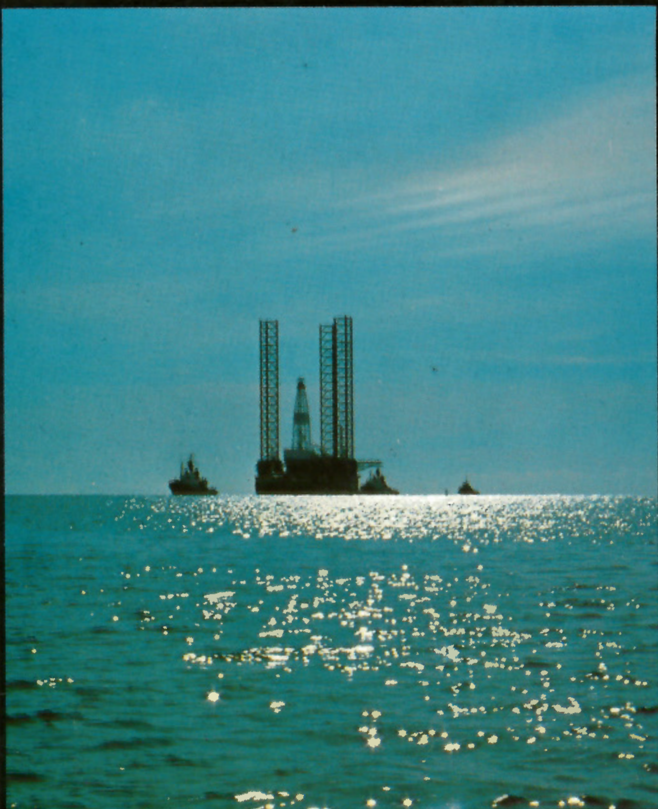
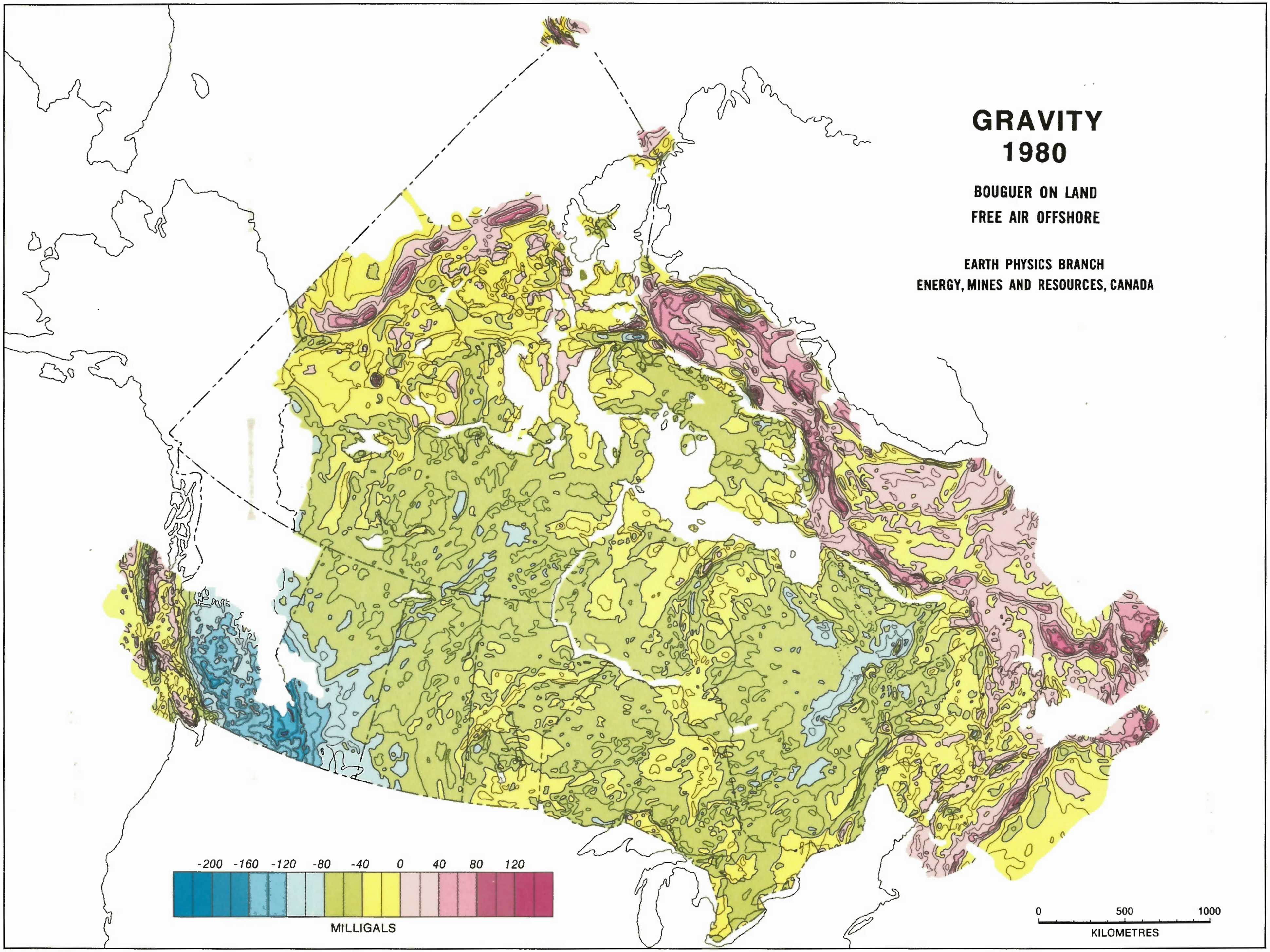


THE GEOSCIENCES
IN CANADA, 1980

# MARINE GEOSCIENCE IN CANADA; A STATUS REPORT

1983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GEOLOGICAL SURVEY
PAPER 81-6, PART 1

# THE GEOSCIENCES IN CANADA, 1980

## Part 1: Marine Geoscience in Canada; A Status Report

Prepared and Edited by

The Marine Geoscience Committee of the
Canadian Geoscience Council

Chairman: R.D. Johnson
Members: J.I. Clark, L.E. Johnson-Ibach, M.J. Keen,
G.E. Reinson and P.J. Savage

1983

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## Preface

Marine Geoscience in Canada involves members of most of the Canadian Geoscience Council's constituency. Starting with the Council's first report[1] (Geological Survey of Canada, Paper 75-6) each annual report has carried a brief commentary on the status of Canadian marine geoscience. Shortly after the Council was formed, Yves O. Fortier suggested that a review of the effort being made in the earth sciences offshore was needed. This need became increasingly apparent with each succeeding annual report, and in 1979 a Marine Geoscience Committee was formed with R.D. Johnson as Chairman and the work commenced which led to the present report.

This "status report" presents the geoscience community involvement in the marine areas of Canada. It provides some appreciation of the nature and distribution of the activities of scientists and engineers in government, university and industry, and draws attention to sectors of strength as well as weakness. The guiding purpose of the report is to gain insight into the present endeavour, capacity and outlook for marine geoscience in Canada.

In this report "marine geoscience" is not limited to geological oceanography, marine geotechnology and shallow geophysics but rather includes all of the earth sciences involved in research, evaluation and development of the offshore areas of Canada and the Great Lakes. The papers presented are from a wide spectrum of recognized workers in various fields and describe a large part of the current activities and those foreseen in the future in the marine geosciences in government, industry and university.

The Overview summarizes the status of marine geoscience in governments, universities and industry from papers in the body of the report. The Conclusions and Recommendations are those of the Committee. They arise in part from points made by individual contributors, in part from a consensus of several contributors, and in part from value judgments based on work experience and from assembling this report.

This report is the product of a volunteer effort. The Canadian Geoscience Council is therefore particularly grateful to the Committe and contributors for providing a scan of information from which its Marine Geoscience Committee can take steps to remedy differences, fill gaps and generally improve the status of the Marine Geosciences in Canada.

*J.O. Wheeler*, President
*D.W. Strangway*, Past President

December, 1981

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# 1. OVERVIEW, CONCLUSIONS AND RECOMMENDATIONS

This report has been prepared by the Marine Geoscience Committee for the Canadian Geoscience Council. It is a status report of the present activities and foreseeable future of marine geoscience in Canada as perceived in governments, universities and industry. Marine geoscience is taken to include all the diverse activities of all the geosciences as they are practised in, or pertain to, the different marine areas of Canada. Major points from each of the papers are summarized in the overview. Conclusions and recommendations presented are those of the Committee, based on points made in the various papers, and opinions formed in the process of assembling this report.

## OVERVIEW

The report is presented in four sections: Introduction; Government, including federal, provincial and international aspects; University; and Industry.

In the Introduction, G.E. Reinson describes the physical setting in which the marine geosciences operate. Canada's offshore domain encompasses a vast region, half the size of our land area. Much of this region is covered by hostile ice-infested waters. M.J. Keen discusses the development of the marine geosciences in Canada and comments on our successes, limitations and outlook for the future. G.E. Reinson describes the relatively high level of activity in the coastal regimes during the past decade and comments on the reasons for this increased activity. The level of future marine geoscience activity in Canada will be influenced by present domestic and international disputes over sovereignty and authority, described by Rowland Harrison. Resolution of these disputes will affect both the size of Canada's marine offshore area and the intensity of future development of offshore resources. A.E. Pallister foresees that in the decade ahead, marine geoscience will be driven and dominated by the search for petroleum.

In the Government section, M.J. Keen presents a unique summary of how and why various sectors of the Federal Government are involved in the marine geosciences. Marine geoscience programs are funded by Parliament and involve complex relationships between departments, agencies, sectors, branches, etc. The number and diversity of activities and achievements by the Federal Government indicate that interdepartmental co-operation has generally been highly successful. Keen paints a picture of a federal organization reasonably well attuned to the demands of our marine environment but which suffers from lack of equipment and staff with which to do the research which is and will be needed. M.J. Keen's comment that we are entering the 80s with ships that were adequate for the early 60s is succinct. Despite the significant accomplishments by federal agencies in their traditional role of mapping and understanding the geological environment of Canada's vast offshore, an immense amount remains to be done. C.P. Lewis believes this is particularly true for the north. Keen indicates that while the Federal Government currently spends $15 million annually on programs directly involving marine geoscience, this support is already thinly spread over the broad array of marine geoscience programs involving many federal agencies. In a separate paper on the Federal Environmental Assessment Review Process (EARP), Keen stresses that there is also an increasing load of resource and environmental assessment being required of federal organizations originally designed to obtain baseline information and undertake research. Keen concludes that without additional funding, staff and equipment, this increased load will result in a serious dilution of research capability, and reduced acquisition of baseline data by the Federal Government.

The Harrison and Townsend-Gault paper on the current domestic and international dispute over the boundaries and jurisdiction of Canada's continental margin highlights the achievements of the Federal Government in marine geoscience in the light of conflict and uncertainty. Resolution of the Law of the Sea negotiations is likely to further increase Canada's responsibility over the offshore. Petroleum resource development in particular is seen as an impetus to the resolution of domestic conflicts regarding sovereignty and authority over offshore resources in the coming decade.

Two papers consider Canada's role in international marine geosciences. The first, by C.E. Keen, D.J.W. Piper and M.J. Keen, briefly outlines Canadian participation in several projects, while the second "international" paper by M.J. Keen outlines Canada's proposed involvement in "The Deep Sea Drilling Project". To date our financial participation in international projects has been miniscule. Both papers stress the benefits to Canada of continued and increased participation in international projects.

R.D. Johnson's survey of various provincial government contributions indicates that provincial involvement in marine geoscience is small and predominantly oriented to the support of university programs and some research projects, as well as limited shoreline work. Johnson indicates that maritime provinces may increase their participation in marine geoscience should there be a legal resolution of provincial right to offshore resources.

The University section provides insight from a number of contributors across Canada. These authors outline the centres where marine geosciences are being taught, levels of funding, areas of research and numbers of graduates. The expenditure by universities in marine geoscience is about $2 million per year. The principal universities involved in the marine geosciences are Dalhousie, the University of British Columbia, McGill and the University of Quebec at Rimouski. In general, universities have traditionally stressed the coastal geosciences (particularly geomorphology, sedimentology and environmental shoreline mapping) relative to other areas of marine geoscience; McMaster University in Ontario is one of several recognized centres for work in coastal regimes. The Committee notes two particular institutional shortcomings: there is no centre in Canadian universities with an outstanding international reputation in marine geoscience, and there is no recognized centre for marine engineering and geotechnology.

University research has provided major contributions to the understanding of our offshore areas, however, most papers indicate that universities are limited by a perennial "lack of adequate funding" and "lack of ship time". Both of these are seen as severely limiting the institutions in their ability to meet their mandate. The present lack of post-graduate candidates, particularly Canadian nationals, is also viewed as a major problem to future expansion of the Canadian marine geoscience community.

Papers in the Industry section indicate that by far the greatest expenditure of money and scientific effort in Canada's offshore areas has been directed toward the search for petroleum. K.P. Appleton states that currently one-fifth of the world's known reserves are in offshore fields, and that this fact supports the philosophy that the offshore areas justify the high risk and huge amounts of capital expenditure required for exploration. Recent petroleum discoveries at Hibernia off the east coast and in the Beaufort Sea appear to support this view.

The petroleum industry is seen as the driving mechanism for greatly increased activity in the geosciences. Papers by Appleton, Roth, and Meneley and Rayer, provide an extensive review of the barebone facts of money spent, holes drilled and kilometres of seismic "shot", then describe the range of technical requirements foreseen for the next two decades. The total effort in terms of capital and expertise is awesome compared with federal expenditures on research and regulation. Appleton's figures indicate that in 1979, industry spent some $400 million in seismic and drilling compared to federal program expenditures of $15 million per year indicated by Keen. Meneley and Rayer stress that, since Canada faces unique problems due to ice-infested waters, marine geotechnical skills are urgently required to develop new cold water technology.

The Committee notes that the petroleum industry has spent over $3 billion to date in seismic and drilling, and roughly one third each has been spent in the Great Lakes, East Coast and Beaufort Sea. There is no figure as to the professional component, but the conceptualization, planning and execution of these enterprises depends heavily on geological, geophysical and engineering skills. The Committee agrees with the conclusions of Meneley and Rayer. The immediate future demand for marine geoscience in Canada will be closely linked with the escalating demands of petroleum offshore exploration and exploitation. Less visible factors, however, including mineral shortages, environmental problems (including climate), technology, human rights, and disparity between nations, will also contribute to the demand.

Mining, dredging and the outlook for exploration other than in hydrocarbons are discussed in two papers by D. Pasho. Pasho foresees only a modest increase in the demand for marine geoscience expertise in this sector, with the exception of a marked increase in demands related to dredging associated with petroleum activity. In particular, dredging in the Arctic will require special large-capacity equipment to meet the deadlines imposed by the short ice-free working period. Pasho also foresees increased mining of sand and gravel in response to local shortages on shore. Pasho notes that placer mining may also develop as baseline inventory programs by federal agencies lead to delineation of areas of interest.

The general grouping of contracting and consulting includes papers on airborne geophysics, activities in cold regions and, on the West Coast, engineering design and the Seabed Project.

Canada has for many years been one of the world leaders in the airborne geophysics industry. N.R. Paterson reports that large areas of Canada's continental shelf were surveyed in the late 1960s and early 1970s. These data have been particularly useful in the broad geological interpretation of these areas and have played a significant part in the start-up phase of petroleum exploration. Paterson reports that very little work is being done at present. However, advances in both instrumentation and interpretative techniques, coupled with improved navigation, should lead to renewed interest. Paterson feels that these factors, when linked with access problems of conventional methods, particularly in the Arctic, give every indication that activity will increase in this field.

Two other papers give some insight into the effort and outlook for consulting and contracting in general. MacDonald considers marine geoscience contracting to be in decline on the west coast, and Clark evaluates the level of research and development for cold water projects as being extremely small. In a second paper, Clark emphasizes the importance of research and development in acquiring expertise in geotechnology for engineering and design consideration. An important reference for this paper is the recent report of the Task Force on Marine Geotechnology in Canada to the NRC Associate Committee on Geotechnical Research. The level of marine geotechnical activity is anticipated to increase greatly in response to the needs of the petroleum industry for offshore engineering design and construction.

An account of the "Seabed Project" by R.W. Hutchins is included under the Industry section since this project was generated by industry as an unsolicited proposal to government. It represents a unique technical development and involves the co-operation and co-ordination of scientists in government, university and industry.

## CONCLUSIONS AND RECOMMENDATIONS

Based on their assessment of the contents of the papers and the experience in the preparation of this report, the Committee offers the following observations and conclusions on the status of marine geoscience in Canada.

The rationale that establishes a national need to map and inventory resources onshore, and to protect the environment, applies equally to the regions Canada claims offshore. There is also a need to be a participant in global aspects of marine geoscience, and in the international assessment of deep sea resources, for national gain, as well as for the economic and political aspects of international association. The exploration and exploitation of hydrocarbon resources on the continental shelf and slope in particular, is seen as the main force driving the demand for marine geosciences expertise in the next decade. Canada needs to develop appropriate technologies and sufficient expertise so it can meet the anticipated demands for offshore development and associated environmental protection. Failure to do so will leave few alternatives to the importation of high levels of expertise. If this importation occurs, Canada will have lost the opportunity to develop the talent and experience necessary to serve its own needs, as well as the capacity to develop talent for export to developing nations.

Government agencies such as the Geological Survey of Canada, Earth Physics Branch and the Canadian Hydrographic Service are direct contributors to the GNP because they provide services directly related to exploration and exploitation. Their substantial contribution to date indicates that the efforts of these departments should not be reduced on account of general fiscal constraint at a time when resource and environmental assessment are being added to the traditional governmental roles of inventory and research. The current level of federal and provincial funding (approximately $25 million) for exercising stewardship over marine resources may appear substantial; when analyzed in terms of the number of required activities, however, it is obvious that the funds available are far too few for such diverse requirements. The Federal Government needs to construct an adequate fleet for scientific work in Canadian waters, raise the quality of instrumentation available for research, and increase the capacity of the government to meet increasing demands for data aquisition, research and regulation of offshore lands.

Canadian universities also lack funding, shiptime and equipment. There is no university institute in Canada comparable to Lamont-Doherty Geological Observatory, Woods Hole Oceanographic Institution or Scripp's Institution of Oceanography. Although joint activities by universities and federal institutes are an attempt to fill this gap, difficulties arise since the primary functions of the two groups are different. Further, there is no university in Canada adequately addressing marine engineering geotechnology. Without substantial university involvement, marine geoscience will be unable to meet anticipated demands for research and expertise, particularly in the applied areas of resource development.

Industry's demand for marine geoscience is anticipated to escalate in the coming decade, particularly with respect to petroleum resource development. Increasingly higher levels of expertise and research are required. Industry will be unable to meet its own needs without the development of specialized industries (i.e. marine geotechnical). These specialized industries will not be available when needed if they do not receive support from industry and government immediately. This is especially true where the trend is one of decline. Federal support by "contracting-out" should not be limited to providing second-level "laboratory and field" services to government scientists, as is partly the case at present. It must also include senior interpretive services if Canadian science and engineering contract industries are to develop in time to meet national demands for offshore resource development.

There are many critical challenges and opportunities facing the Canadian marine geoscience community. The Committee has identified some of these:

A. The federal government can expect to face new challenges and opportunities with regard to maintaining and further developing the requisite technical facilities and professional manpower that it will require to expand the marine geoscience data base, increase the scope and depth of research activities, and to foster and regulate offshore resource development and environmental protection:

   1. Rising fuel costs make it impossible to even maintain past levels of utilization of research vessels without large increases in financial allocations for the operations of these research vessels.

   2. The existing fleet of research vessels was designed to meet the challenges of the 1960s and 1970s. It cannot be expected to serve the expanded demands and new technological opportunities of the 1980s and 1990s.

   3. New technological developments such as deep marine multichannel seismic systems, long range sidescan instruments, hydraulic piston coring devices, and deep-towed instrumental facilities offer the prospect of much more thorough and rapid investigations in the offshore realm, but require significant commitments of financial resources.

   4. Marine geoscience activities in the Federal Government are dispersed through many agencies, departments, sections, branches and divisions. Although the present efforts to co-ordinate are to be commended, effective communications, co-operation and integration such as might be fostered by an Interdepartmental Committee on Marine Geoscience, may offer possibility of more economic use of facilities and personnel.

B. Increased industrial activity in the offshore regions of Canada, associated with resource development and transportation will create an increased demand, in Canada, for marine geoscience and geotechnical services from industry. This will present special challenges and opportunities for the development of a strong and effective marine geoscience and geotechnical research and service industry in Canada; but special efforts on the part of federal and provincial governments, industry and the universities will be necessary to provide the environment in which such a strong Canadian marine service industry will develop quickly enough to meet the anticipated growth in demand.

C. The problem of meeting the anticipated growth in demand for professional expertise in marine geoscience and geotechnology represents a special challenge for the federal and provincial governments, and for industry as well as for the Canadian universities. If this demand is to be met by Canadian universities, they will have to take new initiatives in developing the appropriate academic and research facilities, and will require support from industry and the federal and provincial governments in pursuing these initiatives. Industry and universities may need to co-operate in developing research programs, and in encouraging postgraduate work in marine geoscience and geotechnical studies.

The Committee is unanimous in recognizing these as some of the more important problems that require thorough investigation and prompt action. Recognizing this need, and the general need for better communication, co-operation and collective action among the various groups involved in Canadian marine geoscience and geotechnology activities, the Committee recommends that the Canadian Geoscience Council establish a standing committee on marine geoscience. The Committee on Marine Geoscience should be responsible for monitoring the current developments and future requirements in Canada in marine geoscience. Its first task should be an investigation of the problems identified in the 1980 report.

The Committee should include twelve to fifteen members drawing approximately equal numbers from:

1. The Federal Government, including various agencies but with at least one member common to the proposed Interdepartmental Committee on Marine Geoscience;

2. The provincial governments, with at least one from each of the western, central and Atlantic regions;

3. The universities, including representatives from separate universities in different regions and preferably of different disciplines;

4. Industry, members at large and from recognized industry groups e.g. Arctic Petroleum Operators Association (APOA), Eastcoast Petroleum Operators Association (EPOA), Canadian Petroleum Association (CPA), and Independent Petroleum Association of Canada (IPAC).

The chairmanship should be rotated among the four sectors of Canadian marine geoscience that are represented in the Committee. Members of the Committee should, but need not, come from the societies and associations within the CGC. The qualifications of candidates and the distribution requirements for members of the committee, should be given highest priority. At least two members of the proposed CGC Committee on Marine Geoscience should be members of the Canadian Committee on Oceanography, in order to provide formal liaison with the Canadian Committee on Oceanography.

Implementation of this recommendation will facilitate dialogue between scientists in government, university and industry, and promote greater recognition of each other's problems, capabilities and resources. It will increase the public profile of marine geoscience in Canada. Most important, it will provide the Canadian Geoscience Council with a mechanism for preparing and presenting well-documented arguments to aid the marine geoscience community in meeting the demands of the coming decade. The result will be a stronger, integrated and co-ordinated effort of marine geoscience in Canada toward the advancement of science and the benefit of the nation.

# 2. INTRODUCTION

This report is an account of the current status of the Canadian geosciences in the marine areas of Canada with an emphasis on future requirements. It is not a technical report but rather concerns itself with an overview of the distribution, magnitude and type of activities in the marine geosciences as practised across Canada by government, university and industry sectors.

The involvement of the geosciences in the Canadian offshore and in the ocean basins has been slowly growing over the past three decades. What was originally the preserve of individual scientific enquiry became a matter of national necessity because of the need to establish sovereignty and to map, inventory, and regulate in the national interest. Canada developed a small but excellent coterie of marine geoscientists within its civil service and universities. For the past two decades the petroleum industry has explored the continental shelf off Canada. This activity has involved a large number of scientists and engineers directly employed by industry. Requests by industry for related government services and the need to regulate the increased activity has caused government organizations to grow. Universities have been asked to undertake research particularly directed at the solution of operational problems. With the recent discoveries of commercial hydrocarbon reserves, there is a surge of interest in the marine geosciences arising from increased exploration as well as from offshore development requiring exploitation technology. This report provides insight into the present status of the marine geosciences as perceived in government, university and industry sectors, and the future requirements of these sciences.

The report is presented in three main sections: Government, University, and Industry, preceded by an introductory section on the physical setting, sovereignty, past activity and outlook.

In this brief introduction, G.E. Reinson gives some simple statistics that should be kept in mind while considering the statements of all the other authors: Canada has the longest coastline of any nation; the marine area is about half the size of the land area; nearly half the marine area is under semi-enclosed waters; of these huge areas, ninety per cent lie under ice-infested water. The enormous extent of the area and length of coastline and the requirement to understand and operate in ice-infested waters are dominant factors which challenge the skills and capacities of the earth sciences. Reinson, now a consultant, has had extensive experience with the Federal Government on coastal and surficial marine problems.

M.J. Keen provides a personal view of the accomplishments of the marine geoscientists in Canada. Keen traces the productive effort of small groups of people: the beginnings of scattered work in the 20s and 30s, the development of academic institutions of the 40s and 50s, the increasing scope of government projects of the 60s and 70s and the mushrooming efforts of oil exploration from the 50s to our current success. He considers Canadian contributions to knowledge of global tectonics, ocean basins, and continental margins, and particularly to the geology of our own shelf and slope where truly significant advances in interpretation have been made in all three ocean areas. Keen touches on our contribution to knowledge of coastal regimes and environmental protection and cites noteworthy examples of advances in instrumentation including the early use of on-board computers, satellite navigation in scientific work, development of a rock core-drill, and use of the submersible **Pisces IV** for geological mapping. Factors which limited, or detracted from the national development of marine geosciences are noted, including the lack of resolution of political questions of ownership, the too frequent changes of departmental authority, the need for coherent policy on national and international aspects, and the need for more money and more people. Above all, Keen provides a sense of timing: although the marine geosciences are young in Canada, we have made good starts and done good work; we have found a lot of oil; and we have created the mechanisms to protect the environment. Central to the final recommendation of this status report, he shows how scattered the works are, how new the institutions, and how impermanent the regulations have been.

G.E. Reinson briefly outlines the present relatively high level of coastal geoscience activity in Canada, and touches on the reasons for the increased interest in the coastal zone. It is noteworthy that Canada's coastal workers from university, government and private sectors began to co-ordinate and organize their efforts during the late 1970s. Reinson feels such co-operation and dialogue is essential in order to maintain the present level of coastal geoscience in the future.

R.J. Harrison discusses the current status of the sovereignty and authority under which Canada's offshore areas will be mapped, inventoried and regulated, as well as explored and exploited. Jurisdiction over the continental margins of Canada is in the process of emerging from domestic uncertainty and international conflict. Domestically, this is largely due to oil discoveries off Newfoundland and, internationally, to the Law of the Sea Conference being close to agreement. If the outer limit increases, there will be an increased demand on marine geoscience for baseline data necessary to manage both the living and non-living resources of this vast region. At the same time, resolution of domestic uncertainties regarding offshore petroleum resource rights will affect exploration and the demand for research and expertise in the applied areas of marine geoscience. Harrison is Executive Director of the Canadian Institute of Resource Law and an authority on Canadian involvement with the Law of Sea conferences.

A.E. Pallister has been active in marine affairs as a geophysicist, a senior executive and as a member and officer of the Science Council of Canada. He was active as a principal founder of C-CORE (the Centre for Cold Ocean Resources Engineering) at "Memorial". In his outlook paper Pallister's attention is totally concerned with the role of the marine geosciences in the next decade in the search and exploitation of hydrocarbons in Canada's offshore areas. Pallister believes that petroleum activities will be the major impetus dominating marine geoscience in Canada for the next decade. The manner and extent of this involvement is developed further in the Industry section of this report.

## CANADA'S MARINE AREAS – G.E. Reinson

The immensity of Canada's marine regions (Fig. 2.1) can be put into perspective when we consider the following facts. Canada has a longer coastline (Table 2.1) than any other country in the world (nearly 250 000 km). The area of her continental shelves is about 1 354 000 km$^2$, and of her

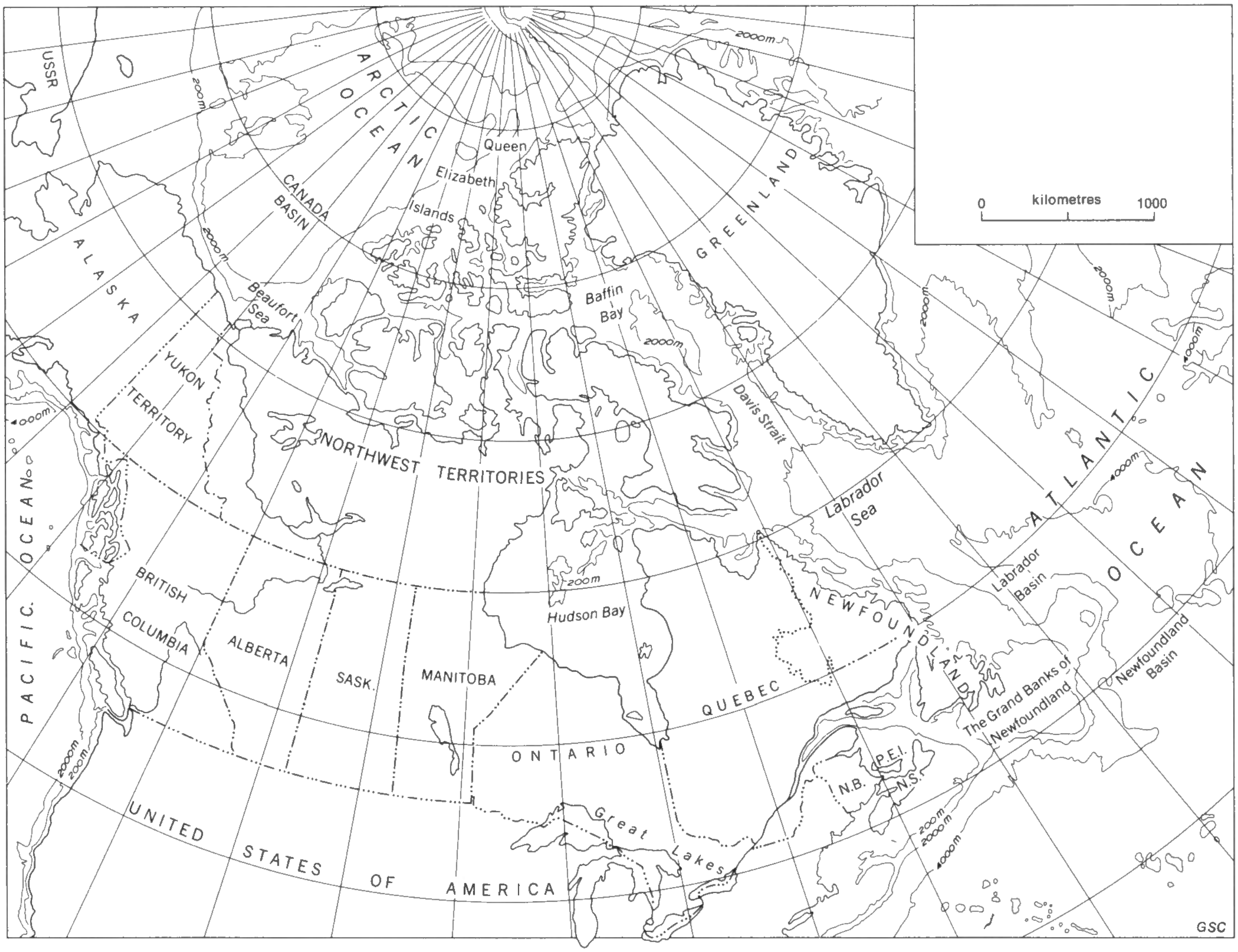



*Figure 2.1.* *Oceanic regions adjacent to Canada (based on Chart 800, 1971, of Canadian Hydrographic Service).*

continental slopes, some 1 457 000 $km^2$ (Table 2.2). Some 2 220 000 $km^2$ of enclosed marine waters (e.g. Gulf of St. Lawrence, Hudson Bay, Hudson Strait, Arctic Archipelago) are confined within the extremities of Canada's land areas: this is roughly the same as the combined areas of British Columbia, Alberta and Saskatchewan. Canada's total submarine area including shelf, slope and enclosed marine waters is 5 031 000 $km^2$; this figure is equivalent to more than 50 per cent of the total land area of Canada.

Canada's marine area is divisible into three main geographical regions, the Pacific, Atlantic and Arctic continental margins. Each of these regions displays distinct physical characteristics which are controlled by a combination of geological, climatic, and oceanographic factors. In addition to her marine regions, Canada is blessed with the Great Lakes system, the largest surface area of freshwater (245 000 $km^2$) in the world.[8] The Great Lakes system, with an estimated coastline length of 15 000 km on the Canadian side and with water depths attaining 400 m[8], presents similar technological and scientific challenges as Canada's ocean regions, and thus should be included within the realm of "marine" geoscience activity in Canada.

### *Pacific Margin*

The Pacific continental margin (Fig. 2.2) adjacent to British Columbia, lies at the boundary between the Pacific and American tectonic plates.[8] This setting is reflected in the morphology and geology of the coast and adjacent shelf and slope. The coastline is structurally controlled and dominated by mountains and fiords. The abundance of inlets, fiords and islands give the coastline a generally rugged and irregular character, the exception being the small coastal plain of the Fraser River delta. The continental shelf is narrow and drops sharply to oceanic depths along a line that parallels the Vancouver Island-Queen Charlotte Islands headlands. West of Queen Charlotte Islands the shelf edge is only 6.4 km to seaward, where it abruptly descends to a depth of more than 1000 metres. Off Vancouver Island the shelf edge lies some 32 km to seaward, having a maximum width of 80 km at the entrance to Juan de Fuca Strait.

Mean tidal ranges on the Pacific coast vary from 2 to 5 m.[3] On exposed coasts the wave climate is a high-energy swell-wave environment with offshore wave heights greater than 1.5 m during 40 to 50 per cent of the year, and greater than 3.0 m during 30 per cent of the year.[8] Sea and shorefast ice are virtually absent along the Pacific margin, except at the head of embayments and fiords where minor ice accumulations may often occur during winter months.

### *Atlantic Margin*

Canada's Atlantic marine region (Fig. 2.3) extends from the United States border to Cape Chidley in northern Labrador. The Atlantic continental margin is tectonically stable, relative to the Pacific margin, and lies on the trailing-edge of the continent.[7] Thus the Atlantic margin is relatively broad and expansive, having been influenced more by Pleistocene glaciation, and by Mesozoic and Quaternary sedimentary processes, than by purely tectonic controls. The Atlantic coastline is some 45 370 km in length (Table 2.1) and is dominated by low relief glaciated rocky shorelines with numerous structurally controlled bays and estuaries. Exceptions to this general coastline physiography are northern Labrador, which is a mountainous fiord coast; the semienclosed gulf of St. Lawrence lying adjacent to the Maritime coastal plain, which features many sandy barrier-beach shorelines, and the Bay of Fundy coast, which is dominated by broad intertidal sand or mud flats.

The Atlantic continental shelf is generally less than 200 m deep with a low gradient of 1:1000, and is divisible into three regions: Scotian Shelf, Grand Banks, and Labrador Shelf.[1] The Scotian Shelf averages 200 km in width, with a discontinuous series of dissected submarine banks (40 to 120 m below sea level) extending along the outer edge. The Laurentian Channel separates the Scotian Shelf from the Grand Banks, lying east and northeast of Newfoundland. The Grand Banks range up to 480 km wide and 725 km long. Northeast of Newfoundland, relief on the bank is 100 to 200 metres and the shelf break lies at an abnormal depth of 300 m. The southern part of the Labrador Shelf is up to 640 km wide, and is characterized by an undulating surface ranging from 80 to 250 m deep. The northern part of the Labrador Shelf is only about 120 km in width and at the 250 m isobath slopes rapidly to oceanic depths. The northern Labrador Shelf is characterized by a series of broad shallow banks (80 m) which are separated from the coast by a marginal channel which attains water depths of 250 m or more.

**Table 2.1.** Canada's coastline measurements (km)[4 8]

| | | | |
|---|---|---|---|
| PACIFIC COAST | | 25 717 | (10.5%) |
| Vancouver Island | 3 496 | | |
| Queen Charlotte Islands | 2 623 | | |
| ARCTIC COAST | | 172 950 | (70.9%) |
| Queen Elizabeth Islands | 34 259 | | |
| Hudson Bay | 13 348 | | |
| Baffin Island | 28 302 | | |
| Ellesmere Island | 10 747 | | |
| Victoria Island | 7 089 | | |
| Devon Island | 3 588 | | |
| Melville Island | 3 107 | | |
| Axel Heiberg Island | 3 060 | | |
| Prince of Wales Island | 2 576 | | |
| ATLANTIC COAST | | 45 369 | (18.6%) |
| Bay of Fundy | 1 413 | | |
| Gulf of St. Lawrence | 7 496 | | |
| Newfoundland (not including Labrador) | 13 656 | | |
| Cape Breton Island | 1 883 | | |
| Prince Edward Island | 1 260 | | |
| | TOTAL: | 244 036 km | |
| Coastline north of the Arctic Circle | | 110 863 | (45.4%) |
| Total mainland coastline | | 58 497 | (24 %) |
| Total island coastline | | 185 539 | (76 %) |

There is a large variation in tidal range within the Atlantic coastal region.[3] The mean range of 8 m in northern Labrador decreases to 1 to 2 m along the outer coast of Newfoundland and Labrador. The Gulf of St. Lawrence has a tidal range of less than 2 m, the St. Lawrence estuary of from 2.3 to 4 m at Quebec City, and the Bay of Fundy from 5 to 12 m in its upper reaches. The Atlantic coastal region is a storm-wave environment with offshore wave heights greater than 1.5 m during 40 to 50 per cent of the year.[8] Pack and nearshore sea ice occur during the winter months over most of the Atlantic nearshore region except off southern Nova Scotia.[2 3 8] Sea ice becomes more prevalent northward; for example the nearshore zone is ice-fast for up to 4 months each year in the Gulf of St. Lawrence and for up to 7 months each year in central Labrador. Icebergs are present throughout the year off Labrador and northern Newfoundland; these icebergs originate in the Baffin Bay – Greenland region, and traverse southward with the Labrador Current.

### *Arctic Margin*

The Arctic marine region (Fig. 2.4) extends from Hudson Strait northward through Davis Strait and Baffin Bay and then westward to the Yukon-Alaska border. Included within the Arctic marine realm is a vast expanse of enclosed marine waters such as Hudson and James bays and the interisland areas of the Arctic Archipelago. The Arctic coastline measures some 172 950 km, almost 71 per cent of the total coastline length of Canada (Table 2.1). The Arctic coastline is characterized by a variety of shorelines ranging from low relief, accretional unconsolidated coasts (e.g., Mackenzie Delta), through low relief rocky coasts (e.g., Somerset and Victoria islands), to mountainous fiord coasts (e.g., northeast Baffin Island). This coastline variation is related directly to geological features, as are the morphological features displayed by adjacent submarine margins. The Arctic Coastal Plain includes the terrain bordering the Arctic Ocean from Meighen Island to Alaska, and extends below sea level to merge with the Arctic continental shelf.[1] North of the Queen Elizabeth Islands the shelf is some 130 to 190 km wide, with a near planar surface which slopes gently seaward at about 2.3 m per km. The interisland channels merge with the shelf to a depth of 450 m and at the 750 m isobath the shelf edge breaks sharply to form a smooth but relatively steep continental slope. North of the mainland the Arctic continental shelf is shallower, with the coastal plain extending at the same slope beneath sea level to a depth of only 100 m some 80 km from shore. At this point the shelf breaks rapidly away to form an irregular, dissected continental slope which drops steeply to ocean depths beneath the

**Table 2.2.** Area of principal physiographic elements of Canada's continental margins ($km^2$)[5]

| | CONTINENTAL SHELF | CONTINENTAL SLOPE | ENCLOSED MARINE WATERS |
|---|---|---|---|
| ATLANTIC | 906 000 | 446 000 | 232 000 |
| ARCTIC | 347 000 | 950 000 | 1 988 000 |
| PACIFIC | 101 000 | 41 000 | -- |
| TOTAL | 1 354 000 | 1 457 000 | 2 220 000 |

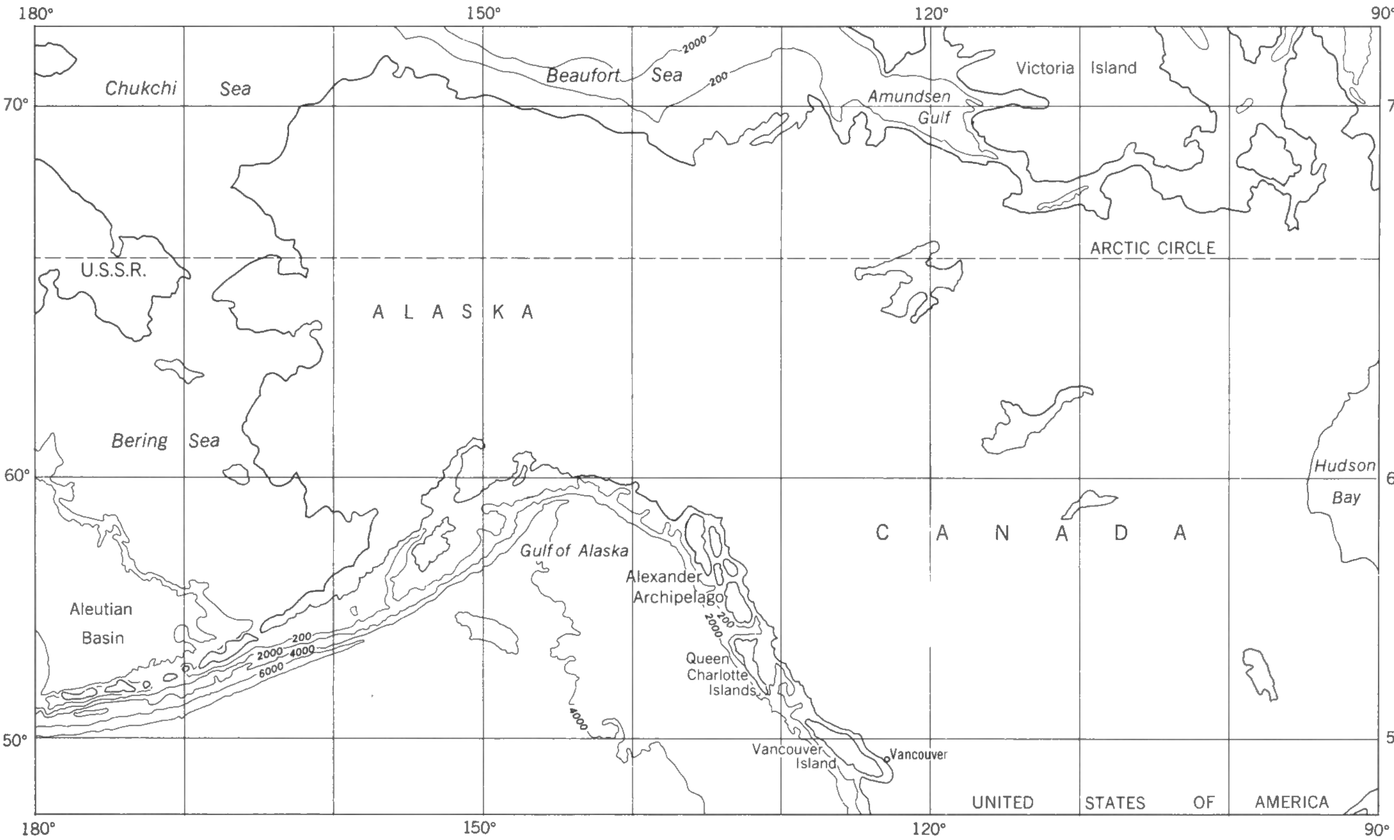



*Figure 2.2.* Oceanic regions adjacent to western Canada (based on General Bathymetric Chart of the Oceans (GEBCO) Number 5.03, 1979).

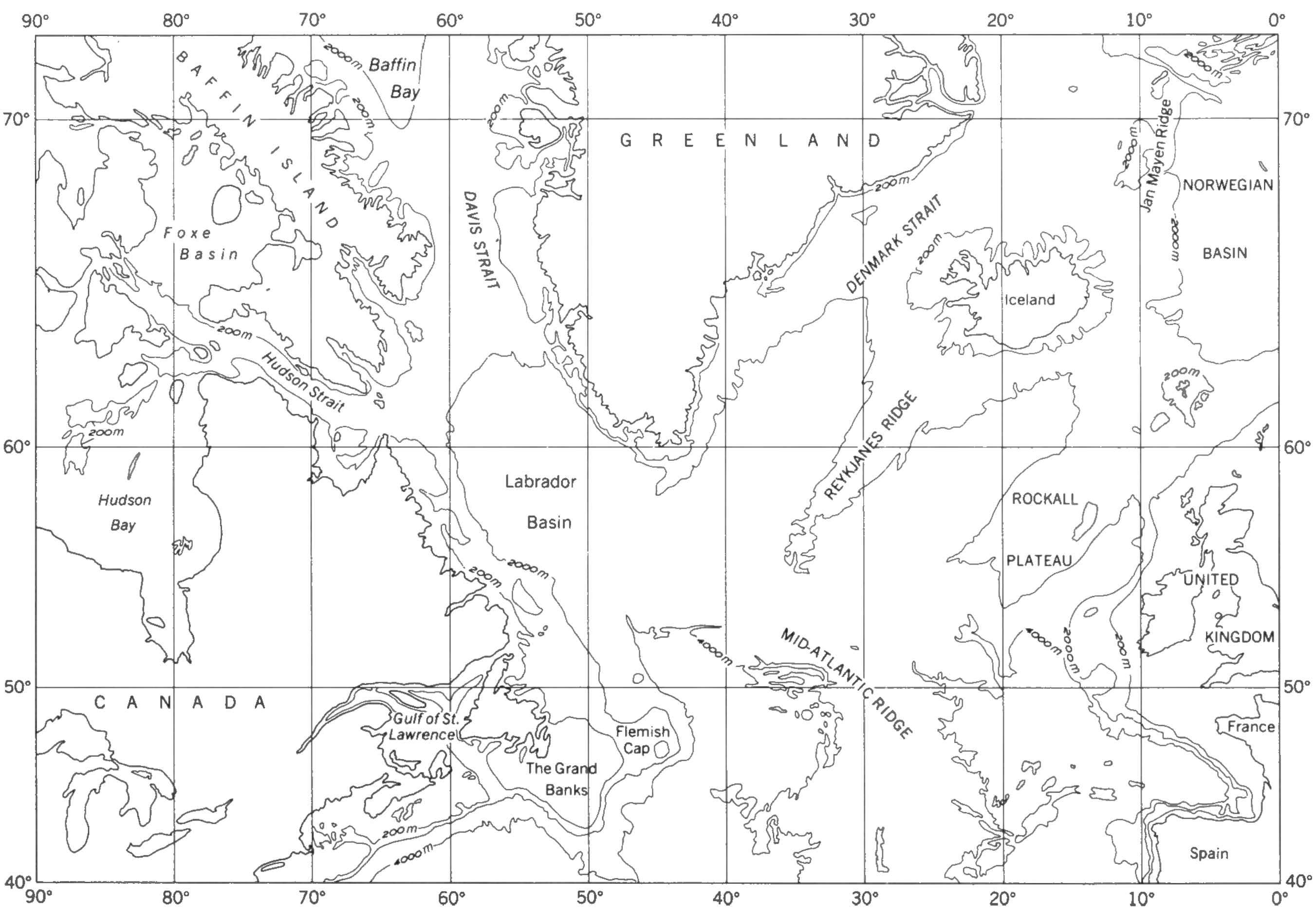



*Figure 2.3.* Oceanic regions adjacent to eastern Canada (based on General Bathymetric Chart of the Oceans (GEBCO) Numbers 5.04 and 5.08, 1979).


