the INQUA Loess Commission, formerly published by the Quaternary Research and Geological Engineering Groups of the University of Waterloo (Dept. of Earth Sciences) and 'Zooarchaeological Research News' (Department of Archaeology, Simon Fraser University) are examples of this type of publication. In the same category is the Newsletter that CANQUA distributes to its members.

In a country in which interaction within the scientific community is handicapped by distance and low geographical density of research workers, means of discussiing preliminary ideas are badly needed and cheap, quickly produced, throw-away, irregular publications should be encouraged.

Large numbers of one-time publications are produced after special meetings of societies, especially those with a field excursion component. Their role in recording research and stimulating further research is outstanding. 'Glacial Lake Agassiz' (eds. Teller, J.T. and L. Clayton, Geol. Assoc. Can. Special Paper 26, 1983) that resulted from a symposium on glacial Lake Agassiz held in Winnipeg in 1982 is an excellent example of this type of publication. Others are the publications that have followed the Quaternary symposia organized initially at York University but now held at different locations across the country. The seventh, most recent symposium on 'Quaternary paleoenvironments' was held at Lethbridge, Alta. in August, 1985.

A continuous stream of major scientific papers and monographs has appeared in the last 15 years. Book-length works are, in contrast, are uncommon in Canadian Quaternary publication lists and it is difficult for the non-specialist to obtain an overview of the recent advances in Quaternary science, although several regional and/or single topic books have appeared (see appendix 5). National coverage of Quaternary geoscience has been limited to the publications of the Geological Survey of Canada, particularly the relevant sections in the 'Geology and Economic Minerals of Canada' Fifth edition, 1970. It will be replaced by a single volume on the Quaternary Period scheduled for publication to coincide with the 1987 INQUA meeting in Canada.

12.2 Scientific associations

12.2.1 The National Scene

In most countries Quaternary geoscience organizations began as sections within the national societies of the parent disciplines from which the science was evolving: professional geology and geography societies would hold specialized sessions on Quaternary topics. In Canada, the Geological Association of Canada, the Canadian Association of Geographers, and the Association canadienne-française pour l'avancement des sciences have fulfilled this role. However in the same way as an international need was felt for the establishment of INQUA, so there has been a comparable demand for a Quaternary association at the national level. In the United States AMQUA (the much older 'Friends of the Pleistocene' which held its first meeting in Toronto in 1949 was by self-definition a non-organisation), in Germany DEUQUA, Scandinavia NORDQUA, in Great Britain, QRA were all in existence by the early seventies.

The development of a Canadian organization was more hesitant. Initially there was uncertainty of the extent to which Canadian Quaternary geoscientists should participate as a group in AMQUA and even when this was resolved, the development of a national association was slow. Meanwhile in Quebec, the Association québecoise pour l'étude du Quaternaire (AQQUA) had been founded at the 42nd congress of ACFAS in 1974. Its subsequent meetings have all been in the province although the organization views itself as embracing the geographical area of northeast North America. A close link with 'Géographie physique et Quaternaire (GPQ) has been formally recognized since 1984. The society with 200 members is active and assisted with the formation of a national organization, the Canadian Quaternary Association (CANQUA) in 1980.

National scientific organizations in Canada face considerable financial and administrative difficulties when they are started, and CANQUA has been no exception. It will need all the support that can be found over the next few years to meet the needs of Canadian Quaternary scientists.

CANQUA has a membership of about 300, it holds biennial meetings in conjunction with the 'York' Quaternary Symposium and is prominent in organizing field excursions to examine major Quaternary problems. It recognizes (with AQQUA) that GpQ is the official Canadian Quaternary journal and this should encourage a wider range of scientists to contribute to it. The success of AQQUA suggests that active regional groupings (of CANQUA) are both possible and desirable particularly with the objective of stimulating local multidisciplinary Quaternary research.

12.2.2 Canadian contributions to International Associations

Several international scientific unions have working groups, projects and commissions examining problems related to Quaternary events. The unions include geologists (IUGS), geographers (IGU), geophysicists (IUGG), and biologists (IUBS). Canada has acted as host to meetings of all four unions within the past two decades and provided field excursions and symposia with Quaternary themes.

The International Union for Quaternary Research (INQUA) arose out of a meeting in Denmark in 1928. Although increasingly active after 1945 no congresses were held outside Europe until 1965. Canadian participation was initially limited but has increased rapidly with the national expansion of Quaternary studies in the past two decades and the twelfth congress will be held in Ottawa in 1987.

13 Quaternary geoscience and society

Quaternary scientists appear to share with most other earth scientists a remarkable ability to be invisible in public. Quaternary science cannot expect to receive national support on the scale adequate for its development unless there is some understanding by society of its objectives and applications.

Quaternary sciences describe and explain Man's physical environment and the land resources on which so much of the economy of the country depends. When suitably presented, the Quaternary is an unbelievably exciting period with great attractions for the layman. Attention has already been drawn (sec. 8) to the inadequate coverage of Quaternary topics in the school systems. This is where information should first be given, but it should be continued into all walks of life and all levels of society. The message that Quaternary geoscience provides basic information for environmental and urban planning, for resource development and effective agricultural land utilisation, and for geochemical environmental studies will have to be repeated many times before the value of Quaternary science is appreciated.

There is potential for reaching a wide audience through popular writing including magazine articles, guidebooks for parks and major highways (e.g. the Trans-Canada Highway) and by identifying amplification of guide books for parks and routes (e.g. the Trans-Canada Highway), the identification and listing of localities with prominent Quaternary land features as national monuments. These are but a few of the ways in which the natural events of the last two million years can be interpreted and presented to the people of Canada.

Quaternary geoscientists are rarely conscious of the role they should be performing for society, which includes describing and disseminating the results of their research. It is a role in which national and regional scientific associations should be actively involved and one in which institutions must also play a part.

Museums at the national and provincial, and university levels are an obvious interface between Quaternary science and the general public (including the schools). Not all museums have natural history sections dealing with the Quaternary and in some provinces they are conspicuously absent. In others, Quaternary displays, usually with a regional focus, are often stimulating but

'throughout Canada the Quaternary displays in museums should be more attractive and better balanced' (a senior museum administrator).

Museums need not be left to generate their own enthusiasm for the Quaternary. Consideration should be given by national and regional Quaternary groups when they hold meetings to encourage local museums to prepare temporary displays developed around the major topics of the meeting. In this way, public notice of the meeting which might have been limited to a small press release, will reach a wider audience.

APPENDIX 1

Questionnaire sent to Canadian Geoscientists

CANADIAN GEOSCIENCE COUNCIL
STUDY OF QUATERNARY GEOSCIENCE IN CANADA

The Canadian Geoscience Council has established a Committee to study the state of Quaternary geoscience in Canada. The Committee is chaired by J. Brian Bird, and is composed of Earl A. Christiansen, Claude Hillaire-Marcel, Jacques Locat, Alan V. Morgan, Peta Mudie, Olav Slaymaker, Archibald M. Stalker and Denis St-Onge. The Committee seeks to determine the status of Quaternary research in Canada, the national need for Quaternary research and the adequacy of current educational, government and industrial sectors to meet these needs. The Committee has also been directed to recommend improvements and new directions for Quaternary geoscience research.

The Committee defined Quaternary geoscience rather broadly so that all areas of expertise listed under questions 6 and 18 are of central importance to our study in so far as they relate to Pleistocene, Holocene, present and future environmental interpretation. If in doubt about the relevance of your research, err in the direction of inclusiveness.

The attached questionnaire is an initial tool to demonstrate the magnitude and scope of Quaternary geoscience, and input is needed from all Canadian Quaternary scientists if the study is to be effective. Please participate. If you feel the questionnaire does not adequately address all salient points, please append additional comments to the last page. All personal information will be held strictly confidential. Please mail your completed questionnaire to:

Olav Slaymaker
Department of Geography
University of British Columbia
1984 West Mall
Vancouver, British Columbia, V6T 1W5
tel (604) 228 2020

If you know of other persons who are interested in participating please request another questionnaire from Dr. Slaymaker or make a copy of this form.

1. Please list your name and title:

2. Company and Division, Government Agency and Division, or University and Department for which you work.

Part 1.

3. Highest degree earned:

____ BSc.
____ MSc.
____ PhD.
____ years post-doctoral fellowship

4. Number of years of work experience you have had in:

____ industry
____ government
____ university (excluding degrees)
____ other (specify)____________

5. What percentage of your work effort is related to:

____ administration
____ consulting
____ research
____ teaching
____ other (specify) ____________

6. What percentage of your research effort is:

________ applied research with specific, practical aims in mind or

________ basic or pure research aimed at advancing scientific knowledge?

7. In what general subject areas is your research focused (indicate as percentages)?

____ archaeology ____ climatology
____ economic geology ____ engineering geology
____ environmental geochemistry ____ geomorphology
____ geophysics ____ geotechnique
____ glacial geology ____ glaciology
____ hydrology ____ marine geology
____ oceanography ____ paleoecology/paleontology
____ pedology ____ permafrost
____ physical geography ____ sedimentology
____ stratigraphy ____ structure/tectonics
____ vulcanology ____ other ________

8. List your specific research interests or specialties in order of personal importance:

____
____
____
____

9. What percentage of your primary data is derived from the:

________ field
________ laboratory
________ literature
________ other ____________

10. What percentage of your data collection is directed towards:

____ process studies
____ interpretation of paleoenvironments
____ mapping
____ methodological development
____ other ____________

11. Describe your specific contribution to theory and method.

12. In what environments (eg. marine, coastal, glacial, mountain) are you primarily interested?

13. What research techniques do you employ routinely (eg. field observation, mapping, radiometric or relative age dating techniques, stable isotope analysis, computer modeling, etc.) ?

14. If interested in more than one of the following, rank in order of importance:

____ pre-Wisconsin events
____ Wisconsin events
____ Holocene events
____ historic and present events?
____ prediction
____ the Quaternary as a whole?

15. What size of region do you study and in what detail?

16. In which areas of the world is most of your Quaternary research conducted?

	nation	region	under what auspices
North America	____	____	____
elsewhere	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____

17. Do you regularly collaborate with researchers in other areas of expertise?

____ from your department
____ from your institution
____ from other institutions:
  ____ university
  ____ provincial government
  ____ federal government
  ____ industry
  other ____________
____ from other countries

18. If the answer to question 17 is yes, what areas of expertise do your co-workers bring to these projects?

____ archaeology ____ climatology
____ economic geology ____ engineering geology
____ environmental geochemistry ____ geomorphology
____ geophysics ____ geotechnique
____ glacial geology ____ glaciology
____ hydrology ____ marine geology
____ oceanography ____ paleoecology/paleontology
____ pedology ____ permafrost
____ physical geography ____ sedimentology
____ stratigraphy ____ structure/tectonics
____ vulcanology ____ other ________