*Figure 2.4.* *Oceanic regions adjacent to northern Canada (based on General Bathymetric Chart of the Oceans (GEBCO) Number 5.17, 1979).*

Beaufort Sea.[1] The submarine area beneath Davis Strait, off eastern Baffin Island, displays a broad sloping shelf which reaches a depth of 600 m some 160 km offshore, at which point the sea floor slopes steeply southeastward to depths of 3000 m. Along the northeast coast of Baffin Island, the shelf is extremely narrow (less than 30 km) with a sinuous rim at the 200 m isobath, which then slopes off abruptly into the 2000 m deep Baffin Bay Basin.[1]

Mean tidal ranges vary from 7.3 m at Frobisher Bay and 3.4 m in Hudson Bay, in the southeast part of the Arctic marine region, to less than 0.5 m at Tuktoyaktuk along the shorelines of the Arctic Coastal Plain.[2 3 8] The wave climate is generally one of very low wave energy because of the short fetches and the extremely short open water period. The most prominent feature of the Arctic marine region is the persistent presence of sea and shorefast ice which nullifies wave generation and littoral processes for much of the time. In winter and spring there is solid ice cover over all of the waters in the Archipelago, and a three-fourths cover over Lancaster Sound, Baffin Bay, Hudson Strait and Hudson Bay. In the Queen Elizabeth Islands and the adjacent Arctic continental shelf, there is no open water season at all in some years.[8]

*Great Lakes*

The Great Lakes straddle the Precambrian Shield and the St. Lawrence Platform borderland, their basins having been formed by the scouring action of Pleistocene glacial events.[1] The coastlines of the Great Lakes are dominated by low relief (<20 m), rocky or cliffed coasts, and in lakes Erie and Ontario, cliffs cut into unconsolidated glacial deposits have provided material for beach development along the north shores.[8] The Great Lakes are tideless, but large enough to experience a low energy wave climate, with wave heights attaining 1.5 m for 20 to 30 per cent of the open water period. Ice occurs on the lakes for a period of 3 to 4 months each year, but rarely are the lakes completely frozen over.[8]

Most of Canada's coastline lies in the Arctic or Subarctic and most of her marginal marine areas are ice-covered or ice-infested for at least part of each year. In addition, 44 per cent of her marine waters lie within the Arctic Archipelago and large semi-enclosed bays and straits. These two factors, the persistent presence of ice, and the existence of much of the marine realm within the extremities of Canada's land areas, present special challenges in achieving the technological and scientific expertise needed to conduct successful exploration and exploitation programs in Canada's marine regions.

Specific challenges already clear to Canadians are the exploitation and production of liquid hydrocarbons from the Grand Banks Hibernia field and Beaufort Sea, and production and transport of high Arctic natural gas, without creating potential environmental and economic disasters to Canada's renewable marine resources. The extension of the fisheries jurisdiction to a 200-mile limit on January 1, 1977, makes it imperative, both from a domestic and an international viewpoint, that Canada increase its resolve to achieve optimum expertise in marine geoscience activity.

## THE EARTH SCIENCES AT SEA: SOME OBSERVATIONS ON CANADIAN ACCOMPLISHMENTS – M.J. Keen

The success of Hibernia P-15 in 1979 was a dramatic consequence of the explosion of our knowledge of the Canadian offshore and adjacent ocean basins in the last twenty-five years. The explosion began in the late 1950s; work before that time had been rather sporadic.

Studies of modern marine invertebrates, some undertaken in connection with investigations of the Pleistocene, were carried out as early as 1835.[136] In the nineteenth and early twentieth centuries, American scientists studied material which had been recovered by fishermen or which they had dredged themselves and concluded that Tertiary and Cretaceous sedimentary rocks occur from Newfoundland to Florida.[19 118 126 127] Sedimentation in the Fraser River Delta was investigated in 1921 in connection with improvements that were needed for navigation, and these studies showed as a byproduct that the average range of seaward advance of the delta had been about 3 m per years in the preceding sixty years.[54] A glacial origin for the Laurentian Channel was put forward in 1931,[111] and the bathymetry and the characteristics of sediment samples from the Labrador Sea and Baffin Bay were described in 1932 as a result of the U.S. Coastguard's "Marion" expedition.[104] A recent account of the breakthrough by the Horton River into Franklin Bay used to advantage the observations of the coastline of the western Arctic made on Franklin's second expedition.[75] The Fisheries Research Board of Canada, founded formally as the Biological Board of Canada in 1912,[103] appears to have played a modest role in marine geology in the early part of the century, but its most notable geological contributions, concerning the Gulf of St. Lawrence, appeared in the 1960s and 1970s.[73]

The pace of investigations offshore accelerated in the 1950s. Lamont Geological Observatory made seismic refraction observations off Nova Scotia and the Grand Banks and, as a result, suggested that a substantial thickness of sediments lay beneath the shelf and slope, analogous to those beneath the coastal plain of the eastern United States.[89 98] Willmore and his colleagues from the Dominion Observatory investigated Sable Island, and the structure of the Gulf of St. Lawrence,[137] in this latter case asking the question "does the circular shape of the southern coastline reflect a meteorite crater?". References to early work will be found in the bibliography.[15 26 61 80 83 85 112]

The onset of the explosion in our knowledge came at the end of the 1950s, and the years 1958 to 1960 were perhaps the most important. Mobil Oil Canada Ltd. leased 0.5 million hectares of exploration permits around Sable Island in 1959, and seismic exploration for Richfield Oil was begun off the west coast. Seismic work began in 1960 off the east coast and in the Beaufort Sea. The National Research Council helped Dalhousie University found its Institute of Oceanography in 1960, creating a sister to that of UBC started in 1949. They were funded substantially for the time by the National Research Council, and shiptime was provided by federal agencies, an arrangement which has continued to the present. The Polar Continental Shelf Project was founded in 1958 which proved beneficial for the earth sciences. Its field capabilities and initially its own scientific and technical staff led in the next decades to substantial contributions by the Project itself, and by the people they supported in the Arctic, onshore and offshore.[39]

The Geological Survey of Canada, through L.W. Morley's initiatives, began aeromagnetic surveys offshore in 1958, and initiated co-operative studies with the Canadian Hydrographic Service in 1959, towing a magnetometer astern their vessels.[10 11] This established a tradition continued in various ways until now, so that potential field and bathymetric maps are available at various scales for a fairly large part of the Canadian offshore. In addition to this work from ships, the North Star aircraft of the National Aeronautical Establishment carried out aeromagnetic reconnaissance of Labrador Sea and Baffin Bay, in collaboration with the Geological Survey of Canada.[31]

The Department of Mines and Technical Surveys founded Bedford Institute of Oceanography in Dartmouth in 1962, and constructed the vessels **Hudson** (1963), **Dawson** (1967), and **Parizeau** (1967), to join the **Baffin, Kapuskasing, Acadia, Sackville** and **Maxwell.** If one person must be given credit for this, then W.E. Van Steenburgh should receive it. He was successively Director-General of Scientific Services and Deputy Minister of Mines and Technical Surveys, and in effect scooped oceanography out from under others involved in fisheries and defence when the time was ripe.

Other events, some earlier, some later, were also clearly significant: the first seismics in Hudson Bay in 1965 and the first offshore wells on the Grand Banks in 1966; the foundation of the Institutes at Burlington and Patricia Bay; the involvement of Earth Physics Branch in seismic work in the Arctic, and the (then) Atlantic Oceanographic Laboratory at Bedford Institute of Oceanography in measurement of gravity offshore; the explorations of the Mid-Atlantic Ridge by Bedford Institute of Oceanography; the formation of the Atlantic and Pacific Geoscience Centres in the Department of Energy, Mines and Resources; the involvement of groups from McMaster University, the University of Toronto and

Memorial University (such as C-CORE and the Faculty of Engineering); the competence in petroleum geology and geophysics developed by regulatory agencies such as Resource Management Branch and Indian and Northern Affairs; and so on. The events of a very few years in the late 1950s and early 1960s were the key events because, for better or worse, they shaped future directions on account of the impetus given, the staff who were engaged, the students who were trained, the facilities which were provided, and the geological concepts which were developed as guides to understanding the earth beneath the sea, and so to exploration for hydrocarbons offshore.

### *Achievements*

### The Global Framework

A few Canadian scientists played a leading role in the revolution leading to plate tectonics in the 1960s. These include people such as L.W. Morley, A. Larochelle[67] and J. Tuzo Wilson, who contributed to the understanding of magnetic lineations in the ocean basins, and in Wilson's case, to the development of the concept of transform faults, a key test of ocean floor spreading as a hypothesis.[138] E. Irving has been extraordinarily influential in the application of paleomagnetism to problems of continental drift.

A larger group of scientists contributed subsequently to the understanding of processes on mid-ocean ridges. The work on the Mid-Atlantic Ridge[72] led to contributions in various fields: petrology and petrogenesis, gravity and magnetics, seismology and heat flow, for example.[4] [5] The role of seawater in the alteration of the oceanic crust, and the concomitant effect on the composition of the oceans themselves, became evident very early, and this interaction now dominates thinking concerning ore deposits associated with the oceanic crust,[29] [32] heat flow in the ocean basins and the whole heat budget of the earth. The mantle below the Atlantic was shown to be less anisotropic in its seismic velocities than in the Pacific, and the crustal structures at the Ridge crest quite different from that proposed by other workers.[59]

The interest of people involved in these investigations led to participation in a number of phases of the Deep Sea Drilling Project (Fig. 2.5) where oceanic crust would first be sampled intensively, and culminated in Leg 37, dominated by Canadian contributions.[4] [49] The myth that the oceanic crust would be neatly magnetized to fit the Vine-Matthews-Morley-Larochelle hypothesis was destroyed, because the magnetization of the rocks drilled did not fit any simple scheme. The traces of menisci of liquids in vesicles were used to investigate the degree of tilting of the oceanic crust. Discrepancies between crustal velocities inferred from refraction observations and velocities in rocks recovered were resolved.[49] Other drilling programs have taken place on oceanic islands such as Bermuda, the Azores and Iceland. The next investigation will take place in 1982, when an international consortium including Canadians will drill into ophiolites on Cyprus, to resolve, among other things, questions concerned with ore deposits and their relationship to oceanic crust.

Work on the sedimentary wedge of the margin off the east coast of Canada led to participation in phases of the Deep Sea Drilling Project concerned with the evolution of the North Atlantic as reflected in the sedimentary record. This work led to definition of the lithostratigraphy and biostratigraphy of the western half of the floor of the North Atlantic, and to elucidation of some of the problems concerning calcite compensation depth, and circulation in the ocean throughout its history.[52]

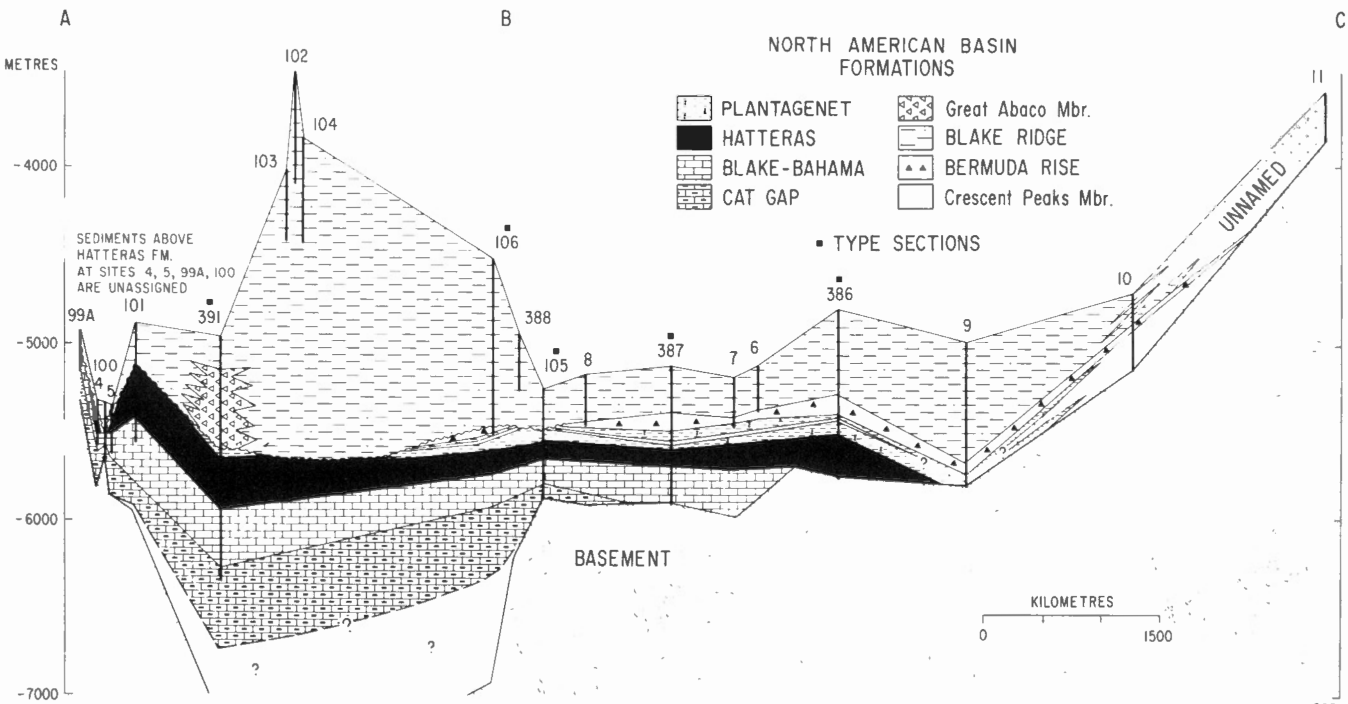



*Figure 2.5. Stratigraphic cross-section of the North American basin from the eastern seaboard of North America (left) to the mid-Atlantic Ridge (right), from Deep Sea Drilling Project sites. Cat Gap: clayey limestones, Oxfordian-Tithonian; Blake-Bahama: limestone, Late Tithonian-Barremian; Hatteras: black carbonaceous clays and marls, Barremian-Cenomanian (?); Plantagenet: variegated claystone, Cenomanian-Paleocene (from Jansa, L. et al., 1979, Maurice Ewing Series 3, American Geophysical Union, p. 1-57).*

These contributions took place mainly in the Atlantic. A seminal piece of work concerning the eastern Pacific, done collaboratively by staff from the Pacific Geoscience Centre, the University of British Columbia and the University of Waterloo recently has been completed.[68 90] Observations of time-varying magnetic fields were measured on the seafloor using ocean bottom magnetometers. These observations led to an interpretation in terms of changes in electrical conductivity as a function of depth in the earth on seafloor of different age.

Canada's third ocean is the Arctic Ocean. Canadians have made a variety of contributions there in attempts to understand its structure and evolution, which so affect comprehension of events on the Arctic margin and the Arctic Islands.[119] The expedition to the Lomonosov Ridge (LOREX) is well known; the gross structure of the ridge was delineated and a rather tentative date on the timing of separation from the Siberian Shelf was established. The Nansen Ridge is the present site of active spreading in the Arctic Ocean basin. The crust beneath this ridge – which is very slowly spreading – is very thin; this observation has led to the suggestion that crustal thickness of ridges is globally related to spreading rate.[51]

Canada did not join the Deep Sea Drilling Project when it became the International Phase of Ocean Drilling; apparently gentle approaches to the Treasury Board of the Government of Canada for its subscription of $1 million per annum were rebuffed. A small group of scientists made significant contributions nevertheless, both at sea on the **Challenger**, in the laboratory, and in various planning committees. Most recently, Canadians contributed to the drilling of diapir-like structures on the Moroccan margin, and in defining the oldest rocks encountered to date in the ocean basin of the Atlantic Ocean. There are numerous practical benefits from Canadian involvement, so obvious that they make the lack of formal (and financial) participation in the International Phase of Ocean Drilling seem ludicrous.

### The Contiguous Ocean Basins

Scientists from federal institutions such as the Geological Survey of Canada, the Earth Physics Branch, the Polar Continental Shelf Project, and the National Aeronautical Establishment of the National Research Council, and from universities such as Dalhousie, McGill, and UBC have worked in these ocean basins since about 1964. The work can be divided into two types – systematic and reconnaissance mapping, and work directed specifically towards processes. Systematic mapping has been dominantly of potential fields – gravity and magnetic, and of bathymetry, with lesser single-channel seismic reflection work. The mapping at sea and through the ice has been in large part in co-operation with the Canadian Hydrographic Service. the choice of parameters to measure in the shipborne work was a matter of logistics and historical accident. Measurements of magnetic and gravity fields and bathymetry are available to reasonably high standards in parts of the western Atlantic off eastern Canada, in Hudson Bay, in the Labrador Sea, in parts of the Arctic offshore, and off the west coast of Canada. Data of lower quality exist for Baffin Bay; these will be upgraded in the next few years. An important byproduct of the systematic geophysical mapping has been continual improvement in navigational standards at relatively low cost.[24] Co-operative work in this field between several federal agencies, industry and the University of New Brunswick is flourishing. The most recent work involves the efforts to use the U.S. satellite-based Global Positioning System, which, if fully implemented and if available to civilian agencies, will revolutionize positioning at sea, and on land. Systematic multichannel seismic surveys were not part of this work.

The assemblage of small oceanic plates off western Canada have been recently studied by a group from the Pacific Geoscience Centre at Patricia Bay and from the universities of British Columbia and Washington. Diverse studies including petrology, seismic refraction seismicity, heat flow and other geophysical techniques have been brought to a common focus to delineate the basic geometry of the plates and their historical evolution in terms of interactions with the North American plate.[6 13 14 50 105 124 130] Baffin Bay has proved to be oceanic in its crustal structure;[57] this has led to controversy in interpretation of the origins of Baffin Bay because most geologists maintain that there is no evidence of significant strike-slip motion along Nares Strait.[22 57 117] If Baffin Bay formed by simple sea-floor spreading, it is difficult to avoid postulating substantial displacement along the strait. Magnetic striping was discovered in the Labrador Sea, and its evolution was explained in the context of spreading in the Atlantic.[31 116]

### The Continental Margins

Canadian scientists are fortunate in having margins which exhibit a variety of structural styles off the Atlantic, Arctic and Pacific coasts.[58 86 113 131] In the case of the Atlantic and Pacific margins, it is probably fair to say that we have reasonable working hypotheses on their origin and development on a very gross scale from which to base experiments to test and extend the models. Companies were initially led to the margins off the east coast by seismic work from academic institutions, and by interpretation of magnetic field observations made by the Geological Survey of Canada.[40 41 42 43 83] The latter work was a prime factor in the exploration of the Labrador Shelf, and in the leasing of a large part of Hudson Bay by Atlantic Richfield.

About 150 wells have been drilled off the east coast, and the samples from them are available publicly after two years. Consequently, in conjunction with information described above a good data base is available for describing and modelling the development of this margin. In addition a large amount of industrial multichannel seismic reflection data is now available. An example of the sort of use made of this information by those working on east coast problems may be useful.

The geological setting of the Scotian Shelf, the Grand Banks and the Labrador Shelf was established by industry and government scientists in the 1970s.[25 30 35 53 81 83 84 99 112 120 125] In the case of the Scotian Shelf, the geological development was shown to be that expected from the rifting apart of continental masses accompanied by the development of a large ocean basin. Wells were drilled on a variety of structures, such as salt domes, with only modest success initially because of lack of maturity in the source rocks and often geographically restricted accumulations of hydrocarbons. The later major success at Hibernia, in the East Newfoundland Basin, came about because of the presence of excellent source rocks. Biostratigraphic studies provided the control for the determination of timing of events, and the history of subsidence of the margin.[8 33] Other controls on timing came from the magnetic anomaly patterns in the contiguous ocean basins.[7 116] In order to predict the subsidence and thermal history, so that the predictions can be compared with observations, the physical properties of the lithosphere have to be known.[9 58] Crustal properties can be determined by seismic refraction observations on the margin; however, in order to investigate the upper mantle beneath, experiments have to be conducted in oceanic regions where the sediment cover is relatively thin. The complex structure of the margins with their very deep sedimentary basins makes it impractical to investigate the upper mantle by experiments on the margins themselves.

This approach has led to a model which predicts the subsidence and thermal history (Fig. 2.6) rather well, and it can be tested against other observations, such as the gravity field.[9, 56, 58] The work has been remarkably successful; it draws on all geological, geochemical, paleontological and geophysical information, which has come not just from the margin itself, but from the continent on one side and the ocean basin on the other.

Many interesting examples could be described. Anomalous maturation of hydrocarbons was discovered above a salt diapir in the Primrose prospect off the east coast, an observation not yet quantitatively explained.[101] The discovery was made that significant quantities of hydrocarbons could be extracted from sediments of Late Cretaceous and Tertiary age in the Mackenzie Delta.[97, 114] This was curious because the organic matter is herbaceous or coaly, not "normally" a source of oil, and the sediments are at low levels of thermal maturation defined by values of vitrinite reflectance. Clever analytical detective work led to the hypothesis that the organic matter was tree resin (resinite); the significance is that rocks with "good hydrocarbon potential" may occur at low levels of thermal metamorphism, contrary to the conventional wisdom of other models for the generation of oil and gas.

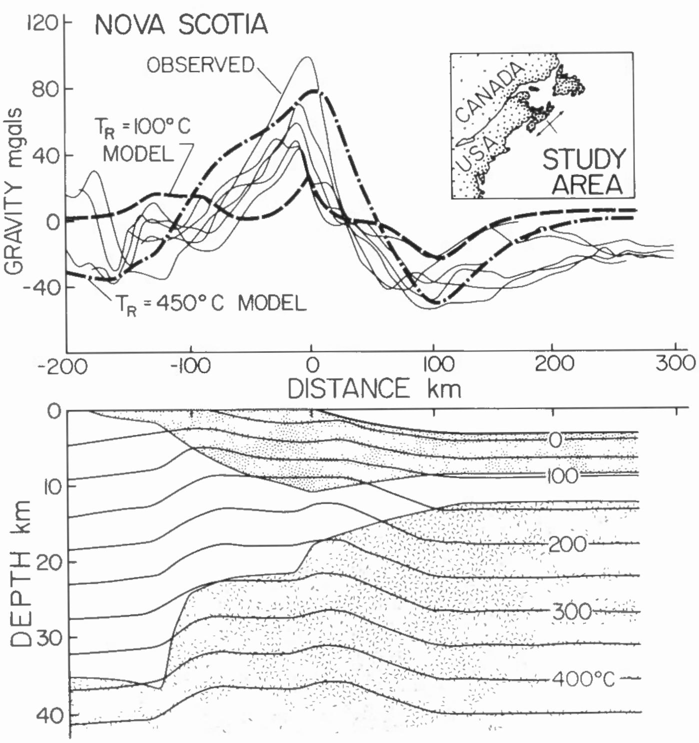



*Figure 2.6.* *A thermo-mechanical model for the evolution of Atlantic-type continental margins. Upper: Observed (thin solid lines) and computed (heavy broken lines) free air gravity anomalies for the Nova Scotia margin. Six observed profiles, from different locations along the length of the margin, are shown to demonstrate the variability of the character of the anomalies. The insert shows the locations of this margin; and the position of the cross-section. The extent of the margin over which the six observed profiles were obtained is denoted by the arrows. Lower: Crustal structure and isotherms predicted by the $T_R$ = 100°C model for the present time. Dots and line pattern indicate sediments and the mantle respectively. The isotherms are shown at 50°C intervals. Note how these are distorted by the low conductivity sediments and that the 0°C isotherm does not coincide exactly with the seafloor. This is because the sediments deposited at 0°C in the last timestep have not yet reached thermal equilibrium (from Keen, C.E., Beaumont, C., and Boutilier, R., 1981, Oceanologica Acta, p. 123-128).*

Exciting work of a different sort has emerged from the west coast; (Fig. 2.7, 2.8) like the work described from the east coast, this too demanded interplay from workers in a variety of disciplines and from a variety of institutions. The Pacific margin contains a variety of allochthonous terrains such as Wrangellia and Alexander terrain; on the basis of biostratigraphic and paleomagnetic information they are thought to have originated in the southern hemisphere.[86, 130] Wrangellia and the Alexander terrain are thought to have amalgamated some 140 million years ago, and the two amalgamated terrains are believed to have been incorporated with the North American Cordillera during the Late Cretaceous or early Tertiary. Rifting is believed to have occurred in the Queen Charlotte Sound in the Late Tertiary, resulting in the development of Queen Charlotte Basin, an important area for future exploration for hydrocarbons.

One major difficulty has been the lack of multichannel seismic data publicly available at reasonable rates. Industry data have been released two years after land has been relinquished; however, (a) the "land" of greatest interest is seldom relinquished, and (b) the time between acquisition of seismic data and release from confidentiality will often be ten to fifteen years, so that much of the data is not of the highest quality by modern standards. Government and academic institutions have not, in general, been funded to acquire multichannel seismic data themselves, or by

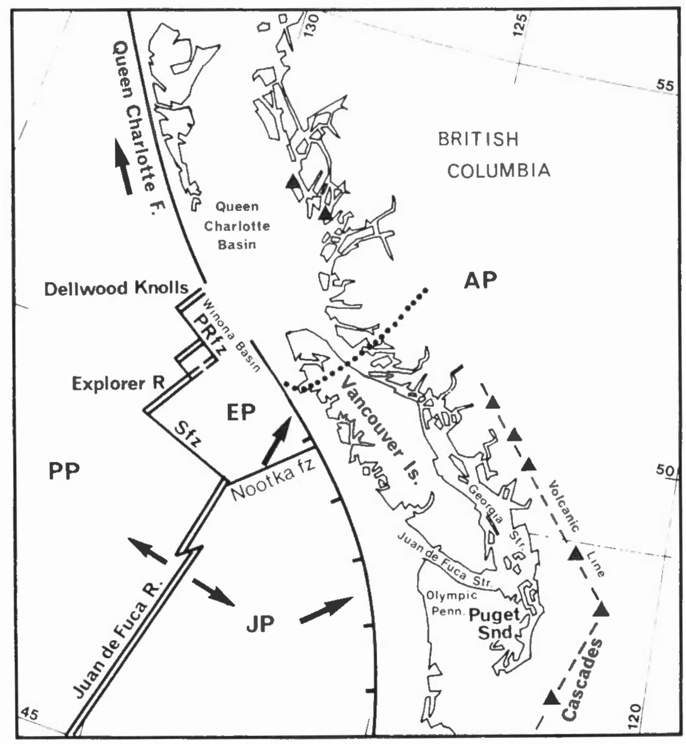



*Figure 2.7.* *The lithosphere plates off western Canada. Tectonic map of western Canada showing the main lithospheric plate boundaries and relative plate motions. The dotted line is the estimated northern edge of the Juan de Fuca plate. PRfz = Paul Revere fracture zone; Sfz = Sovanco fracture zone; PP = Pacific plate; EP = Explorer plate; JP = Juan de Fuca plate; AP = American plate (from Keen, C.E. and Hyndman, R.D., 1979, Canadian Journal of Earth Sciences, v. 16, p. 712-747).*

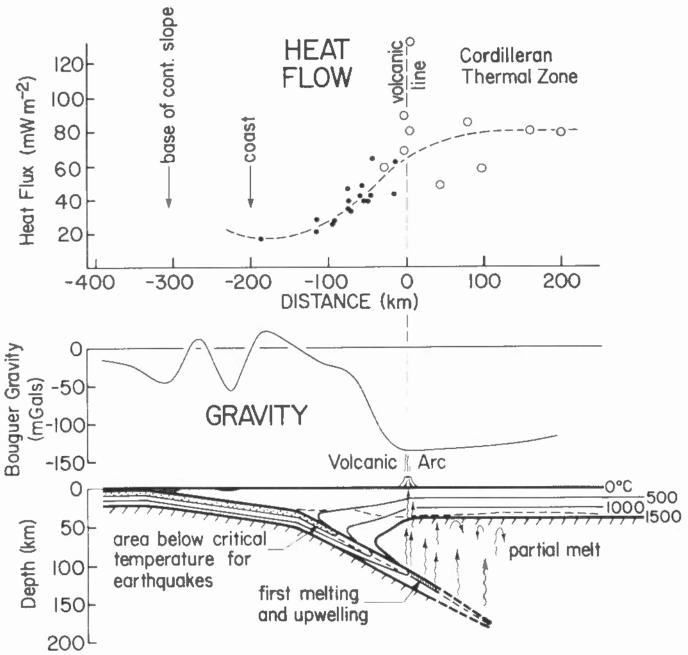



***Figure 2.8.*** *Heat flow and earth structure from the eastern Pacific to British Columbia. Heat flow values across southwestern British Columbia with distance from the volcanic line, a gravity profile and a schematic cross-section. Open circles are borehole heat flow values. The solid dots are values obtained in deep inlets, using the ocean-probe technique. In the cross-section, the dashed line is the base of the crust (from Keen, C.E. and Hyndman, R.D., 1979, Canadian Journal of Earth Sciences, v. 16, p. 712-747).*

contract, and the cost of purchasing data from participation surveys is high. This has meant that the only scientists who have had access to a substantial body of this information have been company geologists and geophysicists, and government scientists using industry data confidentially for the purpose of estimating hydrocarbon resources. Few other scientists have had such access until recently, and those who work on the margins have had to work with an inadequate data base. Consequently, expertise which might have been brought to bear creatively on the study of the margins has been impeded. Under Bill C-48, recently enacted, industry data will in future be released after five years or on relinquishment of the lands which were surveyed; this will clearly alleviate the problem but the lack of funding to government institutions and universities enabling them to create a pool of public data will still mean that data will be available only in areas of immediate interest to industry, and not in adjacent areas which, though not of present commercial interest, may be keys to understanding.

Since 1974, no work credits have been allowed for acquisition of seismic data on Canada lands unless the data have been processed in Canada. Consequently, Calgary is now the second largest seismic data processing centre in the world. All seismic programs in the future will be scrutinized by the Canadian Oil and Gas Lands Administration with respect to Canadian content, so that an indigenous marine seismic capability will be built up.

## Paleozoic Sedimentary Basins and Orogens

Some parts of the older sedimentary basins such as Hudson Bay and the Gulf of St. Lawrence, and of the older orogens, such as the Appalachians, are water-covered. They have been investigated for a variety of reasons.

The Appalachians northeast of Newfoundland provide clues to the fitting of the Atlantic in pre-drift reconstructions, and mapping and the interpretation of bedrock, gravity and magnetic fields offshore have played important parts in this work.[37 69 108] Being water-covered, the Gulf of St. Lawrence, the Appalachians and Hudson Bay were obvious targets for crustal seismic studies in which explosions fired from ships were used as sources, and receivers were placed at land stations.[20 106]

Hudson Bay in the early sixties was not seen as a particularly attractive exploration area because the Paleozoic sediments beneath it were though to be thin.[107] However, interpretation of magnetic field observations suggested that the basin might in fact be 3000 m deep,[41 42] and this was substantially confirmed by short refraction lines run in conjunction with the long crustal lines just mentioned.[38] Industry seismic work was started in the Bay in 1965, following earlier work on magnetic anomalies.

## The Shelf and Slope: Quaternary Sediments and Bedrock

A major contribution to Canadian needs has been the mapping of the sediments and bedrock of a substantial part of the continental shelf;[27 62 63 65 76 77] this has involved development of a methodology designed to determine the stratigraphy and structure of the shallow subsurface rocks and to acquire an understanding of the environments of deposition of surficial unconsolidated sediments. The work was begun on the Scotian Shelf (Fig. 2.9, 2.10) using echograms and bottom samples which had been collected in the course of hydrographic surveys, the echograms providing "remote sensing" of sediment type. The work has been scientifically interesting and useful in many ways: as an incentive to instrument development such as deep-towed high resolution seismic systems, and the quantitative characterization of sediments; to developments in navigation, and as contributions to the solution of many practical problems. These are varied: the installation of pipelines; the location of new coalfields off Cape Breton; the source of silica sand; the source of aggregate for offshore installations; the scour by sea ice and icebergs; the orderly development of hydrocarbon resources in general. Scientifically, the work has contributed to the understanding of sedimentary processes on formerly glaciated shelves in high latitudes, and of the climatic relationships in the Pleistocene between land, shelf and the open ocean.[128] A significant recent contribution which drew upon many disciplines was the use of estimates of postglacial relative sea level in attempts to distinguish between extreme models of late Wisconsinan ice distribution by calculating the response of the earth to the postulated ice loads.[100]

Several gaps can be identified in the work on shelves and slopes. Little attention has been paid until recently to sediment dynamics beyond the coastal regime. Practically this is important on the storm-dominated shelves when considering seabed engineering installations. There is inadequate knowledge of the surficial or bedrock geology of the channels of the Arctic Islands. Engineering geology offshore has been neglected by a substantial part of the university and government communities. We have only modest information concerning the sediments and sedimentary processes on the continental slopes. The contributions of a number of Canadians in the field of modern turbidites and deep sea fans are well known,[88] but this will not be sufficient to cope with the practical problems which will arise with exploration and production in deep water off the shelves. Shell Canada Resources Ltd. plan to drill four wells in water depths of 1900 to 2000 m in the next two years. Canadian scientists are in a position to aid industry in solving its problems in a variety of areas on the shelf, and to

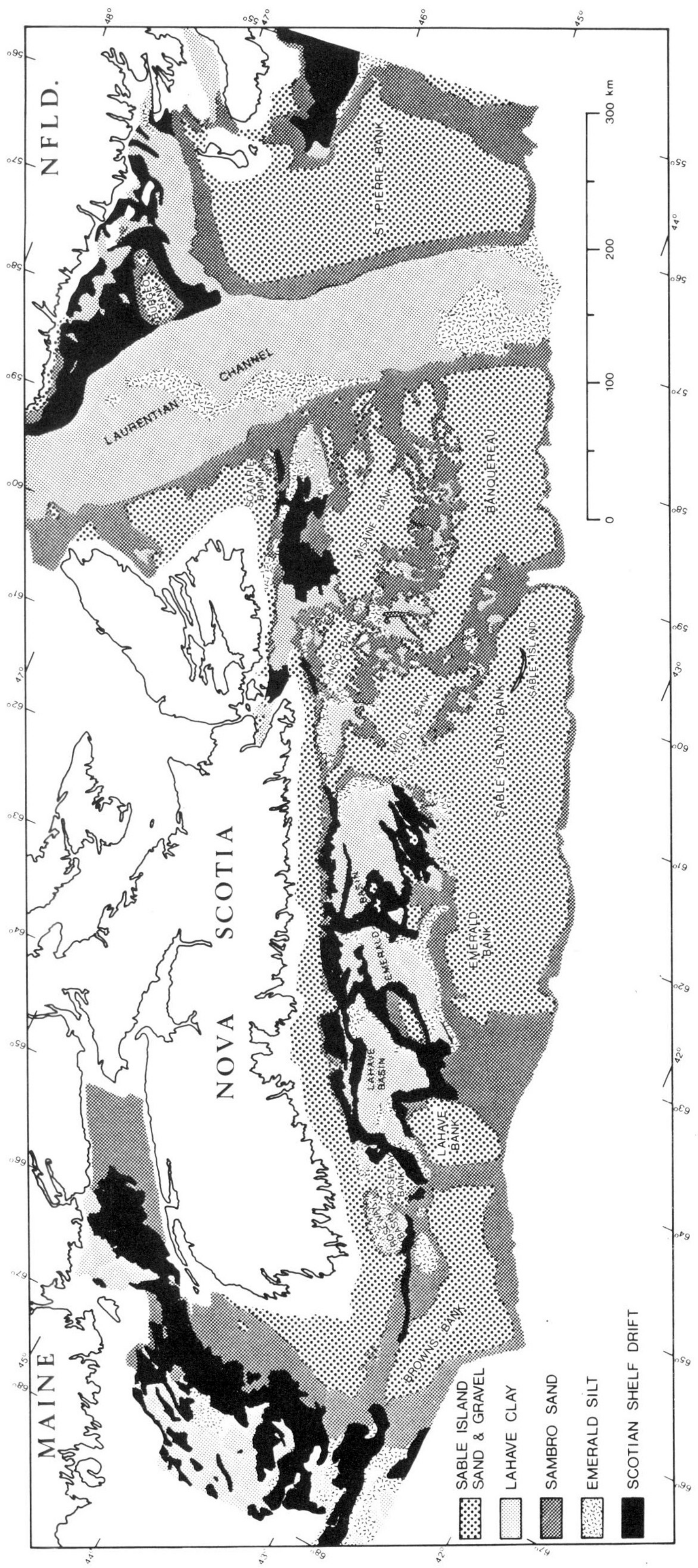



***Figure 2.9.*** *Surficial geology of the Scotian Shelf and adjacent areas showing the distribution of lithostratigraphic units (from King, L.H., 1979, International Conference on Offshore Site Investigations, Society for Underwater Technology, London, England).*

contribute to government's concerns for orderly development and protection of the environment. This will be difficult to do on the slopes without an acceleration of effort there.

### The Coastal Regime

The major contributions to geological studies of the coastal regime have perhaps been of two sorts.[79] Many owe their origin to the unique features of the very long Canadian coastline: the regimes of high tides in the Bay of Fundy;[2] the frozen regimes of the Arctic;[71 122 123] the tectonically active margin of the British Columbia coast with its complex geography of islands and fiords and waves with high energy. Others, particularly those concerned with the interactions of waves and beaches, owe no national allegiance to the region which was used as the laboratory.

The regional studies of our coastal regimes have been vital in establishing the descriptive data base and in establishing a methodology.[91 92] The fact that we have some knowledge of most Canadian coastlines, and reasonably established techniques for describing them quickly and reporting the observations understandably has been of great practical importance in all the industrial developments which have been and are being undertaken.[82] Simple, practical examples of the need for this base of information include: how often should a harbour mouth be dredged, or re-surveyed? if an oil tanker such as the **Arrow** spills oil, which beaches should be protected?[12] what methods of construction should be used in bringing pipelines ashore on Arctic coastlines?[122 123] The competition in the use of the shoreline – should an oil tank farm, or recreational yachting use a British Columbia inlet? There have been excellent studies of the estuaries and coastlines of British Columbia which will be very influential on future developments.[16]

Information on coastal geomorphology and shoreline protection is an integral part of any oil-spill contingency plan required of an operator before an offshore drilling program is approved; it is required, too, in the initial environmental evaluation or environmental impact statement for regional exploration and development, and recent examples include the Labrador Shelf (Petrocanada), Sable Island and Hibernia (Mobil).

Many studies of the coastal region owe their origin to the uniqueness of a feature. The Bay of Fundy is a natural laboratory for macrotidal regimes;[2 21] consequently, the studies have global significance scientifically, and direct practical consequences if a tidal barrage for power generation is ever built. The indirect practical consequences have already been significant; for example, we now know how to use satellite imagery in studying the sediment budgets of estuaries where temporal changes in phenomena are rapid, and conventional sampling techniques are inadequate.[1] Another example of coastal

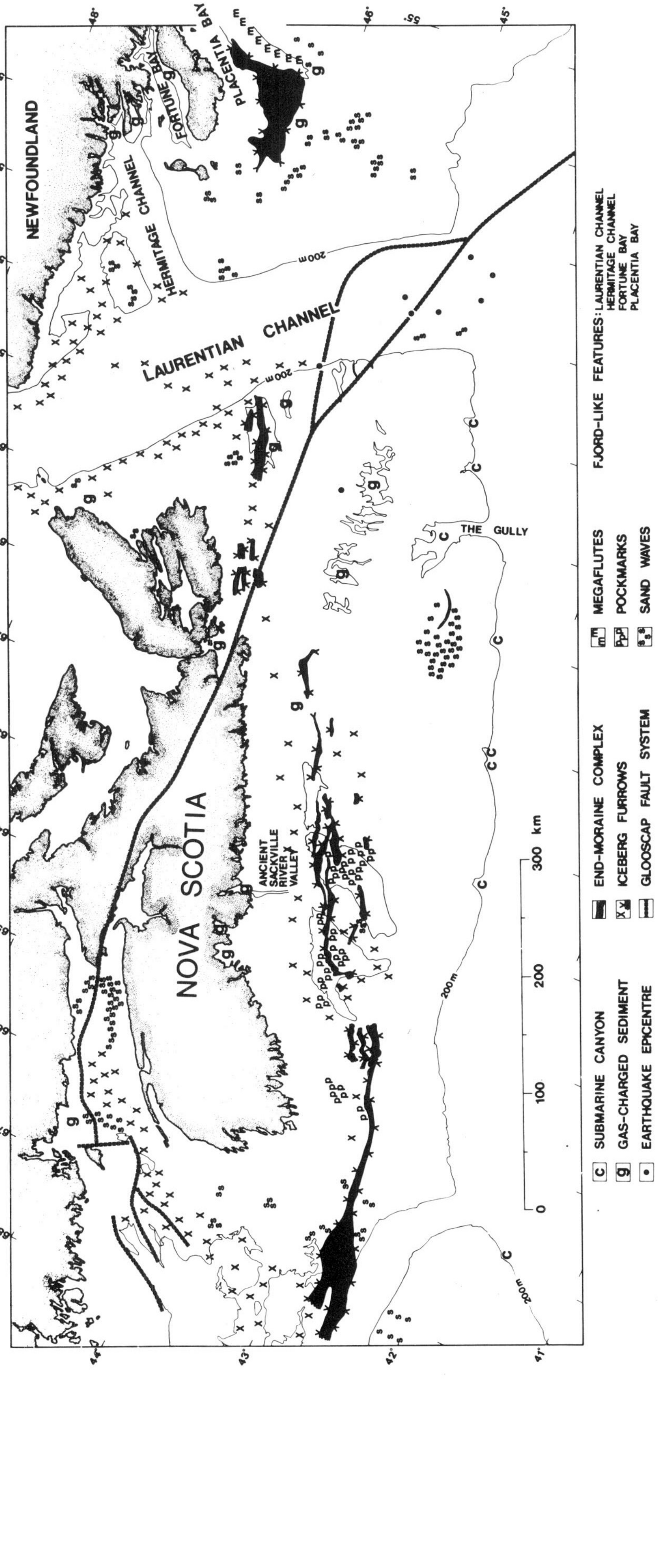



*Figure 2.10. Distribution of geological elements and attributes of the Scotian Shelf and adjacent areas important to engineering studies (from King, L.H., 1979, International Conference on Offshore Site Investigations, Society for Underwater Technology, London, England).*

research with important practical applications is the study of the ice-dominated coastlines of the Arctic, with applications concerned with harbour terminals, pipeline crossings, and similar engineering developments.[122,123]

In some fiords in British Columbia problems related to the disposal of mine tailing have developed. University of British Columbia staff and graduate students have made incisive studies of turbidites in fiords using innovative acoustic techniques, and a team from the Pacific Geoscience Centre and the Coastal Studies Institute of Baton Rouge, Louisiana, have recently used digital side-scan sonar to delineate large slumps in the fiords. Studies of the barrier islands of the Gulf of St. Lawrence have led to the development of excellent facies models,[78,102] which provide a needed complement to those developed from studies in the mid-and low-latitudes of the U.S.A.

An excellent example of the second sort of work is that done by some university workers on beach processes – waves in the coastal regime.[10,36,47] This research is both technically difficult, because of the scale of the phenomena and the violence in the breaker zone, and theoretically difficult, perhaps at present intractable, because the physics of turbulence is poorly understood. However, many advances have been made in instrumentation, and in our understanding of coastal processes. The role of edge waves and the response of beaches as part of a dynamical system are examples.

### The Arctic

The Arctic is, of course, mentioned elsewhere, but at the risk of duplication, it deserves particular attention because of its significance to Canada. Indeed, the formation of the Polar Continental Shelf Project in 1958 and the move by industry to exploration offshore were described earlier as key events in the development of the earth sciences at sea in Canada. They came together in the Arctic in the late 1960s and 1970s as a result of the Prudhoe Bay and Drake Point discoveries.

The formation of Polar Continental Shelf Project led directly and indirectly to a host of scientific programs: "Multiparameter Surveys" of various types over ice-covered waters were initiated with the Project supplying logistics, the Canadian Hydrographic Service measuring water depths through the ice, the Earth

Physics Branch measuring gravity, and the Geological Survey of Canada sampling the seafloor and carrying out aeromagnetic surveys.[39] The work demanded many technological developments: through-the-ice transducers for sounding, portable sampling and photographic equipment for deployment from the ice, and innovative methods for surveying large areas of seafloor through a single hole through the ice.

The work led to many geological and geophysical advances and insights. Y.O. Fortier and L.W. Morley had proposed in 1956 that the Arctic Island channels represent a drowned Tertiary drainage system.[28] The bathymetric information available a decade later was used to illustrate how this drainage system has been modified by glaciation.[94] The gravity observations led interalia to the discovery of the large gravity anomalies associated with the continental margin offshore the Queen Elizabeth Islands.[115 119] On the new gravity map of Canada they are, of course, now seen as part of the continuum of such anomalies at the transition from continent to ocean around Canada.

The Canadian Hydrographic Service devised new techniques for use in the Arctic, not only for working through the ice, but also for use in open water. The service experimented with helicopters towing sounders in the water, and with Air Cushion Vehicles towing similar transducers. The need for this sort of capability became evident in 1969. The **John A. Macdonald** discovered what was later recognized as a "pingo-like" feature when escorting the **Manhattan** through the Northwest Passage to Prudhoe Bay; "Admiral's Finger" rose to only 23 m below the sea surface.[110] Consequently, the **Baffin** surveyed a part of the Beaufort Sea in 1970, at the time **Hudson** was engaged on the voyage around the Americas. Seventy-eight pingo-like features were discovered by the **Baffin** in her survey, with the minimum water depth being 15.4 m. The **Hudson** and **Parizeau** discovered others using a side-scan sonar system; seven of these were not detected on the ship's echo sounders.

In 1970, the **Hudson**, working in the Beaufort Sea obtained what may have been the first side-scan sonar images of scour of the seafloor by sea ice and discovered ice in sediment cores.[132] Problems for exploration and production in the Arctic multiplied: permafrost was present beneath the seafloor, which would pose problems in drilling exploration and production wells; scour by sea ice (and icebergs off the east coast[70]) would pose problems for well-heads and pipelines; transportation by sea would be hazardous because of pingo-like features. The permafrost problem offshore had become evident a little earlier in 1980. The Arctic Petroleum Operators' Association had undertaken an offshore sampling program in the Beaufort Sea; frozen icy sediments and ice were discovered in some of the boreholes, and they may have been the first ice samples to be recovered from below the seafloor.[3 74]

However, the work of **Hudson** in 1970 was not finished; the vessel continued to Baffin Bay where it was made clear that, from seismological evidence, the bay was underlain by oceanic crust.[57] The **Dawson** had earlier in the 1970 season confirmed suggestions that the Tertiary volcanic province of west Greenland extended well offshore, and had shown that a sedimentary deltaic system was to be seen at the mouth of Lancaster Sound in northern Baffin Bay, supporting Fortier and Morley's hypothesis of 1956.[60] The basalts off western Greenland which had been mapped magnetically and recovered by dredging offshore, were shown to be remarkably "primitive".[17] Various contributions were made to the notion that Davis Strait is a "hot spot".[48]

The work of 1969 and 1970 had great consequences for work in the Arctic offshore in the 1970s, leading as it did to studies of the thermal regime, the mapping of permafrost offshore using shallow seismic methods, and charting by the Canadian Hydrographic Service.[44 45 46 87]

Industry drilled its first well in the Mackenzie Delta in the mid-1960s and Imperial drilled its first offshore well in the winter of 1973-74, from the artificial island Immerk B-48. Companies such as Panarctic and Polar Gas had investigated problems of drilling from the ice. They studied techniques such as strengthening the ice cover through flooding and freezing, and "trenching" directly through the ice as a means of laying pipeline in ice-covered waters. Imperial's efforts in developing the technology of drilling from artificial islands are impressive from several points of view – the hostility of the environment in terms of ice and waves, the dependence on supplies of mundane materials such as aggregate for construction, and the improvement in technology over a very few years. The first island was started in 1972 and used in the winter of 1973-74; four islands could be built in the summer of 1976, because of technological improvements.[18] As a result principally of industry activity, the Beaufort – Mackenzie Basin has become geologically well known.[55 66 131 13 135] It became a distinct depositional centre in the latest Triassic or earliest Jurassic time but unlike the east coast offshore, sedimentation since then has been significantly affected by continued orogenic activity onshore. There are a variety of hydrocarbon traps: in the Tuktoyaktuk – South Delta province traps are associated with tilted fault blocks and horst structures, whereas in the North Delta province, the traps are principally faulted anticlines or structures associated with down-to-basin or down-to-margin faults.

A great deal of work was being done in parallel with the activity of industry, contributing to our knowledge of the distribution of sediments,[95 96 129] foraminifera and molluscs in the Arctic offshore and the Arctic Island channels. Some workers later concerned themselves with the coastal regime, the interaction between river and sea and coast and ice. Questions of the following sort have been asked: what is the role of ground ice in the rate of retreat of coastlines in the Beaufort Sea, and where are the sinks for sediment delivered by northern rivers?[71 79 123]

Research in the Arctic in the last twenty years appears to have been a delightful combination of direction by politicians concerned with sovereignty, and entrepreneurial seizing of the opportunity resulting in discovery in an unknown region, explanation and modelling of the phenomena, and research devoted to the solution of practical problems by industry. Very few scientists from universities were – or are – involved; that is surely a pity.

### Instrumentation

Canadian scientists and technologists have led the world in instrumentation in the earth sciences at sea in only a few cases, but have been abreast of global developments in a number of others. The development of the phase-lock loop magnetometer which allowed the magnetic field value, instead of the precession frequency, to be displayed directly, saved a lot of arithmetic at a time when computers at sea were not available.[109] Scientists from Bedford Institute of Oceanography were among the first to use shipboard computers, and implemented the use of satellite navigation at an early stage.[24] The interest in SATNAV arose from the problems of precise positioning in remote areas such as the Mid-Atlantic Ridge, and off our own coasts beyond the limits of the electronic navigational aids. This work was useful to companies such as Shell in their drilling programs off the east cost, and Canadian Marconi who built SATNAV receivers.