19. Do you consider this collaboration essential to your research objectives? Why?

20. Please list your sources of research project funding (exclusive of personal salary) and provide the approximate amounts for the years indicated:

1981 sources ____________
amount ____________
1982 sources ____________
amount ____________
1983 sources ____________
amount ____________

21. Do you regard this funding level as:

____ very good
____ adequate
____ inadequate.

Remarks:

22. What percentage of your research budget is spent typically on

____ student support
____ secretarial, cartographic, and adminstrative services
____ equipment
____ field work expenses
____ laboratory analysis
____ computing
____ other ____________

23. What laboratory and logistical facilities are currently available to support your research?

24. What laboratory and logistical facilities are unavailable to you?

25. Do you use computational facilities? If not, briefly explain why and proceed to question 29.

26. What computational facilities are currently available to support your research?

____ personal or mini computer
____ large, general purpose computer
____ teleprocessing network(specify)
____
____ other ____________

27. What percentage of your computer usage is related to

____ statistical data analysis
____ data processing
____ numerical modeling
____ other ____________

28. Are the computer hardware and software available to you adequate?

29. Are you aware of data sources, such as industrial exploration programmes or government and university research projects that would aid your research significantly but are currently unavailable to you?

30. Why are these data unavailable to you?

31. What should be done to improve the availablity of these data?

PART II

32. What do you, as a Quaternary geoscientist, think are the most important research question(s) being adressed at present, and rank, if possible.

33. Are there any significant research questions that, in your opinion, are <u>not</u> being pursued adequately in Canada? If so, what are these?

34. What are the most significant stumbling blocks to Canadian Quaternary research at present?

_____ inadequate funding

_____ poor interdisciplinary communication

_____ poorly defined research objectives

_____ poorly defined research methodologies

_____ other ______________________________

An extremely small group of scientists spread over and beyond a very large country.

35. What should be done to improve the status of Quaternary research in Canada?

_____ increase the level of funding to individual researchers

_____ establish new, interdisciplinary research programmes including joint efforts by government, industry and university scientists

_____ establish a single, national research center, independent of government and universities, that would provide a core team to lead research activities and provide high quality facilities for its own and visiting industry, university and government scientists

_____ establish new, regional research centers, possibly associated with universities across Canada to focus research

Other ideas:

36. If funding is inadequate, and more funding becomes available, should

_____ more funds be distributed through existing granting organizations and programmes

_____ more funds be distributed through new organizations and programmes

_____ funds be distributed on different criteria than at present

Other ideas:

37. What research topics should receive the highest funding priority?

38. Is there sufficient interdisciplinary communication and cooperation among Quaternary researchers in Canada? If not, what should be done?

39. Where are the centres of excellence in Quaternary research in the world today?

40. What factors do you believe have led to their success?

41. How does the quality of Quaternary research in Canada compare with that elsewhere in the world?

42. Please list the five major research journals and publications which you consult regularly in descending order of importance oftheir present contribution to Canadian Quaternary research.

1. ______________________________

2. ______________________________

3. ______________________________

4. ______________________________

5. ______________________________

43. Do you consult Government publications on a regular basis? Please be specific.

44. Are more media for storage, presentation and publication of Quaternary geoscience data needed and, if so, what should be their purpose and scope?

PART III.

45. Is Quaternary research sufficiently important to the economy, environmental protection, and other national interests of Canada to justify significantly increased public sector support? Please elaborate.

46. Does Quaternary research in Canada currently serve the national interest? If not, what direction should future research take?

47. What areas of Quaternary research require the most intensified national effort in Canada and what is the significance of these research topics?

48. How can the public be made more aware of the importance of Quaternary research to the national interests of Canada?

PART IV.

The following questions are to be completed by researchers in government and private industry. If you are a university researcher, please skip to question # 54.

49. From your experience, what aspects of academic training in Quaternary geoscience are most deficient in Canadian universities with regards to the needs of industry and government?

50. If you feel that improvements are needed in training, what adjustments would you make to Canadian university programmes?

51. Has your research group recently worked jointly with Canadian universities (including supporting graduate student thesis research)? Please describe.

52. Have these joint projects been satisfactory? If not, why not?

53. Is there a pressing need for professional registration, standards and testing of Quaternary researchers on a national or provincial level? If so, why?

PART V.

For University Researchers

54. Is Quaternary research generally recognized as a distinct area of academic activity? If so, is Quaternary research comparable in quality to other academic activities?

55. Does Quaternary research have a unifying theme or theoretical framework? If so, elaborate.

56. What is the current quality of undergraduate training in Quaternary research in Canada and what should be done to improve it?

57. What is the current quality of graduate training in Quaternary research in Canada and what should be done to improve it?

58. Do most of your students find work directly related to Quaternary research upon graduating? If not, why?

59. Do you consult on Quaternary related projects in addition to your academic responsibilities? If so, how many hours per year do you spend consulting?

***** End of Questionnaire *****

Additional comments:

APPENDIX 2

Distribution and Response to the Questionnaire

1.	Total number of questionnaires distributed	984
2.	Total number of questionnaires returned	164

3. Earth science societies and other lists searched for mailing list.

Canadian Quaternary Association	(CANQUA)
Canadian Association of Geographers	(CAG)
Association québécoise pour l'étude du Quaternaire	(AQQUA)
Canadian Geotechnical Society	(CGS)
Geological Association of Canada (Environmental Earth Sciences Division)	(GAC)
International Quaternary Palynologists 'Climatic modellers' (EMR/AES)	
Quaternary distribution list – Atlantic region	
NSERC Quaternary files	
Canadian Permafrost Conference	

4. Distribution of respondents by employment sector

Government:	Federal	31
	Provincial (including territorial)	22
Industry and self employed		21
University:	Geography	40
	Geology and Earth Sciences	26
	Archeology and Anthropology	12
	Biology	5
	Zoology	3
	Engineering	2
	Physics	1
	Planning	1

5. Respondents with doctoral degrees: 70%

by sector:	Government	56%
	Industry	33%
	University	95%
other degrees:	masters	22%
	bachelors	8%

6. Geographical distribution of respondents by region of primary research.

APPENDIX 3

Doctoral dissertations in Quaternary Geoscience (1979-84)

Adshead, J.D. (1983, Missouri). Hudson Bay river sediments and regional glaciation.

Aksu, A.E. (1981, Dalhousie). Late Quaternary stratigraphy, paleoenvironmentology and sedimentation history of Baffin Bay and Davis Strait.

Alam, M. (1979, Dalhousie). The effect of Pleistocene climatic changes on the sediments around the Grand Banks.

Bail, P. (1984, McGill). Problèmes géomorphologiques de l'englacement de la transgression marine Pléistocene en Gaspésie sud-orientale.

Beaudoin, A.B. (1984, Western Ontario). Holocene environmental change in the Sunwapta Pass area, Jasper National Park.

Bednarski, J. (1984, Alberta). Glacier fluctuations and sea level history of the Clements Markham Inlet, Northern Ellesmere Island.

Bouchard, M.A. (1981, McGill). Late Quaternary geology of the Temiscamie area, central Québec.

Broster, B. (1983, Western Ontario). Geochemical trends and stratigraphy of the St. Joseph's till along the eastern shore of Lake Huron.

Clark, P.U. (1983, Colorado). Glacial geology of the Kangalaksiovik-Abloviak region, northern Labrador, Canada.

Cwynar, L.C. (1980, Toronto). Late Quaternary vegetation history from Hanging Lake, Northern Yukon.

Davis, P.T. (1980, Colorado). Late Holocene glacial, vegetational and climatic history of Pangnirtung and Kingnait Fiord area, Baffin Island, N.W.T., Canada.

Dubois, J.M.M. (1980, Ottawa). Environnments Quaternaires et évolution Postglaciare d'une zone côtière en émersion en bordure sud du bouclier Canadien.

Gascoyne, M. (1980, McMaster). Pleistocene climates determined from stable isotope and geochronologic studies of speleothem.

Gilchrist, C.M. (1982, Massachusetts). The glacial geology of the southeastern area of the district of Keewatin, Northwest Territories, Canada.

Hicock, S.R. (1980, Western Ontario). Pre-Fraser Pleistocene stratigraphy, geochronology, and paleoecology of the Georgia Depression, British Columbia.

Hillaire-Marcel, C. (1979, Paris VI). Les mers post-glaciaires du Québec: quelque aspects.

Karlstron, E.T. (1981, Calgary). Late Cenozoic soils of the Glacier and Waterton Parks area, northwestern Montana and southwestern Alberta and paleoclimatic implications.

Kearney, M.S. (1981, Western Ontario). Late Quaternary vegetational and environmental history of Jasper National Park, Alberta.

Kite, J.S. (1983, Wisconsin). Late Quaternary glacial, lacustrine and alluvial geology of the Upper St. John River basin, northern Maine and adjacent Canada.

Klassen, R.A. (1982, Illinois). Quaternary stratigraphy and glacial history of Bylot Island, N.W.T., Canada.

Kvill, D.R. (1985, Alberta). Glacial Geomorphology of the Brazeau River Valley, foothills of Alberta.

Last, W.M. (1980, Manitoba). Sedimentology and Post-glacial history of Lake Manitoba.

Lauriol, B. (1982, Montréal). Géomorphologie Quaternaire au sud de l'Ungava, Nouveau-Québec.

Leonard, E.M. (1981, Colorado). Glaciolacustrine sedimentation and Holocene glacial history, Northern Banff National Park, Alberta.

Liu, K.B. (1982, Toronto). Postglacial vegetational history of northern Ontario: a palynological study.

Locke, W.W. (1980, Colorado). The Quaternary geology of the Cape Dyer area, southernmost Baffin Island, Canada.

Mode, W.N. (1980, Colorado). Quaternary stratigraphy and palynology of the Clyde Foreland, Baffin Island, N.W.T., Canada.

Mudie, P.J. (1980, Dalhousie). Palynology of Late Quaternary marine sediments, Eastern Canada.

Occhietti, S. (1979, Ottawa). Le Quaternaire de la region de Trois Rivières-Shawinigan, Québec.

Osterman, L.E. (1982, Colorado). Late Quaternary history of southern Baffin Island, Canada: A Study of foraminifera and sediments from Frobisher Bay.

Pagé, P. (1982, Paris-Sud). Caracterisation isotopique des milieux glacio-marines de l'Arctique Canadien.

Proudfoot, D.N. (1985, Alberta). A lithostratigraphic and genetic study of Quaternary sediments in the vicinity of Medicine Hat, Alberta.

Quinlan, G.M. (1981, Dalhousie). Numerical models of postglacial relative sea level change in Atlantic Canada and the Eastern Canadian Arctic.

Rodrigues, C.G. (1981, Carleton). Holocene microfauna and paleoceanography of the Gulf of St. Lawrence.

Smee, B.W. (1983, New Brunswick). Sedimentological and mineralogical characteristics of offshore sediments, southeastern Nova Scotia.