Scientists from the Earth Physics Branch have recently pioneered the development of the linear marine gravimeter which is free from cross-coupling effects. They have also been involved in several developments in the field of marine gravimetry and have developed micro-processor based real-time data acquisition systems and gravimeter control hardware for shipboard applications.[139] Canada led the world in the development and use of rock core drills – drills for use from oceanographic vessels for sampling where dredging is impossible or is an unsuitable technique. This was very useful in various programs, such as geological mapping off eastern Canada,[65 77] and geological investigations of mid-ocean ridges. The initial innovative technology of deriving power for a drill by flooding a cylinder of air still at atmospheric pressure when the cylinder is deep in the oceans is being used by U.S.A. scientists in a different application; the more recent technology in which substantial amounts of electrical power are fed by a cable from the ship to the drill at 3500 metres water depth, say, will have a variety of other oceanographic applications, and tests of an instrument designed to filter large quantities of sea water at depth have just been completed. The expertise of Canadian diamond drillers is well known and this has been put to good use in the various drilling programs on oceanic islands, mentioned already. Sumbersibles have been used since the 1960s and most recently **Pisces IV** has been used off the west coast, in the Arctic and off the east coast in imaginative approaches to geological mapping and investigations of features such as ice scours.[23 64 96 134]

A number of other instrumental developments should be mentioned. An instrument called "Ralph" has been devised to monitor sediment movement, waves, tides and currents from the seafloor. Ocean bottom seismometers were successfully developed on east and west coasts, and ocean bottom magnetometers were a development from them. Ocean bottom magnetometers were used for the first time in the world successfully in the mid-sixties for recording magnetic variations on the seafloor off eastern Canada. However, it was probably not until the late 1970s that technology was sufficiently advanced to make instruments such as these worth deploying routinely, and theoretical techniques required for interpretation of the data were not perhaps sufficiently advanced until about the same time.

The Deep Towed Seismic System referred to earlier is able to acquire high quality reflection seismic data in heavy weather.[63 93] It was developed under a project known as Seabed using a team of scientists and engineers drawn from Huntec '70 Limited, the Metrology unit of Ocean Science and Surveys, Atlantic Geoscience Centre, Defence Research Establishment Atlantic and Memorial University. The data produced by this system are highly repeatable due to a unique method of cancelling system noise induced by heavy seas. The high data quality has in turn made it possible to invert scattering models of the seafloor to derive estimates of roughness of texture and correlation distance, quantities which provide a basis for characterizing different sediments. A device has recently been developed which computes these characterization features on line. Other research using the data produced by this system has resulted in a method for estimating subbottom reflectivity and acoustic attenuation in the first layer – quantities of importance to National Defence.

### *The Impact*

The work in the past quarter century by scientists and technologists from Canadian institutions – be they from industry, government agencies or universities – can be fairly easily described. It is not so easy, however, to assess the "impact" because of the lack of guidelines to expectations. Perhaps the question to be asked is: given the people, institutions, resources and political setting, were the demands made implicitly by society reasonable and were the responses to these adequate?

The conditions in 1960 were different from those now. A few of them, touched upon in this essay, were these: the first acreage had been taken out by Mobil one year before; the first marine geological appointment at Dalhousie was made that year; Bedford Institute of Oceanography was a gleam in Van Steenburgh's eye; there was no Institute at Patricia Bay; **Hudson** was a drawing; no wells had been drilled off our coasts; seafloor pingos were not known; Lamont's refraction observations, isolated dredge hauls and the Geological Survey's magnetic field observations were the only clues to the sedimentary wedge offshore; seafloor spreading had not been discovered; a bump rising to a depth of 600 m in the middle of Baffin Bay was still mistakenly on the charts; NRC did not fund geology in the universities; Polar Continental Shelf Project was a babe only two years old; electronic navigational systems extended only some four or five hundred kilometres off a few coasts; multichannel seismic methods at sea were primitive. Even relatively recently, the structures subsequently drilled at Hibernia were obscured from seismic eyes by the Avalon unconformity above.

Many conditions were and are extremely discouraging for marine research. The environment for exploration and production is harsh. Companies were and are still faced with governments debating jurisdiction, money and export policies, when the supply of the product was not, and still is not, assured. Scientists in government agencies were in organizations which changed at the drop of a hat. Dalhousie University was poor. Universities were and are still faced with government agencies and industry owning and managing the major facilities. Although goodwill has prevailed, the development of the marine sciences has surely been hurt by these structural arrangements – should not university staff and industry staff have been parts of the teams at the oceanographic and limnological institutes? Canadian scientists working at sea were – and are – faced with the national problem that we work in an industrial regime which is a branch-plant economy, with only a weak base of high technology, and high technology is one of the keys to success in working at sea.

Only a small number of people have been involved in relation to the sheer physical size of our own offshore and the magnitude of the global problems with which we ought to be familiar for our own good. One or two professionals are concerned with igneous rocks in the ocean basins. One or two are concerned with ice scour. One or two are mapping the shelf off southeastern Baffin Island, an area the size of Nova Scotia. One or two are actively studying modern processes on the continental slopes. A few are concerned with modern marine geochemistry. One or two are familiar with the problems of radioactive waste disposal in the deep oceans. A few are establishing the biostratigraphy of the offshore wells and putting it in the public domain. One or two are attempting to make a geological synthesis of the recent geology of the Beaufort Sea. A few are describing the coastlines of Canada, and a few are concerned with coastal processes. A few have been actively involved in the Deep Sea Drilling Project. One or two at most have been actively involved in modern studies of hydrothermal processes. A few are establishing the properties of crust and mantle, and one or two of these are quantitatively modelling margins. No one is concerned with sedimentological processes in the ocean basins. Three or four in government agencies are assessing the hydrocarbon potential of the east coast offshore, from Georges Bank to Lancaster Sound.

It is not easy to make comparisons with the United States in terms of marine geology and geophysics alone, but some figures will amplify the point just made. The Geologic Division of the USGS has about 3000 people and a budget of \$250 million; the Geological Survey of Canada has a staff of 750 and a budget of \$38 million. There is a total number of 538 faculty and research associates listed in the American Geological Institute's Directory in the marine sciences at Woods Hole Oceanographic Institution, Lamont-Doherty, University of Rhode Island, the University of Miami, the University of South Florida, Florida State, the University of Texas, Texas A and M, Scripps Institution of Oceanography, the University of Oregon and the University of Washington. By contrast, the faculty in the Departments of Oceanography at UBC and Dalhousie and at McGill's Marine Sciences Centre, number 54.

Comparisons such as these are often accompanied by comparisons of populations, as a measure of what a nation can afford. However, if the direct responsibilities are compared it is clear that the Canadian effort lags far behind that of the U.S.A.: land area – Canada 9 970 610 $km^2$, U.S.A. 9 371 829 $km^2$; coastal lengths – Canada 243 800 km, U.S.A. 142 640 km; and offshore area within the 200 mile limit – Canada 5 800 000 $km^2$, U.S.A. 10 500 000 $km^2$. In addition to the negative effect that devoting few resources to the offshore have upon direct national responsibilities, our global participation and our global impact have been much less than that of the U.S.A., for example. This is unfortunate for several reasons. The lack of participation, in say, the work of the last few years in the hydrothermal processes of mid-ocean ridges means that our exploration geologists have only second-hand knowledge of the new ideas on mineral deposits as guides to exploration in Canada.[32] Lack of participation with the French and Americans in the use of sophisticated sounding systems such as "Seabeams", means that activists have been late in insisting that our vessels be equipped with them. As a result, lines of soundings exist for our slopes spaced only some 10 km or so apart, and bathymetric maps available to industry for exploration in deep waters are crude in relation to what could be available; the geological inferences needed to guide regulation of such exploration in deep water will be wholly inadequate. In the few cases where there has been work in a global context, there has been practical spin-off, shortly afterwards. Ocean bottom seismometers were built on the east and west coasts to study the crust of the oceans and continental margins. Excellent work was done with them, of global significance. When they were needed to contribute to the evaluation of the hazards of seismicity to development in the Beaufort Sea, they were available immediately. The argument here is not that good science at sea must be done for its own sake, but because, in a field where developments are rapid, it has practical importance.

Canadian impact in "global marine geopolitics" reflects our credibility in the marine geosciences globally. We have made substantial contributions to bathymetry in the world's oceans by the production of the General Bathymetric Charts of the Oceans (GEBCO), and have substantial influence in the field. A few who have contributed substantially to the program of the Deep Sea Drilling Project and to global understanding of active and passive margins, influence the program of other nations. Canada contributed substantially to the Law of the Sea. There is a lesson to be gained, isn't there? If we want global influence in global problems – all of which affect Canadians, directly and indirectly – we must recognize that a significant proportion of our resources must be devoted to them. If we adopt a narrow attitude and study problems limited geographically to Canada only, then our knowledge of our own real problems will lag by a decade or two, and our contributions to global problems – which affect us too – will be very small.

Many things have, of course, been done well. Industry has made significant discoveries of oil off Newfoundland and in the Beaufort Sea, possibly as much as a significant fraction of Alberta's remaining reserves of conventional crude oil. Canadian consulting and service companies exist where none existed before. Systematic mapping has been done in many areas offshore sufficiently to delineate constraints to development. Problems peculiar to our high latitudes have been made clear – permafrost offshore, pingo-like features, and ice-scour. Some science has been superb. Excellent institutes of oceanography are in place at UBC and Dalhousie. Considering all the difficulties which there have been, Canadians have surely got more than value for money in the last twenty years or so. In hindsight, the return on investment would perhaps have been greater if circumstances had been different. With the vision of hindsight, better conditions might have included the following:

1. An early solution to the political and regulatory difficulties offshore.
2. Regulations governing the release of information in the offshore appropriate to generating the best scientific ideas, and earlier implementation of rules designed to encourage Canadian industry.
3. Different structural arrangements for the federal institutes of oceanography; should they not have been national facilities in ways they have not been because of their ownership by federal departments?
4. Coherent policies concerning the earth sciences at sea, which contained an appreciation of the needs for work of a global nature, as well as the needs for work of a purely national nature.
5. Reasonably stable organizational arrangements for the federal institutes.
6. More money and more people.

What next? This is not the place to try to answer that question completely; one person could not do it. It may be the place, though to suggest an approach. We do now know enough to define the practical problems of the next few years reasonably well, and to make reasonable guesses at the problems which will follow, knowing that there will, of course, be surprises. Geologists, geochemists, geophysicists and geographers working in the oceans will have to contribute to the purely Canadian problems of development on our shelves and slopes of the Atlantic, Arctic and Pacific. Those of us who work at sea will have to help those who work on land in developing models which will aid in finding resources there. We will have to contribute to solutions to global problems which will affect our people – waste disposal in the oceans; the carbonate cycle and carbon dioxide; the problems of climate; and the problems of finite resources in a shrinking world. These all demand good science. Furthermore, we are now sophisticated enough to begin to tackle these problems in a rational way. An excellent granting system is in place for the universities which includes a panel for Strategic Grants on Oceans and this was only embryonic twenty years ago. The Canadian Geoscience Council does exist where all the estates of the earth sciences meet, and this did not exist twenty years ago. We are now sufficiently organized to begin to determine what some of the problems will be in the next twenty years and how collectively we should set to and solve them; we could not have done this twenty years ago.

## COASTAL GEOSCIENCE AND ENVIRONMENTAL MANAGEMENT – G.E. Reinson

### *Introduction*

Over the past 15 years, much geoscience activity has been concentrated in Canada's nearshore and coastal zones (included in these zones are the Great Lakes, and large estuaries and enclosed bays such as the Bay of Fundy). Given our limited resources and manpower, and the immensity of our shoreline areas, our record of achievement is substantial in the fields of sedimentology, geomorphology and environmental geology of our coastal realms. The purpose of this paper is to highlight the level of coastal marine geoscience in Canada, and to identify the driving forces behind this present relatively high level of activity. The attempt at brevity may have resulted in the inadvertent omission of some important individuals and organizations who have contributed significantly to coastal geoscience in Canada. The references, however, include a list of the most topical and current summary documents, conference proceedings, symposia, and organizational publications on coastal geoscience in Canada. Most of the individuals and organizations active in coastal geoscience are cited, in one form or another, in these documents.

University, government and industry sectors have all contributed significantly to coastal geoscience activity. Canada's relatively high effort in coastal geoscience disciplines may, at least in part, be attributed to the fact that coastal studies can be undertaken at relatively low cost compared with offshore shelf and slope programs. Earth science departments in some universities have recognized the value of our coastal sectors as natural laboratories, both to educate students and to conduct research in sedimentology and geomorphology. The major impetus behind Canada's recent coastal geoscience activity, however, has been the need to address applied technological and environmental problems related to:

1. offshore petroleum exploration, production and transportation;
2. erosion of unconsolidated shorelines;
3. development and maintenance of ports and harbours;
4. regulation of coastal-zone dumping and dredge-spoil disposal;
5. potential tidal-power development, and;
6. overall coastal zone management with respect to interrelated, but sometimes incompatible, environmental and technological demands.

### *Universities*

For the past decade coastal geoscience activity in universities has been led by McMaster's departments of Geology and Geography, whose graduate research programs in the Arctic, southern Gulf of St. Lawrence, and the Bay of Fundy, have generated similar activity in other universities, and even in some government organizations. Ongoing coastal geoscience programs have been developed at the University of British Columbia (departments of Geography and Geological Sciences) the University of Toronto (Department of Geography), Dalhousie University (departments of Oceanography and Geology), and the University of Quebec at Rimouski (Department of Oceanography), and the level of activity at many universities, particularly in Ontario and Quebec, has increased significantly in the past few years,[1 2] Most of this recent activity encompasses geomorphological shoreline mapping and classification for use in coastal-zone management.

The contents of this report appear to indicate that coastal engineering programs at Canadian universities are negligible. There are at least three university engineering departments (located at Queens, Laval and Western Ontario) that maintain high quality, ongoing educational and research programs in coastal engineering disciplines. Considering the close relationship between the coastal engineering discipline and that of sedimentology, geomorphology, and nearshore oceanography, it is unfortunate that there has not been any significant interdisciplinary and co-operative research programs between engineers and geologists at the university level.

### *Governments*

M.J. Keen (in this report) has outlined the myriad of departments and agencies within the Federal Government which are directly or indirectly involved in coastal marine geoscience activity in Canada. The Geological Survey of Canada (Department of Energy, Mines and Resources), the Canada Centre for Inland Waters (Fisheries and Oceans, and Environment Canada) and the Environmental Protection Service (Environment Canada), have perhaps played the most important roles in instigating and undertaking coastal geoscience programs in Canada. The Great Lakes have been studied in detail over the past decade,[3] and over the same period, ongoing coastal geoscientific programs were implemented in the Atlantic Geoscience Centre and the Terrain Sciences Division of the Geological Survey.[4 5] Within the Geological Survey much credit must go to D.E. Buckley, B.D. Loncarevic, and B.R. Pelletier, for the development of an Environmental Marine Geology Subdivision, which concentrated initially on interdisciplinary projects in the coastal zone.[4] Coastal geoscience has 'mushroomed' since the early 1970s within the Geological Survey.[1]

Coastline mapping and shoreline classification are geomorphological disciplines which have received considerable attention within Federal Government departments over the past decade. Increased petroleum exploration offshore and in the high Arctic necessitated the obtaining of coastline inventories, which were undertaken either by government departments,[5 6] or contracted out by government agencies to private consulting firms.[7 8] These coastline inventories will provide input into ports and harbour development, liquefied natural gas terminal planning, oiltanker routing and oil-spill contingency planning. The Environmental Protection Service has responsibility for encouraging research on oil-spills, and disseminating information on oil-spill technology.[9] EPS also manages the Arctic Marine Oil-Spill Program (AMOP), a government sponsored program designed to develop oil-spill countermeasures for Arctic waters.[10 11]

Coastal engineering programs are undertaken by many Federal Government departments and agencies (see comments by J. Ploeg and M.J. Keen in this report). Probably the most readily visible programs are the design and modelling studies conducted by the Hydraulics Laboratory of the Division of Mechanical Engineering, National Research Council, and the 'in-field' harbour dredging and maintenance studies undertaken by the Department of Public Works.

Provincial Government departments and agencies, particularly in British Columbia and the Maritime Provinces, have begun in the past decade, or so, to obtain coastal geoscience information related to environmental management and proper utilization of coastal natural resources (R.D. Johnson in this report). Provincial programs, by economic necessity, are relatively small, but there appears to be excellent co-operation between provincial and federal agencies with respect to the transfer of geoscience data for use in provincial planning and policy making. Specific coastal problems such as beach-sand mining, shoreline erosion, oil-spill protection and clean-up measures, and harbour maintenance, have frequently been dealt with on contract, with funding coming directly from provincial agencies requiring the studies.

### *Industry*

Industry has indirectly played a major part in influencing the present relatively high level of coastal geoscience activity in Canada. As mentioned previously, offshore petroleum exploration and potential development have necessitated the identification of the coastal zone as a top priority for immediate geoscience activity. Government organizations responded to the needs of industry, and their own needs, with respect to coastline mapping and environmental management.[1 5 6 7 8 10 11] Individual companies or crown corporations, either through associations such as the Arctic Petroleum Operators Association (APOA), or on their own, have funded and are continuing to fund, private environmental consultants, and university and government groups to undertake coastline inventory studies.

Unfortunately, this report has not clearly elucidated the level of coastal engineering activity in the private sector. Obviously, many reputable coastal engineering consulting firms are active in Canada, particularly in British Columbia, Ontario and certain of the Maritime Provinces. The Associate Committee for Research on Shoreline Erosion and Sedimentation (ACROSES) of the National Research Council maintains a mailing list of coastal engineers active in the private sector.[2 12] ACROSES, among other duties, is attempting to 'bridge the gap' and promote communication between various geoscience disciplines, particularly between engineering and geology.

### *Status*

Within the last five years coastal workers have recognized the need for communication and co-operation between individuals and university, government and private-sector organizations.[1 2 13] ACROSES is an example of this new spirit of co-operation and co-ordination. Formed in 1977, largely by coastal engineers from government and universities, the mandate of ACROSES is to "...further a better understanding of the physical processes involved in erosion and accretion of Canada's lake and ocean shoreline...", by promoting both research into nearshore and coastal processes, and communication between researchers in these fields. The committee is composed of engineers, oceanographers and geologists representing government organizations, universities and the private sector. ACROSES has sponsored a major symposium[2] and publishes a newsletter[12] to disseminate information pertaining to ongoing coastal activities throughout Canada.

The Geological Survey of Canada has also contributed to greater communication and liaison between coastal geoscience workers by sponsoring an interdisciplinary symposium in 1978[1] which brought together geomorphologists, geologists, engineers and oceanographers who were conducting pure and applied research in the coastal zone. A Shore Management Symposium held by the Canadian Council of Resource and Environment Ministers (CCREM) in 1978[14] indicates that not only are coastal geoscientists and engineers beginning to co-ordinate activities, but government regulatory bodies are doing so as well.

Coastal geoscience achievements in Canada, particularly during the past decade, have been noteworthy; the documented record speaks for itself. Nevertheless, much work remains to be done and to rest 'on our laurels' would be retrograde step. The spirit of co-operation and co-ordination that began within the last few years must continue to grow, in order for coastal geoscience activity to be maintained, at even its present level, in the future.

## SOVEREIGNTY AND AUTHORITY – R.J. Harrison

Jurisdiction over the continental margin adjacent to Canada is about to emerge from under a cloud of domestic uncertainty and international transition. On the international scene, the third United Nations Conference on the Law of the Sea (UNCLOS III) is close to agreement on a new definition of national rights in offshore areas. Domestically, oil discoveries off Newfoundland will probably force a resolution of the federal-provincial dispute that has persisted for nearly 15 years with respect to jurisdiction over offshore areas.

Canada's claims over offshore areas are based upon the 1958 Geneva Convention on the Continental Shelf. Under that Convention, coastal states were accorded sovereign rights for the purpose of exploring and exploiting the natural resources of the continental shelf to an outer limit that is likely to emerge from UNCLOS III. This will impose a new outer limit of the area over which sovereign right are accorded, but one which will nevertheless accord to Canada jurisdiction over most areas of its continental margin that are thought to be prospective of hydrocarbon wealth. To a distance of 200 nautical miles from the baseline used for the purposes of measuring the territorial sea – an area to be known as the Exclusive Economic Zone – each nation will be assigned exclusive jurisdiction with respect to the management of both the living and non-living natural resources. Further jurisdiction with respect to the non-living natural resources will be accorded beyond the 200 mile Exclusive Economic Zone to an outer limit defined by combined criteria based on distance, water depth and sedimentary thicknesses. Thus, Canada will likely have exclusive control over such resources to a minimum distance of 350 nautical miles. Production fro the continental margin beyond 200 nautical miles is, however, likely to be subject to a royalty of not more than 7 per cent, payable to the international community through the proposed new International Seabed Authority.

Domestic jurisdiction over this area accorded to the nation by the international community has been subject to competing claims by the Federal Government and the Provinces. In 1967, the Supreme Court of Canada ruled in favour of the Federal Government with respect to the area off British Columbia. However, the Eastern Provinces have consistently argued that differences in their histories would result in favourable court rulings for them. Newfoundland in particular, has based a unique claim on the fact that it had been a self-governing Dominion prior to its entry into Confederation in 1949. Both the Federal Government and the Provinces have been asserting their authority with respect to adjacent offshore areas. To date, the petroleum industry has been able to cope with this competition simply by complying with the requirements of both jurisdictions. Thus, they have taken out both federal and provincial permits or licences. This technique for coping with jurisdictional uncertainty cannot, however, be carried forward to the production phase. While one work program – by way of drilling wells, for example, – might satisfy both federal and provincial demands, one performance of lease obligations at the production stage will not satisfy both. In particular, royalty can obviously be paid only once. Thus, with the discovery of the Hibernia oil field, the pressure to resolve the matter one way or another has intensified. It is impossible at this time, however, to predict whether the matter will be resolved by reference to the Supreme Court of Canada or be a negotiated settlement providing for some form of joint federal-provincial control.

## CANADIAN MARINE GEOSCIENCE: IN THE EIGHTIES – A.E. Pallister

During the past year or so two important events of significance to the Canadian marine geoscience profession took place. First was the confirmation of commercial quantities of oil and gas beneath the waters off Newfoundland and the Beaufort Sea and announced plans for transportation of liquified natural gas from the Arctic Archipelago. Second was the Federal Government's National Energy Program shift to emphasis to the development of "frontier resources". These announcements herald the beginning of a new level of marine activity in Canada during the eighties.

During the past decade an unusually large number of studies and conferences have been sponsored by Provincial and Federal Government agencies on the subject of the industrial opportunities, technological gaps, research and development needs and manpower requirements relating to Canada's future ocean activities. Although these analyses continue to be repeated and updated, some basic facts should be accepted as abundantly clear.

a. The potential oil and gas resources lying beneath Canada's three oceans are several times larger than the rapidly depleting conventional supplies in terrestrial Canada. These resources are comparable to the country's other two big hydrocarbon energy sources – oil sands and deep natural gas.

b. The production of petroleum from these ice-frequented oceans, as from the other major sources, will be expensive and require new technologies. Canada's oceans are characterized by varying combinations of extremes of permanent or dynamic ice cover, iceberg transit, seafloor scour, deep water, and unstable or hard rock seafloors.

c. Ocean technology in Canada is strong. This is, perhaps, surprising in view of the small volume of activity that has taken place in Canada in comparison to other areas such as the Gulf of Mexico or the North Sea. But, Canadian based companies have been actively participating in worldwide industrial offshore ventures and government and university scientists have been active in international programs. Within Canada, during the petroleum exploration phase, three significant new capabilities have been successfully demonstrated: geophysical operations in and on ice, drilling from ice-strengthened vessels and from ice platforms, and drilling in deep water.

d. Accomplishing the next breakthroughs, those of cold ocean production and transportation, require a much larger effort. While exploration activities have had the flexibility of using optimum time "windows", there is a strong economic necessity for production and transportation systems to be conducted year-round.

It is not possible in this space to describe the numerous site-specific requirements which are unique to Canada's oceans. It is possible, however, to assert that each project has its unique need for advanced technology, whether it is related to ice at the surface, water depth, or seafloor characteristics, or a combination of all three. A common element is the high importance that engineering excellence will occupy in the design of acceptable systems. Safety requirements will be paramount to both industrail investors, to government regulators, and to all Canadians. Few places in the world are viewed by the public as critically in need of environmental protection as are northern waters. Production and transportation equipment and operation in Canada's oceans can be expected to exceed the quality of any other theatre in the world.

Geoscientists will play a crucial role in the formulation of safe, yet economic solutions. The seafloor and shallow sub-sea sediments are of particular importance as new requirements are imposed by the presence of ice-scour, extremes of soft and hard bottoms and sub-sea permafrost. The geotechnical component of well completions, down-hole equipment, sub-sea installations, wellheads, gathering systems, manifolds, risers and sub-sea pipelines will be extraordinarily important.

The new thrust towards development of Canada's ocean resources will provide an important and vigorous need for marine geoscientists in the eighties – in research, development, demonstration, design installation and operations.

After three decades of exploration, analysis and planning, the decade of the eighties will be a time of implementation – a time when the nation will depend very heavily on its marine geoscientists.

# 3. GOVERNMENT

This section contains seven papers on government involvement in areas concerning the marine geosciences. Both federal and provincial involvement is outlined, with the dominance of federal activity being particularly apparent. Provincial, federal and international legal aspects are discussed and Canada's participation in international endeavours is reviewed.

A major contribution to this report is made by M.J. Keen in "Marine Geosciences in the Government of Canada". The report received input from some 50 federal contributors, with substantial contributions from P.G. Sly, R.D. Hyndman and C.P. Lewis. In the first part of this account, Keen has organized his material so that, perhaps for the first time, interested nongovernment workers can readily view the organization, areas of responsibility and activities of the various departments and their agencies. Keen then summarizes the financial resources in table form showing allocations by agency to the various programs, currently totalling \$16 million. Finally, comments are offered from other federal scientists. A brief paper on the geosciences in Northern Canada is provided by C.P. Lewis. While perhaps overlapping on the larger paper by Keen, this paper emphasizes the tenuous position of marine geoscientific research in the North.

In a separate paper, M.J. Keen develops an outline of the Federal Environmental Assessment Review Process (EARP), particularly as it relates to the marine geosciences. He adds considerable depth to the paper by personal observation and comment. In particular, Keen points out that departments are required to undertake an increasing load of environmental assessment and resource-related activities without supportive increases in manpower and other resources.

R.J. Harrison and I. Townsend-Gault provide a brief guide to "Legal Issues in the Canadian Continental Margin" with insight as to the status of ownership of various zones and regions under international constitutional law and under exploitation law. At present, national authority, to various limits, is claimed but not necessarily recognized. Further, Canada is involved in boundary disputes with the United States in four areas, and with France. Present federal and provincial laws, which are themselves in conflict, deal only with petroleum resources, presumably leaving other seabed resources to await, perhaps for several years, a Canadian Continental Shelf Act. These matters are significant to geoscientists since the national obligation to inventory and regulate resources and the right to exploit them requires the authority of law.

Papers by C.E. Keen et al. and M.J. Keen consider Canada's role in international marine geoscience. C.E. Keen et al. indicate that there is a high degree of international co-operation in marine geoscience partly because of the absence of legal territorial rights and partly because the marine geoscience community is still in its infancy and the oceans are vast and virtually unexplored. Although Canada actively participates in several major programs, our financial participation is minimal. Both papers stress the need for increased financial resources to participate in international programs in light of the numerous benefits from co-operative research and data acquisition.

R.D. Johnson indicates that there has been little serious involvement of the Provinces directly in the marine geosciences. Indirectly, of course, some provincial support for universities doing marine research does exist but it must be regarded as minimal. In addition, there are some agencies including C-CORE (the Centre for Cold Ocean Research Engineering), and the Nova Scotia Research Foundation Corporation which are provincially funded in part and which carry out various types of contractual work. Most provincial involvement relates to coastline or very nearshore problems, except for Newfoundland which does not accept federal ownership of offshore resources and therefore concerns itself with this aspect. If a legal provincial right to offshore resources is established, provincial involvement in marine geoscience may increase dramatically.

**MARINE GEOSCIENCES IN THE GOVERNMENT OF CANADA** – M.J. Keen, with contributions from P.G. Sly, R.D. Hyndman and C.P. Lewis

Many departments of the Government of Canada have concerns which involve the marine geosciences. The interests of some of them, such as Energy, Mines and Resources, will be obvious to the outside reader, but there are many other departments and agencies which play a very important but less publicly visible role. The basis for the involvement of staff of a department in a particular area of activity, such as the marine geosciences, is ultimately legislation of the Parliament of Canada that service of such-and-such a type will be provided to the public, and the interpretation of this by the department. The term "service" is used here very generally; the provision of maps of the geology of Canada is obviously a service, but so too is regulation of an activity, such as that of drilling exploration wells offshore, to ensure so far as is possible that the potential benefits are not overwhelmed by potential disasters. This account would be very long indeed if an extended account and discussion of all the legislative authority which underlies the activities of all departments and agencies were included; instead, comments are made to illustrate particular points.

The basis for the year-to-year operations within a particular area of activity are the expenditures authorized annually by Parliament; the Main Estimates – the Blue Book – describe what is presented to Parliament. These estimates describe the activity and associated funding by "Program". However, programs (of service) do not always correspond exactly to organizational units, and the relationships change from time-to-time. The general reader will, of course, be more familiar with a unit such as the Geological Survey of Canada than with the components of a program through which it is funded; in the accounts which follow I have extracted from the Program Descriptions – found in the Main Estimates – the parts which fit organizations as closely as possible, but there will be some inaccuracy as a result.

### *Department of Energy, Mines and Resources*

#### Earth Science Sector

The largest contribution from EMR to scientific and technical research in the earth sciences offshore comes from the Earth Science Sector, through its Branches – the Geological Survey of Canada, Earth Physics Branch, Polar Continental Shelf Project and Surveys and Mapping.

The work in the offshore by this sector comes principally under a program with the objective: "To ensure the availability of timely earth science information, technology and expertise for effective management of the Canadian landmass and its resources, for land use and demarcation, the development of primary industries, regional and urban development, transportation, telecommunications and defence". Appropriate parts of this program, with appropriate sub-objectives, correspond to the organization by branches.

*Geological Survey of Canada*

The efforts of the Survey in the marine geosciences are directed principally through its Division at Bedford Institute of Oceanography in Dartmouth, N.S., and its staff at the Pacific Geoscience Centre who are part of the Cordilleran Division. The contribution of the Survey's Ottawa Divisions are, naturally, less focussed on the marine geosciences than are those of their Atlantic and Pacific colleagues, but they are nevertheless substantial and important.

*Atlantic Geoscience Centre*. The Centre is a Division of the Survey, and one of the constituent laboratories of Bedford Institute of Oceanography. We describe the Institute itself – an important complex of laboratories – elsewhere, within the section concerned with the Department of Fisheries and Oceans. However, it is important to draw attention here to the excellent relations which exist between the Atlantic Geoscience Centre and the other laboratories at the Institute, and to the services provided by Fisheries and Oceans to the Geological Survey of Canada through the Atlantic Geoscience Centre.

The Atlantic Geoscience Centre has: the primary responsibility for all the geological and geophysical research work done by EMR in the offshore from the international border to northern Baffin Bay, except seismic monitoring and assessment of seismic risk, which is the responsibility of Earth Physics Branch; shared responsibility in the Beaufort Sea, the inter-island channels of the Arctic, the Arctic Ocean. The Centre has the responsibility in the Geological Survey of Canada for all coastal regions except the West Coast; its staff work from time-to-time in the contiguous ocean basins.

The Centre's programs are, in essence, designed so that the Geological Survey of Canada can provide advice and information concerning problems offshore important to Canada; the problems include those which are important now, and those – less clearly defined – which will be important in the future.

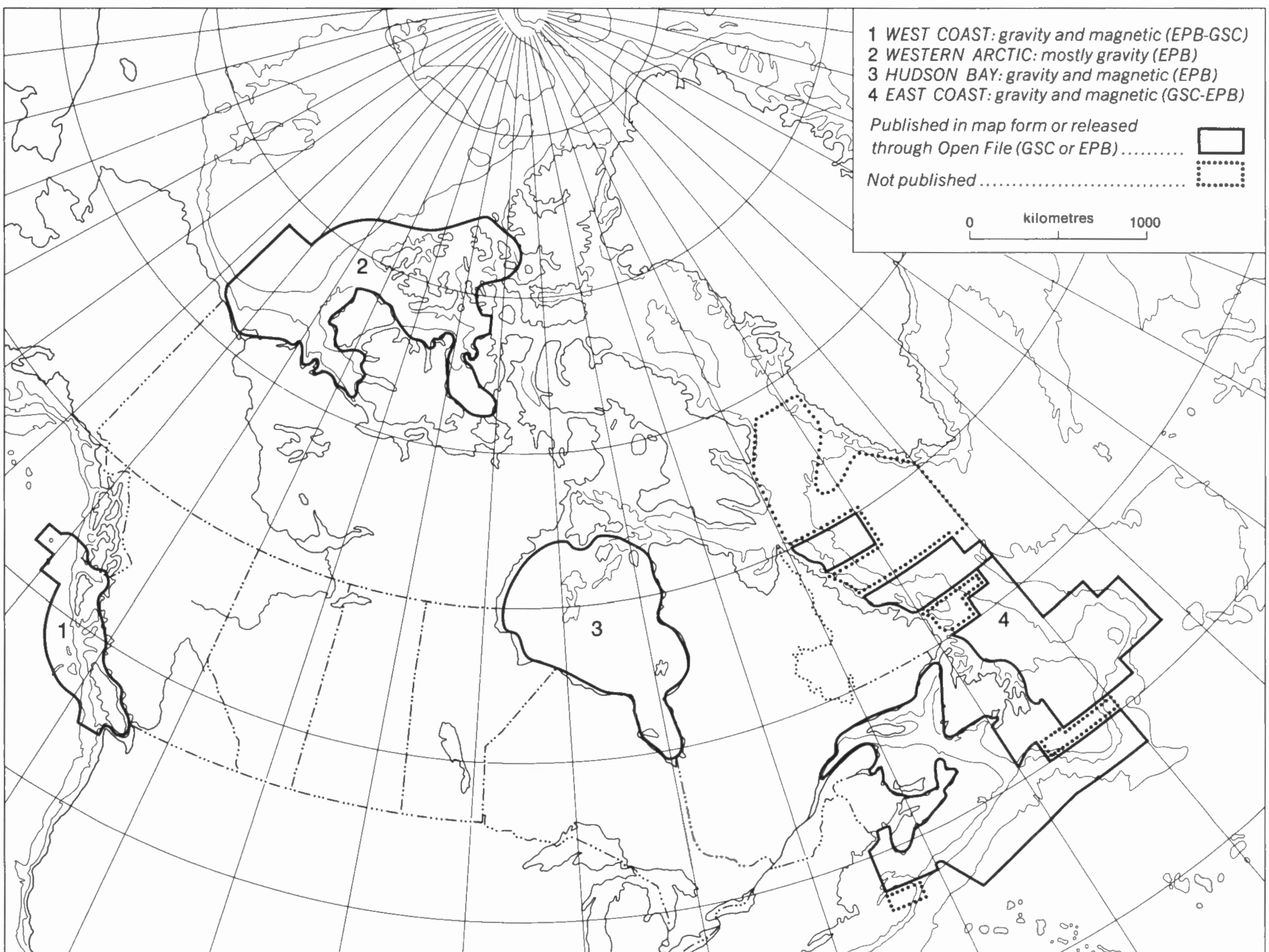



***Figure 3.1.*** *Status of potential field mapping offshore, 1981. Source: Geological Survey of Canada and Earth Physics Branch.*

*Bedrock and Surficial Mapping: Potential Field Mapping*. Mapping programs include surficial geology, bedrock geology, and potential field measurements. Much of the work is conducted under the multiparameter survey program with the Canadian Hydrographic Service, described below, and gravity measurements are incorporated into the data base of the Gravity Division of the Earth Physics Branch. This work has had several practical important consequences and the following are some examples. (1) Geological mapping offshore from Cape Breton Island aided the delineation of 1 billion tonnes of coal off Sydney, needed for development of coal-fired power stations in Nova Scotia. (2) Surficial geology maps of the Scotian Shelf aid delineation of potential routes for gas pipelines from Sable Island to the mainland. (3) Oil seeps and hydrocarbon-bearing rocks have been discovered off Baffin Island and in Davis Strait. (4) Oil from Hibernia must be brought ashore by pipeline or by tanker; geological information acquired by the Centre shows that there may be difficulties with a pipeline because (indurated) Paleozoic rocks of the Appalachians outcrop for some distance east of Newfoundland; pipeline burial in these rocks to avoid iceberg scour could be difficult.

The work feeds other programs of course. It is used in geological compilations needed for resource appraisal. The potential field information (Fig. 3.1) has naturally been used in modelling the geological development of the Appalachians offshore, the Labrador Sea and Baffin Bay, and in developing thermo-mechanical models of the rifted margins off eastern North America.

Geological and geophysical mapping offshore depend on good technology. Advances which have been vital to these programs have been navigation (through the Canadian Hydrographic Service), in sampling with rockcore drills (through the Atlantic Oceanographic Laboratory and Dalhousie University), and in high resolution seismic profiling (through a contract with Huntec ('70) Ltd.).

*Resource Charting*. Working with the Canadian Hydrographic Service over the past 15 years, there have been systematic marine surveys off Canada's east coast of magnetic field, gravity field and associated bathymetry and, more recently, seismic and side-scan profiling.

Coverage has been completed in the Gulf of St. Lawrence, on the Grand Banks and Tail of the Banks. Line spacing in the Labrador Sea has been completed to 5 nautical miles, approximately 85 per cent of the Scotian continental slope has been surveyed at 20 nautical miles and approximately 65 per cent of Davis Strait has been covered at 20 nautical miles. The present plans are to complete the east coast offshore to northern Baffin Bay.

*Crustal Processes*. It is important to be able to model the development of the rifted margins off eastern and Arctic Canada and the adjacent ocean basins quantitatively, so that the history of their development and their physical properties can be predicted. Consequently a number of seismic experiments have been conducted to determine the physical properties of the crust and lithosphere using ocean-bottom seismometers; the history of vertical movement beneath parts of the margin can be found from the data provided by industry wells. The seismic experiments have been conducted over young ocean crust – the Nansen Ridge of the Arctic Ocean Basin (FRAM Experiment) – a ridge spreading very slowly, the Labrador Sea and Baffin Bay, the older part of the ocean crust of the Atlantic (the LADLE experiment – Lesser Antilles Deep Lithosphere Experiment), and over the eastern Canadian margin itself. The experimental results have been a part of the input to theoretical studies with important consequences. We now have a thermo-mechanical model of the margin, which successfully predicts observed gravity anomalies, heat flow, and source-rock maturation. We also have a model which predicts the properties of oceanic crust which has – as it must – variable rates of spreading; this had been ignored before, and the key turned out to be data from the ridges which are spreading most slowly, such as the Nansen Ridge.

*Modern Geological Processes*. Studies of modern processes are conducted in most environments in the Canadian offshore (Fig. 3.2). (1) Work in the coastal regime is part of a program to map the coastlines of Canada and to understand the principal geological processes involved. It is done in co-operation with a variety of other agencies, mentioned elsewhere. Work in this field was important when the **Kurdistan** broke up in 1979 off Cape Breton. It forms the basis for planning harbour developments by the Department of Transport in the Arctic Islands. It forms the basis for planning for oil-spill countermeasures by the Department of Environment, and, as with all the work on modern processes, is an important part of the base of knowledge underlying environmental assessments. An understanding of coastal processes in the barrier-island systems of the Gulf of St. Lawrence has led to the development of facies models, useful to geologists working on land. (2) Work in the Bay of Fundy has been directed towards answering the question: if a tidal barrage is constructed in one of the basins, will the sediment load fill the head pond? This has involved interesting applications of satellite imagery, to determine the suspended sediment concentration in a regime in which, through high tides and high currents, properties are changing rapidly and normal sampling techniques are inadequate. (3) An integrated program is underway in the Hibernia region, involving bedrock and surficial geology; studies of sediment movement; studies of ice-scour. This will enable the Centre to comment credibly on proposals for development of the field. (4) Iceberg scours (Fig. 3.3) are being studied systematically on the shelf of eastern and Arctic Canada, in conjunction with others such as C-CORE, of Memorial University; the aim is to be able to predict the impact of scours, and predict their effects in different areas. The work involves mapping areas repetitively – to identify new scours, and investigating the rates at which scours are filled in, so that the ages of old scours can be estimated. (5) The Centre has a joint program with industry, with other parts of the Survey and with Earth Physics Branch in the Beaufort Sea. Its staff are trying to put together a model for the development of the Beaufort Sea in the Quaternary, and are integrating its own regional studies with industry's site-specific studies. (6) A lot of work has been undertaken with agencies such as the Atlantic Oceanographic Laboratory in inlets of the east coast, to establish, for example, the relationships between river discharge and sediment transport. This relationship has implications for defining the relationships of climatic trends to the local hydrological cycle; in inlets such as the Saguenay Fiord geological and isotopic studies can, in the right circumstances, resolve times as short as one year. Consequently problems of trends in climate with durations of ten to hundreds of years can be addressed. (7) Other work carried out in inlets has emphasized the pathways of chemical transport from natural drainage systems and potential sources of pollution. The emphasis of this work has been to determine mechanisms of transport and deposition of metals in the estuarine environment and coastal waters. We want to know the residence times of metals in estuaries and the open ocean. For example, studies on transition metals such as mercury, cadmium and lead have been carried out in the industrialized Strait of Canso, in the Bay of Chaleur and Miramichi Estuary.

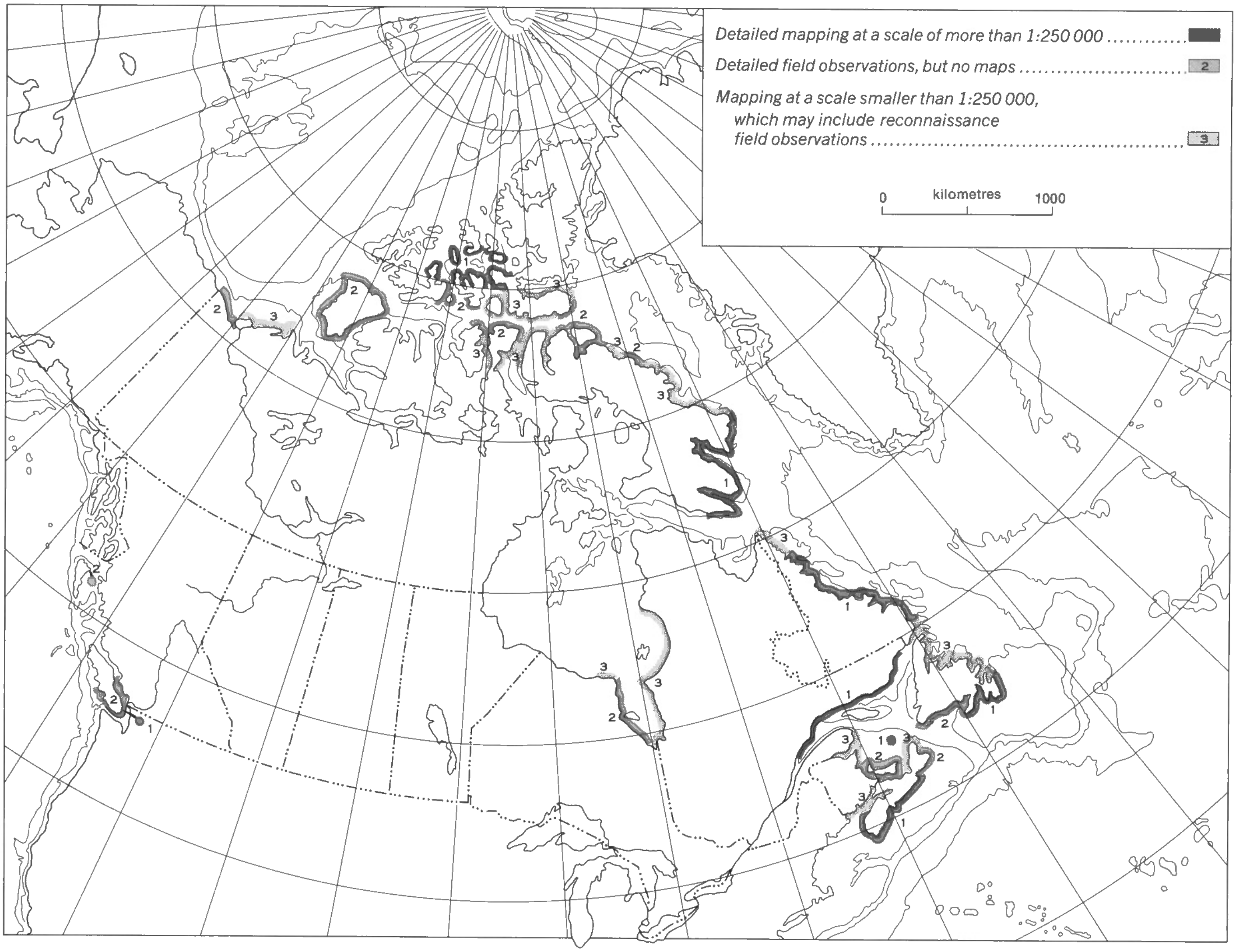



***Figure 3.2.*** *Location of coastal investigations by numerous agencies, to 1981. Source: Geological Survey of Canada.*

A number of nations are considering the possibilities that the seabed of the deep ocean basins may contain suitable sites for the disposal of high-level radioactive wastes from the point of view of reducing the radiation hazard to mankind. Most of these nations participate in the Seabed Working Group of the Nuclear Energy Agency, which is an agency of the Organization for Economic Co-operation and Development (OECD). Canadians will only be able to comment credibly on the seabed as an option if we do comparable work ourselves. Consequently, a small group of scientists from the Atlantic Geoscience Centre has a modest program, primarily geochemical, which is funded in part by Atomic Energy of Canada Ltd.

The program is designed to determine the capacity of deep sea sediment to act as a natural barrier to the diffusion of radionuclides. Work is being done in several parts of the ocean basins, and this includes; regional stratigraphy using high resolution seismic methods; chemical analysis of sediments and their pore waters to determine chemical partition of trace elements; measurement of heat flow to determine advective diffusion (this is with the Earth Physics Branch); sediment stability; and ion mobility. The research on marine clays may, of course, contribute to the solution of problems of disposal on land, where natural barriers may include clays as backfill, subject to interference by groundwater.

The sediments of the seabed would of course only be a first-order barrier; to estimate hazards to mankind from seabed emplacement we have to consider the effects of leakage from the sediments, and the possibility of accidents during emplacement. Both of these could introduce radiation into the deep-sea benthos and into the oceans themselves. Scientific problems of these sorts, when concerned with high-level wastes, are similar to those which arise in low-level dumping, and Canadian laboratories such as the Atlantic Oceanography Laboratory of Fisheries and Oceans have made an impact internationally in this field, working with agencies such as the International Atomic Energy Agency and the Nuclear Energy Agency (mentioned above). Modelling the effects of high-level wastes in the oceans is now being undertaken. Canadians are making a significant contribution to this work, through the body known as GESAMP – the Group of Experts on Scientific Aspects of Marine Pollution. This body is sponsored by a variety of agencies of the United Nations, and is headed by a Canadian from the Atlantic Oceanographic Laboratory.