Stewart, R.A. (1982, Western Ontario). Glacial and glaciolacustrine sedimentation in Lake Maumee III near Port Stanley, southwestern Ontario.

Tucker, C.M. (1979, McMaster). Late Quaternary events on the Burin Peninsula, Newfoundland.

Wightman, D.M. (1980, Dalhousie). Late Pleistocene glaciofluvial and glaciomarine sediments on the north side of the Minas Basin, Nova Scotia.

Williamson, M.A. (1983, Dalhousie). Benthic foraminiferal assemblages on the continental margin off Nova Scotia: A multivariable approach.

Wilson, M.A. (1981, Saskatchewan). The climatic and vegetational history of the Postglacial in central Saskatchewan.

Yonge, C.J. (1982, McMaster). Stable isotope studies of water extracted from speleothems.

APPENDIX 4

Masters Theses in Quaternary Geoscience (1979-84)

Allen, H.D. (1982, Calgary). Dendrochronological studies in the Slims River Valley, Yukon Territory.

Aravena, R.O. (1982, Waterloo). O, H, and C in tree rings and their relationship to the environment.

Arsenault, M. (1979, Québec). Etude morphologique de poissons fossiles de la mer de Champlain (Pléistocene supérieur), en provenance de Green Creek, Ottawa.

Baron-Lafrenière, L. (1983, Montréal). Géomorphologie glaciaire de la région du Mont Jacques-Cartier, Gaspésie.

Barrie, C.Q. (1980, Dalhousie). Late Quaternary geological history of Makkovik Bay, Labrador.

Batterson, M.J. (1980, Memorial). Contemporary frontal moraine formation in the Yoho Valley, British Columbia.

Bell, A. (1980, U.B.C.). Terrain mapping and regional slope stability evaluation in the Fraser Canyon.

Bezada-Diaz, M. (1981, Ottawa). Champlain sea sediments and landforms in the Alexandria Map area.

Bigras, P. (1984, Sherbrooke). Hydrogéomorphologie fluviale Quaternaire du bassin versant de la rivière à la Patate, ile d'Anticosti, Québec.

Blackwell, B. (1980, McMaster). Archeometry of five Pleistocene sites as inferred from uranium and thorium isotopic abundances in travel time.

Boissonault, P. (1983, Sherbrooke). Géomorphologie et lithostratigraphie à l'est du lac Memphrémagog.

Bourgeois, J. (1982, Ottawa). Etude palynologique dans la vallée du Grizzly Creek (Yukon).

Brodeur, D. (1981, Laval). La morphologie et l'histoire Quaternaire de l'Ile-aux-Coudres.

Bruneau, H. (1984, Ottawa). L'évolution post-glaciaire du secteur aval de la rivière Coppermine, Territoires du Nord-Ouest.

Buszka, V.E. (1982, Waterloo). Geomorphological mapping of the Waterloo Region.

Calderwood, B.J. (1979, Carleton). An inquiry into the formation of ridged moraine and its role in interpretation of the glacial history of the Avalon Peninsula, Newfoundland.

Calverley, A. (1984, Calgary). Sedimentology and geomorphology of the modern epsilon cross-stratified point bar deposits in the Athabasca upper delta plain.

Catto, N.R. (1981, Alberta). The Quaternary geology of the western Cypress Hills region, Alberta and Saskatchewan.

Chamney, L.C. (1980, Queen's). Historical and contemporary sedimentation in Peters Lake, southeastern Ontario.

Champagne, M. (1982, Laval). Paléo-milieux sédimentaires, geochimie d'éléments traces et carbone organique total, dans quatre coupes stratigraphiques des Basses-Terres du Saint-Laurent.

Cheel, R.J. (1980, Ottawa). Late Quaternary glaciomarine deposits of the Stittsville area, near Ottawa.

Cloutier, M. (1982, UQAM). Géologie et géomorphologie quaternaires de la région de Montréal.

Cole, M.L. (1979, Rice). Nearshore glacial marine sedimentation, based on Late Pleistocene deposits of the Puget Lowlands, Washington and British Columbia.

Comtois, P. (1980, Montréal). Histoire holocène du climat et de la végétation à Lanorais, Québec.

Cook, R.A. (1981, British Columbia). Composition and stratigraphy of Late Quaternary sediments from the northern end of Juan de Fuca ridge.

Corbeil, P. (1984, UQAM). Géologie du Quaternaire de la région de Rigaud/Rivière Beaudette (Québec): Quelques applications à l'environment.

Cordsen, A. (1980, Dalhousie). Ocean bottom seismometer refraction results from the Continental Margin off Nova Scotia.

Cronin, J.T. (1984, Western Ontario). The raised shorelines of the Northern Penetanguishene Peninsula.

Dale, C.T. (1979, Dalhousie). A study of high resolution seismology and sedimentology on the offshore Late Quaternary sediments northeast of Newfoundland.

Decroix, D. (1984, UQAM). Etude préliminaire de la carte géotechnique de l'Ile de Montréal.

Delure, A.M. (1983, Dalhousie). The effect of storms on sediments in Halifax Inlet, Nova Scotia.

Desmarais, G. (1981, Sherbrooke). Les environnements Quaternaires et l'évolution post-glaciaire du bassin de la Rivière Matamic, Cote Nord du Saint-Laurent.

Desrochers, D. (1983, Ottawa). Permafrost and its relationship to late Quaternary history, high Arctic islands.

De Vernal, A. (1983, Montréal). Paléoenvironnements du wisconsin par la palynologie dans la région de Baie Saint-Laurent, Ile du Cap Breton.