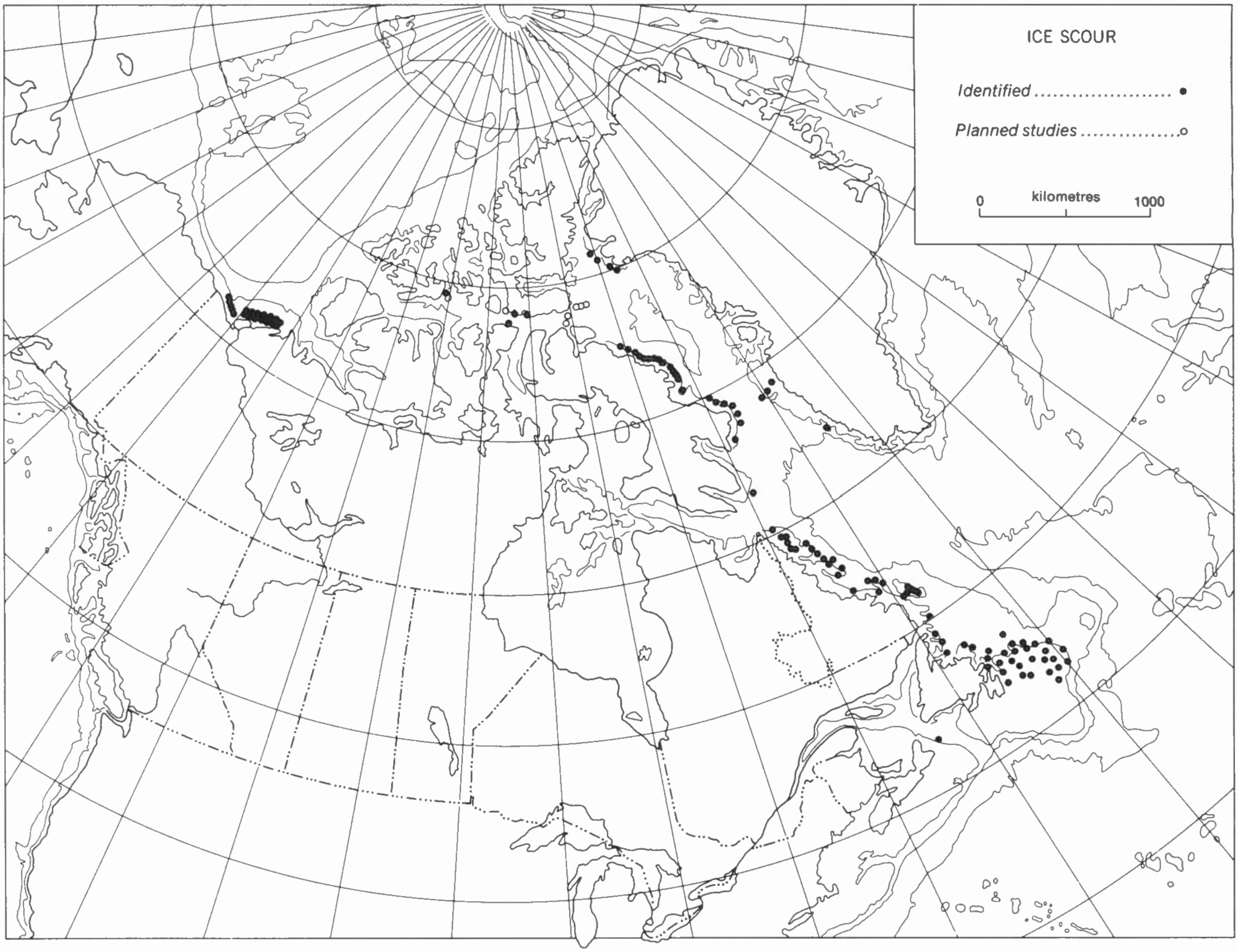



***Figure 3.3.*** *Locations of ice scour studies to 1981, including relict and recent scour.*

*Regional Geology of Sedimentary Basins.* The objectives of this program are to provide a detailed understanding of the subsurface geology of the Paleozoic-Cenozoic sedimentary basins of offshore eastern Canada, the eastern Arctic and the North Atlantic, and to determine the most precise estimates of oil and gas resources in these basins. Similar studies are also carried out on the Carboniferous basins of the Atlantic Provinces and coal reserves and properties are calculated for both onshore and offshore. The regional geology is reconstructed from industry data, which include multichannel seismic records and well samples and reports, and in-house programs such as bedrock mapping and acquisition of gravity, magnetics and refraction data.

The program has resulted in definitive works on the subsurface geology of the Scotian Shelf, Grand Banks, Labrador Shelf and North Atlantic, and maps showing the geology and sediment thickness of our margin. From this major efforts have concentrated on developing predictive models for correlations of the shelf and slope geology with that of the deep ocean basins of the North Atlantic. Further studies are also planned on the Late Jurassic-Early Cretaceous carbonate banks encircling the North Atlantic and comparison of passive and active margin regimes. Throughout, there has been continuing participation in the Deep Sea Drilling Project.

*Stratigraphic Studies.* Biostratigraphic and lithostratigraphic analyses of offshore well samples form the basis for the regional geology studies. Fossil groups used for correlating the sediments and determining paleoenvironments include foraminifera, ostracods, dinocysts, spores and nannoplankton. The biostratigraphic framework established for the Mesozoic-Cenozoic permits correlation with deep-sea sediments of the North Atlantic and European type sections. Considerable effort has been devoted to refinement of the biostratigraphy by introduction of quantitative techniques using sophisticated computer software.

Source rock evaluation, of great significance to the search for oil and gas, includes visual kerogen analyses, and vitrinite reflectance. Organic geochemistry is carried out in Calgary. Collation of such data forms the basis for predictive models of hydrocarbon generation on our margin, and hence on other passive continental margins. It is intended to further refine such investigations in the coming decade.

*Instrument Development and Data Management.* Working at sea or on the ice demands good logistics, advances in instrumentation, and good management of large quantities of data. It is worth mentioning therefore that the Centre has developed its own ocean-bottom seismometers, and an

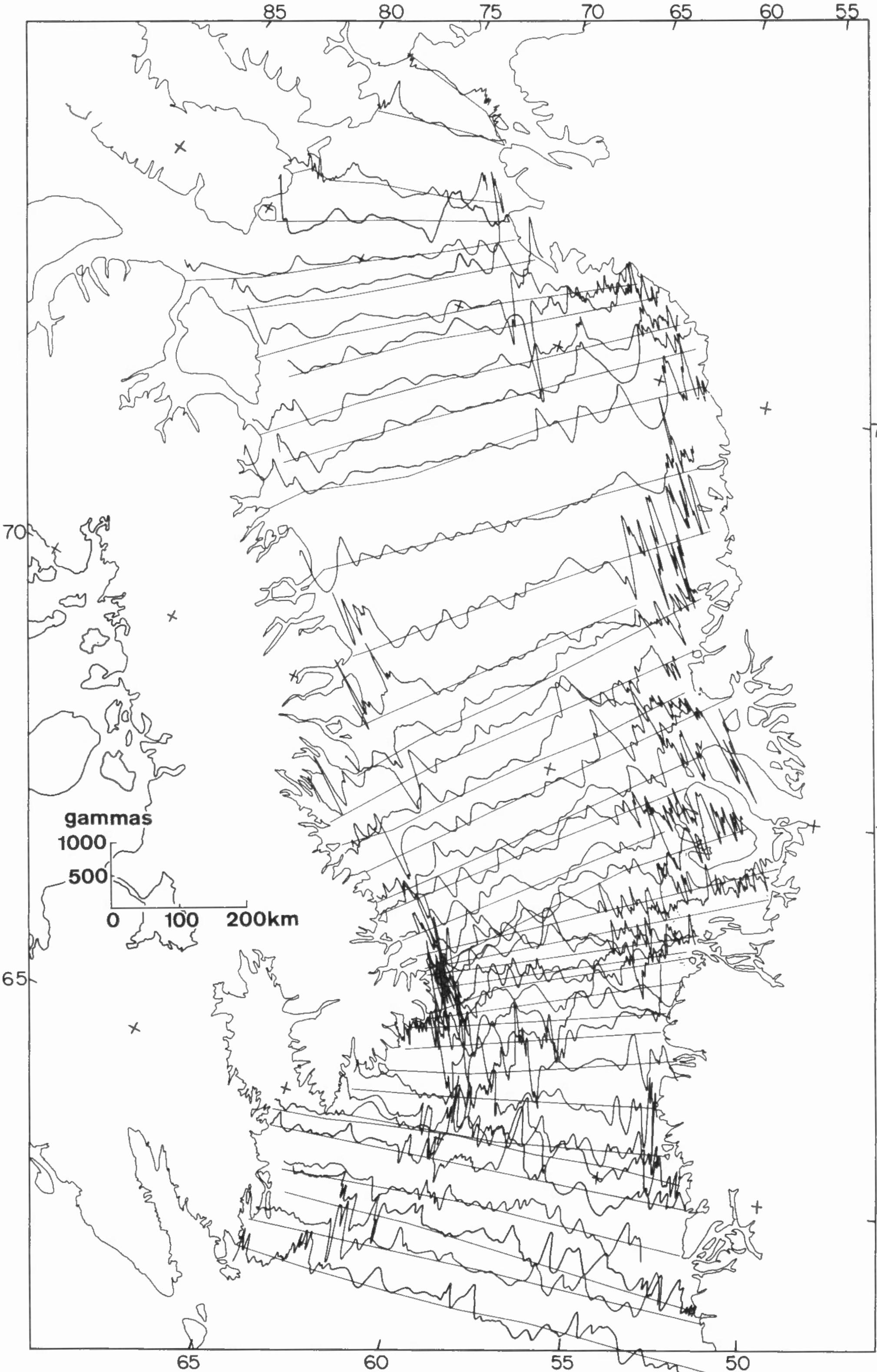



*Figure 3.4.* *Aeromagnetic profiles obtained in Baffin Bay and northern Labrador Sea by the North Star aircraft of the National Aeronautical Establishment in co-operation with the Geological Survey of Canada. The short wavelength anomalies produced by Tertiary basalt in the Davis Strait area produce a distinctive pattern. The U-shaped anomaly in the Melville Bay area of western Greenland reflects the presence of a sediment-filled graben which runs parallel to the Greenland coast (from Hood, P. and M.E. Bower, 1975, Canadian Society of Petroleum Geologists, Memoir 4, p. 433-451).*

instrument for monitoring sediment processes on the seafloor. The Centre has collaborated with many other agencies in a variety of developments, mentioned elsewhere in this report. Data-base systems have been developed for palynology, of various sorts, and for management of potential field and bathymetric data. Huntec ('70) Ltd. have developed a deep-towed high resolution seismic system and real-time acoustical analytical programs for mapping the surficial sediments of the seafloor; this has been done under contract to the Government of Canada, with the Scientific Authority at the Centre, and with funding from several agencies.

*Resource Geophysics and Geochemistry Division, Ottawa.* Staff from this Division contribute to seismic studies of permafrost, ice-bonded sediments and gas hydrates, particularly in the Beaufort Sea, where they work closely with the Atlantic Geoscience Centre and the Earth Physics Branch. From time-to-time the Division runs low level aeromagnetic flights and surveys in the ocean basins contiguous to Canada (Fig. 3.4), as it did on the Lomonosov Ridge experiment, for example. Some of this work is done co-operatively with the National Aeronautical Establishment, who have a very well equipped aircraft. The division has compiled aeromagnetic data for all Canada north of 60°N. This includes water-covered areas, as well as the land; data provided by industry were important in this compilation.

*Terrain Sciences Division, Ottawa.* This Division has had a major influence on the Survey's marine programs because of the presence of a coastal and marine group, transferred recently to the Atlantic Geoscience Centre and the Pacific Geoscience Centre. The Division has the principal knowledge in the Survey of glacial processes and Quaternary stratigraphy, based on their work throughout Canada. Consequently, there is a lot of interaction with colleagues from the Pacific Geoscience Centre and the Atlantic Geoscience Centre where their work interacts (particularly in coastal regions); Terrain Sciences is undertaking a compilation of sea level changes and coastal uplift. The Division consolidates and co-ordinates a great deal of Quaternary geology in the Arctic, on behalf of the Branch. One scientist of the Division located in the Cordilleran Division, Vancouver, is involved in coastal studies on occasion.

*Institute of Sedimentary and Petroleum Geology, Calgary.* This Division of the Survey has the responsibility for the rocks of Phanerozoic and Proterozoic age of the eastern part of the Cordillera, the Interior Plains, and Northern Canada. Consequently, this Division studies the bedrock and sub-surface geology of the Mackenzie Delta and the Beaufort Sea, and the Arctic Islands (Fig. 3.5) using industry wells as one of its data bases. The contributions are

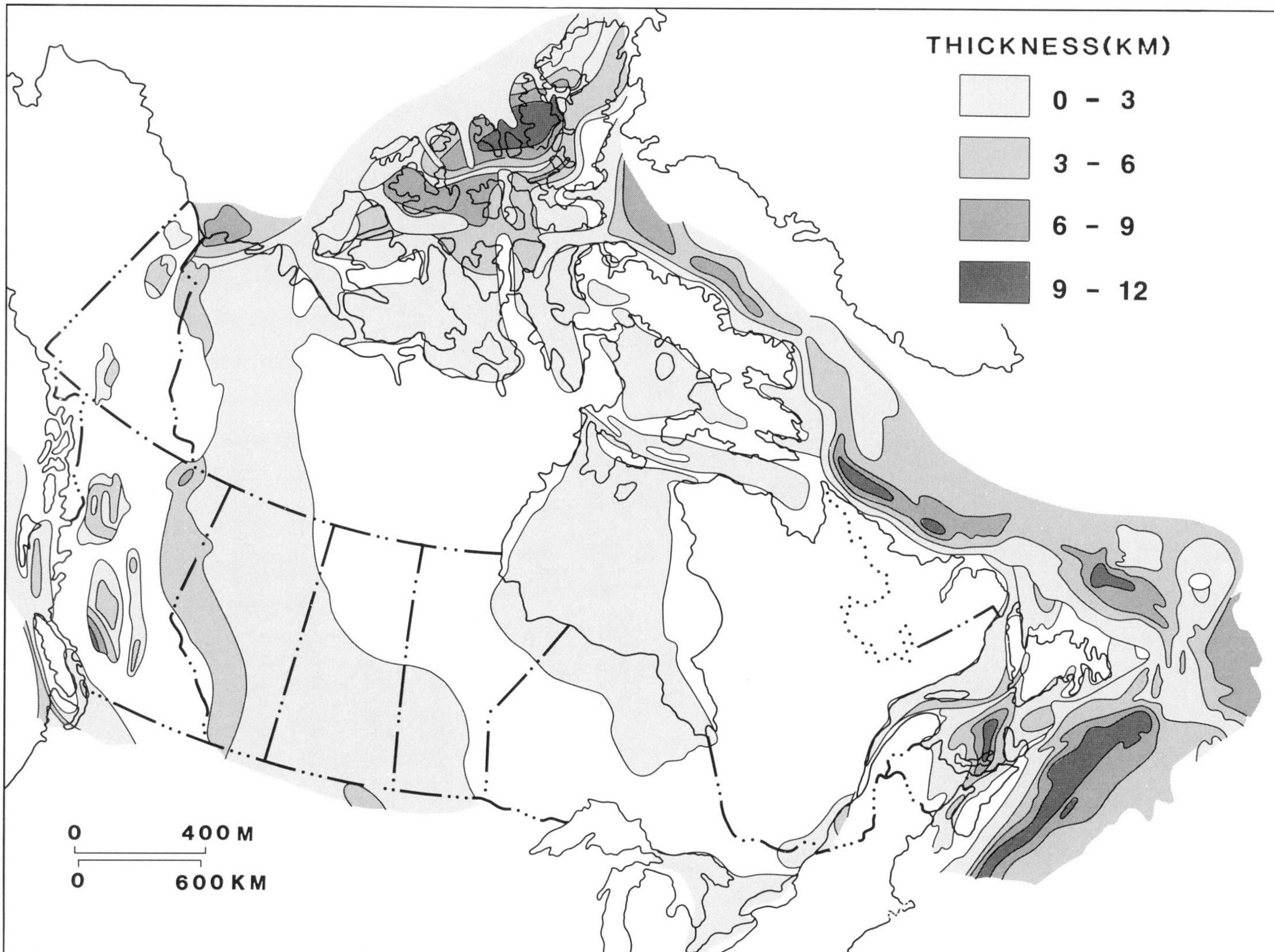



***Figure 3.5.*** *Distribution and thickness of sedimentary basins of Canada, onshore and offshore.*

similar to those of the Atlantic Geoscience Centre's from the point of view of the Mesozoic-Cenozoic sedimentary basins in the Arctic and offshore; for example, biostratigraphic studies, and geological syntheses. The Division has the principal responsibility in the Survey for organic geochemistry, and in this field deals with wells from all frontier areas – many of which lie offshore. It has the principal responsibility too for the hydrocarbon inventory program of Energy, Mines and Resources, discussed elsewhere. The Institute is the repository for samples and cores from wells north of 60°N administered by the Department of Indian Affairs and Northern Development, and from wells in the Pacific offshore, administered by Resource Management Branch of EMR.

*Earth Physics Branch*

The activities of the Earth Physics Branch in the marine geosciences are channeled through five national programs: gravity, geodynamics, seismology, geothermal, and geomagnetic, operating from the Ottawa Office or the Pacific Geoscience Centre.

*Gravity, Geothermics and Geodynamics Division.* This Division of Earth Physics Branch has the responsibility for the Federal government's gravity programs throughout Canada including the offshore (Fig. 3.6*). Operationally, the Division maps the gravity anomaly field over all marine areas of Canada except the east coast offshore which is mapped by the Atlantic Geoscience Centre. As part of this program the Division carries out research and development in hardware and software systems for acquisition and reduction of marine gravity data. In addition, the Canadian Gravity Standardization Net is maintained which provides datum and scale standards for land and marine gravity surveys and the National Gravity Data Base which provides gravity and related data to users in the public and private sectors both nationally and internationally. The data base is used also for in-house geodetic studies and for studies that contribute to an understanding of local geological features and regional geological frameworks in Canada and the offshore. The Division co-operates with a number of other organizations; in measuring gravity at sea, with the Atlantic Geoscience Centre; in measuring gravity from sea ice, with the Canadian Hydrographic Service (interested in bathymetry, needed for reduction and interpretation of gravity observations); in many Arctic operations, with the Polar Continental Shelf Project which provides logistical support. The Division played a leading role in the Lomonosov Ridge Experiment in the Arctic Ocean Basin (LOREX) and has initiated plans for the Canadian Expedition to Study the Alpha Ridge (CESAR) in 1983.

The Division undertakes a wide range of geothermal studies including a broadly based research program on the distribution and physics of permafrost phenomena and gas hydrates throughout the north including the offshore. Much of the fundamental research on the physics of permafrost phenomena is undertaken in co-operation with university groups under contract.

*Seismology and Geomagnetism Division.* The Division of Seismology and Geomagnetism has the responsibility within the Federal Government for the operation of the Canadian National Seismic Network, the determination of seismicity and the making of assessments of seismic risk in Canada, both onshore and offshore. Seismic studies of the crust and lithosphere are undertaken throughout the country, off the west coast, in the Arctic Islands and in the Arctic Ocean.

The Division is responsible for providing information on the direction and strength of the earth's magnetic field over Canada and adjacent waters (Fig. 3.7), for many applications including navigation and geophysical exploration. Magnetic information on current charts is based on three-component airborne surveys at a line spacing of about 50 km, conducted by the Division between 1969 and 1976, updated from land-based and satellite observations.

The Division studies the structure and history of the earth's crust not only through its magnetic properties, as revealed by magnetic anomalies and paleomagnetic evidence, but also through its electrical properties, as deduced from investigations of electromagnetic induction from natural geomagnetic variations. Time-varying magnetic fields, and recently, electric fields have been recorded on the ocean floor west of Vancouver Island, with instruments housed in the same spherical cases and deployed in the same way as the Branch's ocean bottom seismometers. Electromagnetic induction experiments have been conducted for many years from the sea ice of the Arctic Ocean, using unmanned recording stations deployed by aircraft. Recently, magnetotelluric observations were made as well on the Lomonosov Ridge Experiment, with excellent results. Magnetic gradiometers were also operated on this expedition, with one proton magnetometer at the surface and the second suspended 200 m below.

Both divisions are frequently involved in providing advice to industry and regulatory bodies on seismic risk and permafrost problems, and are active participants in the

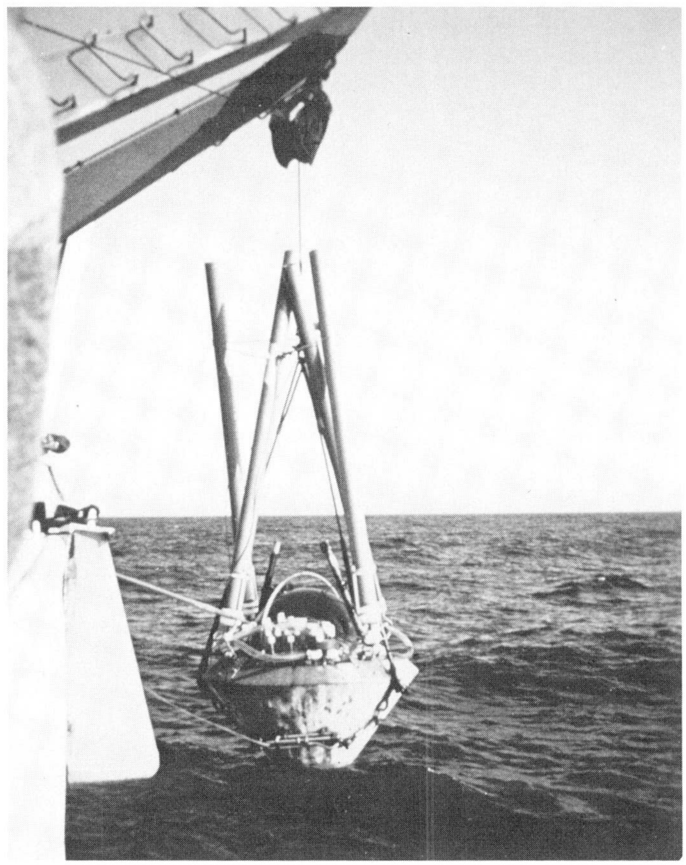


**Figure 3.7.** *Launching the Ocean Bottom Magnetometer. The instrument package is attached to a concrete anchor which retains it on the ocean floor until the recording period is over and the release mechanism is activated. After release the sphere floats to the surface for recovery by the survey ship. (GSC 203922)*

*See inside front cover.

reviewing of environmental impact statements associated with major development and construction projects onshore and offshore.

*Earth Physics Branch and the Geological Survey of Canada*

*Pacific Geoscience Centre*. The Pacific Geoscience Centre is one of the laboratories of the Institute of Ocean Sciences, Patricia Bay, Sydney, B.C. on Vancouver Island. (The Institute itself is described in the section on the Department of Fisheries and Oceans.) The Centre is made up of staff from the Earth Physics Branch, who form the Pacific Geophysics Division, and staff from the Cordilleran Division of the Geological Survey of Canada, who form the Pacific Marine Geology Subdivision. There is a total of about 42 staff members, including visiting scientists and visiting fellows; about 22 are scientific staff. Many facilities are shared with the laboratories of Fisheries and Oceans (who make up the largest part of the Institute), such as computer services, library, and ships. (The administrative arrangements differ in detail from those at Bedford Institute of Oceanography; this is not important here.)

The Centre is charged rather broadly with: the geology and geophysics of the continental margin of the west coast. However, this is also the centre for most of the work by Earth Physics Branch in the whole Cordillera. At sea, staff from the Centre work off the west coast, in the Beaufort Sea, and from time-to-time take part in major expeditions such as LOREX.

The programs of the Centre in the marine geosciences include the following:

*Resource Charting*. Working with the Canadian Hydrographic Service over the past seven years, there have been systematic marine surveys off Canada's west coast of magnetic field, gravity field, seismic profiling and associated bathymetry. The line spacing has been approximately 5 km over the continental shelf and 10 km over the deep ocean, except for the seismic profiles which are at a larger spacing. All shelf areas and deep water areas to 100 nautical miles from the outer coast have been completed. The survey to 200 nautical miles (370 km) should be completed by 1985. A similar program in the Beaufort Sea and Amundsen Gulf has been completed.

*Offshore West Coast Seismicity*. As part of the programs directed at the seismicity of western Canada, a significant effort is made to study earthquakes in the highly active zones just off the coast. The offshore events on the Juan de Fuca ridge system faults and the Queen Charlotte fault zone are monitored, located and studied using both the permanent land array of seismograph stations in western Canada, and by temporary arrays of ocean-bottom seismographs. A major program to accurately determine epicentres and other parameters using a telemetred seismic array is operated in the Vancouver Island area. The onshore and offshore programs contribute information on the tectonic regime along the western margin, because along the coast the dynamic process is continuous from the ridge crests offshore to several tens of kilometres inland.

*Detailed Studies of the Tectonic Framework*. An average of one or two offshore cruises each year are directed toward detailed study of some area that is important to the understanding of the plate tectonic framework of the eastern Pacific Ocean. Studies include seismicity, magnetics, gravity, seismic profiling, heat flow, seismic refraction, etc. Recent investigations have included the Winona Basin, the Queen Charlotte fault zone and the margin subduction zone.

*Geological Structure of the Continental Margin*. Detailed geological studies are carried out along the margin beneath the continental shelf and adjacent deep sea floor through analysis of single and multichannel seismic profiles, wildcat petroleum well data, and through other geological and geophysical data. These studies have been complemented by geological mapping using the submersible **Pisces IV** and by mapping on land, notably on the Queen Charlotte Islands. The work includes studies of the biostratigraphy of the Mesozoic and Cenozoic offshore and onshore. The concepts being developed concerning the allochthonous terrains of the margin have a major bearing on petroleum possibilities off the west coast. A major geological study of the Georgia depression will begin in 1982.

*Continental Shelf Surficial Geological Mapping*. A program of continental shelf surficial geological mapping has continued over the past four years with grab samples being described and analyzed for sediment dynamics, sediment texture, organic carbon and nitrogen. This sampling program is complemented by observations with the **Pisces IV** submersible, by bottom photography and by seismic and side-scan profiles.

*Inlet Sedimentation*. 3.5 kHz subbottom profiling, seismic profiles and side-scan profiles along with gravity cores have been used to study the sedimentary structure and sedimentation processes in the inlets or fiords of the west coast of Canada. Special detailed studies have been carried out where industrial development exists or is proposed.

*Coastal Geology*. An inventory is being made of the coastal types along the British Columbia coast, through existing maps, air photographs and ground mapping. Detailed geomorphological studies are being carried out in areas of Strait of Georgia, Juan de Fuca Strait and Hecate Strait.

*Delta Sedimentation*. A comprehensive study has been carried out of the sediment distribution and sedimentary processes of the Fraser River Delta. Of particular concern are changes to the hydrodynamic and sedimentological environment caused by past and proposed industrial development. This includes ground mapping, cores and other samples, air photographs and current meter data. Studies have been initiated on several other deltas where industrial development is proposed.

*Offshore Seismic Refraction*. A seismic refraction program of the offshore crustal and upper mantle structure has been carried out about once each year, working with the University of British Columbia's Department of Geophysics and Astronomy. The programs have been directed at the structure beneath the deep sea and across the margin from the deep seafloor to the continent.

*Marine Geothermal Studies*. A program of offshore geothermal heat flow measurements using the ocean probe technique has continued for several years directed mainly at the deep thermal structure of the Juan de Fuca ridge system. The radioactive heat production of bottom samples has been determined using a gamma ray spectrometer. The marine heat probe technique has also been employed extensively in the deep west coast inlets. These data complement the conventional land borehole data available for determining regional variations in heat flow and evaluating the geothermal energy potential of western Canada.

*Geomagnetic Induction Studies.* Self-contained deep ocean bottom magnetometers and electric field recorders have been developed and operated over short periods during the past five years to determine the deep electrical structure of the oceanic crust and upper mantle. The data have proved to be very valuable for determining the age dependence of the thickness of the lithosphere. The offshore recording has also been combined with simultaneous onshore recording to determine the deep electrical structure across the continental margin.

*Polar Continental Shelf Project*

The Polar Continental Shelf Project is a Branch of the Earth Science Sector of EMR. Its objective – one of the sub-objectives of the Earth Science Services Program, through which it is funded – is: "To contribute to the orderly scientific investigation of Canada's polar continental shelf, the contiguous Arctic Ocean and mainland regions and to maintain and improve the logistics required for scientific investigations in an Arctic environment". The Project is described as: "The study of scientific problems unique to Arctic Canada and the provision of co-ordinated logistic support to public and private sector groups conducting scientific studies in the Arctic; the provision of information about scientific operations in the Arctic to the scientific community and to the local inhabitants".

The Project has contributed significantly to the marine geosciences in its studies of sea ice. The Sea Ice Atlas produced recently is an example; volumes covering 1961-1974 have been published, and the volume for 1975-1978 will be published in 1981. However, its greatest contribution is the organization and logistical support it contributes to the Arctic programs of other organizations; this is a vital service. The Project supports many Arctic programs: the universities; Fisheries and Oceans, including the Canadian Hydrographic Service; Geological Survey of Canada; Earth Physics Branch; Canadian Wildlife Service; Freshwater Institute, Winnipeg. The type of support provided includes: establishment of navigation systems for work offshore; charter and provision of aircraft and helicopters; establishment of field camps; maintenance of bases at Resolute Bay and Tuktoyaktuk each field season. The Project carries out an important liaison function with the native people of Canada.

The Project provided the major logistical support for the Lomonosov Ridge Experiment, and will do the same in the Canadian Expedition to study the Alpha Ridge in 1983.

*Surveys and Mapping Branch*

This Branch has an important role in service to the marine geosciences, and in regulating positioning offshore. Two of the Branch's sub-objectives are: "To ensure the availability of geodetic information concerning the Canadian landmass based on international standards and national criteria for geodetic reference systems"; "To ensure that surveys of Canada lands are executed and preserved in accordance with the Canada Lands Surveys Act and other existing statutes and regulations; to ensure the integrity of the boundary between Canada and the United States". The Surveyor-General is responsible for approving plans for positioning proposed by a company engaged in exploration offshore, under the Canada Lands Surveys Acts. The Branch establishes geodetic control onshore. One program of the Branch is of direct interest to earth scientists; geodetic control has been established across Nares Strait between Canada and Greenland. A survey in years to come may establish directly whether or not there is crustal motion now along the feature.

The Branch co-operates with many others; it prints general bathymetric charts for the Hydrographic Service; base maps are provided at appropriate scales for coastal mapping; advice is given on appropriate scales and projections for maps for a whole host of purposes.

**Research and Technology Sector**

*Canada Centre for Remote Sensing*

The Canada Centre for Remote Sensing is the nucleus of a national program in remote sensing which is introducing this relatively new technology into established research management and environmental monitoring agencies in Canada.

The Centre operates under the guidance of the Inter-Agency Committee on Remote Sensing, on which sit representatives of appropriate departments of the Federal Government and the general public. This Committee co-ordinates the national efforts in conjunction with the working groups of the Canadian Advisory Committee on Remote Sensing. There are thirteen working groups representing the disciplines which support or use techniques of remote sensing; of particular interest here are the working groups on: geoscience; water resources; oceanography; ice. The activities of the Centre are concentrated on earth resource satellite programs (LANDSAT), airborne research sensing programs, and applications programs. The facilities available include two receiving stations (Shoe Cove, Newfoundland and Prince Albert, Saskatchewan), four aircraft with a variety of sensors, and equipment for image processing and analysis.

There have been a number of programs interesting to marine geoscientists. We give several examples. (1) LANDSAT imagery was successfully used to estimate suspended sediment concentrations in the basins of the Bay of Fundy; because of extremely high tides, and strong currents, leading to sediment concentrations in the water changing with time, "normal" shipboard sampling programs would have been inadequate. (2) Ice reconnaissance, using LANDSAT images and airborne Synthetic Aperture Radar. This is devoted to iceberg movements, studies of multiyear ice, detection of pressure ridges and the movement of ice in general. Icebergs which are a good deal smaller than the nominal resolution of LANDSAT (80 m) can be detected in open water. (3) Oil seeps off Scott Inlet, Baffin Island were successfully mapped using laser fluoro-sensors and television systems working at low light levels. (4) Airborne hydrography.

There are several proposals for future advances. (1) Canada is negotiating with France for access to the data from its satellite "Spot"; (2) Canada is proposing a major program for our Synthetic Aperture Radar, for incorporation in satellites proposed by NASA or the European Space Agency; (3) A third possibility is that Canada builds its own satellite. A major application of future programs involving Synthetic Aperture Radar would be ice reconnaissance in the Arctic.

The USA will be launching a new satellite LANDSAT-D in 1982, which will have higher spectral and spatial resolution than LANDSAT 1, 2 and 3. Canada will participate in acquiring data from this satellite, which will require a major investment because of increased data rates.

*Canada Centre for Mineral Technology*

"CANMET" has little active participation in the marine geosciences. However, the expertise of its staff extend to problems of welding underwater and to considering sources of silica sand from the offshore, needed in foundries.

## Canada Oil and Gas Lands Administration

Canada Oil and Gas Lands Administration, COGLA, is responsible to two departments, Energy, Mines and Resources and Indian Affairs and Northern Development, for management of hydrocarbon resources on all federal lands – those of the Northwest Territories and the Yukon, and the Canadian offshore. The Administration's responsibilities are somewhat intertwined with three other departments (in addition to EMR and Indian Affairs and Northern Development) – Environment Canada, Transport Canada and Fisheries and Oceans. The Department of the Environment has the responsibility for: matters concerned with the quality of the environment where Canada has jurisdiction and which are not assigned to other departments; responsibility for environmental emergencies to see that proper mechanisms are in place, and that appropriate environmental advice is received by an on-scene commander in an emergency (who, offshore, will be from COGLA, or the Department of Transport); the Department is responsible for weather services. The Department of Transport has regulatory responsibility for clean-up of pollution which comes from vessels; COGLA takes the lead role in problems which may result from wells offshore. Fisheries and Oceans have the major responsibilities for research and surveys in physical, chemical and biological oceanography (and many other matters, naturally). The potential problems which overlapping "jurisdictions" could lead to are addressed by appropriate interdepartmental agreements, committees, and close contacts at working levels. As an example, there is agreement between COGLA and the Department of Transport that in the event of an oil spill from an oil tanker the on-scene commander will be selected by Transport, but in the event of a blow-out from an offshore well, by EMR; in the latter case, Transport will provide water-borne clean-up and expertise to EMR. Scientific advice is provided by a variety of agencies if an emergency arises. For example, a team from Bedford Institute of Oceanography is established to advise on oceanographic matters; the team is organized by Ocean Science and Surveys of the Department of Fisheries and Oceans, and includes staff from the Geological Survey of Canada of EMR to provide advice and information concerning the coastal regime.

COGLA naturally plays a substantial role in the Federal Environmental Assessment and Review Process, which is described elsewhere. However, quite apart from this formal process, the Administration encourages companies planning developments offshore to make proper environmental studies. Consequently, initial environmental evaluations are encouraged at early stages of planning; examples of such work are: the assessment of delineation drilling in the area of Sable Island (Mobil), and an initial environmental evaluation of the Labrador Shelf (Petro-Canada).

COGLA has five Branches. (1) Land Management – distribution and management of Canada lands; petroleum interests and condition of tenure, etc., (2) Engineering and Control Branch – regulation and safety of offshore operations, (3) Resource Evaluation Branch – resource appraisals, in conjunction when appropriate with the Department Oil and Gas Appraisal Program, (4) Environment Protection Branch – environmental safety connected with hydrocarbon development on Canada Lands, (5) Canada Benefits Branch – to ensure that hydrocarbon developments benefit the nation in their utilization of goods, services and people.

COGLA maintains small units in Dartmouth (Bedford Institute of Oceanography), and in St. John's. Most of the Administration are in Ottawa.

The proper management of geological samples and geophysical data provided by companies is most important from the point of view of geological and geophysical research in the offshore. COGLA maintains curation facilities at Bedford Institute of Oceanography, and facilities for public examination of material which has to be supplied by companies working in the offshore. This material comes from wells on the federal lands in the Atlantic offshore, the Hudson Bay and Hudson Strait regions and the eastern Arctic offshore. A similar facility for materials from the Pacific offshore, from lands in the remainder of the Arctic, and in the east coast offshore is maintained in Calgary by the Geological Survey of Canada.

We should note here that much of the scientific data used by COGLA are provided by industry. The organization could not carry out its mandate but for the excellent quality of these data.

## Department Oil and Gas Appraisal Program

The Government of Canada needs appraisals of the nation's oil and gas resources so that energy policies can be properly formulated. Many of the nation's potential resources lie offshore, and so the program may be of interest to marine geoscientists.

The Petroleum Resources Appraisal Panel is a panel of senior officials representing those who need information on resources offshore – for economic projections, for example, and those who can supply it. The information on offshore resources is provided by the Petroleum Resources Appraisal Secretariat, whose headquarters are at the Institute of Sedimentary and Petroleum Geology of the Geological Survey of Canada in Calgary.

The Secretariat is served by geologists and geophysicists from the Geological Survey of Canada (Atlantic Geoscience Centre, and the Institute in Calgary), and Canada Oil and Gas Lands Administration, Ottawa. They will work initially individually, but meet in due time as a committee of scientists to discuss their individual results. The data base which is used by the scientific staff is a mixture of confidential geological and geophysical data provided by industry (available only to the scientists involved in the appraisal exercises), and data provided by scientific staff of the government agencies themselves. The industry data will include, for example, multichannel seismic data acquired in the course of exploration, and well-logs. The government agencies' own data will range from geochemical analyses pertaining to maturation, to biostratigraphic syntheses.

We must not neglect here the very important role which is played by the government agencies' scientific staff who in the course of their own work provide information and ideas without which appraisals would be difficult to do. As an example, the individuals conducting appraisals of prospects need biostratigraphic and lithostratigraphic analyses. Without the scientific base, the appraisals cannot be done. Biostratigraphy and lithostratigraphy in their turn rest on other good science – good taxonomy, advances in quantitative biostratigraphy, and advances in seismo-stratigraphy; and the regional geology cannot be well done without an understanding of the behaviour of the lithosphere, vertically during subsidence, horizontally during ocean-floor spreading.

## *Department of Fisheries and Oceans*

The Department of Fisheries and Oceans has a large impact on the geological and geophysical activities offshore of many organizations from government, industry and university, for a variety of reasons. (1) The Department's program specifically includes: "...promotion and support of international co-operation on the study and use of the ocean, seabed, and resources thereof, and international efforts to deal with marine environmental problems; conduct of hydrographic and other types of coastal and oceanic surveys directed towards the production of navigation, resource and recreational charts ...systematic survey and chart production of coastal and inland navigable waters and mapping of the offshore waters." One consequence of this is that the Department has the principal national representation on major international oceanographic bodies, many of which deal (in part) with geological and geophysical matters. A second, more obvious consequence, is the Department's programs in hydrographic charting, nearshore and offshore, and all geologists and geophysicists need to know the shape of the seafloor. (2) The Department operates the nation's two major oceanographic institutes which support directly and indirectly the work of other federal departments such as EMR, industry, such as the petroleum industry and high-technology companies, and university staff and students. Fisheries and Oceans owns and operates the vessels at Bedford Institute of Oceanography, the Institute of Ocean Sciences, Patricia Bay, and Canada Centre for Inland Waters, Burlington. (3) The Department's own scientific and technological activities are often directly related to the earth sciences. There are many examples of this, ranging from the purely practical to the purely scientific.

For example, scientists concerned with hydrocarbons in seawater, establishing base levels perhaps, have participated in studies of natural marine oil seeps such as those off Baffin Island. The Department's scientists and engineers played major roles in side-scan development, rock core drills and navigation.

These inter-relationships can be described by giving accounts of the institutes, and of programs which affect the earth sciences.

**Bedford Institute of Oceanography, Dartmouth, N.S.**

The Institute is a group of laboratories from three federal departments: Fisheries and Oceans: Marine Fish Division (fish stock assessment), Atlantic Oceanographic Laboratory (physical and chemical oceanography), Marine Ecology Laboratory (biological oceanography), Canadian Hydrographic Service, Atlantic (navigational and offshore charting), Institute Facilities (major services, including ships, computers, library, engineering facilities); Energy, Mines and Resources: Atlantic Geoscience Centre, Maritime Office of COGLA; Department of Environment: Environmental Protection Service – Atlantic Regional Laboratories, Environmental Conservation Service – Canadian Wildlife Service. There are about 700 staff members at the Institute. Major vessels such as **Hudson, Baffin** and **Dawson** operate out of the Institute, and there are smaller vessels such as the **Maxwell** and a variety of launches.

The laboratories at the Institute make a very real – surely successful – attempt to work as an Institute in spite of belonging to different departments with different reporting systems and different budgeting systems. This is accomplished by appropriate formal arrangements, shared facilities, joint work, and close liaisons at working levels.

The formal arrangements are: the Bedford Institute of Oceanography Director's Committee, and the Management Committee of the major scientific and technical laboratories of Fisheries and Oceans; the Director of the Atlantic Geoscience Centre sits on both. The principal laboratories of the Institute share many of the major facilities – ships, computers, and library, which are funded mainly by Fisheries and Oceans, on behalf of all the laboratories, including the Atlantic Geoscience Centre. There are several sorts of joint work. A major program exists between the Canadian Hydrographic Service, Atlantic and Atlantic Geoscience Centre for bathymetric (Fig. 3.8), geological and geophysical surveying offshore – the multiparameter survey program. A joint program has operated in the Bay of Fundy, to share logistical support, and to take advantage of expertise available in several different laboratories.

The Institute serves industry and universities in several ways. (1) Shiptime is provided to universities; assistance is provided in supervision of graduate students, with mutual benefit. (2) Advice is provided to industry on a variety of problems. As an example, the Institute took the lead in Canada in the use of satellite navigation systems at sea, and in integrated navigational systems. This expertise was at times developed jointly with industry, for example when satellite navigation was first used for geodetic surveying on land, and industry has been actively encouraged to use the integrated navigation system. (3) High technology companies make use of the expertise at the Institute in research and development; for example, under the Seabed contract Huntec ('70) Ltd. is providing a broadband, high-resolution, deep-towed seismic system for seafloor mapping, and the geological and technical expertise of numerous staff at the Institute have contributed to this. An industrial liaison office – Bedford Institute of Oceanography Marine Industrial Liaison (BIOMAIL) has recently been established to help with industrial problems.

**Institute of Ocean Sciences, Patricia Bay, B.C.**

This Institute is also a complex of laboratories from three departments. Fisheries and Oceans: Ocean Ecology, Ocean Chemistry, Ocean Physics, Canadian Hydrographic Service (Pacific), Ship's Division; Energy, Mines and Resources: Pacific Geoscience Centre; Department of Environment: Atmospheric Environment Service, Canadian Wildlife Service. The major vessel **Parizeau** and the smaller vessels **Vector** and **Richardson** operate from the Institute. The vessel **Pandora II** is on charter, as an Arctic survey vessel, and tender to the submersible **Pisces IV**. The **Radium Express** is also on charter. (The vessel **Endeavour** is owned and operated by the Department of National Defence, but is a part of the west coast ships' "pool".)

The Institute of Ocean Sciences also, like Bedford Institute, tries to work as an institute, in spite of the different departments involved. The Director of the Pacific Geoscience Centre is a member of the management committee. The laboratories all share major facilities – ships, computers, library, etc. There are several sorts of joint work. The Canadian Hydrographic Service, Pacific, and the Pacific Geoscience Centre engage in joint multiparameter surveys for bathymetry, gravity and magnetics, off the west coast, and with staff of Energy, Mines and Resources from Ottawa, in the Beaufort Sea. There are several joint programs between Fisheries and Oceans and the Pacific Geoscience Centre. One example of this co-operation is the study of the fluctuations of the magnetic fields on the continental slope. Recent measurements with an ocean bottom magnetometer and current meters have shown that the fluctuations observed in the magnetic field are caused both by electric storms in the atmosphere and the water movements associated with edge waves. As far as is known, this is the first time that water movement has been detected with an ocean bottom magnetometer, and it has stimulated a joint investigation of the effect by oceanographers and geophysicists.

Like Bedford Institute of Oceanography, the Institute at Pat Bay serves industry and universities. The Institute at Patricia Bay, founded at a later date, was established with the objective of bringing together the various components of ocean science and ocean technology of the Federal Government scattered throughout the west coast. An Ocean Information Service has been established to provide oceanographic information to industry and an industrial park


NORTH POLE
ARCTIC OCEAN
UNION OF SOVIET SOCIALIST REPUBLICS
CHUKCHI SEA
QUEEN ELIZABETH ISLANDS
BEAUFORT SEA
ALASKA
(UNITED STATES OF AMERICA)
YUKON
ELLESMERE
ISLAND
Banks Island
Melville Island
Devon Island
Somerset Island
Southampton Island
AMUNDSEN GULF
VISCOUNT MELVILLE SOUND
VICTORIA ISLAND
YUKON TERRITORY
NORTHWEST TERRITO
DISTRICT OF MACKENZIE
DISTRICT OF KEEWATIN
GREAT BEAR LAKE
GREAT SLAVE LAKE
GULF OF ALASKA
PACIFIC OCEAN
QUEEN CHARLOTTE SOUND
VANCOUVER ISLAND
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTAR
HUDSON BA
EDMONTON
CALGARY
SASKATOON
REGINA
WINNIPEG
Lake Winnipeg
Lake Nipigon
VANCOUVER
SEATTLE
SAN FRANCISCO
LAKE SUPERIOR
LAKE MICHIGAN
MINNEAPOLIS ST. PAUL
MILWAUKEE
CHICAGO
UNITED STATES

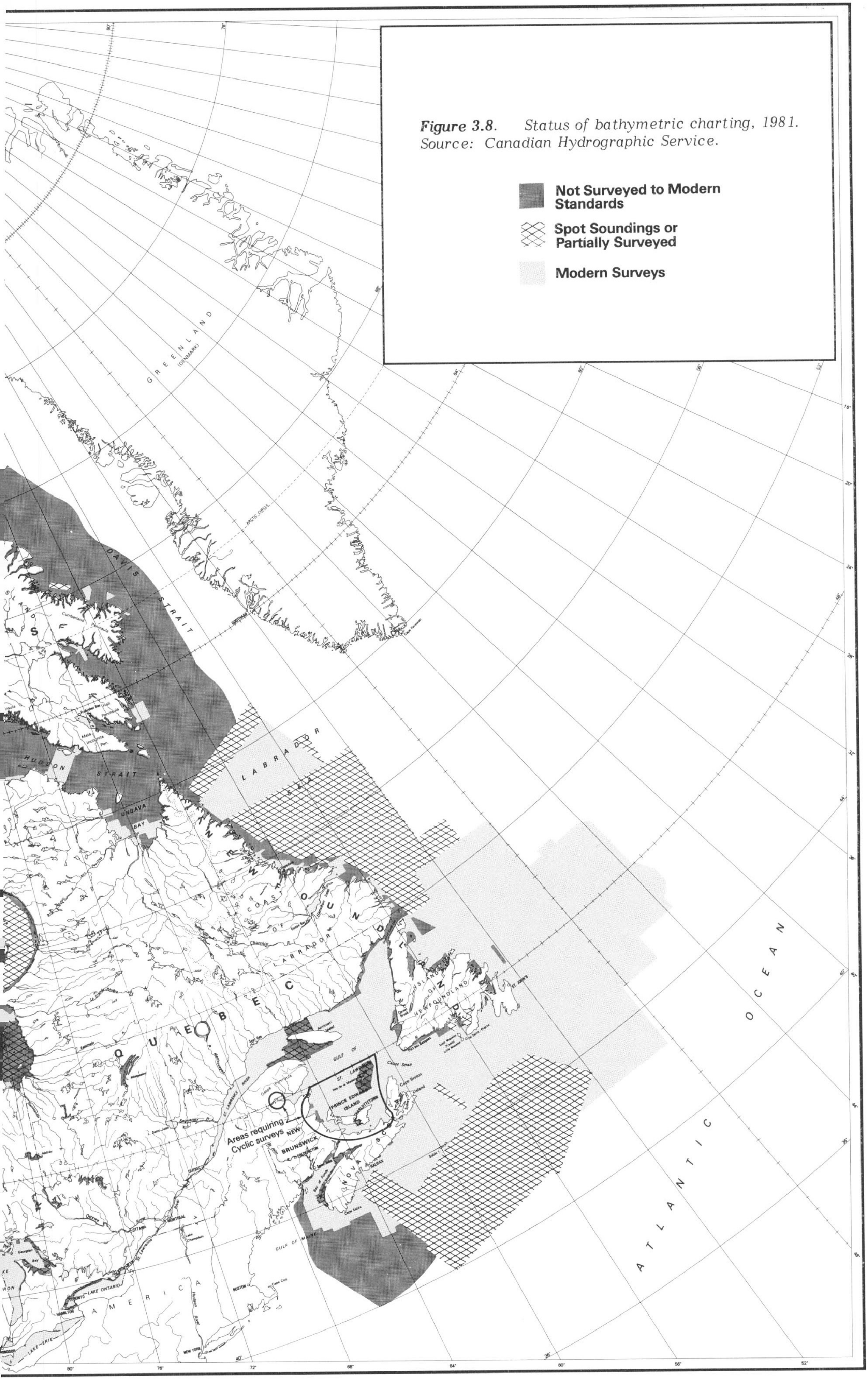



*Figure 3.8.* Status of bathymetric charting, 1981.
*Source:* Canadian Hydrographic Service.

to service ocean and marine industry is under construction by the British Columbia Development Corporation, with the assistance of the Institute.

The two problems of real significance to both institutes – and so to all marine research workers in Canada are: inadequate resources or unstable resources for running ships, and lack of resources for major instrumentation. The costs of running ships so dominate the budgets of the institutes that any difficulties in ship funding have profound effects on all other operations. Charting for safe navigation, offshore geological and geophysical surveys, and scientific experiments – including those planned jointly with industry, are all proceeding at far too slow a pace. There are a number of major instruments which should be available as national facilities, but which do not exist in the country at all. These include long-range side-scans and multibeam sounding capability. There is no capability for multichannel seismic work in any academic or government institution.

The problem of costs of funding ships arises principally because of increases in fuel prices; marine diesel fuel delivered at Bedford Institute of Oceanography cost $107 per tonne in 1976, $165 in 1979, and $225 in 1980. Estimates for 1981 range from $300-$400, and for 1982, from $350-$450. The effects of these increases over the three fiscal years 1979-80 to 1981-82 for the Pacific, Ontario and Atlantic regions of Ocean Science and Surveys of Fisheries and Oceans are as follows. In 1979-80 the cost of diesel fuel for all vessels in these regions was $1 332 000 and the same quantity will cost an additional $1 114 400 in 1981-82. Increases in the budget of Ocean Science and Surveys were allowed for the first time in 1981-82 to cover these increases in costs. As far as is known now, this will be true for the 1982-83 year. However, no funds will be available to charter vessels in the 1982-83 year, the first time for many years. Adequate and stable funding is a necessity.

**Canadian Hydrographic Service**

The Canadian Hydrographic Service is important to all marine geoscientists. The Service engages in field hydrography and chart production; nautical geodesy, observations of tides, chart production and instrument development. It has made significant advances in navigation, in sounding through ice; its official charts are recognized as the basis for defining the limits of offshore Canadian jurisdiction. As a consequence the Service interacts with a variety of other federal agencies, particularly from Energy, Mines and Resources, and the Department of Transport. The Service is divided into several regions; Headquarters, Ottawa; Atlantic – at Bedford Institute of Oceanography; Central – at Canada Centre for Inland Waters; Quebec – at the Gare Maritime Champlain, Quebec; and Pacific – at the Institute of Ocean Sciences, Patricia Bay.

We can single out a number of activities which are important to marine geoscientists.

*Multiparameter Surveys*

The Canadian Hydrographic Service undertakes a program of mapping offshore with Energy, Mines and Resources; various aspects of this have been discussed already under the section devoted to EMR. Until recently this program usually included only bathymetry, gravity and magnetic fields, and on the west coast single-channel seismic profiling, but in 1980 this program was expanded on the east coast to include some single-channel seismic reflection profiling, high-resolution reflection profiling, and side-scan sonar. This was done by surveys in the Davis Strait and on the Labrador Shelf (at the expense, because of slower speeds, of the number of line miles). These programs are conducted by the Canadian Hydrographic Service in co-operation with the Atlantic Geoscience Centre, the Pacific Geoscience Centre, and the Ottawa divisions of Earth Physics Branch.

*Arctic Hydrography and Gravity*

The Central region of the Canadian Hydrographic Service co-operates with the Earth Physics Branch in programs in ice-covered waters, where it is sensible from the point of view of logistics, and necessary from the point of view of gravity, to make observations of depths and of gravity at the same stations, in the same field program. Much of this work is funded by the Polar Continental Shelf Project, which supplies helicopters and Twin Otter aircraft.

*Geoscience Mapping and the General Bathymetric Chart of the Oceans*

A unit in Ottawa is responsible for producing the bathymetric maps for the Canadian offshore at scales of 1:250 000, 1:1 000 000, and 1:2 000 000. These also form the bases for the gravity and magnetic maps at the same scales. Offshore bathymetric data are acquired from industry and from government agencies working offshore which are incorporated in the Service's bathymetric data base after appropriate checks on quality.

The unit has a substantial responsibility for the series of world ocean bathymetric maps at a scale of 1:10 000 000 called "the General Bathymetric Chart of the Oceans" (GEBCO). A Commission of geoscientists and hydrographers representing the International Oceanographic Commission (IOC) and the International Hydrographic Organization (IHO) supervises the production of this series. Individual scientists are responsible for interpreting the bathymetric data available for individual maps. The whole series is being drafted by the Hydrographic Service, and is being printed by Energy, Mines and Resources. The next complete edition, the fifth, will be complete in 1982.

The programs undertaken in the multiparameter surveys and in Arctic hydrography and gravity, the work of the geoscience mapping unit and a number of other programs are reported to, and where necessary co-ordinated by the Guiding Committee on Offshore Surveys; this Committee has members drawn from Energy, Mines and Resources, and Fisheries and Oceans.

*Nautical Geodesy*

A bank of horizontal control data is being developed with EMR, so that a new datum can be adopted in 1983. This unit and the regional offices of the Service are responsible for the calibration of the LORAN-C system, so that the correct lattices can be applied to navigational charts. Such work includes applied research in the propagation velocity of ground waves at 100 kHz over varying terrain.

*Instrumentation*

The Service has been a leader in the use of satellites for navigation, and in the development of "integrated" systems of navigation – in which all navigational data are adjusted to provide "best" positions, speed and course. Good navigation is vital, naturally, in measuring gravity from surface ships. The Service has also been a participant in the work of the Seabed contract with Huntec, and in developments with side-scan sonar.

*Permanent Water Level Gauging Network*

Changes in water levels are interesting to the oceanographer on the one hand, in tidal analysis for example, and the geologist and geophysicist on the other, concerned with vertical crustal movements. The Service maintains the permanent Canadian network for water level gauging, in co-operation with the Inland Waters Branch of the Department of Environment. The Service conducts analysis of tidal data and predicts future tidal heights, published in the form of Tide Tables. The tidal group at Bedford Institute of Oceanography has a modest program in the measurement and analysis of the tide in the deep ocean, in addition to the tidal work being done on the continental shelves. Future work in this area will consist of mapping the tide in the more northerly areas of the Canadian continental shelf and participation in the measurement of the deep ocean tide with the Institute of Oceanographic Sciences at Bidston, U.K.

***Department of the Environment***

Several Programs or components of this Department are pertinent to the marine geosciences: the Environmental Services Program; Parks Canada; within the Administration Program, the Federal Environmental Assessment Review Office; and the Canada Centre for Inland Waters at Burlington.

**Environmental Services Program**

The objective of this Program is: to provide and undertake programs to protect and enhance the quality of the environment, and programs designed to improve the management and sustained economic utilization of the forest, wildlife and inland water resources of the nation. Sub-objectives include: to promote the quality, management and use of inland water resources, and: to assist in the improvement of the quality, management and use of the land.

Several Services exist to implement this Program. They include Atmospheric Environment Service, Canadian Wildlife Service and Canadian Forestry Service; the two of greatest interest to the marine geosciences are the Environmental Protection Service, and the Environmental Conservation Service (formerly Environmental Management Service).

*Environmental Protection Service*

The Service is responsible for (among other things): "national and international air and water pollution control operations and measures for environmental protection from activities affecting whole ecosystems ... co-ordination of national response to environmental crises ... management of a regional structure for the operation of environmental protection programs". The Service is, in a sense, the control arm of Environment Canada, and it interacts with the marine geosciences in a number of ways.

The Environmental Protection Service, through the Environmental Emergency Program, has a national responsibility to prevent accidental spills of oil and other hazardous materials, to develop contingency plans for dealing with such spills, to develop new control and clean-up technology, and to maintain a national alerting and reporting network.

As part of the effort to fulfill the responsibility for technology development the Service has implemented projects which relate directly to marine geosciences. For example, the Service funded the first comprehensive review of the Canadian coastline. As part of the Arctic Marine Oilspill Program (AMOP), the Geological Survey of Canada was contracted to undertake studies of the coastal regimes of eastern Baffin Island and Labrador. The Service also manages an internally funded, government-industry project known as the Baffin Island Oilspill (BIOS) project which involves a series of coastal experimental oilspills on northern Baffin Island.

The Canada Centre for Remote Sensing, Energy Mines and Resources, has been funded through AMOP to develop and test aerial systems for the remote surveillance of oil slicks. As part of this effort, missions involving prototype systems were flown over the oil seep off Scott Inlet, Baffin Island, and during the bunker-C oil spill from the tanker **Kurdistan** off Nova Scotia.

The Environmental Protection Service administers the Ocean Dumping Act, and this affects other agencies of the Federal Government because they are called upon to advise.

Applications to dispose of potentially hazardous wastes at sea, be they mine tailings or dredge spoils from harbours, have to be approved by the Department of Environment under this Act, and the normal process involves other federal agencies who will be asked to comment on an application in areas of their expertise. A geochemist will be asked about cadmium levels, and a sedimentologist on problems of sediment transport, etc. We can use the Atlantic Geoscience Centre of the Geological Survey of Canada to obtain some idea of the work involved. The Centre reports on about 100 applications per year which are referred to it when geological or geochemical advice is needed. However, in association with this work for the Department of the Environment, the Centre monitors a dump-site in Chaleur Bay, and a former site of massive dredging for aggregate in Halifax Harbour. These are scientifically interesting studies in their own right, and doing the work means expertise is maintained which can be applied to other practical problems which will arise. Staff of the Geological Survey of Canada at the Pacific Geoscience Centre undertake comparable work.

*Environmental Conservation Service*

Two agencies in this Service are of interest to us – the Inland Waters Directorate, and the Land Directorate.

*Inland Waters Directorate.* The Water Quality Branch maintains both an ongoing sampling network and an analytical laboratory to enable it to report on ambient surface water quality. It also undertakes special regional water quality studies of interest to the marine geosciences (e.g. mapping of areas sensitive to acid rain phenomena, based largely on geological factors). Thus, information on the chemistry of water entering the ocean is available from this Branch. The Water Resources Branch maintains a cost-shared hydrometric and sediment data network with the provinces. It also undertakes special studies related to water quality variables and water levels. Data are, therefore, available from this Branch concerning the quality of water and sediments entering the ocean as well as tide levels and backwater conditions in estuaries. The Water Planning and Management Branch is involved in specialized water management programs, some of which incorporate marine geoscience variables. For example, the Flood Damage Reduction Program included flood routing and mapping studies, both of which vary with the geomorphology of the river. In addition, flooding problems in the Atlantic Region are heavily influenced by the effects of tidal action and ice jamming in the estuaries of some rivers. The Branch also carries out interpretive and other environmental assessment studies which involve marine geoscience elements (e.g. studies of the potential for groundwater in coastal areas).

*Lands Directorate*. In essence, the Lands Directorate advises the Federal Government on policy concerning the use of land. The Directorate interfaces with the marine geosciences in the coastal regime. As an example, the Atlantic Region Office is conducting an Ecological Land Survey of the coastline of Newfoundland from the beach to 2 km inland, to provide baseline information from which to predict the impact of any offshore oil spills. The information may also be used to assist in selecting sites for onshore facilities related to offshore activities. The Directorate is working with Mobil Canada Ltd. and the Province of Newfoundland in this project. Consideration is also being given to the feasibility of a computer-based Coastal Marine Environmental Information System using the Canada Lands Data System.

*Atmospheric Environment Service*

The Atmospheric Environment Service is, of course, Canada's national weather service. However, its concern with meteorology includes not only the physics, chemistry and dynamics of the atmosphere, but their effects upon the earth's surface. Consequently the Service is interested in the formation and movement of ice, and in climatology (pointing to examples of direct interest to earth scientists). The Ice Services program involves ice reconnaissance predictions of the formation and movement of ice in Canadian waters for periods of up to one year in advance, and consultation and advice on ice data to meet special needs, such as those of offshore energy developments. The Climate Service program provides a central focus for Canadian activities related to climate. These activities include those of the effects of man's activities on climate, and vice versa, the impact of climate on human activity. The Service, with related groups in Fisheries and Oceans, has the principal federal mandate for the Canadian Climate Program (which includes estimating the effects of $CO_2$, etc.).

**Federal Environmental Assessment Review Office (FEARO)**

This Office administers the Federal Environmental Assessment Review Process (EARP) which was established to ensure that: environmental effects are taken into account as early as possible in federal programs, projects and activities; environmental assessments are carried out before irrevocable decisions are made that could have an adverse effect on the environment; and the results of assessments are used in planning, decision-making and implementation. Federal agencies are obliged to screen their activities and, if it is found that an activity may have significant adverse effects, it must be referred by the agency to FEARO for a formal review by an independent panel. Federal projects are considered to be those that are initiated by federal departments and agencies, those for which federal funds are solicited and those involving federal property. Proprietary crown corporations and regulatory agencies are invited, rather than directed, to participate in the process.

The objective of FEARO is to establish an environmental assessment process within the Federal Government to ensure that: environmental effects are taken into account as early as possible in the planning of new projects, programs and activities; an environmental assessment is carried out for all projects, programs and activities that may have a significant effect on the environment; and the results of those assessments are used in planning, decision-making and implementation.

FEARO will consider offshore, nearshore, and estuarine activities which will entail geological studies.

**Parks Canada**

Parks Canada is entrusted with the responsibility of protecting nationally significant heritage places on behalf of Canadians. Its system of national parks includes some with a significant "offshore" component: Forillon, Quebec; Kouchibouguac, New Brunswick; Auyuittuq, Baffin Island; and the Pacific Rim National Park, Vancouver Island. Consequently Parks Canada is interested in these areas in the coastal regime – particularly in coastal land forms, for example, as a part of the representation of a variety of themes. Parks Canada is exploring the possibility of national marine parks – ranging from marine parks offshore with no component which is land, to parks like some of those existing now, where the major component is on land. The studies being made include considerations of geology and physiography, and of questions of ownership and potential conflicts in use. The Lancaster Sound Green Paper illustrates some of these problems.

**Canada Centre for Inland Waters, Burlington, Ontario**

This Centre provides facilities for several hundred research, technical and support staff, of whom a limited number are engaged in geoscience or directly related activities. These staff are drawn from two departments, Environment, and Fisheries and Oceans. The staff of the Department of Environment are drawn from the Environment Protection Service and Environment Conservation Service; within the latter Service many staff belong to the National Water Research Institute of the Inland Waters Directorate. Staff in Fisheries and Oceans are part of Oceans Science and Surveys – including the Central Region of the Canadian Hydrographic Service, an Oceanography Division, and, separately, the Great Lakes Biolimnology Laboratory program. The Department of Environment owns and operates the facilities such as the building, a major computer and a library; Fisheries and Oceans owns and operates a large vessel **Limnos**, a smaller vessel **Bayfield** and a range of smaller vessels, such as launches.

An executive committee at the Institute oversees the operations of the Institute as a whole.

Staff of the National Water Research Institute and its regional detachments in western Canada are responsible for a variety of studies, throughout Canada, associated with water supply, use and management, which include important work on both qualitative and quantitative aspects of sediment/freshwater interaction. Most of the work by the Institute at Burlington is centred in the Laurentian Great Lakes but, in addition, a number of major regional studies have involved the staff of the Institute's regional detachments in Vancouver and Winnipeg (both individually, and co-operatively with Burlington staff).

The region of Fisheries and Oceans based at the Canada Centre for Inland Waters encompasses the Great Lakes, the inland waters of Ontario, Manitoba, Keewatin and Franklin districts of the Northwest Territories as well as the marine waters of Hudson Bay, James Bay and the central Arctic Archipelago.

The region has three main programs:

a. A major hydrographic survey program for the production of charts of all Canada's navigable waters in central Canada including Hudson Bay and the central Arctic Archipelago, together with other associated programs such as tidal and current studies. Of particular interest in the field of geoscience are the hydrographic resources charting activities in conjunction with Earth Physics Branch of EMR in the Arctic and Hudson Bay.

b. A small but viable oceanographic program conducting research and resource management studies in the fresh and marine waters of central and northern Canada. The strength of oceanographic research expertise is concentrated in physical aspects, with, however, a small but growing biological content in Arctic waters.

c. The Great Lakes Biolimnology Laboratory program, which is confined to the Great Lakes and to a lesser extent the lake systems within the Province of Ontario. The program is largely developed from the requirements of the Canada/USA Great Lakes Water Quality Agreement and in this regard conducts research to establish water quality objectives specifically for the Great Lakes through an Environmental Toxicology activity, monitoring lake conditions for primary production and contaminants through a Surveillance activity and through an activity named Ecosystem Studies, representing a concerted effort, while working closely with provincial agencies to understand the Great Lakes Ecosystem. Supporting the three programs, the fleet of ships and launches provides the waterborne platforms for the programs of both the Department of the Environment and the Department of Fisheries and Oceans based at the Centre.

For the purpose of this report, no further distinction is made between the various components of the Centre and only those activities directly significant to the marine geosciences are included in the following summary.

*Regional Limnology*. This includes limited studies of the distribution and characteristics of lake sediments. Previous work has been reported from the Okanagan, Kamloops and Kootenay Lakes, the Athabasca River, Lake Athabasca and Great Slave Lake, the Qu'Appelle Lakes and Lake Winnipeg, Flin Flon area lakes and lakes of the English-Wabigoon River system, for much of the Great Lakes – St. Lawrence River system, and for the Shubencadie Lakes in Nova Scotia. Further work continues in the Qu'Appelle Lakes and the Laurentian Great Lakes, and new work is being proposed in the Yukon Basin. In the Great Lakes, a resource inventory mapping program is underway with maps and special reports in preparation for Lake Ontario and Lake Huron. These will supply detailed information about the bathymetry and sediment distribution in the nearshore zone.

*Shoreline Management*. This work includes a program of shoreline erosion monitoring in which shore profiles at 162 sites are surveyed at least once each year in the Great Lakes (other site specific surveys are also included in this study program). A long term assessment of these annual profile data provides significant input to evaluating benefits of further lake level controls and the development of shore management guidelines.

*Shoreline Process Studies*. These include studies in both lacustrine (based mainly on work from the Laurentian Great Lakes and selected prairie and western lakes) and marine environments (based mainly on work in the Hudson Bay-James Bay area):

- defining the form, origin, characteristics and behaviour of active and relict gravel deposits in lakes;
- defining seasonal bed profile changes and littoral transport of lake beach and nearshore sediments of sand facies;
- defining relationships between wind/wave conditions and suspension of fine lake sediments;
- defining the mechanisms of subaqueous lake erosion of till surfaces;
- developing models of lacustrine littoral drift;
- developing comparative freshwater/marine sedimentological regime models;
- analyzing surface weathering and slope stability controls on erosion of unconsolidated bluff deposits;
- investigating littoral drift and estuarine erosion in James Bay, in support of coastal wetland studies;
- investigating freshwater transport in Hudson Bay and James Bay to define the impact of hydroelectric developments on the LaGrande and Great Whale River systems (planning to observe for possible effects of modifications on the Rupert and Great Whale rivers is in progress).

*Recent Geological Evolution of Lake Basins*. This work includes stratigraphic and sedimentological investigations of late glacial and recent sediment and physical structures as a basis for interpreting the geological evolution of lake basins or special features. Studies at Point Pelee have been published and reports are in preparation describing the Kingston and Niagara areas of Lake Ontario. A new study is in progress at Long Point, in Lake Erie, as a means of predicting long term trends in shoreline evolution.

*Paleoenvironmental Studies*. These studies are being undertaken to provide information about geologically recent environmental, water quality and climatic conditions in lake and river systems, prior to the availability of historic data:

- determine the periodicity of climatic changes (droughts) affecting the Qu'Appelle Lake system and to investigate the "history" and effects of nutrient and contaminant changes;
- define the nature of events or conditions causing destruction of significant benthic population communities in Lake Erie and the Qu'Appelle Lakes (climatic regime, lake levels, dissolved oxygen, etc.).

*Geochemistry*. These studies are designed to show the changes in natural geochemistry resulting from cultural impact (for example, acid rain effects on sediments) and the associations between toxic substances and sediments.

- heavy metal pathways related to sediment/water interaction, microbial activity, and biological availability;
- availability (biological/chemical) of toxic substances associated with bed and suspended sediments in rivers and lakes;
- isotope composition of selected sediment cores and lake waters (dated by $^{210}$Pb) as a means of showing recent changes in the sources and dispersion of different forms of sulphur;
- characteristics of dredged materials as a means of showing the importance of harbour and nearshore sediments as sources of Great Lakes contaminant loading;
- changes in organic geochemistry of lake sediments under the influence of progressive acidification;
- establishment of sediment data bank for subsequent and comparative analysis of toxic substances in sediments.

*Hydrogeology*. In relation to studies on groundwater contaminants and the long range transport of air pollutants:

- development of models of transport through porous media, as related to the diffusion of radionuclides or other toxic contaminants in groundwater;
- application of remote sensing techniques to develop hydrological models of subsurface contaminant transport in noncalcareous basins;
- effects of acid precipitation on groundwater geochemistry and ionic budget in noncalcareous basins.

*Channel Forms.* These studies include an analysis of meander forms, and rates of change and causes, as a basis for hydraulic models; and studies on dune formation in open channels to define the time required to re-equilibrate after disturbance (for example, to predict rate at which dune forms can re-establish or migrate in river channels after dredging, as a guide to dredging frequency).

*Acoustic Techniques.* Developments in this field by the Fisheries and Oceans staff at the Institute have a wide application to hydrographic, oceanographic and geoscientific investigations and have been influenced, in part, by progress in northern oil and gas developments and the need for suitable transportation and navigation:

- application of different side-scanning sonar techniques and methods of image enhancement, to provide high resolution of underwater structures;
- application of digital scanning sonar for reconnaissance mapping under arctic conditions (MARRS – marine actic route reconnaissance system);
- application on nonlinear transducers for under ice survey, to characterize ice type, ice thickness, ice/water surface, and subbottom materials (0-1 m), in addition to measurement of water depth.

### *Department of Indian Affairs and Northern Development*

This Department is of interest to marine geoscientists because of its responsibilities for hydrocarbons and minerals on Canada lands of the Northwest Territories and Yukon, including the offshore. The southern limit of the jurisdiction is 60°N on land; it is 61°18'N in the east coast offshore, so that Energy, Mines and Resources has jurisdiction in Hudson Strait. We see one of the Department's main responsibilities from its Northern Affairs Program. One sub-objective of this Program is: "To manage the natural resources of the North and to stimulate economic development and employment opportunities for northern residents". Part of the Program is devoted to Northern Economic Planning, including: "...co-ordination of socio-economic studies and public review process and analysis of energy transportation proposals for the North; ...". Other parts are devoted to Northern Environmental Protection and Renewable Resources, and to Northern Non-renewable Resources: "...environmental protection in the Territories...;" "Development of policies, plans and management of non-renewable natural resources of mineral and oil and gas in the Territories".

#### Northern Non-Renewable Resources Directorate

This Directorate has three Divisions: Mining; Oil and Gas Policy Co-ordination; and Oil and Gas Operations Co-ordination. The Mining Division is responsible for planning and development of mineral policies in general. The other two Divisions are responsible for the management of non-renewable resources in Canada Lands onshore and offshore north of 60°N. The administration and regulation of oil and gas in these areas is undertaken by the Canada Oil and Gas Lands Administration (responsible for the whole offshore, as well as Canada Lands onshore). This administration is responsible to both the Minister of Indian and Northern Affairs, and the Minister of Energy, Mines and Resources, and brings together the administration of the Canada Oil and Gas Act and the Oil and Gas Production and Conservation Act. The establishment of COGLA has not altered the Minister of DIAND's responsibilities for oil and gas development and related issues. Within the Northern Program, the Northern Non-Renewable Resources Directorate is responsible for the monitoring and assessing of all hydrocarbon exploratory programs and provides the Department with advice regarding the pace, magnitude, and implications of non-renewable resource developments. It is also responsible for ensuring that northern concerns and northern policies are adhered to in the decision making processes.

#### *Northern Environment Branch*

Three Directorates of this Branch are concerned with Renewable Resources: (Lands, Water Resources, and Forestry), and, Northern Environmental Protection. The latter provides environmental services to all the Northern Affairs Program. This Directorate and the Water Resources Division are of the greatest interest to marine geoscientists. For example, the Water Resources Division is responsible for marine waters, and so in conjunction with Environmental Protection, will establish conditions for offshore drilling. Environmental Protection is concerned with advice on environmental problems, such as the impact of resource development in the North, and is the Department's main interface with the Federal Environmental Assessment and Review Office (described elsewhere). The Directorate engages in a variety of studies, done by themselves or by contract. One example of the sort of work which they do is the Eastern Arctic Marine Environmental Study (EAMES), an environmental program organized by the Division, but funded largely by industry. This study was an attempt to review and settle region-wide environmental issues before exploratory drilling began. As a result, the requirements for extensive base-line studies for particular projects – a specific drilling proposal, for example – would be lessened. In its interface with the Federal Environmental Assessment and Review Office the Directorate in essence works with companies proposing developments, advises them on studies directed towards initial environmental assessments, following guidelines issued by the Office, before the proposal is formally reviewed by the Office.

The Directorate works closely with other agencies of the Federal Government: Department of the Environment and Department of Fisheries and Oceans – environmental matters; National Research Council – ice reinforced islands, etc.; Public Works – structures; Geological Survey of Canada – marine geology; Earth Physics Branch – permafrost, gas hydrates and seismic risk.

*Scientific Resource Centres in the Arctic.* The Department maintains scientific resource centres at Inuvik, Igloolik and Frobisher Bay, and, noted earlier, the Polar Continental Shelf Project of EMR maintains bases at Resolute and Tuktoyaktuk. Various universities and private groups have permanent facilities accessible from the sea at Pond Inlet, Rankin Inlet, Poste de la Baleine and Churchill.

The research laboratories of Indian Affairs and Northern Development are described by the Department in the following way.

The labs lend equipment – everything from boats and motors to boots, snowshoes, tents and sleeping bags. Their technicians will take readings on equipment left behind once a researcher has finished his or her initial work, help repair equipment and, often enough, even help in building experiments.

All three labs also have accommodation available where visiting scientists can prepare their meals as well as sleep. They maintain radio links with field camps through Canadian National Telecommunications; lab staff act as expediters, forwarding mail, parts and food.

With the opening of the Ikaluit Research Centre Northern Affairs now has three research laboratories in the N.W.T. which provide support for scientific parties – government and privately funded – working in the field.

The oldest is the Scientific Research Laboratory at Inuvik. The second lab is at Igloolik, at the northwestern end of Foxe Basin. They differ in size and appearance, but each can provide assistance in many areas in a land where everything is expensive.

Each lab has a library, designed primarily for scientific use but open to the general public too. They can provide office space, as well as space in their well equipped laboratories.

Theirs is a year-round operation, though the summers are busiest. They do some continuing research work themselves; Inuvik monitors cosmic rays 24 hours a day and Igloolik maintains a watch for earthquakes for the Earth Physics Branch of EMR. But the prime reason for their existence is to provide assistance to other scientists.

Some of their best customers are students doing postgraduate work... and some of the most important and exciting research which has been done in the North has been undertaken by students who would not have been able to carry out their programs without the labs' help.

## *National Research Council*

### Mechanical Engineering

This Division has interests which relate to geological processes in the coastal regions, and to their effects on structures and on major engineering projects. (1) Coastal Processes: the Division is trying to model littoral drift of sediment, and the onshore-offshore drift of sediments. The modelling is at present mathematical, based on the results of laboratory experiments, but it will eventually involve field work, following for example, work already done by others in areas such as the Magdalen Islands. The results of the Division's investigations of the coastal regime have been applied widely throughout Canada: the Magdalen Islands, the northeast coast of New Brunswick, and artificial islands in the Beaufort Sea. (2) Mud: the Division is trying to model the behaviour of mud in estuaries and bays, to solve problems concerning the rapidity of siltation after an estuary has been dredged or closed. These studies have been applied in the Miramichi Estuary, and will be applied in the Bay of Fundy. The Division co-operates with numerous organizations in Canada, with which it is in close contact through the NRC Associate Committee for Research on Shoreline Erosion and Sedimentation (ACROSES). Through this Committee they seek co-operation in establishing a well instrumented field study of sediment transport in the coastal regime.

### Building Research

The Division's interests lie in the design performance of structures, and so although its staff are well known for work on permafrost on land, involving structures, the Division has not been involved in permafrost offshore. However, the same interests lead them to work on the properties of sea ice, ice-forces on structures, and the use of ice covers for load-supporting platforms. (This is mentioned in the section on the Department of Indian Affairs and Northern Development.) The Division is interested in the design and performance of shoreline structures, and has for example investigated the forces upon the dock at Nanisivik; it is interested too in foundations in permafrost both onshore and offshore.

This Division, with many other agencies, contributes expertise to the Canadian National Committee on Earthquake Engineering, which in turn advises the Associate Committee for the National Building Code. In this way provisions are made for example for seismic loading in engineering design of the normal structures covered by the code. The Code itself has no authority – it has to be adopted by a Province or Territory to have legal effect. It is not adequate for structures offshore – it is not meant to be, and there is at present no equivalent for use offshore. Canada Oil and Gas Lands Administration is preparing a set of regulations, guidelines and verification systems for use in the offshore, which will include all aspects of offshore structures, including the effects of seismic loading.

### Electrical Engineering

The Division has worked co-operatively with Huntec on the Seabed contract, because of their joint interests in signal processing. Experiments in the application of radar techniques for measuring the thickness of sea ice are approaching the end of the phase of laboratory studies. This work has been done in the field in co-operation with C-CORE, St. John's, Newfoundland.

The National Research Council has various programs to aid industrial development, and their interaction with Huntec in technological matters led them to be interested in funding an adjunct program Seabed Mosaics, and to consider funding developments beyond the Seabed Project itself.

## *Department of Transport*

The influence of the Department of Transport on the marine geosciences as a discipline is rather greater than may be appreciated, because of their mandate in national transportation. Phrases selected from the Objectives and Program Descriptions of the Department's Administration Program and Marine Transportation Program include the following: To efficiently develop ... facilities and services essential to the national transportation system ...; The provision of aids to navigation ... radio location systems for the guidance of ships at sea ...; The provision of (ice-breaking) services in support of other departments and agencies; The ... provision of pollution clean up and other emergency services; The development ... of designated harbours, terminal facilities and services.

Consequently the Department interacts with many others, including those with interests in the marine geosciences. The Canadian Coastguard is the agency responsible for marine operations. We provide the following examples of interactions:

1. The Hydrographic Arctic Research Project (HARP) is devoted to research in hydrography and in arctic transportation, and is carried out by the Canadian Hydrographic Service. It is funded through the Office of Energy Research and Development of the Department of Energy, Mines and Resources. The Transport Section is co-ordinated by the Department of Transport.
2. The Department is interested in harbour developments and pipeline terminals (etc.) in the Arctic Islands. As a consequence they have funded coastal geological research by the Geological Survey of Canada which would not otherwise have been done, and which has contributed significantly to our knowledge of the coastal regime generally.
3. The Department has the mandate for oil-spill clean up where the source is a vessel; this has been described in the section devoted to Energy, Mines and Resources.

4. The Department provides navigational aids; as a consequence they work closely with the Canadian Hydrographic Service, who calibrate systems such as the new LORAN-C chains, and provide new latticed charts, and systems for conversion from DECCA aids to LORAN-C.
5. The Department provides support of ice breakers to the Canadian Hydrographic Service and Energy, Mines and Resources. As a result, for example, the bathymetric and gravity survey of Hudson Bay is far advanced, and the research program into offshore permafrost in the Beaufort Sea is maintained. Because the Department is the only government agency with ice breakers it provides the main platform for Arctic hydrography, and also provides logistic support to other government departments by carrying fuel, supplies and equipment to Arctic sites not served by commercial marine carriers.
6. The Department, through funding from the Office of Energy Research and Development of EMR, supports contract research by the Earth Physics Branch of EMR on the physics of permafrost and gas hydrates.

### *Department of National Defence*

The Department of National Defence has a requirement for marine geoscientific data in support of such activities as the acoustic and magnetic detection of mines and submarines, acoustic communications and in the engineering of bottom supported systems. The performance of acoustic systems is affected when the propagated sound energy interacts with the ocean bottom. In order to model these effects and predict the performance of such systems it is necessary to have detailed data on a number of bottom characteristics: slope, scale of roughness, reflection coefficient, and, within the first few metres of the bottom, sound velocity, density and sound attenuation coefficients. In mine countermeasures involving ground mines and for systems deployed on the ocean bottom, the load-bearing stability of the bottom material must be known. To meet these requirements the Department depends on data produced by EMR and Fisheries and Oceans, mostly in the form of publications and charts but in some cases by specific tasking or by direct consultation at the working level.

These interests have prompted the Defence Research Establishment Atlantic to participate in a program designed to investigate sediments in Canadian Shelf areas. This is the Seabed Project described elsewhere.

The largest contribution of the Department of National Defence to the geosciences has been in the fields of geomagnetic micropulsations, ocean swell generated magnetic noise, geological noise surveys and Very Low Frequency studies. The Defence Research Establishment Pacific in Victoria has carried out theoretical and experimental research in these areas since the mid-1950s. Their interest derives from defence concerns with magnetic and electrical systems for sensing military targets in the ocean. Such systems must function against the natural geomagnetic micropulsation background and in the case of airborne systems, against geological and ocean-swell noise. The Pacific Laboratory, Defence Research Establishment Pacific, has carried out studies of the character of the geomagnetic background of geological origin using data from aeromagnetic surveys carried out for them by the National Aeronautical Establishment. It was Defence Research Establishment Pacific that discovered and published the theoretical explanation for the magnetic noise generated by ocean swell. Their high quality, long term records of geomagnetic micropulsations have proved to be a valuable data base for theoretical studies and have been loaned to several universities for comparison with satellite data. Over the years they have provided scientific support to industrial development of magnetometer systems and they have contracts with CTF Systems Ltd. for the development of a sensitive magnetometer gradiometer based on a superconducting quantum interference device.

Liaison with scientists from EMR working in this field is maintained and the two departments have jointly funded some of the industrial development activities.

One further activity of the Department related to marine geoscience is a small research program on the sea bottom carried out at the Canadian Forces Royal Roads Military College, Victoria. Using a subbottom acoustic profiler and side-scan sonar, harbours and anchorages on Juan de Fuca Strait have been surveyed and cores of some subbottom features are being obtained. Magnetic measurements are made in conjunction with the acoustic surveys.

The Department of National Defence owns and operates the Canadian Navy Auxiliary Vessel **Endeavour**, which is part of the pool of vessels on the west coast, operated in conjunction with other agencies, such as Fisheries and Oceans.

### *Department of Industry, Trade and Commerce*

The Department of Industry, Trade and Commerce has the role of fostering Canadian economic growth through trade promotion and industrial development. In discharging the industrial development role the market potential of marine resource developments, such as petroleum, is of course taken into account. In particular, Canadian companies needing financial assistance to undertake equipment development related to the marine geoscience activities should contact Industry, Trade and Commerce.

The Department is also interested in increasing Canadian capability to supply the equipment and services needed for resource development in Canada's offshore. The Canadian offshore market is expected to be large and it is important that we get our share of it.

These interests are in addition to ITC's traditional role in trade promotion which can help Canadian companies sell equipment and thus establish a stronger base for a wider range of products.

### *Canadian International Development Agency*

CIDA has funded two major oceanographic ventures in the last decade as part of its program of assistance to lesser developed countries. One of these was a multidisciplinary survey from the **Baffin** in 1976 of the continental margin off Senegal and Gambia. The Agency funded the project and the Canadian Hydrographic Service ran it. The work involving the marine geosciences was done by the Atlantic Geoscience Centre of the Geological Survey of Canada. There have been two other ventures with only a little geoscientific content. CIDA funded a cruise of the **Baffin** to Peru, and assistance from Fisheries and Oceans to the design of an Indian research vessel.

### *Department of Public Works*

The interest of Public Works in the marine geosciences arises from their work in designing structures in the coastal zone, such as break-waters. Consequently, the Department is concerned with wave refraction, with the erosion, transport and deposition of sediments in the coastal zone, and with the forces of ice on structures. Public Works does little research and development of its own, except in the field of computer systems for analysis of wave and wind data, but works co-operatively with many agencies, often funding the projects. They work with private industry, the universities, and federal agencies such as the National Research Council, Canada Centre for Inland Waters, and the Geological Survey of Canada. As examples, the Department interacted with the Survey on dredging problems in the Miramichi Estuary, with Arctec Canada Limited on ways of measuring ice forces, and with Memorial University on the design criteria to be used when considering the force due to ice on coastal structures.

### *Resources Used in the Marine Geosciences by the Government of Canada*

The figures which follow must be used with care, for several reasons:

1. Resources used in "marine geosciences" are considered here to be those expended on research or on baseline studies in the marine geosciences, or on rather direct support to those activities; these figures are in Table 3.1A. However, many activities which are invaluable to the marine geoscientists are collected as a part of national programs which exist for other reasons. An arbitrary selection from these is given in Table 3.1B. This list also includes the costs of a few other well defined federal programs (Table 3.1C), so that the expenditures on the marine geosciences can be put in context.
2. The fiscal year used was 1978-79 or 1979-80, depending upon the source.
3. Figures marked * are approximate – either, for example, because data for agency involvement outside the central agency were never collected (e.g., LOREX) and an estimate had to be made, or because the division of costs between agencies is uncertain.
4. All costs (total $) include salary dollars; where salary dollars were not included in the figures given, salaries were estimated at the rate of $40K per person year. This is too low, but provides consistency (NRC would use $55K).
5. The figures do not include: contributions in terms of shiptime by Transport Canada to the marine geosciences – perhaps 20 days at $25 000 a day, $500K; contributions by CCRS, in, for example, remote sensing for sediment budgets; contributions by DOE in their environmental programs.
6. The source figures can be re-cast in various ways, depending on the questions.

*Editor's Note*. Despite the difficulties in providing an accurate evaluation of the resources used by the Federal Government, the tables presented here outline the magnitude of Federal expenditures on programs which directly or indirectly support marine geoscience activity in Canada. Table 3.1A indicates that the Federal Government currently spends some 250 person years and $16 million per year on programs that directly support marine geoscience. EMR and DFO have been the dominant funding agencies ($6.5 million and $5 million, respectively) while GSC has been the dominant operating agency ($10 million). The great majority of the $16 million has been directed at regional geology and geophysics, mostly in eastern Canada and the Arctic ($10 million, Table 3.2). This compares with some $250 million going to Parks Canada and the Canadian Forest Service; some $110 million going to the Atmospheric Environment Service; and some $120 million to the Environmental Protection Service and the Environmental Conservation Service, all operated by the Department of the Environment.

### *Commentary*

*Editor's Note*. M.J. Keen invited comments on the preceding paper. The following comments were received (in various formats) and edited for inclusion.

*By B.R. Pelletier – GSC (an addendum)*

1. Liaison activity between government scientists and their counterparts in industry.

   A good example of the nature of this work is that carried out by S.M. Blasco in the Beaufort Sea, together with J.A.M. Hunter and A. Judge. These people serve on research stearing committees and participate with private consultants and contractors on the working projects. The widespread contribution by means of consultation and joint projects is also exemplified by C.F.M. Lewis and numerous colleagues on the Hibernia field off the coast of Newfoundland. This practice extends to many offshore and coastal areas of Canada including Baffin Bay, Davis Strait, and the Arctic Archipelago.

2. Contributions to the solving of scientific problems, and their related practical applications.

   These are too numerous to list but some important ones should be noted. Our understanding of the relationship between surficial geology and engineering hazards in the Canadian offshore has been developed mainly by marine geologists of the Geological Survey. This work ranges from studies on the dangers of migrating sediments (silts and sands, mainly in the forms of ripples and waves) and associated current scouring along the coastal region and inner shelf, through to substrate collapse due to mechanical instability at the shelf edge and continental slope.

   It also includes the discovery and analyses in the Beaufort Sea of seabed ice scouring, submarine pingos, and submarine thermokarst, and the effects such phenomena will have on marine transportation and the exploration and development of offshore hydrocarbon deposits. Other features such as gas and frozen gas hydrates have been analyzed jointly by scientists from both industry and government from the standpoints of hazards and commercial activity. Ice scouring of the seabed along the eastern seaboard is also being investigated jointly with industry and research institutes in Dartmouth, Nova Scotia and St. John's, Newfoundland.

   Other projects worthy of note are: the paleoceanographic studies on the Labrador Shelf by G. Vilks and R. Fillon; the enormous mapping contribution by L.H. King and associates; the huge support role by the Eastern Petroleum Geology Subdivision; the geochemical pathways elucidated by D.E. Buckley and M.A. Rashid; the sediment budget worked out by C. Amos for the Bay of Fundy region; the specific contributions of the coastal workers (Fig. 3.2, 3.9); the long-continuing studies by the marine geophysicists on the continental margins, and the relationship to crustal behaviour around all three oceans; the new geological insight into the Pacific margin gained from submersible work and geophysical observations; and the new surficial geology map of the Pacific shelf. No doubt a canvas of the scientists will give more pertinent results.

3. Working groups, task forces, and committees.

   The role of the marine geologist on working groups and task forces with other departments is noteworthy in achieving success on certain projects. An example of such an activity is the Lancaster Sound Regional Study Group (under DIAND) which is working toward the production of a cabinet document (green paper) on the

**Table 3.1.** Resources used in research in the marine geosciences by the Federal Government: 1979-80

(A) Programs with direct involvement

| Program | Operating Agency | Location | FUNDING P.Y.'s | Total $K | Agency | Note |
|---|---|---|---|---|---|---|
| Marine geology and geophysics, offshore eastern Canada and Arctic | GSC | BIO | 99<br>-- | 4319<br>2588 | EMR<br>DFO | Atlantic Geoscience Centre<br>e.g., shiptime |
| Geology and geophysics of the western margin | GSC and EPB | IOS | 17.35 | 1300<br>1000 | EMR<br>DFO | Pacific Geoscience Centre<br>Shiptime |
| Arctic marine geology | GSC | Ottawa | .75 | 40 | EMR | Terrain Sciences |
| Arctic hydrography and gravity | EPB,CHS and PCSP | Ottawa, CCIW | .25 | 100<br>730 | EMR<br>EMR | Earth Physics Branch<br>PCSP (aircraft, etc.) |
| Lomonosov Ridge Experiment (LOREX) | EPB,PCSP | Ottawa | 15* | 1500 | EMR | Typical of a major program; PCSP (aircraft, etc.) |
| Geoscience and hydrocarbon assessment; curation, east coast offshore | COGLA | Ottawa, BIO | 13 | 400 | EMR | |
| Ocean mapping and GEBCO | CHS with GSC | Nationally | 27 | 909 | DFO | |
| Permafrost seismics | GSC | Ottawa | 3 | 160<br>6 | EMR<br>EMR | GSC<br>PCSP |
| Ocean aeromagnetics | GSC | Ottawa | 1 | 104<br>150* | EMR<br>NRC | <br>Aircraft estimate |
| Arctic aeromagnetic map | GSC | Ottawa | 3 | 100* | EMR | Not strictly marine |
| Geological studies of the Great Lakes | CCIW | CCIW | 25<br>3 | 610<br>60 | DOE<br>DFO | |
| Shoreline management, Great Lakes | CCIW | CCIW | 8 | 205 | DFO | |
| Acoustic techniques | CCIW | CCIW | 13<br>2 | 300*<br>40* | DFO<br>DOE | |
| Coastal morphology | NRC | Ottawa | 2 | 85* | NRC | |
| Coastal structures in ice | NRC | Ottawa | 2 | 285 | NRC | |
| Wave dynamics | NRC | Ottawa | 4 | 230 | NRC | |
| Geotechnical programs: permafrost and sea ice | NRC | Ottawa | 2 | 130 | NRC | |
| Coastal zone studies | DPW | Ottawa | 1 | 630* | DPW | |
| Marine geology and geophysics | DREA | Dartmouth Nanaimo | 3 | 210* | DND | Minor support from PCSP |
| Geoscience and hydrocarbon assessment north of 61°18'N offshore | COGLA | Ottawa | 6 | 348 | COGLA | |
| Geological studies of Beaufort Sea wells and curation for COGLA | GSC | Calgary | 7* | 362 | EMR | ISPG |
| Departmental oil and gas Appraisal Program | GSC | Calgary | 5 | 325 | EMR | Pro-rated, 5/8 of total cost, ISPG only |
| Marine geology at Inuvik and Igloolik labs | DIAND | Inuvik & Igloolik | 1 | 50 | DIAND | Estimate from total expenditure of labs |
| Beaufort Sea geology | GSC | Calgary | 7 | 362 | EMR | |
| | | TOTALS: | 270 | 17 638 | | |

Principal omissions: CCRS offshore; DOT shiptime contributed. Sundry small items. Maybe $500K?

**Table 3.1** (cont.)

| Program | Operating Agency | Location | FUNDING P.Y.'s | FUNDING Total $K | FUNDING Agency | Note |
|---|---|---|---|---|---|---|
| (B) Some programs with peripheral involvement | | | | | | |
| Offshore engineering: east coast south of 61°18' | COGLA | Ottawa | 14 | 560 | EMR | Regulatory, etc. |
| Physical and biological environment | COGLA | Ottawa | 5 | 183 | EMR | Environmental concerns east coast south of 61°18' |
| Tides, currents and water levels | CHS | Nationally | 44 | 1968 | DFO | |
| LORAN-C | CHS | Nationally | -- | 300 | DFO | |
| Navigational requirements for marine transportation in Arctic | CHS | Nationally | -- | 3779 | DFO | |
| Office of Environmental Affairs | EMR | Ottawa | 4 | 151 | EMR | Co-ordinating and expediting |
| Federal Environment Assessment and Review Office | DOE | Ottawa | 21 | 1400 | DOE | FEARO |
| Northern Environment | DIAND | Ottawa | 8 | 600 | DIAND | Mainly regulatory |
| (C) To put in context: costs of some other federal services | | | | | | |
| Atmospheric Environment Service | DOE | Ottawa | 2333 | 114 300 | DOE | i.e., $114.3 million |
| Environment Protection Service | DOE | Ottawa | 747 | 34 200 | DOE | |
| Environment Conservation Service | DOE | Ottawa | 1580 | 83 500 | DOE | |
| Canadian Forestry Service | DOE | Ottawa | 1029 | 47 400 | DOE | |
| Parks Canada | DOE | Ottawa | 5175 | 213 100 | DOE | |

Abbreviations

| | |
|---|---|
| GSC | Geological Survey of Canada |
| EPB | Earth Physics Branch |
| CHS | Canadian Hydrographic Service |
| PCSP | Polar Continental Shelf Project |
| COGLA | Canada Oil and Gas Lands Administration |
| BIO | Bedford Institute of Oceanography, Dartmouth |
| IOS | Institute of Ocean Sciences, Patricia Bay |
| CCIW | Canada Centre for Inland Waters |
| EMR | Department of Energy, Mines and Resources |
| DFO | Department of Fisheries and Oceans |
| DOE | Department of Environment |
| DIAND | Department of Indian Affairs and Northern Development |
| NRC | National Research Council |
| DPW | Department of Public Works |
| DND | Department of National Defence |
| DREA | Defence Research Establishment Atlantic |
| DREP | Defence Research Establishment Pacific |
| * | Approximate |

uses of Lancaster Sound. The works of several marine geoscientists in EMR was co-ordinated by one officer of the Geological Survey. Several years earlier such work was similarly co-ordinated for a document on drilling hazards in Lancaster Sound (DFO), on engineering in cold regions (NRC), and on numerous environmental assessment panels for all of Canada's coastal zones.

Liaison with industry on technical sessions at symposia has long been a practice of the government marine geoscientist. The first Canadian Marine Geotechnical Conference is an excellent example of this effort, both in terms of organizational duties and actual participation at the conference. This last point is important because it permits the industry to have immediate contact with the government scientist, and offers exposure of this scientist to the private sector.

This workshop concept extends to the university and other private research establishments. A good case is the organizing of Canada's First National Conference on the coastline, a work that has had its proceedings published by the Geological Survey of Canada. The numerous associate committees of NRC, particularly ACROSES which deals with coastal research, have provided enormous impetus to the important area of marine geoscience.

4. Department of Industry Trade and Commerce.

In addition to its assistance to Huntec Ltd., this Department (ITC) has assisted the marine geoscience community in its promotion of the **Pisces IV** submersible (DFO) and the **Pisces** divers lock-out submersible (SDL-1, for DND). The **Pisces IV** has been used to make direct observations of the seabed, as well as to collect geological samples, all of which have proved to be invaluable in producing descriptive reports of an area. The observations have also led to more explainable geological interpretations in areas remote from direct viewing. **Pisces** submersibles have been used in all three of Canada's bordering oceans as well as the Arctic channels, Hudson Bay and the eastern seaboard.

*By W.W. Milne – Earth Physics Branch.* It can be said that although the Department of Fisheries and Oceans assigns a reasonable portion of the available shiptime to marine geoscience, this is only sufficient to continue the systematic surveys at present pace. However, the geoscience community finds it difficult to respond to problems associated with the development of offshore resources. This capability may need to be developed in the private sector, with proper quality control so that the observations can be included in the national data sets.

**Table 3.2.** Summary Breakdown of Federal Expenditures by Topic: 1979-80

| | | $K |
|---|---|---|
| (1) | Regional Geology and Geophysics | |
| | Eastern Canada and eastern Arctic | 6 567 |
| | Western Canada | 1 040 |
| | Arctic | 3 362 |
| | Great Lakes | 1 215 |
| | Oceans Hydrographic Mapping (GEBCO) | 909 |
| (2) | Engineering Oriented Coastal Studies | 1 230 |
| (3) | Defence | 210 |
| (4) | Hydrocarbon Assessment and Curation | 1 443 |
| | | 15 976 |

Note that this breakdown is approximate.

As for positive commentary, it can be said that off both coasts, and in the Arctic, the federal geoscience programs have made major contributions to resource development, and major contributions in the science of understanding tectonic processes along the continental margins.

*By C.R. Mann – Institute of Ocean Sciences, Patricia Bay.* The point should be made very strongly, that the government scientists have the task of assembling all the data to provide a large scale picture of the geology and to interpret it in terms of processes. However, there are not enough staff to do this and feed the results back to industry.