Dorion, A. (1981, UQAM). Les dépôts quaternaires de la région de Granby-Waterloo, Québec – Cartographie Sédimentologie et Stratigraphie.

Dove, J.E. (1981, Calgary). Towards a Holocene paleoecology of the Ghost River and Water Valley areas, southwestern Alberta.

Dubé, C. (1983, Sherbrooke). Géomorphologie Quaternaire et déglaciation à l'Ouest ou Lac Memphrémagog.

Eilers, W.D. (1982, Saskatchewan). Near-surface glacial till stratigraphy and its effect on soil genesis.

Evans, D.J.A. (1984, Memorial). Glacial geomorphology and chronology in the Salamiut Range/Nachvak Fiord area, Torngat Mountains, Labrador.

Eyles, C.H. (1982, Toronto). The sedimentology of the early and middle Wisconsin deposits at Scarborough Bluffs, Ontario.

Fick, S.F. (1981, Simon Fraser). Louis Agassiz's contributions to glaciology.

Fitzgerald, W.D. (1982, Waterloo). Post glacial history of the Minesing Basin, Ontario.

Forbes, J.R. (1980, Alberta). The paleolimnology of two shallow lakes in Central America.

Gauthier, R. (1981, Montréal). Histoire de la colonisation végétale postglaciaire des montérégiennes, deux sites du Mont St. Bruno.

Geddes, R.S. (1980, Western Ontario). The Vixon Lake indicator train, Northern Saskatchewan.

Glover, B.W. (1979, Alberta). Late Quaternary river terrace evolution in part of the Athabasca River Valley.

Glynn, P. (1982, UQAM). Le transfert au sol du $^{14}CO_2$ en fonction de la latitude (46°-70°N) et de la saison au Québec et sur la terre de Baffin.

Gratton, D. (1984, Sherbrooke). Les paléoenvironnements sédimentaires au Wisconsinien moyen et tardif, ile d'Anticosti, golfe du Saint Laurent.
spruce at Arctic treeline near Inuvik, Northwest Territories, Canada.

Guay, F. (1985, Ottawa). Etude palynologique d'une partie du postglaciaire dans la région de la rivière Coppermine, T.N.O.

Hall, R.K. (1985, Dalhousie). Inner shelf acoustic facies and surficial sediment distribution of the Eastern Shore, Nova Scotia.

Hamil, G.B. (1982, Calgary). Quaternary interpretation of southwest Tofino Basin, Pacific Margin, Canada.

Hayward, M. (1979, Ottawa). Aspects of Champlain Sea sedimentation associated with glacial ridges in the South Ottawa region.

Hill, P.R. (1981, Dalhousie). Detailed morphology and Late Quaternary sedimentation of the Nova Scotian slope, south of Halifax.

Holland, D.K. (1979, Western Ontario). The pollen stratigraphy of two Holocene sections in Sunwapta Pass, Jasper National Park, Alberta.

Jennings, D.B. (1984, Alberta). The Late Quaternary geomorphology of Elk Island National Park, Central Alberta.

Jones, N. (1981, Alberta). Glacigenic streamlined landforms near St. Paul, Alberta.

Jones, P. (1982, U.B.C.). Sediment movement in a sub-alpine basin in the Coast Mountains.

Karakostanoglou, I. (1983, McMaster). ESR isochron dating of speleothems.

Kingston, M. (1982, Western Ontario). An evaluation of the recommended methods for Paleosol investigation: A case study of a Holocene Paleosol, Calgary, Alberta.

Kostaschuk, R.A. (1980, Calgary). Late Quaternary history of the Bow Valley near Banff, Alberta.

Kristjansson, F.J. (1980, Ottawa). Cirque multiple glaciation, Grizzly Creek, Yukon Territory and paleoclimatic implications.

Kulig, J. (1985, Alberta). A sedimentation model for the deposition of glacigenic deposits in central Alberta.

Lacomfe, J. (1979, Laval). Géomorphologie glaciare de la partie centrale du comté de Bellechasse.

Lapierre, G. (1983, UQAM). Caractéristiques isotopiques (^{18}O) d'une tourbière â palses et détermination des variations de composition isotopique des précipitations dans la région de Poste-de-la-Baleine, durant une année hydrologique.

Larocque, A. (1983, Sherbrooke). Developpement des lacs proglaciaires et déglaciation des hauts bassins des rivières au Saumon et Chaudière, sud du Québec.

Larocque, G. (1983, Sherbrooke). Géologie et géomorphologie du Quaternaire dans le bassin du haut-Saint-Francois, sud du Québec.

Larouche, A. (1979, Laval). Histoire postglaciare comparée de la végétation, a Saint-Foy et au mont des Eboulements, Québec, par l'analyse macrofossile et l'analyse pollinique.

Leckie, D.A. (1980, McMaster). Late Quaternary history of the Hermitage Bay area, Newfoundland.

Leveque, G. (1982, UQAM). Géologie des dépôts quaternaires de la région de Oka – Ste-Scholastique, Québec.

Leyland, J.G. (1984, Brock). Quaternary geology of the Campbellford, Trenton, Consecon, Tweed, Belleville, Wellington, Sydenham, Bath and Korkshire map-areas, Ontario.

Liveman, D. (1981, Alberta). Sedimentology and drainage history of a glacier-dammed lake, St. Elias Mountains, Yukon Territory.

MacDonald, G.M. (1980, Calgary). The post-glacial paleoecology of the Morley Flats and Kananaskis Valley Region, Southwestern Alberta.