*By O.H. Loken – Northern Environmental Protection Branch*

1. Your concern for the diversion of scientific manpower to assessment work is fully supported. The problem is more pronounced, however, in the environmental sciences, e.g. wildlife, vegetation studies, etc. Hibernia only is referred to but with the great number of other projects (Beaufort Sea, Polar Gas, Arctic Pilot Project, Eastern Arctic Offshore Drilling, Norman Wells) this becomes a real problem.

***Figure 3.9.*** *Ice push on the northern coast of Somerset Island. An 8 km long ice flow struck the western shore of Cape Fisher in July 1973. This "ice-pushed scar" outlines the position of the finger of ice pushed 185 metres inland; the photograph was taken in July 1974 (from Taylor, R.B., 1977, Arctic, v. 31, p. 133-149). (GSC 202728-G)*

2. With the extensive involvement in co-operative projects our scientists run the risk of focussing on near term research of importance to a specific industry proponent. As federal scientists it is important that they maintain their capability to address a wide range of scientific questions and also questions that can only be answered in the long term.

3. Government scientists have responsibility for identifying quality standards for industry collected data so there is full concurrence here with the need for improving our archiving competence to industry sponsored research.

4. Industry sponsored studies are generally considered to be industry funded but the fact is that the Federal Treasury through tax write-offs, depreciates and now more recently through federal grants de facto subsidizes these studies to a very large extent. This federal support via industry is given at a time when the federal science establishment as such suffers under financial constraints. Should more of this federal support be provided directly to federal scientists?

*By J. Ploeg – Division of Mechanical Engineering, NRC*

1. Something that our scientists in the Hydraulics Laboratory feel very strongly about is the responsibility of the coastal engineering branches of government (Public Works, Transport, Fisheries and Oceans) to follow up on the effects of their work. So long as they continue to stop thinking about their designs once they have been built, they are doomed to repeat their mistakes.

   A good example might be the recent modification to Point Sapin Harbour in New Brunswick, where a fairly radical approach was taken to stop sedimentation in the harbour mouth. Both Public Works and Fisheries and Oceans were involved in the design, and model testing was carried out here at NRC. Since the new breakwater was built in 1979, the only monitoring that is known of is one hydrographic survey of Public Works in 1980, and a series of three sets of aerial photographs made for Mechanical Engineering. Whether the fairly radical approach succeeds or fails, I doubt that one will ever be certain why. And already the Hydraulics Laboratory is being approached by the same two departments about a similar study of a small harbour on the Magdalen Islands!

   The channel dredging due to begin this year in the Miramichi estuary, New Brunswick, is another case requiring monitoring during and after construction. The Miramichi Channel Study of the feasibility of such dredging cost millions of dollars and involved many of Canada's foremost marine scientists. There appears to be no budget for checking the assumptions and conclusions of that study against the real estuary.

   This is perhaps a general fault of engineers, rather than one peculiar to government engineers. Nevertheless, the government is much more active in the coastal zone than is the private sector, and is thus in an excellent position to change the attitude of Canada's coastal engineers.

2. We should comment on the need to carry out baseline studies in the Arctic using the PCSP concept and these studies should lead and not follow industry requirements (environment and climate).

**GOVERNMENT AGENCIES, INSTITUTES AND UNIVERSITIES IN NORTHERN CANADA** – C.P. Lewis

From the discussion to this point, it should be apparent that the involvement of government agencies, institutes and universities in marine geoscience research in northern Canada is considerable. Given the size and rapidly increasing importance of the Arctic marine area, this is, in itself, not surprising. What is somewhat surprising, at least at first glance, is that none of this involvement is presently northern based nor has it been in the past: there are no research projects in marine geoscience funded from within either the Yukon or the Northwest Territories; no government or university marine geoscientists are based in the north; and no permanent facilities dedicated to marine research, including the earth sciences, exist in the north.

Closer inspection, however, reveals a number of good reasons for this situation. The lack of a university in the north makes a continuing university presence in any given scientific field much less likely. The distribution of government responsibilities between the south and the north also decreases the probability of northern based research, particularly in the physical sciences. Those federal activities that are based in the north are primarily directed toward the provision of services and enforcement of regulations; northern research is, for the most part, structurally integrated with southern research in federal departments and agencies. Some projects have been funded through the federal mining geology groups in the north but, to this point in time, the marine area has not been involved. Nor have the territorial governments had much to do either with the earth sciences or with related research in cold regions engineering; the work they have initiated has focussed on social and economic topics and on renewable resource development.

Although there are no facilities in the north dedicated solely to marine research of any type, there are a number of organizations with northern facilities, both permanent and temporary, dedicated to the support of science in general. These include the federal Polar Continental Shelf Project with bases at Resolute and Tuktoyaktuk; the Department of Indian Affairs and Northern Development with scientific resource centres at Inuvik, Igloolik and Frobisher Bay; and various universities and private groups with permanent, marine-accessible facilities at Pond Inlet, Rankin Inlet, Post de la Baleine and Churchill. Types of support offered may include supply of scientific and logistical equipment; accommodation and meals; transportation including air transport; communications equipment and services; expediting services; laboratory, office and workshop space; and technical assistance. Some of these organizations, especially the Polar Continental Shelf Project, have provided and continue to provide extensive and valuable support to both ship- and shore-based marine geoscience research.

The present situation appears unlikely to change in any very substantial way in the immediate foreseeable future. The population of northern Canada is still considered by most to be too small and dispersed and the infrastructure too limited to support the development of a multifaceted university in the southern style. The same applies to research institutes like the recently suggested "Institute for cold regions engineering research and development" which are most effectively located on or near a university campus. Nor are changes in the distribution of government responsibilities between the south and the north likely to have any great effect on geoscience research in the north. There is some potential, however, for an increase in the level of general scientific support within the north, an increase which will be of benefit to marine geoscientists among others. The Department of Indian Affairs and Northern Development is currently developing a new framework for science support in the north, a framework which is intended to be more sensitive to the needs of the north but which, at the same time, should lead to improved services for southern researchers. The detailed nature of this new framework will be defined by 1982 and implementation should be immediately thereafter. Even with improved services in the north, though, most marine geoscience – particularly ship-based projects with their large costs, extensive logistic requirements and dependence upon related expertise – will still require southern support and a southern base.

## THE FEDERAL ENVIRONMENTAL ASSESSMENT REVIEW PROCESS – M.J. Keen

The Environmental Assessment Review Process has been applied to projects and developments in the offshore; it has taken a lot of time and money of industrial companies and of government agencies, and, as a consequence deserves study. Much of the factual information which follows comes from a document prepared by Environment Canada.

### *The Process*

Cabinet decided in December, 1973 that the process of environmental assessment and review should be established within the Federal Government to ensure that departments and agencies take environmental matters into account throughout the planning and implementation of projects, programs and activities initiated by the department or agency, or for which federal funds are solicited, or for which federal property is required. Proprietary crown corporations and regulatory bodies were to be invited, but not required to participate in the Process.

More particularly, the departments and agencies were:

a. to undertake or procure an assessment of potential environmental effects in time, before commitments or irrevocable decisions are made for all projects which may have an adverse effect on the environments;

b. to submit the assessments made for all major projects that will have a significant effect on the environment to the Department of the Environment to review;

c. to incorporate the results of the environmental assessments and review in the design, construction, implementation and operation of the projects, giving environmental problems the same degree of considerations as that given to economic, social, engineering and other concerns;

d. to include in program forecasts and annual estimates the funds necessary to carry out the intent of this policy and program.

The Minister of the Environment in co-operation with other Ministers was to establish the necessary procedures for administering the Process, for enabling the public to comment on environmental issues, for public hearings when appropriate, for Environmental Assessment Panels to include a representative of the department sponsoring a project, for co-operation with provinces and territories in the review of interjurisdictional projects and, in special cases, for organization of an Environmental Review Broad external to the government service.

The composition and functions of Environmental Assessment Panels to review the statements of the sponsoring departments were stipulated and Panels were to make appropriate recommendations to the Minister of the Environment on the environmental acceptability of the project.

The Environmental Assessment Review Process was formally established on April 1, 1974 following the 1973 Cabinet decision. This Cabinet decision allowed for changes to be made as experience was gained. Consequently, Cabinet decided in February 1977 that the Process should be adjusted:

a. to permit the appointment of panel members from outside the Department of the Environment (DOE) and the initiating department;

b. to strengthen the existing review mechanisms to provide sufficient information to evaluate the effectiveness of the assessment phase of the Process;

c. to ensure that federal departments and agencies provide information on, and seek public response to their projects early in the planning stage before vital decisions are taken that may be difficult to alter regardless of public opinion;

d. to provide for the allocation of environmental assessment costs between the Federal Government and project proponents.

In the Government Organization Act 1979, Parliament directed, in part that:

i. "The Minister of the Environment, in exercising his powers and carrying out his duties and functions ... shall (a) initiate, recommend and undertake programs, and co-ordinate programs of the Government of Canada, that are designed...

ii. to ensure that new federal projects, programs and activities are assessed early in the planning process for potential adverse effects on the quality of the natural environment and that a further review is carried out of those projects, programs and activities that are found to have probable significant adverse effects, and the results thereof taken into account..."

Initially, the Process was administered and panels were established by a branch of Environment Canada as part of the departmental mandate. However, the administration of the Process and the operations of the panels have become a separate function operating at arm's length from Environment Canada. This is done by the Federal Environmental Assessment Review Office headed by an executive Chairman reporting directly to the Minister of the Environment on operational matters. Environment Canada funds the Office, under the Administration Program of Environment Canada.

As of the summer of 1980, the Process has been in operation for over six years during which period thirteen Review Panels have reported to the Minister of the Environment and the environmental assessments of some eighteen other projects are at various stages of review by the respective Panels.

The Environmental Assessment Review Office itself recognizes that the present process could be improved. For example:

1. Should the "proponent" – the government agency initiating the Process – have membership on the panel or influence the appointment of panel members?
2. Government agencies themselves decide whether or not a project is likely to be "environmentally significant". If the early decision is that it will not be, then the project will proceed in the normal way, with no invitation through the mechanism of the Environmental Assessment and Review Process for public comment. Is this proper?

As a consequence of comments of this sort, of which these are only two examples, proposals are being discussed (Fall, 1980) for changes in legislation. The proposals' aim in essence is to strengthen the Process and to ensure greater public participation.

### *Some Consequences Offshore*

Consideration has to be given to the environmental consequences of many projects in the offshore for several reasons. A project may demand federal funds, as did the Annapolis Basin Tidal Power Project. A project may be on federal lands – on federal property – as is exploration drilling on the Scotian Shelf, for example (in the view of the Federal Government). Departments which "initiate" projects – supplying federal funds, for example, or which administer federal lands, have the right to say that a "project" will not have substantive environmental consequences, and so does not need referral to the Federal Environmental Assessment Review Office. Energy, Mines and Resources took this attitude to offshore exploration drilling in federal lands south of 61°18'N; Indian Affairs and Northern Development took the opposite attitude with respect to applications to drill in Davis Strait (granted), and to drill in eastern Lancaster Sound (denied). Energy, Mines and Resources will, however, require Environmental Assessment and Review of any proposals to produce hydrocarbons in the Hibernia area, and in the Sable Island area. (There are several projects in the offshore of this sort; only examples are given here.)

There are several observations to be made of the Environmental Assessment and Review Process, as it affects the marine geosciences.

1. There is probably a much greater awareness of environmental consequences because the Process exists, whether or not a particular project is referred for review. This comment applies to staff in industry and government, and to the general public. Various formal and informal mechanisms exist to ensure that this awareness is maintained. As one example, the regional office of Environment Canada in Halifax has established a Regional Screening and Co-ordinating Committee with members drawn from the numerous federal agencies in the Atlantic Provinces.
2. The work demanded of geologists and geophysicists in organizations such as the Geological Survey of Canada and the Earth Physics Branch as a result of the Environmental and Assessment Review Process is very great, and additional resources have not been made available to these organizations. This is the situation in spite of the instruction in the original Cabinet decision that departments and agencies were to include in their forecasts of expenditures an annual estimate of the funds required to carry out the intent of the Process.

The sort of work involved is: assessment of guidelines drafted by an Environmental Assessment Panel for an environmental impact statement which a company planning to undertake a project – production from Hibernia, for example – must file as a part of the Process; comment on the Environmental Impact Statement itself; participation in meetings concerned with the project; scientific work designed to enable the federal agency to comment on proposals which will come forward. Public servants working for organizations such as the National Research Council, the Geological Survey of Canada and Earth Physics Branch are involved in these ways for at least two reasons:

a. The Federal Government has expertise on its staff, and this should be used;

b. Scientists and technologists in the federal agencies are often the only ones in the country with any expertise in a field who are not members of the staff of proponent companies, or of consulting companies engaged by the proponents.

As an example, the only expertise on sea ice scour or iceberg scour in Canada outside the companies or organizations such as C-CORE, funded itself in part by companies, lies with a very few individuals in the Geological Survey of Canada. (Expertise on sea ice itself exists of course in other agencies.)

The consequences of this involvement are severe. The work required for the environmental review process means that other work does not get done, and programs of scientific agencies may be changed in anticipation of demands which the process may make. People outside the Public Service – the Advisory Committee to the Geological Survey of Canada, for example, often demand that the Survey: "maintain its traditional role"; people inside the Public Service demand: "you have the expertise; advise on these environmental problems". Without additional resources, the two demands are not compatible.

3. A third observation which is pertinent to the Environmental Assessment and Review Process is that the Process has probably resulted in more collaborative work between government scientists and industry scientists than there would have been. Examples are: joint work by Petro-Canada and the Geological Survey of Canada in mapping the coastal regimes of eastern Baffin Island and of Labrador; joint work under the umbrella of the Arctic Petroleum Operator's Association between the Geological Survey of Canada, Dome Petroleum, Gulf and Esso in the Beaufort Sea, where site-specific geological studies and regional geological studies are being integrated. It is proper to applaud such collaborative work, in which resources are channelled properly, not dissipated by duplication. However, collaboration does have its disadvantages:

   a. The public servant involved in collaboration may be the only one to turn to for advice under the Environmental Assessment and Review Process;

   b. The public servant may be seen by other companies, not involved in a particular piece of collaborative work, as a servant or agent of the collaborating companies, and this is not a proper status for a public servant;

   c. The obligation on the Geological Survey of Canada, the Earth Physics Branch and other scientific and technological agencies of the Government of Canada is to publish information obtained in a timely and accurate manner. This is not a view held by companies to whom information is, naturally, a competitive advantage and an asset.

These are real difficulties which the federal agencies have to face. The situation is probably this, however:

a. Until massive resources are available to these agencies, comparable to those of the United States Geological Survey, for example, collaborative work will remain the only way to obtain information needed to perform the mandates which the government agencies perceive that they have, including the need to respond to the demands of the Environmental Assessment and Review Process.

b. The number of earth scientists working in Canada's offshore is pitifully, laughably, small. Until that is rectified, collaboration will remain the only way to get jobs done, even though this will create situations where there is, apparently, conflict-of-interest. Collaborative work allows a company and government scientist to obtain understanding of processes which will, hopefully, ensure that the potential damage to the environment from a project is minimized, and, vice versa, that the damage to a project from the environment itself is minimized. If this happens, it can be argued that the price – apparent conflict-of-interest – is an acceptable one.

4. A fourth observation concerns the data being obtained through the work demanded of companies as a result of the Environmental Assessment and Review Process, or indeed as a result of surveys needed for their own sake. There is an enormous amount; for example, Petro-Canada has many times more observations of currents on the Labrador Shelf than has the Atlantic Oceanographic Laboratory of the Department of Fisheries and Oceans at Bedford Institute of Oceanography. This sort of data – current observations are only an example – will be very valuable to generations of scientists to come, and it is not obvious that the proper systematic efforts are being made to ensure that these data are archived properly, or being published properly. The responsibility belongs, rather clearly, with the government agencies as well as with the companies; again, unless government agencies do not do something else, they cannot accept this – important – burden without additional resources.

5. The final observation is a philosophical one, and is perhaps out of place in this document. The strategic objective of the Environmental Assessment and Review Process is surely: to ensure that as Canadians we play our part in seeing that planet Earth remains a marvellous, habitable place. To this end we dedicate analyses of cadmium in material destined for disposal offshore, and studies of sea ice scour in relation to glory-holes and well-heads. We may despair and regard our puny efforts as futile when we see the Atlantic Salmon – one of nature's wonders to which our efforts are devoted – disappearing through acid rain, knowing that this is totally beyond our control as scientists. We should surely not despair; we have to be optimists and continue to try to save the Earth.

## LEGAL ISSUES IN THE CANADIAN CONTINENTAL MARGIN

– R.J. Harrison and I. Townsend-Gault

### *Introduction*

The law applicable to the Canadian continental margin is in transition. On the international front, the Third United Nations Conference on the Law of the Sea (UNCLOS III), which has been meeting at intervals since 1977, appears to be moving towards a comprehensive Convention dealing with all users of the seas, the seabed and subsoil, and with jurisdiction over them. On the domestic scene, competing claims over offshore resources may be resolved soon between the federal and provincial governments. At the same time, new regimes are being implemented to deal specifically with the exploitation of offshore petroleum resources.

Thus, within a few years, the basic legal issues that arise in the Canadian continental margin are likely to be largely resolved, at least in terms of the legal framework that will apply for probably several decades.

At present, however, it is impossible to write with any certainty or finality. Few, if any, of the issues have been resolved.

It is, nevertheless, possible to identify the issues that will have to be resolved as Canada moves towards commercial exploitation of the resources of the adjacent seabed. In this paper, we group those issues under the three headings of International Law, Constitutional Law and Exploitation Law.

### *International Law*

#### The Continental Shelf Doctrine

States derive their rights in respect of offshore natural resources from the rules of international law, usually referred to as the doctrine of the continental shelf which has been an accepted rule of international law for more than two decades. Following the initiative of the United States in 1945, a consensus developed among coastal states that the resources of the shelf would be under the exclusive jurisdiction of the proximate coastal state. Consistent state practice gave rise to a rule of international customary law. The principles were codified and developed at the First United Nations Conference on the Law of the Sea which resulted in the 1958 Geneva Convention on the Continental Shelf, as well as three other laws of the sea Conventions. The Convention entered into force in 1964, and Canada became a party in 1973. The Convention is, therefore, declaratory of the nature and extent of the rights claimed by Canada in respect of the natural resources of the shelf. It is intended, however, that it will be replaced by the Convention that is now emerging from UNCLOS III.

#### Seaward Limits to National Jurisdiction

One of the most unsatisfactory features of the 1958 Geneva Convention was the ambiguity in its definition of the seaward limits of the area in which national jurisdiction could be exercised. The continental Shelf referred to "the seabed and subsoil of the submarine areas adjacent to the coast but outside the area of the territorial sea, to a depth of 200 metres or, beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said areas..." This is the legal or juridical shelf (Fig. 3.10) as distinguished from the physical continental shelf as a geographic phenomenon.

The unsatisfactory nature of this rule is obvious. Some states, for example France, have adopted a restrictive approach, and regard the 200 metre isobath as the seaward limit of the shelf. The United Kingdom, on the other hand, has issued licences in respect of shelf areas of much greater depths, as indeed has Canada.

The Convention that will likely emerge from UNCLOS III will define the outer limit of the juridical shelf much more clearly. The coastal state would exercise exclusive jurisdiction over the resources of the seabed and subsoil within 200 nautical miles as an aspect of a new concept known as the Exclusive Economic Zone. The coastal state would retain all revenue derived from the resources of the zone.

Jurisdiction over the shelf beyond the 200 mile Exclusive Economic Zone would extend to a distance fixed by combined reference to distance from shore, depth of the superjacent waters and characteristics of the physical shelf. In simplified terms, this outer limit would extent to 350 miles, or 100 miles beyond the 2500 metre isobath, whichever was greater. Production or resources within this additional area beyond the Exclusive Economic Zone would be subject to the payment of a royalty to the International Seabed Authority, which is discussed in the next section. The coastal state would, however, exercise exclusive jurisdiction with respect to issuing exploration and production rights and generally with respect to exploitation of the area.

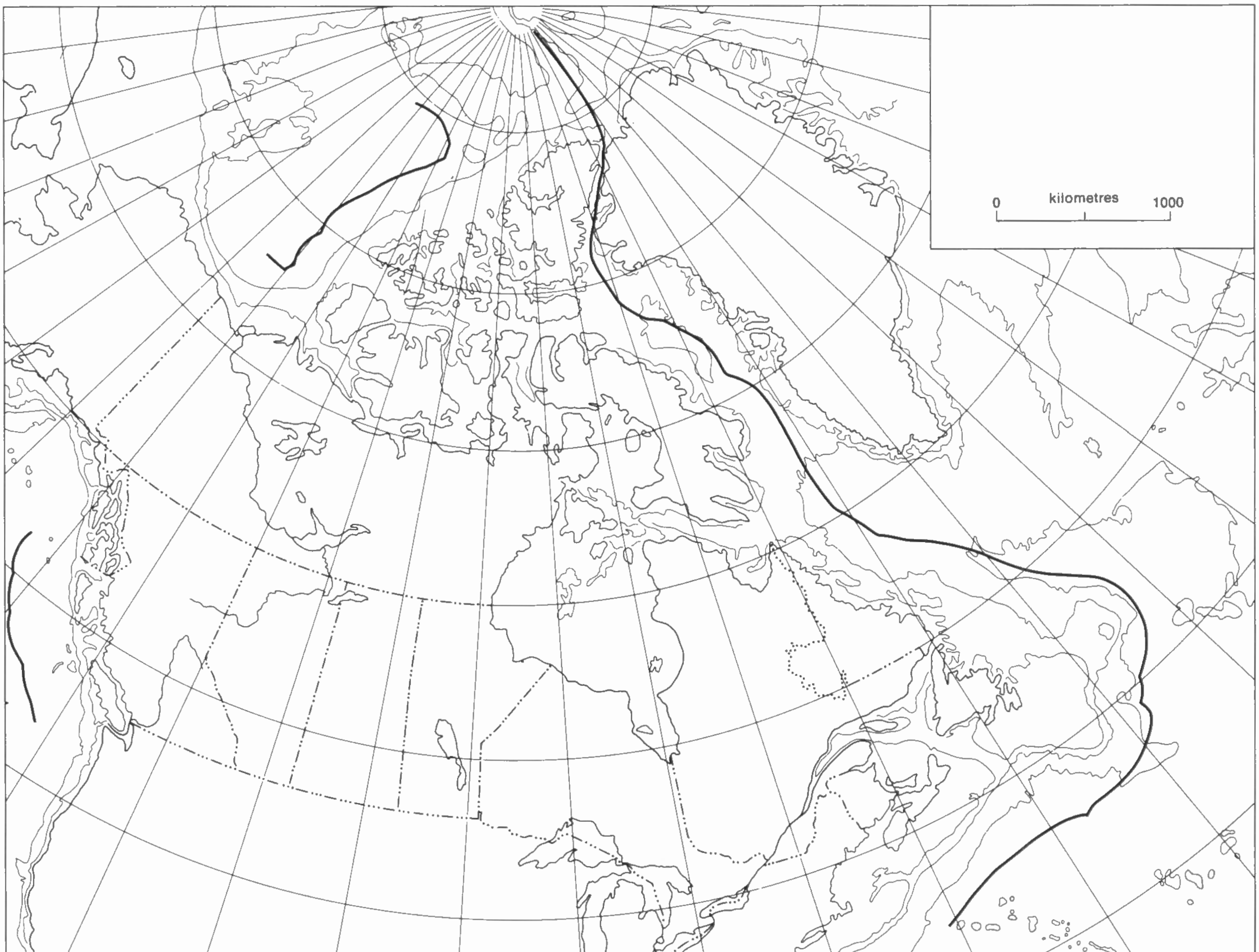



*Figure 3.10.* *A sketch of the extent of the juridical "continental shelf" off Canada according to an interpretation of Article 76 of the Draft Law of the Sea Convention (based on work by D. Sherwin and D. Crosby). This sketch does not represent any official position taken by the Government of Canada.*

Canada has in fact been issuing oil and gas permits for areas well beyond 200 miles on the basis of the 1958 Geneva Concention where, it will be recalled, the outer limit of the continental shelf was fixed by reference to the limits of exploitability. Under Bill C-48 for the Canada Oil and Gas Act, it claims jurisdiction for purposes of exploiting the natural resources in:

> ...those submarine areas adjacent to the coast of Canada and extending throughout the natural prolongation of the land territory of Canada to the outer edge of the continental margin or to a distance of two hundred nautical miles from the baselines from which the breadth of the territorial sea of Canada is measured, whichever is greater.

This claim is based on the definition of the continental shelf proposed by the draft Convention that is under discussion in UNCLOS III.

### The Deep Seabed

A fundamental principle that has emerged from the UNCLOS III deliberations is that offshore areas beyond the limits of national jurisdiction known as "the Areas", and the resources thereof, "are the common heritage of mankind". As such, it is proposed that they be exploited under international control and that revenues derived therefrom be shared equitably "for the benefit of mankind as a whole, irrespective of the geographical location of States, whether coastal or landlocked, and taking into particular consideration the interests and needs of the developing States...".

The Area will be administered by the proposed International Sea-Bed Authority to be composed of all States that become parties to the new Convention. Activities in the Area will be carried out either in association with the Authority or by an organ to be known as the Enterprise. Thus, the Authority will occupy a position somewhat equivalent to that of the Crown with respect to Crown-owned mineral resources on shore and will exploit the resources of the Area through the equivalent of a leasing or licensing system and through the equivalent of a national oil company like Petro-Canada.

### Boundary Issues

As well as establishing the seaward limits of national jurisdiction, the law of the sea also deals with the determination of boundaries in offshore areas between opposite and adjacent states. Offshore boundaries between Canada and the U.S.A. are yet to be determined in four areas: in the Georges Bank area in the Atlantic Ocean; between British Columbia and Washington, and between British Columbia and Alaska, in the Pacific Ocean; and between Alaska and Canada in the Beaufort Sea. Canada also has an unresolved boundary issue with respect to the French islands of St. Pierre and Miquelon off the coast of Newfoundland.

A treaty was concluded between Canada and Denmark in 1973, delimiting the shelf between Canada and Greenland according to the median line principle. Application of this principle, enunciated by the 1958 Geneva Convention, and generally recognized as the primary means of effecting a delimitation between opposite states, results in a line equidistant from the two shores.

The appropriate method of delimitation applicable to adjacent states is that of equidistance, which provides for a line proceeding seawards from the coast, the direction being influenced by the configuration of the coastline. The course of a continental shelf boundary may be affected by "special circumstances", for example, an unusual coast configuration, islands, reefs, etc.; the median or equidistance principles are not to be applied blindly.

Determination of boundaries in the Georges Bank, and around St. Pierre and Miquelon, is complicated by the special circumstances of each case. Normally, Georges Bank boundary would be determined by the ordinary application of the equidistance principle. However, the U.S.A. claims that the geological configuration of the seabed in the area is such as to indicate a "natural" shelf boundary. There is also the question of the effect to be given to Nantucket Island in determining a boundary. These matters are crucial, for a small deflection of the line in favour of one state or another near the coast makes a difference of hundreds of square kilometres at the outer limits of the continental margin.

Years of negotiations failed to resolve the dispute, which became complicated by the differences of opinion concerning fisheries. Canada and the U.S.A. had agreed to send the boundary dispute to arbitration by a Chamber of the International Court of Justice in The Hague. The agreement was part of a "package deal" which included an agreement on the fisheries dispute. The U.S. Senate, dissatisfied with the fisheries agreements, refused to ratify them, and the arbitration treaty was lost with the others. The U.S.A. has since indicated that it wishes to divorce the shelf boundary dispute from the others, and send it to arbitration at once. Canada is reluctant to agree to this, feeling the loss of leverage if the package deal approach is abandoned would hamper satisfactory resolution of the fisheries dispute.

The problems posed in relation to St. Pierre and Miquelon are of a different order. These islands, under the sovereignty of France, lie off the coast of Newfoundland. A strict application of the median line principle would give the islands an enormous area of shelf, reaching into the Atlantic, at the expense of Canada. The situation is not unlike that which faced France and the United Kingdom concerning the Channel Islands, the small group of British islands off the coast of France. The two states resorted to arbitration concerning this and other delimitation problems. The court of arbitration awarded the Channel Islands a twelve mile enclave in the French shelf. The Canadian government would be in a good position to insist that France accept a similar solution for St. Pierre and Miquelon, given the factual similarity.

Until recently, there seemed to be no reason for haste in determining the Pacific boundaries; however, oil and gas exploration off the coast of British Columbia seems likely to pick up in the near future, bringing resolution of the shelf boundary higher up the list of priorities. As the prospect of commercial exploitation of petroleum resources in the Beaufort Sea increases, resolution of that shelf boundary also becomes more urgent.

The legal issues in the Arctic, however, go beyond merely resolving the boundary with the U.S.A. in the Beaufort Sea. Canada has claimed the right, for example, to regulate shipping in the northwest passage, and enforce a 100 mile pollution prevention zone in Arctic waters.

The legal status of Arctic waters, and in particular, the waters between the Canadian Arctic islands, is not conclusively settled. States exercise absolute sovereignty over internal waters, that is, those waters lying landward of the baselines from which the breadth of the territorial sea is measured. The baselines should follow the direction of the coast, but straight baselines, enclosing areas of sea are permissible, for example, across the mouth of a bay, between the islands of an archipelago, but, according to the 1958 Geneva Convention on the Territorial Sea and Contiguous Zone, to a maximum of 24 miles. These rules have been considerably developed at UNCLOS III, in response to pressures from states such as Indonesia, the Philippines, and Malaysia. Rights of passage through the internal waters of archipelagic states are preserved, subject to certain safeguards.

Canada has always maintained that the Arctic environment is especially vulnerable to damage from oil pollution, and hence a special legal regime in respect of these waters must be enforced. For these reasons, tanker traffic in the area must be regulated by Canada.

### *Constitutional Law*

International law is not at all concerned with the distribution of public power within a state. This is a matter for domestic constitutions. Thus, the question arises in a federal state of whether the rights accorded over offshore areas by the international community are to be exercised within that state by the central or regional units of government. In the Canadian context, the question has focussed particularly on the competing claims made by the Federal Government and by Newfoundland.

In 1967, the Supreme Court of Canada presented the unanimous opinion that, as between the Federal Government and British Columbia, the Federal Government had exclusive jurisdiction with respect to the seabed and subsoil of offshore areas. The basis of its opinion was that, at common law, the jurisdiction of the realm ended at the low water mark. The realm might be extended by legislative action but in the case of British Columbia there had been no such action before its entry into confederation in 1871. The offshore areas in question were, therefore, outside the province and thus beyond its legislative competence.

Newfoundland points to its unique history in arguing that the B.C. reference does not apply to it and that the continental margin adjacent to its shores is under its, and not the Federal Government's, jurisdiction. Prior to its entry into confederation in 1949, Newfoundland had been a self-governing dominion. In that capacity, it argues, it acquired the same right as any other nation with respect to offshore areas and in particular with respect to the continental shelf beyond the territorial sea. These rights were not, the argument continues, surrendered under the Terms of Union upon which Newfoundland became part of the Canadian federation and, therefore, still abide with Newfoundland. Most legal opinion, however, is to the effect that the argument would not prevail in a judicial resolution of the issue and Canada would be found to have exclusive jurisdiction off the east coast as well as the west coast.

Meanwhile, both the Federal Government and Newfoundland have been asserting jurisdiction. Each has in place a comprehensive exploitation regime for petroleum resources. The petroleum industry has been coping with the situation by taking out both federal and provincial permits and by complying with the requirements of each jurisdiction. This has been possible during the exploration phase as one work program can be used to satisfy two masters. However, this method of side-stepping the jurisdiction issue cannot be carried forward to the production phase as the two regimes have different requirements at that stage. While one work program might satisfy two masters, the payment of royalty to one will obviously not satisfy the other. Furthermore, it would be extremely difficult, not to mention expensive, to apply both federal and provincial provisions with respect to direct state participation in commercial exploitation, through Petro-Canada and the Newfoundland and Labrador Petroleum Corporation respectively.

It is likely, therefore, that the jurisdiction issue will be resolved in the near future, either by a court ruling or by a negotiated agreement between the governments concerned. The Federal Government has offered Newfoundland 100 per cent of the revenues it would derive if the resources of the continental shelf were located onshore until it has reached "have" status, with a sharing of these revenues thereafter. It is not, however, prepared to concede ownership of the resources of the province.

### *Exploitation Law*

As indicated in the previous section, both the Federal Government and the Newfoundland Government have put in place comprehensive regimes governing the exploration for and production of offshore petroleum resources. The federal regime has been found in the Canada Oil and Gas Land Regulations, first promulgated in 1961 and substantially revised in 1977. Parliament has before it now Bill C-48 for a new Canada Oil and Gas Act which will completely replace the existing regime. It provides for a two phase licensing system under which exploration activities will be conducted in accordance with a negotiated Exploration Agreement. After commercial discovery, this will be converted to a Production Licence. Under the Newfoundland and Labrador Petroleum Regulations, promulgated in 1977, the equivalent instruments are an Exploratory Permit and a Lease.

Both the federal and provincial regimes deal only with the exploitation of petroleum resources. Neither purports to deal with the extension of the general legal system to offshore activities, leaving a major lacuna. It is expected that this will be addressed by the enactment in the next few years of a Canadian Continental Shelf Act.

## CANADA – ITS ROLE IN INTERNATIONAL MARINE GEOSCIENCE – C.E. Keen, D.J.W. Piper, and M.J. Keen

There is perhaps a higher degree of international co-operation in marine geoscience than in any other aspect of the earth sciences. This arises, in part, because of the absence of territorial rights over much of the world's oceans, and in part because of the recognition by marine geoscientists that a small community of geoscientists studying such a large region must share data, resources, and ideas. Some examples of large scale international programs, which are visible in the sense that they involve the use of significant resources, and in which Canadians actively participate are the following.

### *Arctic Ocean Geology and Geophysics*

A series of expeditions have used free-floating ice islands in the polar pack of the Arctic Ocean as bases from which to collect geophysical, geological and oceanographic data. These expeditions are: Canada Basin Acoustical Reverberation Experiment (CANBARX, 1978), FRAM (named after the vessel, 1979-1982), Lomonosov Ridge Experiment (LOREX, 1979), and the Canadian Expedition to Study the Alpha Ridge (CESAR, planned for 1983). The first two of these, in which Canadian geoscientists have played a major role in the geological and geophysical aspects of the program, are funded mainly by the U.S. Navy (Office of Naval Research). Participating countries other than the U.S.A. include Canada, Norway, and Denmark. LOREX and CESAR are largely Canadian projects with major input from the Polar Continental Shelf Project, Earth Physics Branch, and the Geological Survey of Canada. There is minimal participation by other countries in these programs.

### *LADLE (Lesser Antilles Deep Lithosphere Experiment, 1980), and LASE (Large Aperture Seismic Experiment, 1981)*

These are seismic experiments for studies of deep crustal and subcrustal seismic experiments for studies of deep crustal and subcrustal seismic properties. LADLE was aimed at the definition of the subcrustal oceanic lithosphere using ocean bottom seismometers. It involved British, Canadian, French, and West Indian scientists. The object of LASE is to investigate the deep structure of the continental margin off New Jersey, using high resolution, deep penetration multichannel seismic techniques. It is largely a U.S.A. funded project, but there is significant input, including shiptime, from Canadians.

### *Deep Sea Drilling Project (DSDP)*

Although Canada is not a member of the International Phase of Ocean Drilling (IPOD), significant input to the project has been provided by Canadians, particularly those from Dalhousie University, in drilling deep holes into layer 2 of the oceanic crust. There was a major Canadian contribution to Leg 37 of this project in 1974, when the first deep holes were drilled into the ocean crust. The success of Leg 37 led to further participation in DSDP through membership on various advisory panels. Scientists from the Atlantic and Pacific geoscience centres and several Canadian universities have recently been involved in many DSDP sites, investigating sediments and sedimentary processes on continental margins, paleooceanography and down-hole experiments in oceanic crust.

### *Ocean Island Drilling*

In order to sample greater depths within oceanic crust than possible with present DSDP facilities and to minimize costs, Dalhousie University has been a leader in drilling the oceanic crust exposed on oceanic islands. Deep holes (2 km) on Bermuda, the Azores and Iceland have been completed. The Iceland project was a co-operative venture, with participation from Canada, Britain, U.S.A., Iceland and West Germany.

### *Nuclear Waste Disposal – Seabed Project*

This is an international project in which research groups from different nations concerned with the problems of disposal of nuclear wastes carry out site surveys in deep ocean areas and share the results to establish whether any parts of the deep ocean might be suitable for waste disposal. Participants are from Canada, France, Japan, U.K., U.S.A., and West Germany. Canada joined the project in 1980; the

Atlantic Geoscience Centre has undertaken at least one major cruise directed towards this project, and has participated in several others. This involvement is based on the plans by other nations to consider sites in the deep ocean for waste disposal; Canada should be able to evaluate these plans critically.

*North American Transects Project*

The Canadian Committee on the Lithosphere and the U.S. Geodynamics Committee jointly sponsor this project whose goal is to construct cross-sections of the continental margins around the North American continent, from the Arctic to the Gulf of Mexico. A total of 24 transects are in progress, of which 8 are off Canada. Working groups, involving Canadian government, university and industry scientists have been established for eastern, western and Arctic margins.

These are some of the more visible international programs, in terms of costs and people. However, there is a whole spectrum of equally productive collaborative programs, ranging from personal contacts, to larger scale, more formal, efforts. It is important to recognize, for example, that in the five years from 1976 to 1980, perhaps 25 per cent of Dalhousie University shiptime was on foreign ships. Two graduate students participated on different U.S. cruises to the mid-Atlantic ridge, one gathering most of her thesis material on one cruise. Co-operative work on the west coast of the U.S.A. involved participation in two cruises by a professor and graduate student, resulting in three substantial publications in which Canadian input was at least 50 per cent. Another graduate student participated on two British cruises from their Institute of Oceanographic Sciences, gathering long-range sidescan data from the eastern Canadian margin; these data formed an important part of the student's thesis.

Similarly, at UBC there have been several co-operative programs with American universities, in the Juan de Fuca Ridge region. At Memorial, studies of modern carbonate rocks in the Bahamas have been undertaken from U.S. ships and submersibles. At McGill, there have been co-operative projects on West German ships. Two common themes to many of these studies are the use of equipment not available in Canada (deep tow, Gloria and Alvin), and the lack of shiptime on Canadian research vessels.

Other co-operative experiments deserving mention include multichannel seismic measurements over the western continental margin, involving the United States Geological Survey and the Pacific Geoscience Centre. Similar experiments over the eastern continental margin have been carried out between BGR (West German Federal Institute for Geosciences and Natural Resources) and the Atlantic Geoscience Centre. In all these experiments, the work was carried out from foreign ships, with equipment not readily available within Canada.

Several generalizations can be made from the level of Canadian participation in international projects as outlined above. First, there is an acceptable level of individual, informal co-operation with non-Canadian scientists, although this is difficult to quantify. Second, the rationale behind many projects stems from the inaccessibility of Canadian shiptime or advanced technology to those within government and, more particularly, university laboratories. Third, the level of Canadian participation in large scale international projects is inadequate. This is illustrated by the fact that in the four years from 1977 to 1980, only 13 per cent of the total Canadian shiptime (east coast only) devoted to geoscience studies was spent on international programs; this figure reaches 13 per cent only by liberal interpretation of the work "international". A much smaller proportion was allocated to similar programs on the west coast. It is further noted that very little international participation has occurred on the Canadian-run LOREX and present plans suggest that foreign participation in CESAR ice island studies will also be very low.

International programs have some decided disadvantages. The Deep Sea Drilling Project, for example, discourages graduate student participation largely because of the way in which results are published (rapidly, and with a large group of coauthors). Sometimes results of co-operative projects are inaccessible to all but a few because one participating agency may wish to sell the data and hence maintain a certain level of confidentiality. The biggest disadvantage is often the sheer hard work in organizing ventures which include many, widely scattered participants, with different masters to satisfy. It is also true that big, international projects do not necessarily produce any better science than smaller scale research projects carried out by Canadians in Canadian waters.

However, Canada stands to gain tremendously through major international research projects. The marine geoscience community in Canada is pitifully small and we need, and should welcome, the infusion of new ideas, technologies, and opportunities which international co-operation can provide. The resources necessary to carry out the work decrease in direct proportion to the number of non-Canadian participating agencies. The number of international programs in other countries, notably West Germany, Britain, and the U.S.A., is substantially higher. It is, therefore, not surprising that Canada's marine efforts are often viewed by non-Canadians as being parochial, but competent and useful.

The major difficulty faced in attempting to increase Canada's level of participation in international projects is inadequate resources to properly carry out even our present programs. This is equally true for people, technology, and ships. This difficulty could be eased by contracting many routine mapping functions to private industry. A successful example of this approach is the USGS aeromagnetic survey of the eastern margin of the U.S.A. This could free scientists from an overwhelming burden of data collection, reduction and dissemination, allowing more emphasis on interpretation and global relevance of the results. However, it cannot be funded under the present funding structure. Joint programs with industry, particularly those which involve the development of new technology are encouraged at present; the availability of additional funds to support expansion of these programs would be beneficial.

An inescapable conclusion is that the resources available for marine geoscience research must be increased. This could be accomplished by a significant increase in university marine research; universities are perhaps the natural focus for fundamental research on a global scale. At present, we have no academic institution comparable to Lamont, Scripps, or Woods Hole in the U.S.A. Government laboratories, such as the Atlantic and Pacific geoscience centres at Bedford Institute of Oceanography and the Institute at Patricia Bay, try to fill the role of these institutions. The problem is that these laboratories have several mandates; research scientists are urged to do front line research of global problems on the one hand, but asked to contribute to problems of immediate concern to Canada within territorial waters on the other; they are asked to play the role of an academic research institute and act as the scientific advisory arm of the government. Strengthening these laboratories is desirable, but it is not a long term solution, if only because Canada needs strength within the universities to train and develop the manpower necessary in marine research in five to ten years time. The lack of trained Canadians is already a severe problem.

Research within the academic community could be strengthened in a number of directions mentioned elsewhere in this report. First, there is an urgent need for more technological development within the universities. The present levels of funding are inadequate to allow for proper technical support staff, and purchase and development of "state-of-the-art" equipment. Second, shiptime must be available to universities to carry out their own research projects. Without access to shiptime, new staff will not find Canadian universities attractive, programs will not be developed, and students will not be trained.

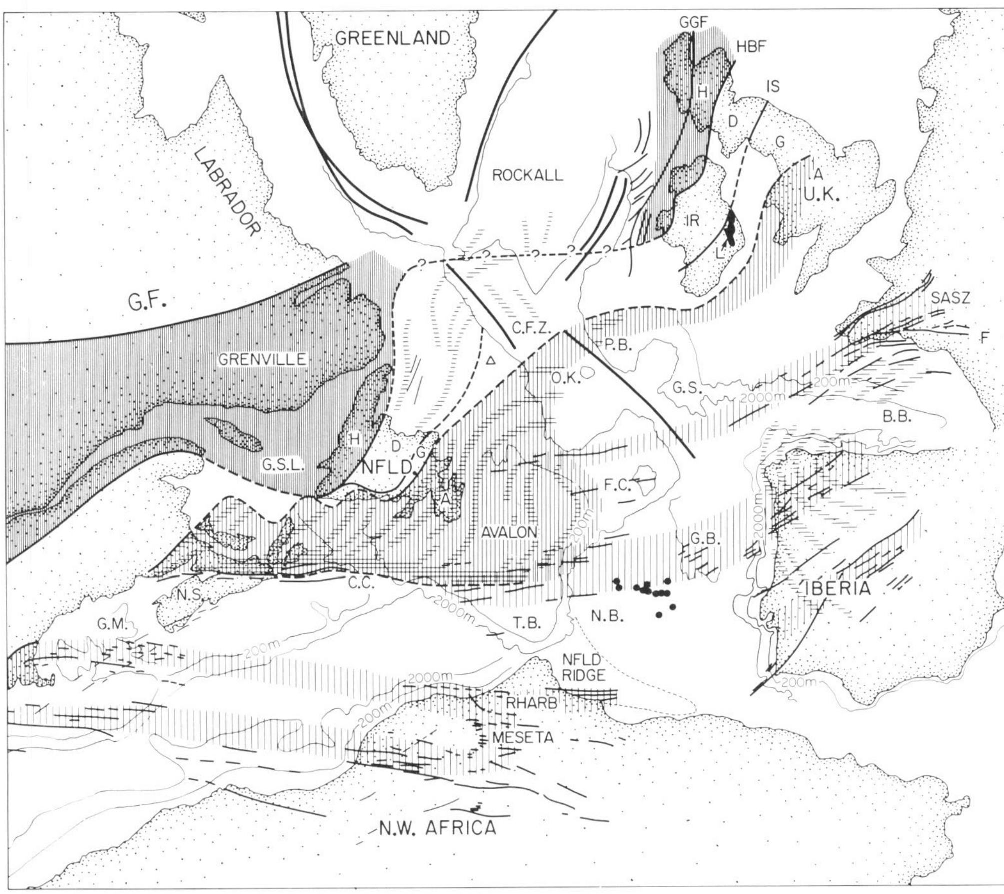
In summary, Canadians do participate in international marine projects, and enjoy a good reputation in several areas of marine geoscience. Good research carried out by Canadians within Canadian waters is recognized abroad, although we are viewed as being more provincial in our outlook than countries who have less to gain than we do from marine research. We could greatly benefit from increased participation in large international projects, but to do so, more resources must be available to government and academic research groups.

## INTERNATIONAL PHASE OF OCEAN DRILLING: CANADIAN PARTICIPATION – M.J. Keen

The Deep Sea Drilling Project is a program of drilling in the ocean basins and continental margins. This goal is being realized by drilling and coring sediments and parts of the underlying oceanic crust. The Project has been an unqualified success; if a single achievement is mentioned that must surely be that the Project "proved" that the ocean floors spread and the continents drift.

The Project began in 1966, organized wholly by institutions in the United States and funded by the United States through the National Science Foundation. Other nations became partners in 1975 when the International Phase of Ocean Drilling began; these partners have been Japan, Britain, West Germany, France and the U.S.S.R. All these nations have contributed financially to the Project, but the largest share has been assumed by the U.S.A. The Project receives direction from representatives of oceanographic institutions in the member nations, and is operated by one of them, Scripp's Institution. The drilling vessel used at present is the **D/V Glomar Challenger** owned by Global Marine Inc., and operated by that company on behalf of the Project. Funding is organized through the National Science Foundation. The Foundation's funds come from the U.S.A. and the other participating nations. Canada is not a member nation of this International Phase.

In spite of this, a select few enthusiastic Canadians have participated in the program at a modest – but often critically important – level throughout the program, as members of the scientific team on board, occasionally as co-chief scientists, and as investigators of archived material. Canadians are invited to participate when they have skills




*Abbvreviations used:*

*A = Avalon-Anglesey Zone,*
*BB = Bay of Biscay,*
*CC = Cobequid-Chedabucto-Collector Lineament,*
*CFZ = Charlie Fracture Zone,*
*D = Dunnage-Dundee Zone,*
*F = France,*
*FC = Flemish Cap,*
*G = Gander-Greenore Zone,*
*GB = Galicia Bank,*
*GF = Grenville Front,*
*GGF = Great Glen Fault,*
*GM = Gulf of Maine,*
*GS = Goban Spur,*
*GSL = Gulf of St. Lawrence,*
*H = Humber-Hebrides Zone,*
*HBF = Highland Boundary Fault,*
*IR = Ireland,*
*IS = Iapetus Suture,*
*L = Leinster granite,*
*NB = Newfoundland Basin,*
*NFLD = Newfoundland,*
*NS = Nova Scotia,*
*OK = Orphan Knoll,*
*PB = Porcupine Bank,*
*SASZ = South Armorican Shear Zone,*
*TB = Tail of the Bank,*
*UK = United Kingdom (from Haworth, R.T., 1981, Canadian Society of Petroleum Geologists, Memoir 7, p. 429-449).*

***Figure 3.11.*** *Possible trans-Atlantic correlation of Appalachian-Caledonide features. Structural lineations are indicated by narrow bands of horizontal lines. Heavy lines indicate continent-ocean boundaries. Faint northeast trending lines on the North American margin are dykes. Other lines indicate boundaries of geological zones or faults. The east-west faults lie in zones indicated by the widespread vertical lines. The extent of the Avalon-Anglesey and the Humber-Hebrides Zones are indicated by the closely spaced vertical lines. The Newfoundland Seamounts are indicated by heavy dots.*

critical to the solution to a particular scientific problem. However, not being a member of the International Phase means that Canada has no rights to participation, and only a select few have actively participated, and Canada has no influence on site selection. No site proposed by Canada has been accepted – the site proposals of member nations have always had precedence – rather naturally.