Mathieu, C. (1984, Montréal). Morphogenèse holocène des dunes et des palses de la basse vallée du Koroc (Nouveau-Québec).

Malott, M.L. (1981, British Columbia). Distribution of foraminifera in cores from Juan de Fuca ridge, North East Pacific.

McCourt, G.H. (1982, Alberta). Quaternary palynology of the Bluefish Basin, Northern Yukon Territory.

Mellars, G. (1981, Memorial). Deglaciation of the Pouch Cove Area, Avalon Peninsula, Newfoundland: a palynological approach.

Miller, A-A., L. (1983, Dalhousie), Elphidium excavatum (Terquem): paleobiological and statistical investigations of infraspecific variation.

Miller, R.F. (1980, Waterloo). Paleoentomological analysis of a postglacial site in northwestern New York State.

Miles, M. (1980, U.B.C.). Bank and slope morphology as an indicator if arctic terrain stability.

Montgomery, K. (1980, Waterloo). Air-Photo interpretation of micro-relief in the Conestoga Lake area, Ontario.

Nadler, D. (1984, U.B.C.). Groundwater hydrology and slope movement at Pavilion, B.C.

Naldrett, D.L. (1981, Ottawa). Aspects of the surficial geology and permafrost conditions, Klondike Goldfields and Dawson City, Yukon Territory.

Nolin, A. (1981, Sherbrooke). Sédimentologie et géomorphologie associées au lac glaciaire Algonquin, près du site paléo-indien Fisher, Stagner, Ontario.

Ouimet, D. (1983, Ottawa). Etude palynologique des argiles de la Mer de Champlain dans le canton de Cumberland, Est Ontario.

Painchaud, A. (1984, Sherbrooke). Déglacement par Calotte Résiduelle au Wisconsinien Tardif et émersion de L'Ile D'Anticosti, Golfe de Saint-Laurent.

Parent, M. (1979, Sherbrooke). Géomorphologie quaternaire de la region de Stoke-Watopéka, Québec.

Pehme, P.E. (1984, Waterloo). Identification of Quaternary deposits with borehole geophysics in the Waterloo Region.

Rajewicz, R. (1979, UQAM). Analyse de séries chronologiques de l'est du Canada, appliquée à l'étude des cycles climatiques.

Rhine, J. (1984, Calgary). Sedimentological and Geomorphological Reconstruction of the Late Pleistocene Athabasca Fan Delta, Northeast Alberta.

Roberts, R.G. (1984, U.B.C.). Stream channel stability in the Queen Charlotte Islands.

Saunders, I. (1985, Simon Fraser). Late Quaternary Geology and Geomorphology of the Chilliwack River Valley, British Columbia.

Schreiner, B.T. (1980, Saskatchewan). Quaternary geology of the Precambrian Shield south of 58°N. lat., Saskatchewan.

Seaman, A. (1983, Toronto). The late Quaternary History of the Burtt's Corner Area of New Brunswick.

Souch, C.J. (1985, U.B.C.). Holocene Lacustrine Sedimentation in a small Sub-Alpine watershed.

Smith, D.L. (1984, Dalhousie). Modern and fossil diatoms of Porters Lake, Nova Scotia: a postglacial history with special reference to marine intrusion.

Squires, C. (1984 Windsor). The late Foxe Deglaciation of the Burton Bay Area, Southwestern Baffin Island, N.W.T.

Stea, R.R. (1982, Dalhousie). The Properties, Correlation and Interpretation of Pleistocene Sediments in Central Nova Scotia.

Steele, K. (1985, Alberta). Utilizing glacial geology in uranium exploration, Dismal Lakes, Northwest Territories.

Stewart, T.G. (1981, Alberta). The Holocene paleoenvironment of Clements Markham Inlet, Northern Ellesmere Island, N.W.T., Canada.

Stravers, L.K.S. (1981, Colorado). Palynology and deglaciation history of the central Labrador-Ungava peninsula.

Styan, W.B. (1981, U.B.C.). The sedimentology, petrography and geochemistry of some Fraser Delta peat deposits.

Todd, B.J. (1984, Dalhousie). Iceberg scouring on Saglek Bank Northern Labrador Shelf.

Veldhuyzen, H. (1982, McGill). Sources and transport of Late Quaternary sediments, Kavlesfin Trough, Labrador Shelf.

Villeneuve, P. (1981, UQAM). Etude de l'impact glaciaire sur la morphologie et la résistance du socle rocheux dans la réjion de Montréal.

Waters, P.L. (1979, Alberta). Postglacial Paleoenvironment of southern Alberta.

Williams, K.M. (1984, Colorado). Marine diatom assemblages from Baffin Bay and David Strait.

Wolcott, J.F. (1984, U.B.C.). The grain size gap in river bed gravels.

APPENDIX 5

A selection of book-length publications prepared by Canadian Quaternary Geoscientists during the decade, 1976-1985.

Andrews, J.T., (ed.), 1985. Quaternary Environments: Eastern Canadian Arctic, Baffin Bay and West Greenland, George Allen and Unwin, London, 774 p.

-----------, 1984. The Laurentide Ice Sheet: Evidence from the Eastern Canadian Arctic of its geometry, dynamics and history. University of Reading, Geographical Papers, No. 86, 61 p.

Bird, J.B., 1980. The Natural Landscapes of Canada, 2nd ed., Wiley, Toronto, 260 p.

Canadian Soil Survey Committee, 1978. The Canadian system of soil classification. Canada Department Agriculture Publication 1646. Supply and Services Canada, Ottawa, 164 p.