The project is at a critical stage. (1) The drilling vessel **Challenger** is getting worn out. (2) The vessel is limited in its operational capabilities in terms of weather conditions in which it can work, penetration into the seafloor which can be attained, and type of rock which can be drilled without great difficulty. (3) The U.S.A. Government is cutting the Foundation's budget. The National Science Foundation has examined four possible courses of action. (1) To stop the Project in 1983. This would mean that many important scientific and technological questions would not ever be answered. (2) To refit the **Challenger** and continue the Project for at least five years; this would mean that a number of questions would not be answered, and an opportunity to make both scientific and technological advances would be lost. (3) To fit out the vessel **Glomar Explorer** as a drilling vessel with the capability for well-control and the use of a riser in deep water. This would demand major technological advances, with most uncertain costs, and the scientific community in the member nations and industry in the U.S.A. would not support this proposal (called the Ocean Margin Drilling Program). (4) To fit out the vessel **Glomar Explorer** as a drilling vessel, but without the capability for well-control and the use of a riser initially. It is this last option which is being pursued. The Foundation proposes to:

1. Phase out **Challenger** operations in October 1983.
2. Convert the **Explorer** for drilling operations during 1984 and 1985.
3. Continue scientific efforts in 1984 and 1985 by using the existing data, and by planning the use of **Explorer**.
4. Operate the **Explorer** as the drilling vessel from October 1985 onwards for eight years.

The **Explorer** has many advantages over **Challenger**: she is effectively new; she is larger and will be able to operate in high latitudes; she can drill deeper because she can carry drilling mud and casing, and a longer drill string. The initial conversion would not include the capability for well control and a riser. This could be added later. A decision will be made to proceed or not with **Explorer** conversion early in 1982 (following an appropriate scientific review which was held late in 1981).

The scientific and technical program over the next 5-10 years will accommodate several thrusts: (1) the geological framework and the geological history of the continental margins; (2) the nature of the crust of the ocean basins – for example, the composition of the lower crust, and the nature of mineral-forming processes; (3) the history of development of the ocean basins – their climates and their oceanography – over the past 200 million years; (4) the technology of drilling in deep water, in difficult rocks, and of instrumenting drill holes. Specific examples are given later. The assumption has been made here that riser and well-control will not be fitted later; if they were, the range of problems which could be tackled would be greater.

The United States is seeking participation from other nations. (1) October 1983-September 1985: as members in the planning process; the entry fee for each foreign nation would be about $200K per year, a total cost in terms of fees of about $400K. New members would be "candidate" members. The United States would bear the cost of the conversion of the **Explorer**, about $60 million; if the value of the vessel is added, this contribution will be about $100 million. (2) October 1985-September 1993: as full members in the operational phase with **Explorer**: the membership fee will be about $3 million per annum (1983 dollars) for eight years; consortia of nations are being invited to become full members, with members of consortia sharing rights, privileges, and costs. Canada expressed substantial interest in becoming a "candidate member" at a meeting of the present member nations of the International Phase of Ocean Drilling on May 19, 1982, at which we were represented by two observers. A commitment to join as full members for the eight years of operations will be required by some time in 1984 (during the planning period).

### *Canadian Needs and the Deep Sea Drilling Project*

Canada needs geological knowledge of the ocean basins and the continental margins and the technical ability to study them for a variety of reasons. (1) So that we can better develop and manage our own landmass and its large offshore extensions. Geological knowledge of the ocean basins contributes to this because a knowledge of geological processes is essential to management of our own offshore, to the direction of exploration programs for minerals and hydrocarbons onshore and offshore, and to understanding of climatic processes. Technical capability is needed for exploration in deep water, and for management of production of hydrocarbons from deep water. (2) So that we can contribute to the proper management of the use of the oceans globally. The health of the oceans affects all nations. Canada has an extraordinarily long coastline – some 250 000 km – and is bounded on three sides by oceans. The health of the oceans clearly affects Canada very directly: should they be used for disposal of wastes? What is the fate of effluents from the continents – will they remain in the waters of the oceans, so affecting food chains, or will they be incorporated into ocean sediments? If they are apparently locked-up in sediments, can they be re-cycled back into the water column? Canada has to have knowledge of the ocean basins so that we can take an appropriate part in international discussions. (3) So that we can contribute to the development of knowledge globally. The nation has often acknowledged its responsibility to contribute to this, as a member of the community of nations.

The Deep Sea Drilling Project has led to substantial contributions in all these categories since its beginning and is being designed so that this will continue in the next few years.

Examples of some specific Canadian needs in relation to the Deep Sea Drilling Project follow:

(1) Canadian needs for mineral science and technology

Canada is a major world supplier of metals. The country is at a disadvantage with respect to its competitors in terms of wage costs, which are relatively high, and ore grades which are relatively low. These disadvantages have been offset to some degree by the nation's competitive edge in mineral science and technology. The discovery of mineral deposits in Canada has become progressively more costly and difficult as the easy-to-find ore bodies are located and mined. Consequently, we have to remain at the forefront of new ideas and new technology; among these new ideas must be better guides to exploration for ore bodies on land.

There have been discoveries recently on mid-ocean ridges of metal-rich deposits forming now, at vents of hot water charged with metals which deposit the metals as the hot water comes into contact with the cold seawater. Metals deposited include: copper, zinc, iron, lead, molybdenum and vanadium. These are analogs of some major ore-forming processes known in Canada: of the massive sulphides of some parts of the Shield and perhaps New Brunswick in terms of processes, and of sulphides of some other parts of the country in terms of processes and geological setting.

Investigations of these deposits have been made using a variety of techniques, including direct observations of the deposits and the conduct of seafloor experiments with submersibles, and drilling from the **Glomar Challenger**. The processes which lead to their formation will be understood following investigations in the future using a comparable array of techniques, of which drilling will be a part. From the point of view of understanding and benefit to Canada, it does not matter where the processes are studied; however, convenience suggests that sites close to Canada should be a focus for Canadian-based efforts. Mid-ocean ridge mineral deposits have been found on ridges west of Washington and Oregon, and comparable sites are available for investigation west of British Columbia well within the 200 mile extended economic zone off the west coast of Canada.

The emphasis here is on the usefulness of information concerning processes. It is premature to comment on the direct economic significance of the metal-rich deposits of the mid-ocean ridges in terms of mining.

These investigations would be a part of a thrust directed to comprehension of the oceanic crust. It is now realized that the whole oceans cycle through the upper ten kilometres or so of the earth beneath the sea once every ten million years or so, and investigations of the mineral deposits of mid-ocean ridges are a part of this huge plumbing system.

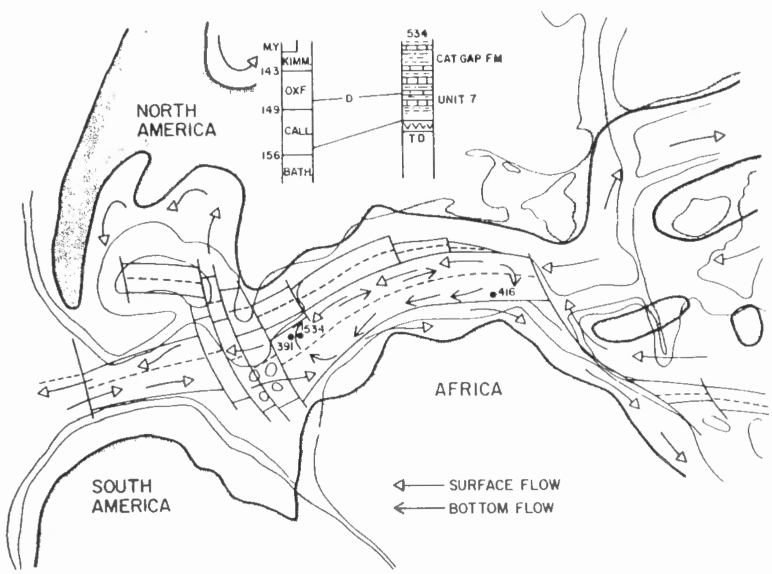



***Figure 3.12.*** *Sketch of North Atlantic paleoceanography, at M-26 magnetic anomaly time, or approximately Middle Oxfordian (145 Ma ago, on the best timescale available so far). This time is shortly after Site 534 appeared on the Central Spreading Ridge, which was drilled during DSDP Leg 76 in 1980 and bottomed in Middle Callovian dark shale on ocean basement rocks. This is the first time an actual date was found for rocks formed during the early spreading history of the modern oceans. Surprisingly, the age is at least 2 stages or 10-20 Ma younger than postulated in the literature. The sedimentological and seismic evidence in the basal sediments of site 534 for contourite-type deposits suggests that there was some bottom circulation at this time, as shown. Also depicted are the paths of surface currents from the Tethys in the east through the incipient Atlantic, to the Pacific, driven from east to west by the trade winds (from Sheridan, R., Gradstein, F., et al., 1982, Geological Society of America, Bulletin, in press).*

(2) Hydrocarbons: security of supply

The National Energy Program of 1980 envisaged Canada moving from a net deficit of 215 thousand barrels of oil per day in 1979 to a net surplus of 45 thousand barrels of oil per day in 1990. This projected surplus is to come in substantial part by increasing non-conventional supply (e.g., oil sands) as conventional supply from the western Provinces declines in this decade. This is clearly an uncertain projection. Offshore frontier developments (e.g. Hibernia) were regarded as a welcome bonus to the potential supply. The present developments offshore will have taken 30 years from initial exploration (in the late fifties) to production (in the late 1980's). These developments are all in relatively shallow water. Future developments will come from the deeper waters of the continental margin; exploratory drilling has taken place off Canada in water depths of 1500 m, and is planned for 1982 in 2000 m of water. A large part of Canada's continental margin, worth prospecting for hydrocarbons, lies in water depths beyond those of the shelf, up to water depths of about 6000 m. Exploration using the **Challenger** under the Deep Sea Drilling Project has already contributed to hydrocarbon development on our shelves by providing control on stratigraphy, and ideas on geological models. Exploration in deep water leading to the discovery of hydrocarbons will need good geological models as guides to exploration strategies; the Deep Sea Drilling Project has already contributed to this, by recognition of potential sources of hydrocarbons beneath deep water, for example.

Some proposals for future drilling bear directly upon Canadian problems. For example, some reservoirs beneath the Beaufort Sea demand a predictive capability for the location of old channels on a former continental margin. One specific proposal for future drilling by **Explorer** is on analogs, this very problem.

(3) Disposal of wastes beneath the deep ocean floor

Disposal of wastes such as high-level radioactive waste is being considered as an option by some nations such as the United States and the United Kingdom. These nations may press for changes to the London Dumping Convention which at present forbids such disposal. This will affect future discussions concerning the use of the seabed. Canada will need to know what effects disposal of this sort would have on the oceans as a whole over a wide range of time scales so that Canada can calculate the risks involved for this means of disposal, and so contribute properly to the international discussions. The Deep Sea Drilling Project has contributed to this problem in terms of providing a regional knowledge of the floor of the ocean and its properties globally, and by technological developments such as the hydraulic piston corer. This device provides a complete relatively undisturbed sample of the uppermost hundred metres or so of the sediments below the seafloor; it is not possible to obtain such samples in any other way. (A "Long Coring Facility" being developed now by the U.S.A. will obtain cores only 50 metres long.) They will be vital in serious study of sites which are being assessed for suitability for radioactive waste disposal.

Information needed to address problems of this sort will come from the studies planned of the details of the physical and chemical processes affecting the uppermost 100 metres or so of the sediments of the seafloor, and of the details of their history.

(4) Technology

Canada needs high technology of all sorts for economic development in the 1980's. In terms of regional initiatives, development of high technology in industries related to the oceans is an obvious target for the Atlantic Provinces and British Columbia.

The Deep Sea Drilling Project has contributed itself, or has contributed by providing opportunity and incentive for others, to a large number of technological developments; examples are: drilling technology for deep water; new materials for drill-pipe; the hydrostatic piston corer; and instrumentation for experiments "down-hole". A bore-hole televiewer, a "state-of-the-art" in-hole seismometer, and instrumentation for in-hole chemical analyses of water are examples of such developments "down-hole". The Project will need innovative technology in the future in a variety of fields, including those mentioned already, but in addition in technology for mapping the seafloor in ingenious informative ways as a vital prelude to drilling. Canada will need comparable technology in exploration and production on its own continental slopes – to assess hazards to development through slope failure and seismicity, for example. Various developments are underway which have great potential for this type of study, for work with the Deep Sea Drilling Project, and for Canadian-based investigations of metal-rich deposits on mid-ocean ridges. Examples are: developments of mapping systems by Huntec (Toronto) under a PILP/COPI project, and by ISE (Port Moody, B.C.), and seafloor sampling devices (Nordco, St. John's, under a PILP/COPI project, and Dalhousie University).

### *Deep Sea Drilling Project in Context: An International Facility Meeting a National Need*

Canada needs knowledge of the ocean basins beyond the shelf edge. To gain this knowledge alone, in isolation, would be extremely expensive; it should be possible to gain this knowledge in consort with other nations in a variety of ways. Mechanisms which have been adopted already include joint work of all sorts in the Arctic, the Atlantic and Pacific using a whole host of techniques. The Deep Sea Drilling Project is the most organized of these global geological investigations; it can be viewed as an international facility for drilling in the ocean basins over the next decade. Work through the Project will tie with major projects already contemplated within Canada, of which Lithoprobe is a particular example, and the earth science thrusts proposed by EMR and being discussed now by the community are more general examples.

### *The Canadian Scientific Community*

This community has strongly supported active Canadian participation in the International Phase of Ocean Drilling through Canadian membership. The feelings of the community – including industry, federal and provincial governments and universities – have been expressed by the Canadian Geoscience Council which recommended to Energy, Mines and Resources in December 1980 that Canada joins the project.

### *Summary*

Canada needs geological knowledge of the ocean basins for its own purposes. There are several mechanisms which, taken together, will lead to acquisition of this knowledge. One of the mechanisms, which is the most visible and the most direct, is participation in the International Phase of Ocean Drilling of the Deep Sea Drilling Project. Membership would allow participation by staff from a variety of institutions in industry, university and government at a substantial level. Membership entails: participation in the planning and management of the Project and payment of a fee of about \$3 million per annum as a full member; associated laboratory studies which would cost \$1-2 million per annum; associated site survey work at sea appropriate to Canadian interests and capabilities at a cost of \$1-2 million per annum. Benefits would accrue to: mineral exploration of the Canadian landmass; exploration for hydrocarbons; management of the Canadian offshore; the proper use of the oceans, and informed participation in international fora concerned with this.

## MARINE GEOSCIENCE IN PROVINCIAL GOVERNMENTS

– R.D. Johnson, with contributions by A. Sutherland Brown (B.C.), W. Potter (N.S.), D.E. Gemmell (N.B.), D.S. Rankin (N.S.), M. Sheppard (Nfld.), and B. Small (Council of Maritime Premiers)

This account is not viewed as complete since many agencies must have an interest in marine affairs, particularly in the coastlines and in coastal concerns. However, from the nature of the accounts received it is obvious that the level of involvement in the marine geosciences by the provinces is very small and predominantly oriented to shoreline problems. This level of participation is different in Newfoundland where Federal ownership of offshore resources is not acknowledged and where the hydrocarbon resources may be substantial. If ownership of offshore resources should become in whole or in part the responsibility of various provincial governments, then the level of their involvement in marine geosciences would necessarily increase.

### *British Columbia*

Two agencies in British Columbia have a minor participation in offshore geoscience programs: the Geological Division of the Mineral Resources Branch, Ministry of Energy, Mines and Petroleum Resources; and the Resource Analysis Branch, Ministry of Environment.

The Geological Division has been involved in funding co-operative offshore research for sedimentary or hydrothermal mineral deposits at spreading centres of mid-ocean ridges. The program has been called Pacific Ocean Minerals Project (POMP). For four years UBC was provided with \$10 000 for this program and has published preliminary results of geological fieldwork. In 1977-78 an additional \$10 000 was provided to consultants for chemical analysis of cores related to the same program.

The Resource Analysis Branch, in a co-operative program with the Pacific Geoscience Centre, has developed and applied a system of describing materials, processes and resulting landforms of the coastal zone. This system is based on mapped shore units within which the characteristics of the supratidal, intertidal and subtidal zones may be separately described. The system has been applied to the northern two-thirds of the Saanich Peninsula at a scale of 1:25 000 and to the shore zone of Salt Spring Island, at a scale of 1:30 000. Funding for the two studies totalled about \$20 000 provincially, and \$6000 federally. On Salt Spring Island the geological work co-ordinated sediment transport work by the Geological Survey of Canada and concurrent biophysical mapping (soils, vegetation, terrain, marine biology).

### *Nova Scotia*

Nova Scotia reports marine geoscience activities under the Department of the Environment and through the Nova Scotia Research Foundation Corporation. It also participates in the joint provincial agency, the Maritime Resource Management Service.

Studies of the Department of Environment are often management-oriented and associated with geotechnical problems. These studies include problems of coastal water pollution or accelerated eutrophication requiring evaluation of the effects of geomorphological features on the circulation patterns and the investigation of complaints related to such phenomena as coastal erosion, coastal flooding and saltwater intrusion.

Nova Scotia Research Foundation Corporation (NSRFC) for the last ten years has seen a steady growth in marine related contracts. This growth has been accomplished mainly by continual development of high resolution seismic instrumentation to meet present and future needs of industries constructing oil production platforms, pipelines, wharves, artificial sand islands, etc. in the marine environment. In addition, surveys for geological purposes are carried out by using magnetometer, gravity meter, or seismic equipment; an example of the latter was a survey off Cape Breton Island to determine geological structures in detail and surficial sediment thickness overlying the Carboniferous coal measures. Geographically, personnel of the Geophysics Division have worked in most of Canada's provinces and territories, as well as internationally in the North Sea and the Strait of Magellan.

To develop instrumentation and conduct the field surveys, the Geophysics Division employs five professionals and three technicians totalling six and one-half person years per annum. When required, the Geophysics Division can call upon the several other divisions and services within the Foundation including the Centre for Ocean Technology.

### *New Brunswick*

Present activity in marine geoscience is directed at a $100 000 contracted-out project. The study region comprises the outer coastal zone of the Bay of Fundy extending from the Nova Scotia border to the U.S.A. border, a distance of approximately 250 km (150 miles). It includes the Fundy Isles but excludes the inland estuaries. The study area is a corridor approximately 3000 metres wide centred on the outer beaches.

The objectives are to document coastal processes and the beach and biological resources of the Bay of Fundy. The scope of the work includes: coastal morphology, coastal currents, sediment transport, erosion or accretion, sand and gravel reserves, beach quarry activity, shore frontage cultural features, effluent disposal zones, and recreational lands.

The work includes description of the biological productivity and potential. Recommendations sought are relative to management of coastal natural resources including: sand and gravel reserves, shore protection and erosion control, recreational frontage development, ecological preserves, recreational reserves, allocation of coastal natural resources, and potential dump sites for oil contaminated sand in the event of an oil spill. The project should be completed in November, 1980.

### The Maritime Resource Management Service

The Maritime Resource Management Service, an Agency of the Council of Maritime Premiers, maintains an expertise in tidal and river engineering and undertakes applied research related to coastal and tidal processes. MRMS has undertaken design and impact studies of structures on tidal marshes, estuaries and streams. These structures are part of coastal protection works and of road systems.

Recent studies include impact and design criteria studies and design advice for structures in estuaries in Nova Scotia (Bras d'Or Lakes, Sissiboo River Estuary); in New Brunswick (Petitcodiac River); and in Prince Edward Island (Hillsborough and Murray River estuaries).

MRMS has recently completed the programing and testing of a computer assisted tidal hindcasting and prediction service for all primary and secondary ports in the Maritimes. A continuing program of analysis of ice growth and movement within tidal rivers in the Bay of Fundy is carried out. Particular attention is also being given to the mathematical analysis of the formation of tidal marshes and long term trends arising from changes in mean sea level.

One professional is engaged full time and is supported by a number of technicians part time (equivalent to an additional 1 person year) in marine investigations and analysis. The level of activity represents approximately 2.5 per cent of the total MRMS budget. An additional nine person years of construction related services are also performed.

### *Newfoundland*

The Petroleum Directorate appears to be the sole provincial agency with staff directly involved in the geomarine sciences. The present complement comprises three geologists, a reservoir engineer and a production engineer, all of whom are directly concerned with offshore hydrocarbon resources.

Provincial regulatory requirements have been effective in causing marine-related work by petroleum exploration companies as well as substantial donations to support research. Studies with a value in excess of $1.5 million performed in the last two years to satisfy requirements include: icebergs and iceberg scouring, bottom sampling, paleomagnetism, and oil spill management. In the same period, over $0.3 million was spent in related technical education and an additional $0.73 million was donated to the Centre for Cold Ocean Resources Engineering (C-CORE) in support of related research at Memorial University.

Nordco Limited, an independent corporate organization funded in part by the Federal Government through funds from the Department of Regional and Ecnomic Expansion, specializes in research and technology related to cold water environments, including offshore petroleum technology.

# 4. UNIVERSITY

The university section includes four papers on marine geoscience in Canadian universities.

A summary of the status of Activities and Expenditures of the universities in marine geoscience is presented by D.J.W. Piper, formerly Chairman of the Geology Department at Dalhousie University and now at the Atlantic Geoscience Centre. Piper indicates university involvement in marine geoscience is small ($2 million/year; 25-30 university scientists and engineers across Canada) and concentrated in relatively few fields (coastal studies, ocean crust and, to a limited extent, marine geophysics, sedimentology and stratigraphy). Most of the expenditures are split between faculty and graduate salaries ($1 million) and grants in aid of research ($0.86 million) together with shiptime costs on the east coast ($0.2 million).

R.D. Johnson gives additional statistics on the level of Funding To Universities. Relative to other ocean sciences, the marine geosciences account for 11.5 per cent of the student enrollment and receive 7 per cent of NSERC (National Science and Engineering Research Council) Operating grants. Of the $6.5 million in new NSERC research grants, $1.6 million went to ocean sciences of which $0.26 million went to the marine geosciences at six universities. Of the $0.6 million in total grant awards by EMR, ($0.08 million) went to marine geosciences at nine institutions. Approximately $0.5 million is currently being spent on marine geotechnical research.

The status of Marine Geoscience In Universities is presented by region based on information provided by R. Chase (British Columbia), J.I. Clark, (Alberta), D.H. Shields, (Saskatchewan and Manitoba), S.B. McCann, (Ontario and Quebec), D.J.W. Piper, (Nova Scotia, New Brunswick and Prince Edward Island) and G.R. Peters, (Newfoundland). Special emphasis is placed on the University of British Columbia and Dalhousie University which are the major Canadian sources of professionals for the marine geosciences. These two universities have an average output of four or five postgraduate marine geoscientists per year, with Dalhousie University outproducing the University of British Columbia in a 3:2 ratio. The areas and ratios of specialization are similar:

| | |
|---|---|
| Geophysics/Crustal studies | |
| (Dalhousie 35%: UBC 38%) | 40% |
| Sedimentology | |
| (Dalhousie 50%: UBC 48%) | 50% |
| Geochemistry | |
| (Dalhousie 15%: UBC 4%) | 10% |

Both Chase and Piper respectively stress the need for shiptime and less obsolete equipment for the University of British Columbia and Dalhousie University. Piper, in particular, is concerned that there should be sufficient funding to develop the manpower needed by federal agencies and industry. In this regard, it is interesting to note that while most universities report involvement in coastal sediment studies followed by oceanic crustal studies, Dalhousie University and the University of British Columbia are the only universities listing significant involvement in marine geochemistry, and Dalhousie is the only university with development programs in marine resource management; only the University of Alberta reports any significant involvement in marine geotechnical activities.

In January, 1981, ninety-eight university professors met in Ottawa in a workshop, "Universities – The Next Decade", to discuss future developments in earth science. Piper presents a draft report prepared by the Marine Geoscience Group of this workshop. In assessing the direction of scientific studies in the coming decade and the obstacles universities will face, the report recommends action directed toward: increasing the availability of shiptime; upgrading the number of professionals teaching, and the quality of technicians.

Together the four papers indicate that the critical factor in University marine geoscience in Canada is the small scale of the operations in terms of numbers of scientists, technicians and students; research grant support; and access to shiptime. As indicated, total expenditure by universities in marine geoscience is about $2 million.

In preparing the University section, the following comments were heard by the committee and are offered here as significant observations. Most "marine" training is received at graduate levels; however, most undergraduates are going directly into industry at present. As a result, very few professionals trained to the M.S.c. and Ph.D. levels will be available within a year or two despite a predicted large demand for marine specialists in the immediate future. Job opportunities in this area have been relatively scarce to date. Although many with this training have found employment in petroleum exploration, they do not necessarily work on marine projects. There is a noticeable lack of Ph.D. level marine geoscientists, and most university faculty positions have to be filled by non-Canadians. Although there is a present tendency for universities to call for increased funding from industry, universities do not necessarily want the constraints and direction that such funding may entail. There appears room for trade-offs between universities and industry whereby industry supports both long term and short term research, and universities address more areas of research applicable to industrial needs.

## UNIVERSITY ACTIVITIES AND EXPENDITURES – D.J.W. Piper

The most prominent feature of marine geoscience in Canadian universities is that it is on a small scale. Marine geoscience faculties total about twenty scientists across the country and an additional five to ten engineers. As a result, research and graduate education is concentrated in relatively few fields; there is rarely the "critical mass" necessary for a vibrant graduate program and adequate equipment and technical support.

The present status of various subdisciplines is discussed below:

*Coastal* studies are well represented. Work on beaches is largely by the Ontario universities, with good interaction with physical oceanography. Estuarine and suspended sediment research is active, both on the west coast and in Quebec, with considerable interaction with other marine disciplines. As with other disciplines, there is minimal university work on the coastlines in the northern two-thirds of the country, largely because of costs.

*Ocean crust* studies are strong, with involvement of substantial numbers of geologists whose normal interests are not marine, and a high level of international co-operation.

*Marine geophysics* is carried on by extremely small numbers, which is surprising and a cause for concern, given the importance of marine geophysics in both the government and industry sectors. Most work is concerned with continental margins. There is virtually no university work in marine gravity, heat flow, or high resolution seismics, and little in geomagnetism. Recruitment of marine geophysicists to university positions is lagging and made difficult, by lack of state-of-the-art equipment, shiptime, and other geophysicists with whom to interact. All these problems could be reduced substantially by better co-operation with government and industry.

*Sedimentology and stratigraphy* (excluding coastal work) is also very limited. There is almost no work on continental shelf or deep water sediments or their dynamics (partly because those interested receive insufficient shiptime). The offshore Mesozoic-Cenozoic sediment sequence is worked on by occasional graduate students, but there are almost no continuous programs. Quaternary stratigraphy is limited to a little east coast work and coastal zone studies. There is little geologically oriented chemical work.

**University Expenditures in the Marine Geosciences**

*Direct expenditures by the universities*

There are probably 25 faculty members involved, who spend half of their time on marine geosciences. If the average cost of a faculty member is $60 000 per year (including overhead, and this seems a low figure) this cost is then $750 000.

The additional costs of about 25 graduate students at $10 000 per year is $250 000. Hence, the total direct cost is, very approximately, $1 000 000.

*Grants in aid of research*

Grants in 1980-81 in the marine geosciences were:

| | |
|---|---|
| NSERC Strategic Grants | $ 250 K |
| NSERC Operating Grants, etc. | $ 400 K |
| EMR Research Agreements | $ 90 K |
| Other Federal Grants | $ 30 K |
| Provincial Aid | $ 70 K |
| Industry Contracts and Grants | $ 20 K |
| | $ 860 K |

*Shiptime*

*(a) Canadian Government* We do not have costs for all university shiptime, but we do have the costs for 1979-80 for east coast work, using Ocean Science and Surveys' vessels from Bedford Institute of Oceanography.

| By Discipline | |
|---|---|
| Geology and geophysics | $108.3K |
| Biological oceanography | 300.0K |
| Physical and chemical oceanography | 208.5K |
| General (eg. equipment testing | 18.7K |
| | 635.5K |

| By University: all disciplines | |
|---|---|
| Acadia | 170.5K |
| Dalhousie | 296.9K |
| U. of Q. Rimouski | 62.1K |
| McGill | 79.6K |
| Memorial | 26.4K |
| | 635.5K |

The comparable figure for total cost of shiptime in 1979-80 incurred by Ocean Science and Surveys of the Department of Fisheries and Oceans (Atlantic) is $7786.9K. The figure for universities for 1979-80 is, according to Ocean Science and Surveys, abnormally low. If we take this into accont, and add estimates of west coast university costs borne by ocean Science and Surveys, the "normal" figure for shiptime for the earth sciences in the universities is probably close to $200K.

*(b) Foreign Governments* and 'institutions' shiptime. Dalhousie estimates that about one-third of its work is on foreign vessels; this puts the value in the region of $25-$50K per annum. Consequently, a figure of $225K may be close to the total cost of shiptime for marine geosciences in the universities.

*Totals*

The total expenditure by universities in the marine geosciences is then:

| | |
|---|---|
| Direct by the universities: | $1 000 000 |
| Grants-in-aid, etc. | 860 000 |
| Shiptime (79/80 $'s) | 225 000 |
| | $2 085 000 |

This figure, $2 million, is approximate because of the uncertainty of the salary costs. It is almost certainly high because of the liberal interpretation of the term "marine geosciences" in terms of faculty. However, it is clear (a) that expenditures are of the order of $2 million, and (b) that the cost of shiptime used in the marine geosciences in the universities is only a small component of this total expenditure, and is only a minor component of the total shiptime costs of Ocean Science and Surveys.

**FUNDING TO UNIVERSITIES** – R.D. Johnson

The availability of research funding is critical to university research. Some indication of the sources and level of funding is gleaned from four sources.

The Canadian Committee on Oceanography prepared a report for the Committee on Grants and Scholarships, National Research Council (NRC) on "The Marine Science Facilities of Canadian Universities" (March, 1976). The report indicates that between 1972 and 1975, the graduate students enrolled in marine geosciences represented 11.5 per cent of the students in all marine sciences and received 7 per cent of the operating grants through NRC. Marine biology (together with freshwater biology and limnology) accounted for 63 per cent of the students and received 72 per cent of the funds. The level of funding indicates that on average the equivalent of four to five fellowships went to the marine geosciences each year.

The paper, "Results of a Survey of Research in Geotechnics in Canadian Universities", (Canadian Geotechnical Society, Technical Memoir no. 126, 1979) shows that about $5 million is being spent on geotechnical research of which only 10 per cent is marine related. Research was in progress at Queens, McMaster, UBC, University of Saskatchewan, and Memorial and covered subjects including Arctic beach studies, submarine slumping, sea ice and icebergs, site investigation, foundation studies and sediment properties.

An information publication of Natural Science and Engineering Research Council Canada (NSERC), entitled "Research Grants in Areas of National Concern in 1979-80", indicated that 'Oceans' was one of five areas receiving NSERC strategic grants, the others being communications, energy, environmental toxicology, and food/agriculture.

Of the \$6.5 million in new grants, \$1.6 million went to 'Oceans' (more than one-fifth). Of this \$1.6 million, \$0.26 million went to support marine geoscience activities at six universities. The NSERC grants averaged \$30 000 and covered a wide range of subjects including ocean sediments, crustal spreading, crustal seismic, marine geodesy, trace elements and icebergs.

The Report of the Canadian Geoscience Council on Current Research in the Geological Sciences in Canada, May 1979 – April 1980 (GSC Paper 80-5), provides insight into the current distribution of marine geoscience research and the funding levels. Grant awards by EMR in this area were made to nine of the twenty-nine institutions receiving awards. These nine institutions received eleven awards totalling \$83 350; the largest grant was \$15 000 and the average grant was \$7500. These marine related geoscience grants accounted for 15 per cent of the nearly \$600 000 total grant awards. Twenty-one NSERC Operating Grants for marine geoscience projects were allocated to ten institutes as follows; University of British Columbi (5), Dalhousie University (5), McGill University (2), University of New Brunswick (2), Lakehead University (2), University of Windsor (1), University of Calgary (1), University of Guleph (1), University of Toronto (1), Queen's University (1). Of these projects 11 were sedimentological while 4 concerned tectonics, 3 paleontology and 2 geochemistry.

**MARINE GEOSCIENCE IN UNIVERSITIES** – Contributions by R. Chase, J.I. Clark, D.H. Shields, S.B. McCann, B. d'Anglejan, D.J.W. Piper and G.R. Peters

***British Columbia** – R. Chase*

*1. The University of British Columbia*

Geoscience research in the three British Columbia universities is concentrated at the University of British Columbia, the only one of the three possessing an engineering school as well as departments of Geological Sciences, Geophysics and Astronomy, Geography, and Oceanography.

To review developments, a study of sediments and structure of deltas, fiords, straits, and the continental shelf commenced in the late 1960s. Recently this has broadened to include studies of particulate matter suspended in fiords and the Fraser River. Tectonics and petrology of plate margins and seamounts in the northeastern Pacific have been studied since 1969. The Department of Geophysics and Astronomy has investigated aspects of the structure of the western Canadian continental margin and adjacent ocean floor since 1971. A study of the sediments of active ridge crests in the northeastern Pacific commenced in 1977. In 1979, research began into the geochemistry of sediments of continental margins and the deep ocean. Diverse studies include: contributions of marine algae to recent coastal sediments, strengths of marine sediments, and processes affecting mine waste and tailings dumped into coastal inlets.

The number of faculty members and graduate students working in the geomarine field at the University of British Columbia grew between 1964 and 1971, then remained stable through the 1970s. If the present situation is not perturbed, the prospect for the 1980s is that numbers will remain unchanged except, possibly, for micropaleontology and marine geochemistry in the Department of Oceanography. Obvious personnel gaps at the University of British Columbia include micropaleontology and geomagnetism.

Equipment at the University of British Columbia includes a single-channel continuous seismic profiling (CSP) system, sediment- and rock-sampling devices, geochronology laboratories for Sr, K/Ar, and Pb, computer facilities, analytical facilities for major and trace elements, electron microprobe and scanning electron microscopy (SEM), and laboratories for sedimentology.

University of British Columbia scientists operate only one vessel, an 18-foot boat with inboard motor, owned by the Department of Geological Sciences. Most research is done aboard federal vessels, obtained through the west coast working group of the Canadian Committee on Oceanography.

The level of teaching and research in the various departments comes to 4.5 person-years/year with the number of graduates averaging seven/year. Research funds in the order of \$100 000/year come from the Federal and Provincial governments and industry.

UBC GRADUATE STUDENTS IN MARINE GEOSCIENCE 1969-80

Total Number of Students Graduating 1969-80: 28

| | |
|---|---|
| M.Sc./MASc | 56% |
| Ph.D. | 44% |

Fields:

| | |
|---|---|
| Geophysics/Crustal | 48% |
| Sedimentology | 48% |
| Geochemistry | 4% |

*Major Equipment Requirements.* Equipment not possessed by the universities but desirable for effective exploration by Canadian scientists of deeper parts of the continental margin and the nearby ocean floor includes a ship equipped with a multibeam sonar system for detailed bathymetric contouring and a submersible capable of operating at depths greater than 2 km. The great expense of acquisition and maintenance of such equipment make a government department the most obvious choice for operating agency. With her long coast-line and adjacent largely unexplored continental margin, Canada could benefit greatly by ownership of a multibeam sounding system. Exploration for possible hydrothermal vents and deposits at depths of 2-3 km on Juan de Fuca and Explorer ridges and direct observation of processes at such sites would be possible from a manned submersible capable of operation at depths of 2-6 km. At present, the **Pisces IV**, owned by the Canadian Government, has a capability of only 2 km, allowing direct observation of only the upper continental slope.

*2. Simon Fraser University*

Two members of the Physics Department are studying ways to date ocean sediments using thermoluminescence and alpha-scintillation counting.

*3. Royal Roads Military College, Esquimalt, B.C.*

Personnel from the Coastal Marine Sciences Laboratory at Royal Roads have undertaken subbottom surveys of harbours near Victoria using 3.5 kHz sonar.

*4. University of Victoria*

At present there is no geomarine activity. A research vessel suitable for coastal waters is operated by the University.

*5. British Columbia Institute of Technology*

There is no geomarine activity at present.

*6. Bamfield Marine Station*

The Bamfield Marine Station, run by the Western Canadian Universities Marine Biological Society at Bamfield, on the west coast of Vancouver Island, has accommodation and laboratories for staff and students and offers courses and opportunities for research in marine biology and ecology. No geomarine research is conducted there presently.

**Alberta** – *J.I. Clark*

*University of Alberta*

Some research activity is being carried out on geotechnical properties of marine sediments. A great amount of research, some of which is applicable to offshore permafrost, has been conducted on permafrost-related geotechnical problems. Although the current marine geotechnical program at the university is modest, some of the staff have been very actively involved in consulting on marine geotechnical aspects of the developments in the Beaufort Sea and off the east coast.

**Central Canada** – *S.B. McCann with contributions by B. d'Anglejan and D.H. Shields*

These comments summarize university activities in marine geoscience in those provinces bordering Hudson and James bays and the St. Lawrence-Great Lakes system, namely, Manitoba, Ontario and Quebec. Manitoba reports no present marine research (D.H. Shields). Coastal or civil engineering work, particularly at McGill and Queens universities, has not been included.

**Ontario**

There is no major marine science effort in Ontario universities, but research and graduate teaching in coastal and nearshore sedimentology and geomorphology is being actively pursued by seven individuals in different institutions, six of whom contributed papers to the Coastline of Canada volume (GSC Paper 80-10) published by the Geological Survey of Canada in 1980. All are presently training graduate students and continuing their research at a variety of loations around the coastline of Canada. In addition an extensive program of studies of the modern intertidal sands in the Bay of Fundy was carried out between 1968 and 1976 by members of the Geology Department at McMaster University.

The scale of operations is modest in terms of overall budgets, equipment holdings and technical support. Costs of field operations, often in remote locations, have consituted a relatively large proportion of total research budgets. Three of the groups have small open boats for inshore surveys, together with echo-sounders and shallow water coring equipment, and all report access to good laboratory facilities for the study of sediments. Scarborough has a mini-computer-based Hydrodynamics Monitoring System with continuous resistance wave staffs and electromagnetic flowmeters.

A variety of coastal research projects carried out at Ontario universities are listed:

*Guelph (Geography)*

1. Sediment transport processes resulting from storm-wave activity on a sandy, barred coast.
2. Sedimentation in Georgian Bay.
3. Problems of coastal erosion between Grimsby and Hamilton.

*Guelph (Land Resource Science)*

1. Geomorphology and sediments of shallow marine environments of the Ontario coast of Hudson and James bays.
2. Sedimentological processes and sequence of the estuarine reaches of the rivers of the Hudson Bay lowlands.

*McMaster (Geography)*

1. Subarctic tidal flats in an area of large tidal range, S.E. Baffin Island.
2. Sediment dispersal patterns and shore morphology, Georgia Strait coastline of Vancouver Island, B.C.

*McMaster (Geology)*

1. Possible environmental effects of Bay of Fundy tidal power development, especially in relation to intertidal benthic communities.

*Queens (Geography)*

1. Fiord and shallow marine sedimentation, SE Baffin Island.

*Scarborough College, Toronto (Geography)*

1. Nearshore hydrodynamics: empirical studies of water motion under shoaling and breaking waves.
2. Sediment transport, bedforms and sedimentary structures generated by shoaling and breaking waves in a barred nearshore environment.
3. Numerical modelling of sediment transport patterns in the Toronto Waterfront.

*Windsor (Geography)*

1. Shore platform development in eastern Canada – Gaspé, Bay of Fundy, Newfoundland, and lakes Erie and Huron.

**Quebec**

In Quebec there are two main groups involved in oceanographic research and teaching, and each has a geological component: G.I.R.O.Q. (Groupe Interuniversitaire de Recherches Océanographiques du Québec) and, at Rimouski two closely related groups namely:

L'Institut National de la Recherche Scientifique (I.N.R.S. – Océanologie) de Rimouski, and
Département d'Océanographie de l'Université du Québec à Rimouski.

G.I.R.O.Q. was founded in 1970 as an affiliation of oceanogrpahers from McGill University, Université de Montréal, and Université Laval to co-operate in research projects on the St. Lawrence estuary. The optimistic introduction to their most recent report (G.I.R.O.Q., Rapport Septième, 1978-1979) indicates that the group has established its scientific credibility and continued to provide the infrastructure for a variety of different studies. Much of the research was biological and of the 49 projects listed for 1978-79 only 8 or 9 could be classed as geological. Most of this was being undertaken at the Marine Science Centre of McGill University.

Research in marine geology at the centre consists of sedimentological and geochemical studies in shallow coastal waters and estuaries in the St. Lawrence estuary and also in similar environments along the eastern shores of James Bay.

It can be summarized under these headings: Quaternary evolution of the estuarine morphology and sedimentation regime; sediment transport processes under present oceanographic conditions; geochemistry of the suspended matter and surface sediments.

At Rimouski, both organizations are housed in the Laboratoire Océanologique de Rimouski, opened in 1975 and operated by I.N.R.S. – Océanologie, on the Université du Québec campus at Rimouski. Both groups are relatively new, as indeed is the establishment of a university at Rimouski, and it is too early to evaluate properly the success of this planned establishment of an isolated oceanograhic centre in Quebec. Recent reports of both groups emphasize the collaboration between them and the mood is optimistic.

The mandate of I.N.R.S. is applied research for coastal management, and the research is grouped into two programs – marine biology, physioecology and biochemistry; and littoral sedimentology – with more emphasis to date on the former. The littoral sedimentology projects in 1978-79 were concerned with sedimentation in the port of Gros-Cacouna and shore sediments at Trois Pistoles in the St. Lawrence estuary, and with littoral sediments and processes in the Magdalen Islands. With the addition of a new coastal sedimentologist, studies are now being undertaken on the estuaries and deltas of the north shore tributaries of the St. Lawrence.

The Département d'Océanographie was created in 1979 from a somewhat looser grouping of researchers in oceanography within the Department of Science (Section d'océanographie de l'Université du Québec à Rimouski) which was established in 1973 and had been offering a Master's program since that time. The program is multidisciplinary and includes physical, geological, chemical and biological oceanography. There are plans to start a Ph.D. program. The number of staff involved full time with teaching and research in oceanography is six, including one physicist, one geologist, two geochemists, and two biologists. Five other faculty members contribute to the program with teaching and thesis direction. Three faculty members are involved in geological and geochemical research, investigating the biogeochemistry of the benthic boundary layer.

***Maritime Provinces*** – *D.J.W. Piper*

Almost all university marine geoscience work in the Maritime Provinces universities is carried out at Dalhousie University in Halifax: thus Dalhousie forms the first and greater part of this account.

*Dalhousie University*

Marine Geoscience at Dalhousie is undertaken by two separate departments, those of Geology and Oceanography. There is close informal co-operation between the two departments, and the division of research work, teaching and equipment is largely the result of interests of individual faculty members. The univesity is known for its work on oceanic crust, structure of the continental margin, recent marine sedimentation and Quaternary studies. Most of the work is carried out in the North Atlantic and contiguous seas.

*Staffing.* The University has recently created two new marine geoscience faculty positions in the Oceanography Department, and one new position in the Geology Department which may be filled by a marine geoscientist. These positions are not included in Table 4.1, which lists staffing as of January 1, 1981. Almost all of the marine geoscience faculty have some nonmarine teaching responsibilities. There are a large number of faculty with marginal interest in marine geoscience (e.g. chemical oceanographers and an igneous petrologist).

**Table 4.1.** Marine geoscience staffing, Dalhousie University

| | Number | Total Person-Years |
|---|---|---|
| Regular faculty with primary interest in marine geoscience | 5 | 3.5[1 2] |
| Special (term) faculty appointments[3] | 2 | 1.5[4] |
| Regular faculty with marginal interest in marine geoscience | 7 | 1 |
| Grant-funded research associates, post doctoral fellows | 2 | 2 |
| University-funded technicians | 2 | 1.2 |
| Grant-funded technicians (including part-time student assistants) | ? | 3 |

[1] Of which, say, 70% research and graduate student supervision, 20% teaching of marine geoscience and 10% administration. Remaining 1.5 person-years divided 60% teaching and 40% research not in marine geoscience.
[2] Total Geology Department 12 (11 person-years), Oceanography Department 13 (12.5 person-years).
[3] One University-supported, one largely NSERC-supported.
[4] Predominantly research. Remaining 0.5 person-years largely in research not in marine geoscience.

In addition, there are some 20 faculty members with interests in the oceans, both the science of oceanography (Departments of Oceanography and Biology), and the legal, economic and social aspects of the oceans (Ocean Studies Program).

There is very little in-house equipment development expertise (although some work is done co-operatively with AGC in the electric rock drill program) and effectively no contact with marine engineers.

The University maintains close contact with Bedford Institute of Oceanography, particularly AGC: Atlantic Geoscience Centre staff serve on supervisory committees, and serve as primary supervisor for some 20 per cent of the marine-oriented graduate students.

*Research Funding.* There are three main continuing sources of research funding (Table 4.2):

i NSERC Operating and Capital Grants to individual investigators

ii NSERC Group and Individual Strategic Grants (Oceans), and previously NSERC Co-operative Grants.

iii Department of Energy, Mines and Resources Research Agreements.

In addition, there has been some industry support for specific projects.

The University provides very limited non-salary funds (start-up funds for new faculty, occasionally support for new projects). It does support a fulltime marine technician, and a geophysics technician who does considerable marine work. There is no provincial government funding.

Funding in the period 1978-80 is summarized in Table 4.2.

*Teaching Programs.* The Department of Geology teaches a regular undergraduate degree program. This does not have any special marine emphasis, although several advanced classes and one "interest class" are offered in marine geology and geophysics. These attract 5 to 10 per cent of total class enrolments in the Department. The relatively small size of the Department, and heavy undergaduate teaching loads, have resulted in a limited program of graduate courses. At any one time, about 40 per cent of the graduate students in the Geology Department are in marine or marine-related fields (Table 4.3).

Thus, there tend to be two groups of faculty in the Department: those with marine interests who play a lesser role in mainline undergraduate teaching, but carry heavy graduate student supervision loads; and those with land interests who carry the main undergraduate teaching program. This problem may be as much concerned with perceptions as with reality, but leads to internal stresses.

**Table 4.2.** Total Marine Geoscience Research funding, 1978-80, Dalhousie University

| | $K |
|---|---|
| NSERC Operating | 240 |
| NSERC Strategic | 150 |
| Other NSERC | 30 |
| EMR Research Agreements | 100 |
| Industry grants | 5 |
| Industry contracts | 5 |
| University* | 10 |

All figures pro-rated where funds only partly for marine geoscience research

* Excluding regular salaries and facilities, and conference travel funds.

**Table 4.3.** Graduate students in marine geoscience, 1975-80, Dalhousie University

Total number of students graduating 1975-80: 20 (total 22 degrees)

| | | | |
|---|---|---|---|
| | M.Sc. 55% | | |
| | Ph.D. 45% | | |
| Fields: | Geophysics (mostly regional) | 25% | |
| | Ocean crust | 10%* | |
| | Sedimentology | 20% | |
| | Quaternary/micropaleontology | 30% | |
| | Geochemistry | 15%** | |
| Present employment: | Canadian | | |
| | industry | 35% | |
| | university (professional) | 15% | 55% |
| | government | 5% | |
| | Foreign | | |
| | industry | 5% | |
| | university (professional | 10% | 30% |
| | government | 15% | |
| | Student or Post doctoral fellow | 15% | |
| Nationality at beginning of graduate degree program: | | | |
| | Canadian or landed immigrant | | 35% |
| | Non-Canadian | | 65% |

* Does not include related studies on oceanic islands
** Does not include chemical oceanography

A new honours program in marine resource geology has recently been approved by the University Senate. This parallels developments in several other science departments (e.g. Biology) in developing marine-oriented honours B.Sc. programs, and might eventually lead to the establishment of a B.Mar.Sc. (bachelor of marine science) degree. The geology program aims to give geology students a thorough basic science grounding in both geology and areas of oceanography relevant to mineral and hydrocarbon exploration. The University approved this program on the understanding it would initially require no additional funds, and the Department plans to seek industry funding and benefits from the spin-off from NSERC strategic grant and research fellowship programs.

The Department of Oceanography is a graduate Department. It teaches one general introductory undergraduate course, and two service undergraduate courses for Biology and Geology honours students. It is under some pressure from other sectors of the University to teach more undergraduate courses, probably sufficient for an honours student to minor in Oceanography. (There is not any pressure for an undergraduate major in Oceanography). The Department was, until recently, severely understaffed in marine geoscience (1 1/2 positions), but has recently gained two additional faculty positions which are being filled. At present, the Department offers adequate marine geoscience graduate courses only in geophysics. It graduates few students in marine geoscience.

*Facilities.* Shiptime is obtained through Bedford Institute. On average, Dalhousie obtains 2-3 weeks of dedicated shiptime (mostly on **CSS Dawson**) for marine geoscience work, and perhaps an equivalent amount of opportunity-basis time on Atlantic Geoscience Centre (AGC) programs. Coastal work is carried out from rented fishing vessels, and from the 6 m boat owned by the Department of Oceanography. A small amount of time is also obtained on American and British ships.

Availability of shiptime limits the type of research work carried out, but does not yet limit the amount of research work time since this is "tailored" pragmatically to available shiptime. It is not difficult to give graduate students shipboard experience through Bedford Institute of Oceanography (BIO). More difficult and costly is small boat experience, which is valuable in developing skills needed to function well as senior scientist on a larger vessel.