Chapman, L.J. and Putnam, D.F., 1984. The Physiography of Southern Ontario, 3rd ed., Ont. Geol. Surv., Spec. vol. 2, 270 p.

Church, M. and Slaymaker, O. (eds.), 1985. Field and Theory: Lectures in Geocryology. University of British Columbia Press, 213 p.

Davidson-Arnott, R. et al. (eds.), 1982. Research in Glacial, Glacio-fluvial and Glacio-Lacustrine Systems. Proceedings 6th Guelph Symposium on Geomorphology. University of Guelph Geographical Publication no. 6, 319 p.

Eyles, N. (ed.), 1983. Glacial Geology. Pergamon, Toronto, 409 p.

French, H.M., 1976. The Periglacial Environment. Longman, London, 309 p. (2nd edition in press).

Fulton, R.J. (ed.), 1984. Quaternary Stratigraphy of Canada – a Canadian Contribution to IGCP Project 24. Geological Survey of Canada Paper 84-10, 210 p.

Harington, C.R. (ed.), 1985. Climatic Change in Canada 5, Critical Periods in the Quaternary Climatic History of Northern North America. National Museum of Canada, National Museum of Natural Sciences, Syllogeus No. 55, 479 p.

Johnston, G.H. (ed.), 1981. Permafrost. Wiley, Toronto, 540 p.

Karrow, P.F. and Calkin, P.E. (eds.), 1985. Quaternary Evolution of the Great Lakes. Geol. Assoc. Can. Spec. Publ. 30.

Lauriol, B., 1982. Géomorphologie Quaternaire du sud de l'Ungava, Paléo-Québec, no. 15.

Legget, R.F. (ed.), 1976. Glacial Till. Royal Society of Canada Publication no. 12, 412 p.

MacPherson, A.G. and MacPherson, J.B. (eds.), 1981. The Natural Environment of Newfoundland Past and Present. Memorial University, St. Johns, 265 p.

Mahaney, W.C. (ed.), 1984. Quaternary Dating Methods, Elsevier, New York, 431 p.

-----------, (ed.), 1981. Quaternary Paleoclimate. Geo-Abstracts, 464 p.

----------, (ed.), 1976. Quaternary Stratigraphy of North America. Dowden, Hutchinson and Ross; Stroudsburg, Pennsylvannia, 512 p.

Hillaire-Marcel, C. and Vincent, J-S, 1980. Stratigraphie de l'Holocène et évolution des lignes de rivage au sudest de la baie d'Hudson, Canada. Paléo-Québec, no. 11.

McCann, S.B. (ed.), 1980. The Coastline of Canada. Geological Survey of Canada Paper 80-10, 439 p.

Menzies, J., 1984. Drumlins: a bibliography. Geobooks, Norwich, 136 p.

Mollard, J.D. and Janes, J.R., 1984. Air Photo Interpretation and the Canadian Landscape. Energy, Mines and Resources, Ottawa, 415 p.

Morisset, P. and Payette, S. (eds.), 1983. Tree-line ecology. Proceedings of the northern Québec Tree-Line Conference. University of Laval, Coll. Nordiques no. 47, 188 p.

North, M.E.A., 1976. A Plant Geography of Alberta. University of Alberta Studies in Geography, no. 2, 147 p.

Occhiette, S., 1980. La Quaternaire de la région de Trois-Rivière – Shawinigan, Québec. Paléo-Québec, no. 10.

Okuda, S., Netto, A., and Slaymaker, O. (eds.), 1983. Extensive Land Forming Events. Zeits. fur Geomorph. Supp. BD. 46, 163 p.

Paterson, W.S.B., 1981. The Physics of Glaciers. Pergamon, Oxford, 380 p.

Prest, V.K., 1983. Canada's Heritage of Glacial Features. Geological Survey of Canada, Miscellaneous Report 28.

Radforth, N.W. and Brawner, C.O., 1976. Muskeg and the Northern Environment in Canada. University of Toronto Press, Toronto, 399 p.

Richard, P. 1981. Paléohytogéographie post-glaciaire en Ungave par l'analyse pollinique. Paléo-Québec, no. 13.

Ritchie, J.C., 1984. Past and Present Vegetation of the Far Northwest of Canada. University of Toronto Press, Toronto, 251 p.

Rutter, N.W., (ed.) 1985. Dating Methods of Pleistocene Deposits and their Problems. Geoscience Canada Reprint Series [1]2, 87 p.

Slaymaker, O. (ed.) 1981. High Hountains. Zeits. fur Geomorph. Supp. BD 37, 147 p.

----------, Dunne, T. and Rapp, A. (eds.), 1980. Geomorphic Experiments on Hillslopes. Zeits. fur Geomorph. Supp. RD. 35, 194 p.

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Teller, J.T. and Clayton, L. (eds.), 1983. Glacial Lake Agassiz. Geological Association of Canada Paper 26, 451 p.

Tinkler, K.J., 1985. A Short History of Geomorphology. Croom Helm, Beckenham, 317 p.

Valentine, K.W.G., Sprout, P.N., Baker, T.E., and Larkulich, L.M., 1978. The Soil Landscapes of British Columbia, Resource Analysis Branch, Victoria, 197 p.

Vincent, J.S. and Dredge, L.A. (eds.), 1982. Numéro spécial en l'honneur du XIe congrès de l'INQUA. Géographie Physique et Quaternaire, vol. XXXVI (1-2), 250 p.

Williams, P.J., 1982. The Surface of the Earth. Longman, London, 212 p.

Energy, Mines and Resources Canada
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