The timing of shiptime applications compared with acceptance and identification of research programs for graduate students leads to some conflicts. Graduate students usually have to work in programs for which shiptime is pre-arranged; shiptime applications thus involve considerable guesswork on likely graduate student enrollment.

Major shipboard equipment is listed in Table 4.4. Frequently additional equipment can be borrowed from BIO. Holdings of standard equipment for sediment marine geology are adequate; holdings for geophysical work totally inadequate, and in practice likely to remain so because of cost. Standard laboratory equipment is adequate but ageing. The Aquatron seawater/tank facilities of the Department of Oceanography are little used for marine geoscience. The lack of equipment development expertise, and the very slow transfer of new methodology to the University in most fields (largely because of cost, inertia and lack of skilled people) is a serious threat to progress. Much closer co-operation with government and industry (along the lines of the electric drill

**Table 4.4.** Shipboard instrumentation for marine geoscience, Dalhousie University

| |
|---|
| Air gun, compressor, hydrophone array* |
| Sparker* |
| Varian magnetometer* |
| Portable winch-boom system |
| Two seismic recorders |
| 3.5 kHz profiling system |
| Alpine piston corer |
| 50 cm² box corer |
| Deep-sea camera |
| Rock dredges |
| Heat flow probe* |
| Excludes equipment primarily for chemical or physical oceanography |
| * Indicates more than 10 years old, or obsolete. |

and seabed programs) is essential. The new NSERC Strategic Grants provide opportunities to remedy some of these problems.

*Outlook.* The future of marine geoscience at Dalhousie University is uncertain. Although there is a University commitment to marine geoscience, the commitment is inadequate in many ways. In particular, the physical plant is poor (the Geology Department is housed in four different buildings) and salaries uncompetitive. Faculty unionization has split the faculty, diverted money away from promoting excellence, and hampered the development of a strong management policy to deal with many of the financial problems of the University. Nevertheless, the concentration of marine scientists and facilities in the Halifax area offsets these various disadvantages.

The future of marine geoscience appears to depend heavily on Federal Government funding or assistance. Both the NSERC Strategic Grant program, and the close co-operation with AGC/BIO do provide opportunities for future development. The NSERC Strategic Grant funding effectively replaces negotiated development grants and oceanographic institute block funding, and, so far, appears much more flexible and responsive to research needs than the previous programs.

The lack of graduate students and the high proportion of non-Canadians remains a problem. At the present time, this is due mainly to the high salaries offered by industry, but partly to a lack of awareness of marine science in much of Canada. There is already a shortage of trained marine geoscientists, and none of the new NSERC programs appears to be having much effect in attracting more graduate students. Industry must develop ways of ensuring adequate education of the people that they employ.

*Other Maritime Provinces Universities*

A small amount of marine geoscience research, often in co-operation with BIO is carried out at universities other than Dalhousie in the Maritime Provinces, mostly in fields of sedimentary geology and paleontology in geographically proximal areas. This totals an average perhaps of 0.5 professional years plus 0.5 graduate student graduated each year. There is a small marine geoscience component in most undergraduate teaching programs.

***Newfoundland** – G.R. Peters*

*Memorial University of Newfoundland*

Memorial has an Ocean Engineering Research Group which undertakes ocean geotechnology projects amongst others. At present, three projects concerning marine geoscience are in progress, involving seven people. These are funded by NSERC Operating Grants and NSERC Strategic Grants of $60 000 per year, plus internal funding. The three projects are briefly described:

1. Ocean Sediment Properties Using Acoustic Sensing. The main effort is to develop means to classify marine sediments acoustically and to extract geophysical and geotechnical properties based on data taken in Placentia Bay.
2. Identification of Subsurface Layering by Acoustical and Signal Processing Techniques. This work is concerned with determination of geometry of subsurface sediment layers and rock strata. A multiple reflection model is being used.
3. Impact Penetrometer. A penetrometer has been designed and tested at sea in depths to 100 m. Correlation of the penetrometer data with standard soil properties is continuing.

**UNIVERSITIES – THE NEXT DECADE** – D.J.W. Piper

On January 24-25, 1981, there was a workshop in Ottawa on "The Next Decade of Earth Science in Canadian Universites", organized by the Committee of Chairmen of Earth Science Departments, and assisted by NSERC. A marine geoscience subgroup was created of seven members representing all marine scientists eligible to receive grants through the Earth Science Grant Selection Committee (and thus included physical and chemical oceanographers). This subgroup prepared a report, based on their own views, written or telephoned submissions from about fifteen other marine scientists, and the oral presentations of six marine scientists who were involved in other subgroups. An edited version of this report is presented below, highlighting principal concerns and recommendations.

The group asked two main questions: what types of science should we do in the next decade?; and what will prevent us from doing this science?

**1. What science?**

The group identified some common threads to the specific research proposed by individual scientists.

a. In areas which have been intensively investigated in the last decade, we have progressed from answering scientific questions by basic description to wanting to understand the fine scale processes and must soon think of passing to the predictive stage. For example: what will the ice cover in the Gulf of St. Lawrence be next February?; can we design experiments to determine how sediment is transported under particular conditions in the surf zone?; what is the role of benthic organisms in the vertical transport of dissolved and particulate organic matter in surficial sediment?
b. In other areas, major scientific problems can be solved just by finding out better what is there. How does water flow through newly formed oceanic crust? What is layer 3 of the oceanic crust? What erosive processes lead to fine scale dissection of the continental slope? Can we use remote sensing with satellites to predict ocean circulation?

c. We are best situated to answer certain types of scientific problems that have a strong Canadian content. For example sea ice dynamics; continent ocean transform margins; aseismic subduction; iceberg scour.

d. Canada has missed great opportunities by not participating in the largest co-operative geoscientific program of the past decade, the DSDP-IPOD. The continuation of this project will again be the largest international geoscientific project of the next decade. It carries great scientific and technological potential for Canada for a small share of the total coast.

**2. Why can't we do it?**

*a) Access to ships*

The group believed present access to ships is inadequate. This is partly because there are not enough Canadian ships, and partly because ships are operated by government departments, and as one participant put it, universities are at the bottom of the totem pole. Both present and past grant proposals have been tailored to this lack of suitable shiptime, and by and large university scientists don't ask for more because they are told that they will not get any more, and that they do themselves harm by appearing greedy.

Although the group was concerned with the total amount of time made available to universities, more serious is the time of year and geographic distribution of the shiptime. It is virtually impossible to do research requiring repeated visits to one area unless it is within 200 km of a major port. Thus university students cannot look at time-dependent or seasonal problems which require frequent sampling, or at deep ocean problems. For many geological seafloor problems one first collects and interprets data, and then identifies what additional information is necessary to solve the problem. This requires going back again to the same area. Collaboration with government laboratories is essential for carrying out such projects. There is also a clear lack of research ship capable of operating in heavy ice conditions. Thus there are amost no winter ocean observations off the Labrador coast.

It seemed to the group that it was impractical for NSERC to put large sums of money into the Oceans Strategic Grants Program without some regard to shiptime to service this program. The group recommended that NSERC should press for an accelerated research shipbuilding program, and that NSERC seek formal representation on bodies responsible for the allocation of shiptime.

*b) Access to deep-drilling capability*

The problems to be addressed by future deep marine drilling are of prime scientific importance and will impact a large cross-section of the geoscience community. The group thus recommended that NSERC support the attempts by the Canadian Geoscience Council and others to negotiate Canadian participation in IPOD, and agree to contribute an appropriate proportion of the costs.

*c) Access to state-of-the-art equipment*

Field equipment, especially that dragged through water or left at the bottom of the sea, is expensive, needs a lot of maintenance, and is easily lost or damaged, usually through no fault of the researcher. Fear of equipment loss inhibits curiosity-motivated science.

University scientists cannot do much of their science without access to expensive equipment: multichannel seismic, deep tow, seabeam, deepwater submersible, Huntec etc. However, universities cannot use such systems for more than 10 or 20 per cent of the year, and maintenance and technical support is very expensive. Government agencies and industry also need such equipment. The group therefore recommended that NSERC develop co-operative arrangements with government agencies to contribute to the capital cost of major sea going equipment (more than \$100K) in exchange for guaranteed university priority use of such equipment for part of the year.

The group also recommended that NSERC adopt the policy of the DFG (Deutsche Forschungsgemeinschaft) and automatically and immediately replace NSERC funded field equipment lost or damaged in the field (with some provision on liability if there is gross neglect, or for equipment over \$1 million).

*d) Human Resources*

Equipment is becoming increasingly sophisticated; it generates more and more data, and it operates in a harsh environment. Highly qualified technicians are essential to develop, operate and maintain such equipment. University support for research technicians was always at a very low level and has now almost dwindled away. Operating grants are too small to support technicians, and provide no job security for highly qualified people. If equipment is funded, a way to maintain and operate it through technicians must also be funded.

The numbers of professional marine geoscientists within the universities needs to be maintained or expanded. This may require competitive salaries and fringe benefits for post-doctorates, research fellows and even full time faculty. Not enough marine scientists are produced in Canada and Canadian universities are unable to attract many good people on the international market, because shiptime and research funds are not competitive.

**Editor's Addendum**

In addition to the above report of the Marine Geoscience Subgroup, a summary of the overall conference, presented to the Canadian Geoscience Council by W.S. Fyfe in March, 1981, includes the following excerpts of interest to marine geoscience:

> "There was also wide support for developments in the study of the continental margin, either by joining the International Program of Ocean Drilling (IPOD) and the Ocean Margin Drilling Program (OMDP) or by ship development for ice-bound waters. It was agreed that NSERC and the universities will require co-operation with the entire Earth Science community to fund such projects and that the Geoscience Council should initiate such developments."
>
> "A proposla was the funding of an ocean-going drilling ship with ice-breaking capability. Such a facility would be very expensive, but would be particularly valuable to Canada, with its extensive ice-bound coastal waters. It would complement the U.S. drilling ships, and could be used as a bargaining point to gain access to the projected U.S. Ocean Margin Drilling Project. In this way we could expect OMDP to drill off southern Canadian continental margins to a greater extent than it is presently scheduled to do."
>
> "It was generally agreed that expensive equipment and special facilities (both machines and talent)...must be placed on mechanisms to make them available to the entire community.
>
> It was generally agreed that present NSERC funding (for sciences generally) is about 50% below the required level for productive and efficient science. In addition, special funds are needed for specific problems such as field research in areas where logistic support is very expensive."

# 5. INDUSTRY

The ten papers in this section focus on industry. The authors are from a wide range of industries and from government. The section is dominated by the petroleum industry, although insight is also provided into more general contracting as well as mining and dredging.

Industry and government interface in the area of "contracting out" through the Department of Supply and Services (DSS). This Department operates on behalf of all other federal agencies either by request for industry involvement or in response to unsolicited proposals from industry. A review of the DSS figures for the first ten months of 1980 suggests certain relationships. At present about $2 million, or roughly 10 per cent of the total federal budget for marine geoscience, is contracted out through DSS research and development contracts: 80 per cent through DFO and EMR; 15 per cent DOE; and 5 per cent DND. Of this $2 million, over 95 per cent went to industry and 5 per cent to universities. DSS is therefore a major source of government research funding for industry. In the ten months, DSS gave out 71 contracts. Ten contracts represented 50 per cent of the dispersed funds and these were from DFO, EMR and DND in the area of instrumentation. These contracts had an average value of $100 000. For the remaining bulk of the DSS contracts, the average value was only $15 000. Six areas of work each represented 5 to 10 per cent of these DSS contracts (i.e. $0.1 M to $0.2 M) and are in decreasing order: dumping and dredging, training, ice scour, and paleontology. Of the 50 per cent of the DSS contracts which went into instrumentation-related work (i.e. $1 M), about 85 per cent went to projects undertaken by a single organization.

It should be noted that, excluding instrumentation, a significant but unidentified proportion of the work is in analysis (e.g. geochemistry, sedimentology). Such work is supportive to government research but in itself does not represent research and development which industry is carrying out, and does not represent a transfer of research and development capacity to industry.

As to the future outlook for industrial work in Canada, some indication of the magnitude of offshore projects scheduled for the next decade is given by the size of capital requirements of three of the projects given by the Canadian Council of Professional Engineers in "Engineering and Manpower Requirements, 1980-2000, For Major Energy-Related Projects in Canada" (October, 1980). Nova Scotia tidal power development is estimated to require in the order of $6.5 billion by 1998. Hibernia will require $30 billion by 1998. All of these projects depend heavily on marine geoscience and geotechnical engineering skills.

In the lead paper in this section, K.P. Appleton of Gulf Canada Limited, outlines industry offshore exploration expenditures and the development of the industry over the past two decades in a dozen exploration theatres each presenting special geoscientific problems. Of a total expenditure of three billion dollars, nearly one billion has been spent in the Beaufort Sea. The Scotian Shelf, Grand Banks and Labrador jointly equal that expenditure while the expenditures in the remaining eight theatres total only one-third that in the Beaufort Sea.

A perspective for geoscience might be gained from the huge cost of drilling. The total expenditure of the Federal Government in marine geoscience as outlined by M.J. Keen is in the order of $16 million per year or about one-quarter the cost of a single well from a drillship in the Beaufort Sea. Industry expenditures are largely directed at site selection, detailed information collection and technical problem solution. Conversely, on limited budgets, government engages in a number of quality scientific endeavours providing data on a regional framework while universities dominate research on marine processes. It is seldom accomplished, but the early integration of activities and information gained by each sector would benefit all.

"Canadian Geophysical Activity" by M. Roth of Geophysical Service Inc. is a contractor's account of the marine geophysical activity area-by-area for the past two decades. The paper relates geophysical survey activity to highlights in drilling and other factors drawing heavily on oil industry publications. Unlike most of this report, the names of contractors, boats and operators have been left in the text. The graphs of statistics presented for each area provide a ready base for time-and-activity comparisons. It should be noted that there was generally strong activity in the first half of the 1970s and greatly reduced activity in the second half. Only in the Beaufort Sea has the same level of activity been again achieved. Roth presents his views of the causes for these trends.

Throughout this status report the relationship between the marine geosciences and petroleum exploration and development is omnipresent. Meneley and Rayer of Petro-Canada provide keen insight into this relationship in their paper, "The Role of Marine Geoscience in Petroleum Exploration and Development, 1980-2000". Increased activity in seismic and drilling caused demands not only in capital but also in personnel. Teams comprising geologists, geophysicists, oceanographers, geochemists and geotechnical engineers will be required to solve problems of production, transportation, pipelining, support systems and environment protection. Particular problems of seafloor stability and protection from ice, unique to Arctic waters, must be understood and conquered. Meneley and Rayer closely relate the development of marine geosciences in Canada for the next two decades to needs generated by Canadian offshore resource development.

Two sister papers on nonpetroleum mineral resources in the offshore are presented to D. Pasho. In "Mining and Dredging" Pasho gives the purpose and status of operations for the various regions. In "Minerals" he provides an outlook for future development of offshore mineral resources. The requirement for constructional materials is significant with respect to certain projects but the outlook for production of other nonpetroleum mineral resources appears to be slow and somewhat distant.

Areas of specialization and involvement in marine geoscience by contracting and consulting organizations are extremely diverse. "The Airborne Geophysics Industry" by N.R. Paterson of Paterson, Grant, Watson Ltd. outlines the nature of the industry in Canada with both past activity and future outlook, including the significance of technical developments. The past offshore operations are reviewed by regions both for petroleum and metallic resources. Paterson expresses the belief that these tools often used in the past for early exploration reconnaissance, could substantially aid in current exploration with the present refinement in techniques.

In a brief paper, "Engineering and Design", J.I. Clark calls for the federal effort in research and development to include a system of archiving data from all geosciences into a format to provide ready input for geotechnological requirements foreseen in the next decade. An important reference for this paper is the recent report of the Task Force on Marine Geotechnology in Canada to the NRC Associate Committee on Geotechnical Research.

Two other papers give some insight into the effort and outlook for consulting and contracting in general. Clark, president of Golder Associates (Western Canada) Ltd., summarizes the marine content of a recent inventory of Canadian research and development capabilities for engineering in cold regions and finds our present level of research and development is extremely small. Meanwhile, R. MacDonald of Vancouver discussing contracting and consulting on the West Coast considers that marine geosciences in industry are presently in decline. Both Clark and MacDonald call for increased impetus by the Federal Government to encourage the industry, or present companies may not be capable of sufficient growth to become significant contractors in major projects foreseen in the next decade.

Engineering projects scheduled for the next two decades are valued in excess of $40 billion and involve a large component of marine geotechnical skills. The magnitude of the new work projected can be visualized by comparing this figure with the $2 billion spent to date on all seismic and drilling offshore. It is apparent then that these new projects will require more professionals than Canadian industry and universities can immediately supply. Professional talent in the marine geosciences should be nurtured both in universities and in industry. The projected scenario, if Canadians are not available, is that while Canadians will get work, they will not be able to control the expertise. When the projects are over, Canada will have lost the opportunity to do its own work and to develop and export expertise.

The unique Seabed Project is described by R.W. Hutchins. The project was initiated by Huntec and is referred to by several contributors. It is an outstanding example, and one of the very few, of what can be done through government-university-industry liaison. The project is based on concepts presented in an unsolicited proposal.

**REVIEW OF DRILLING AND GEOPHYSICAL ACTIVITIES AND EXPENDITURES** – K.P. Appleton

Since the start of worldwide offshore exploration in 1938, giant reserves of hydrocarbons have been discovered on continental margins. Currently one fifth of known reserves are in offshore fields and this expertise supports the philosophy that the offshore areas justify the high risk and huge amounts of capital expenditure required for exploration. Because of the escalating costs of drilling (Grand Banks wells cost an average of $35 million each in 1980) most ventures

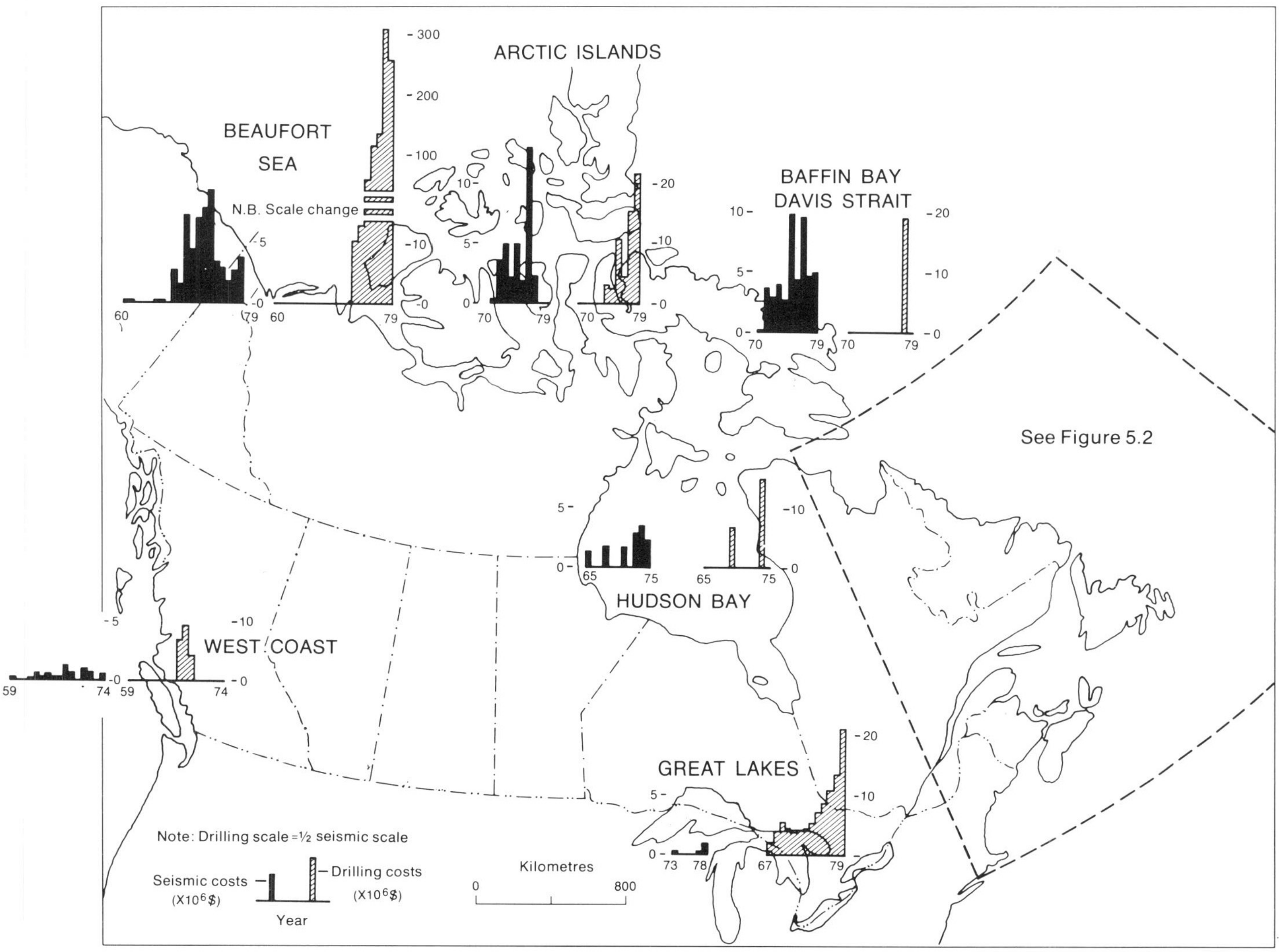



*Figure 5.1.* *Oil industry offshore seismic and drilling costs.*

now comprise a consortium of companies and it is doubtful if there will ever be a return to the days of single company undertakings, both because of cost and government involvement. Due to its preferential back-in rights, Petro-Canada is, in fact, now the largest individual landholder in the offshore areas of Canada.

As seen in Figures 5.1 and 5.2 the Canadian offshore areas have been divided into three groups:

a. The East Coast, comprising Labrador, NE Newfoundland, Grand Banks, Scotian Shelf, Gulf of St. Lawrence and Bay of Fundy.

b. High Arctic, comprising the Beaufort Sea, Arctic Islands, Baffin Bay and Davis Strait.

c. Other areas, including Hudson Bay, West Coast and the Great Lakes.

Costs are shown in histogram form for both seismic and drilling on Figures 5.1 and 5.2, with Table 5.1 showing a tabulation of the figures used to construct the histograms.

### *East Coast*

The continental margin of eastern Canada covers a vast area and, if Baffin Bay is included, stretches some 5600 km (3500 miles) with an average width of 100-400 km

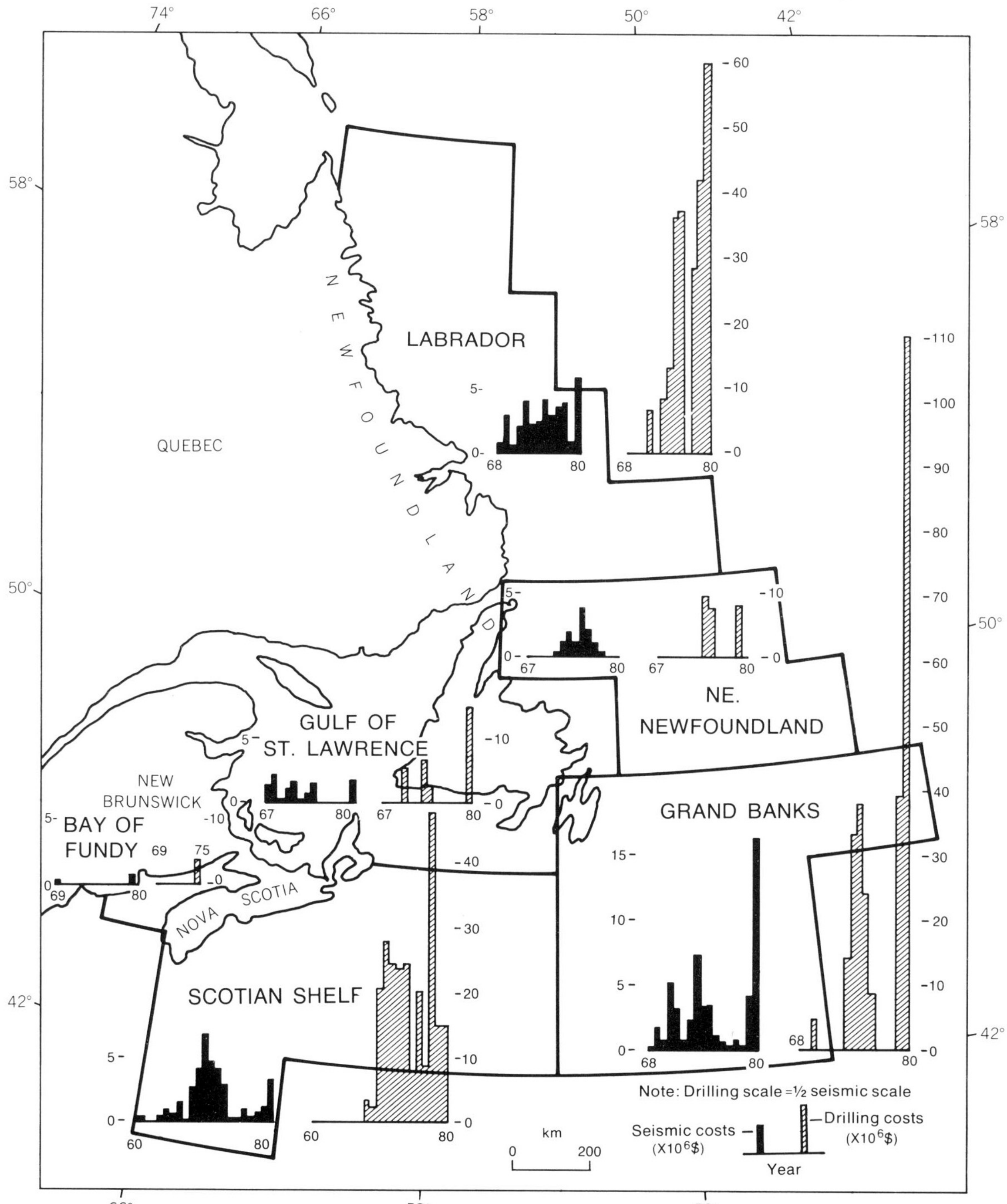



*Figure 5.2.* *Oil industry offshore seismic and drilling costs.*

**Table 5.1.** Oil industry offshore exploration expenditures (thousands of dollars)

| Year | BEAUFORT SEA Seismic[2] | BEAUFORT SEA Drilling[1] | ARCTIC ISLANDS Seismic[4] | ARCTIC ISLANDS Drilling[3] | BAFFIN BAY/ DAVIS STRAIT Seismic | BAFFIN BAY/ DAVIS STRAIT Drilling |
|---|---|---|---|---|---|---|
| 1960 | 91 | - | - | - | - | - |
| 1961 | 6 | - | - | - | - | - |
| 1965 | 47 | - | - | - | - | - |
| 1966 | 15 | - | - | - | - | - |
| 1968 | 2 837 | - | - | - | - | - |
| 1969 | 1 656 | - | - | - | - | - |
| 1970 | 7 418 | - | 432 | - | 139 | - |
| 1971 | 4 550 | - | 3 693 | - | 3 644 | - |
| 1972 | 7 275 | - | 4 823 | - | 2 953 | - |
| 1973 | 7 953 | 10 503 | 2 271 | - | 3 961 | - |
| 1974 | 9 531 | 13 131 | 4 911 | 3 188 | 2 606 | - |
| 1975 | 3 535 | 59 074 | 1 982 | 2 681 | 9 858 | - |
| 1976 | 3 125 | 116 955 | 13 274 | 10 781 | 4 474 | - |
| 1977 | 1 947 | 133 528 | 2 327 | 4 260 | 9 683 | - |
| 1978 | 2 729 | 310 215 | - | 15 289 | 4 772 | - |
| 1979 | 3 824 | 253 630 | - | 21 869 | 4 913 | 19 158 |
| | 61 539 | 902 086 | 34 713 | 58 068 | 47 013 | 19 158 |

| GREAT LAKES Year | Seismic | Drilling |
|---|---|---|
| 1967 | - | 2 200 |
| 1968 | - | 3 400 |
| 1969 | - | 5 200 |
| 1970 | - | 4 700 |
| 1971 | - | 3 600 |
| 1972 | - | 4 000 |
| 1973 | 150 | 4 500 |
| 1974 | 570 | 5 300 |
| 1975 | - | 7 200 |
| 1976 | - | 8 800 |
| 1977 | 100 | 11 000 |
| 1978 | 1 000 | 13 600 |
| 1979 | - | 21 100 |
| | 1 820 | 846 000 |

| Year | SCOTIAN SHELF Seismic | SCOTIAN SHELF Drilling | GRAND BANKS Seismic | GRAND BANKS Drilling | N.E. NEWFOUNDLAND Seismic | N.E. NEWFOUNDLAND Drilling | LABRADOR Seismic | LABRADOR Drilling |
|---|---|---|---|---|---|---|---|---|
| 1960 | 330 | - | - | - | - | - | - | - |
| 1963 | 330 | - | - | - | - | - | - | - |
| 1964 | 950 | - | 221 | - | - | - | - | - |
| 1965 | 666 | - | 1 837 | - | - | - | - | - |
| 1966 | 1 426 | - | 747 | 4 913 | - | - | - | - |
| 1967 | 44 | - | 5 115 | - | 158 | - | - | - |
| 1968 | 2 739 | 3 713 | 3 147 | - | - | - | 908 | - |
| 1969 | 4 153 | 2 054 | 827 | - | - | - | 2 830 | - |
| 1970 | 6 845 | 20 945 | 2 340 | - | - | - | 747 | - |
| 1971 | 4 673 | 28 052 | 7 412 | 14 153 | 338 | - | 2 114 | 6 524 |
| 1972 | 4 162 | 24 552 | 3 331 | 33 211 | 1 201 | - | 4 060 | - |
| 1973 | 2 980 | 23 838 | 3 549 | 38 025 | 2 022 | - | 2 186 | 8 405 |
| 1974 | 393 | 24 916 | 1 108 | 23 931 | 1 140 | 9 515 | 2 421 | 13 167 |
| 1975 | 298 | 7 593 | 528 | 8 464 | 3 839 | 7 312 | 4 136 | 36 292 |
| 1976 | 979 | 20 346 | 268 | - | 2 174 | - | 2 913 | 37 394 |
| 1977 | 414 | 8 838 | 610 | - | 1 209 | - | 3 653 | - |
| 1978 | 799 | 47 909 | 432 | - | 450 | - | 3 880 | 28 643 |
| 1979 | 1 141 | 15 000 | 4 150 | 39 000 | 50 | 8 000 | 944 | 42 000 |
| 1980 | 3 310 | 15 000 | 16 250 | 110 000 | 96 | - | 5 850 | 60 000 |
| | 36 632 | 242 753 | 51 862 | 271 697 | 12 678 | 24 827 | 36 642 | 232 425 |

| WEST COAST Year | Seismic | Drilling |
|---|---|---|
| 1959 | 192 | - |
| 1962 | 41 | - |
| 1963 | 630 | - |
| 1964 | 324 | - |
| 1965 | 523 | - |
| 1966 | 304 | - |
| 1967 | 272 | 7 024 |
| 1968 | 1 262 | 9 290 |
| 1969 | 592 | 4 336 |
| 1971 | 1 084 | - |
| 1972 | 701 | - |
| 1974 | 571 | - |
| | 6 496 | 20 650 |

| GULF OF ST. LAWRENCE Year | Seismic | Drilling |
|---|---|---|
| 1967 | 1 437 | - |
| 1968 | 2 290 | - |
| 1969 | 312 | - |
| 1970 | 1 103 | 5 831 |
| 1971 | 1 625 | - |
| 1972 | 398 | - |
| 1973 | 694 | 6 789 |
| 1974 | 1 519 | 2 568 |
| 1980 | 1 800 | 15 000 |
| | 11 178 | 30 188 |

| BAY OF FUNDY Year | Seismic | Drilling |
|---|---|---|
| 1969 | 291 | - |
| 1975 | - | 3 600 |
| 1980 | 700 | - |
| | 991 | 3 600 |

| HUDSON BAY Year | Seismic | Drilling |
|---|---|---|
| 1965 | 1 335 | - |
| 1968 | 1 881 | - |
| 1969 | - | 6 987[5] |
| 1971 | 1 708 | - |
| 1973 | 2 905 | - |
| 1974 | 3 507 | 15 052 |
| 1975 | 2 369 | - |
| | 13 705 | 22 039 |

[1]Includes man-made island wells and offshore wells
[2]Includes geology and research programs
[3]Ice-island wells only
[4]Marine seismic only
[5]Stratigraphic tests onshore

(250 miles). This is an enormous area to test satisfactorily and the present number of wells at over 150, just scratches the surface. A comparison should be made with the 43 000 wells drilled onshore in the Western Canada Basin and the 800 or more wells in the North Sea. The East Coast has 1 well per 5200 $km^2$ (2000 square miles) of prospective area compared with the North Sea at 1 well per 130 $km^2$ (50 square miles).

Exploration on the East Coast started in 1960 with speculative reconnaissance seismic surveys and gravity and magnetics. This was followed by more detailed oil company seismic surveys and drilling on the Scotian Shelf and Grand Banks. Although the single company ventures had little success, expenditures built up gradually to a peak in 1973 at which time most companies diverted their exploration funds away from the frontier areas causing a decline in activity until 1978 in all but the Grand Banks and Labrador Shelf. In these latter areas activity continued until 1977 when a halt came due to a jurisdictional dispute between the Federal and Newfoundland governments. Drilling resumed in 1978 after Newfoundland issued provincial permits.

The Crown Corporation, Petro-Canada, entered the scene in 1976 and invested \$85 million in "farm in" deals for exploration on the Scotian Shelf (70 per cent of the industry total). This involvement helped pick up the exploration pace again on the Scotian Shelf but the big incentive for industry in all frontier areas was the introduction of Frontier Exploration Allowance (Super Depletion) in 1978 by the Federal Government, which provided companies with an additional two-thirds of cost tax write off of all drilling costs in excess of \$5 million. This generated a surge in exploration of the offshore areas until March, 1980 when 'super depletion' expired. The discovery of the Hibernia field on the Grand Banks of Newfoundland has to some extent, offset this lack of tax incentive and in 1980 over 40 000 km of seismic lines have been shot, which is 200 per cent over the average for the past four years. It remains to be seen if current incentives and future discoveries will offset the escalating costs of drilling and the lack of clear government legislation and frontier production pricing to maintain a high exploration effort.

### Scotian Shelf

The Scotian Shelf as a whole has proved rather disappointing. The first seismic survey was shot in 1960, with the first well being drilled in 1968. This well cost only \$3 million since it used Sable Island as a natural platform. From 1969 to 1976 one company drilled nearly 25 wells for over \$100 million all along the Scotian Shelf with only two small gas shows.

The Sable Island area showed more promise with a well in 1971 on the west end of the island which evoked the largest headlines in the Halifax Herald since the end of World War II – "IT'S OIL". The discovery was short lived and, along with another 3 gas discoveries and 1 oil discovery in the Sable Island area found by subsequent drilling (costing around \$25 million per year until 1975), proved to have problems with reservoir size and continuity. Appraisal wells have been drilled in the Sable Island area with an expenditure of around \$15 million per year for the last two years using both jack up and semisubmersible rigs. It is not yet known whether an affirmative development decision will be made in the near future. If development proceeds, production facilities will probably cost over \$1 billion.

No money has been spent on the eastern extension of the Scotian Shelf into the Laurentian fan area due to the moratorium imposed on exploration until boundaries have been settled with the French islands of St. Pierre and Miquelon.

### Grand Banks and Northeast Newfoundland

Exploration in the southern Grand Banks started in 1964. A well was drilled in 1966 for \$5 million and then, after 25 unsuccessful wells had been drilled to 1974, exploration stopped. The northern Grand Banks and northeast Newfoundland nearly went the same way. The first well was drilled in 1972, but after 11 unsuccessful wells at a cost of over \$100 million, drilling tapered off. In 1979 a four-company consortium together with Petro-Canada (who acquired an interest through preferential rights) drilled the Hibernia P-15 discovery well. This large discovery drastically changed the activity in the area and has led to a seismic expenditure of \$16 million for 1980 alone, including over \$5 million for a three-dimensional grid survey, and drilling expenditures of over \$100 million for the same year using three semisubmersible rigs. Each well currently costs \$30-\$50 million.

### Labrador Shelf

The first well was drilled on the Labrador Shelf in 1971, some four years after the first seismic survey was shot. The number of wells reached 15 by 1977 at which time drilling stopped due to uncertainties caused by the Newfoundland/Federal Government jurisdictional dispute. Drilling resumed in 1978 with Petro-Canada becoming operator in 1979.

The Labrador Shelf is hampered by what is possibly the most hostile exploration environment in the world with a drilling season averaging only 90 days. There have been 5 noncommercial discovery wells, indicating that it is an area of good hydrocarbon potential. Industry expenditures have been over \$36 million in seismic surveys and over \$230 million in drilling to date, and there appears to be little slowdown in the effort to prove this to be a major gas and oil province. Wells have cost around \$15-25 million each, and will soon escalate to \$25-35 million with higher rig tariffs and deeper prospects. Drilling ships utilizing dynamic positioning are employed because of the propensity of icebergs to drift over the area. The latter will contribute to a high cost of production for hydrocarbons in "iceberg alley" which the shelf is often called.

### Gulf of St. Lawrence

The area has been explored at a low level since 1967 with \$11 million having been spent on seismic surveys and \$30 million on drilling 7 wells with no success. Of the \$30 million, \$15 million was spent in 1980 on one well alone. It is of interest to note that, together with one well off Newfoundland, these are the only east coast wells in which Petro-Canada did not participate in 1980.

### Bay of Fundy

After \$291 000 was spent on a seismic survey in 1969 there has not been much interest shown in the area. One well was drilled in 1975 at a cost of \$3.6 million but did not offer much encouragement for further drilling. More recently, however, a seismic survey of about 1000 km was shot in 1980 at a cost of over \$700 000, indicating that there may be renewed interest in future exploration in the bay.

## *High Arctic*

### Baffin Bay/Davis Strait

Although over \$47 million has been spent in geophysical exploration only two wells have been drilled in the area. One well discovered hydrocarbons and although \$19 million was spent on drilling in 1979, another \$45 million was spent to reach the projected total depth in 1980. Exploration in the area is slow, not due to lack of potential, but due to logistical and environmental problems. Environmental studies are currently being carried out by industry at a cost of \$13 million in northern Baffin Bay.

Until the recent discovery on the Canadian side of Davis Strait there had been 5 unsuccessful wells drilled on the Greenland side which did not encourage further drilling.

### Arctic Islands

Exploration was at a relatively low level in the late sixties and early seventies until the formation of the Arctic Islands Offshore Group which boosted seismic surveying (both ice and marine) from under 1500 km per year to over 8000 km per year from 1974 to 1976, with a maximum expenditure of \$13 million in 1976. Since that time the newly formed Arctic Islands Exploration Group (AIEG) has kept one or two crews employed each year shooting an average of about 1500 km per year over specific prospects.

Drilling costs in the inter-island seaways are the lowest of the frontier areas as land techniques may be used on the ice with the addition of submarine blowout prevention equipment. From 1974 to 1979, \$58 million has been spent on drilling some 13 wells from the ice. Three more wells are to be completed in 1980 with a total drilling depth of 5.5 km (compared with 7 km from three wells in 1979). Member companies of the AIEG are currently allocating as much as 10 per cent of their budgets to seismic expenditures, the rest being for drilling and interpretation.

### Beaufort Sea

After initial magnetic, gravity and seismic surveys of a reconnaissance nature in the early and mid sixties, more detailed seismic surveys were shot in the late sixties with drilling activity following from man-made islands in shallow areas of the Beaufort Sea in 1973. The use of man-made islands is extending into deeper water as technology improves, but drillships have been used in deeper water since the mid seventies. Over 30 wells have been drilled to date, about half from drillships and half from artificial islands, with encouraging results.

The Beaufort Sea is by far the most expensive frontier area in which to drill and as such consumes from 40-100 per cent of participating companies' budgets. The average cost of a well from a drillship is around \$60 million (which exceeds the total western Canada budget of most oil companies) and to date over \$1 billion has been spent on drilling, together with about \$70 million on seismic surveys.

## *Other Areas*

### West Coast

Interest has centred around the Queen Charlotte Basin between the Queen Charlotte Islands and the mainland, and the Tofino Basin immediately west of Vancouver Island. Magnetic, gravity, seismic reflection and seismic refraction surveys were carried out between 1959 and 1974 for a cost of \$6.5 million. Interest has waned in the area after 14 wells were drilled by a single company in both basins between May, 1967 and May, 1969 costing over \$20 million. Oil and gas shows were encountered but no commercial accumulations were found.

### Hudson Bay

The first seismic survey was shot in 1965 which, together with gravity and magnetic surveys, prompted stratigraphic test wells to be drilled on the southwestern shore of the bay. Five wells were drilled at a cost of \$7 million in 1965. The one show of oil and gas and the general similarity of this basin to the Michigan Basin generated enthusiasm although the lack of structural traps and the fact that reserves would have to be greater than in Michigan for offshore production were recognized.

Between 1971 and 1974 a group of six oil companies known as the "Hudson Bay Group" drilled 3 wells in the bay. In 1971, the first well ran into problems due to bad weather (weather is similar to the Labrador Shelf) which necessitated the use of a specially build semisubmersible for the following 2 wells in 1974. The results of these wells caused the group to abandon the play after having spent over \$20 million, \$15 million of which was for drilling.

In 1980, at the request of an oil company, the government offered 4 parcels, each of over 7 million hectares, for lease but received no offers. Many companies feel that reserves would be too small to be economically viable for offshore production even though existing pipelines and lack of icebergs give it an advantage over the Labrador Shelf. Also, government requirements of a commitment of over \$60 million for a five year permit including 2 wells are thought, by many, to be excessive. It is of interest to note that any production in Hudson Bay could well involve the governments of Manitoba, Ontario and Quebec in jurisdictional claims.

### The Great Lakes

Exploration and production in the Great Lakes is virtually confined to Lake Erie. There are over 1 million hectares under disposition which constitute most of the lake's Canadian waters. Although there are nearly ten operators using both floating and jack-up rigs, most of the rights are under licence or lease from the Ontario Ministry of Natural Resources to only two companies, neither of which would be considered a major oil company.

Drilling in Lake Erie started about 30 years ago with over 50 wells having been drilled by 1955. Table 5.1 and Figure 5.1 show activity since 1967, at which time there were already 500 wells in the lake. Because of the maturity of exploration, only a small percentage of costs is devoted to seismic surveys, although \$1 million was spent for marine seismic surveys in 1978. Drilling costs have escalated primarily due to inflation and the number of wells and feet drilled per year have increased only gradually over the last decade (200 000 feet in 1979 compared with 100 000 feet in 1969). As actual expenditures were unavailable, drilling costs in Table 5.1 and Figure 5.1 have been estimated by using the figures for 1980 of \$130 per foot and \$90 per foot for floating and jack-up rigs, respectively, and deflating these figures back to 1967. Seismic costs were calculated similarly using present costs of \$850 per mile for seismic shooting in addition to \$450 per mile for data processing.

There have now been about 1200 wells drilled in Lake Erie with production being mostly gas for the Ontario market.

## CANADIAN GEOPHYSICAL ACTIVITY – M. Roth

### *Northern Canada*

#### Introduction

The history of marine geophysical exploration in the Canadian North is a fascinating scenario, influenced by many factors. The original exploration catalyst was an announcement on July 18, 1968 that a major oil and gas discovery had been made on the Arctic Slope of Alaska at

**Table 5.2.** Geophysical activity (actual kilometres of reflection and refraction)

| Year | Beaufort Sea | Arctic Archipelago | Baffin Bay/ Davis Strait | West Coast | Lake Erie | Hudson Bay/ Hudson Strait | East Coast |
|---|---|---|---|---|---|---|---|
| 1959 | - | - | - | 322 km | - | - | - |
| 1960 | - | - | - | 113 km | - | - | 1 406 km |
| 1961 | - | - | - | - | - | - | - |
| 1962 | - | - | - | 420 km | - | - | - |
| 1963 | - | - | - | 1 752 km | - | - | 1 448 km |
| 1964 | - | - | - | 2 253 km | - | - | 13 497 km |
| 1965 | - | - | - | 9 828 km | - | 6 598 km | 15 584 km |
| 1966 | - | - | - | 1 458 km | - | - | 9 282 km |
| 1967 | - | - | - | - | - | - | 24 622 km |
| 1968 | 3 970 km | - | - | 4 749 km | 2 594 km | 5 558 km | 29 611 km |
| 1969 | 1 652 km | - | - | 2 047 km | 2 026 km | - | 34 270 km |
| 1970 | 3 600 km | 9 903 km | - | - | - | 5 483 km | 45 923 km |
| 1971 | 4 332 km | 4 177 km | 7 739 km | 2 704 km | - | 5 859 km | 78 122 km |
| 1972 | 6 625 km | 6 388 km | 11 835 km | 2 847 km | - | - | 70 394 km |
| 1973 | 7 412 km | 8 061 km | 17 834 km | - | 536 km | 5 272 km | 64 693 km |
| 1974 | 2 776 km | 6 697 km | 8 167 km | 959 km | 1 931 km | 8 853 km | 33 564 km |
| 1975 | 4 135 km | 5 380 km | 14 638 km | - | - | 5 751 km | 29 716 km |
| 1976 | 4 515 km | 2 151 km | 7 879 km | - | - | - | 15 671 km |
| 1977 | 4 669 km | 3 410 km | 4 130 km | - | 1 044 km | - | 14 814 km |
| 1978 | 5 747 km | - | 6 896 km | - | - | - | 13 205 km |
| 1979 | 8 056 km | - | 7 110 km | - | 543 km | - | 9 269 km |
| 1980 | 10 748 (est.) | 1 548 (est.) | 1 502 (est.) | - | 1 421 (est.) | - | 30 163 (est.) |

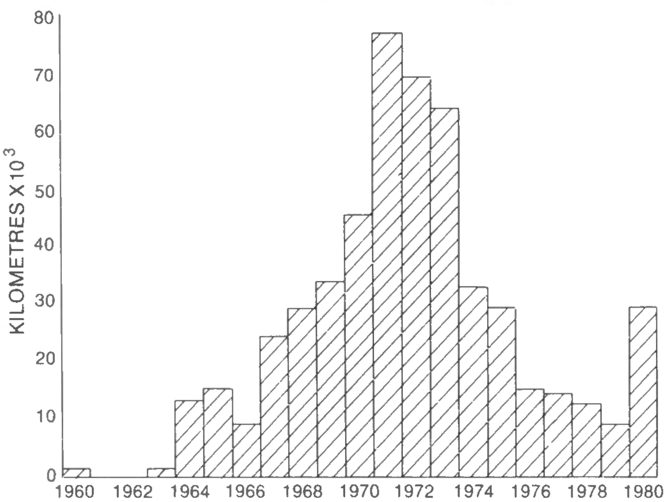



***Figure 5.3.*** *Geophysical activity, Beaufort Sea (actual kilometres of reflection and refraction) 1968-80.*

Prudhoe Bay. Subsequent visions of a petroleum "El Dorado" precipitated a major exploration effort that has continued to the present day.

Seismic activities in this region are governed by a complex collection of technological, environmental, economic, social and political influences. In the context of this paper it will not be possible to delve into these factors, however, the interested reader should refer to the Science Council of Canada Background Study No. 34.

What will be discussed in this paper are the who, what, where, when and why of marine geophysical contracting in the north. Due to strikingly different conditions, the northern region will be divided into three exploration provinces: the Beaufort Sea (including Mackenzie Bay), the Arctic Archipelago and Baffin Bay/Davis Strait. (Although included with the statistics, ice shooting and shallow water operations will not be considered in this discussion.)

### The S.S. Manhattan

In response to the discovery at Prudhoe Bay, Humble Oil Company embarked on a feasibility study for transporting petroleum by tanker. In 1969 the 150 000 ton reinforced tanker **S.S. Manhattan**, traversed the Northwest Passage, accompanied by the Canadian Government icebreaker **Sir John A. MacDonald.**

While Prudhoe Bay turned the oil industry's eyes northward, the journey of the **Manhattan** was to do the same for the Canadian public and government. Claiming that the Northwest Passage was "open sea", Humble attempted to prove that the journey could be made without entering Canada's three-mile territorial limit. To their misfortune, M'Clure Strait was no more hospitable to the **Manhattan** than to the **Investigator** 117 years previous.

The importance of this event to the discussion at hand is the quick response of the Canadian Government to assert its sovereignty over the Arctic Islands and passages. On April 8, 1970 the Arctic Waters Pollution Prevention Act was introduced to the House of Commons and passed unanimously. Furthermore, the three-mile territorial sea and nine-mile exclusive fishing zone was replaced by an outright claim to a twelve-mile territorial sea. This legislation laid the regulatory foundations for subsequent rules limiting areas of operation, type of seismic sources, and the like.

### Beaufort Sea

The first marine survey in the Arctic was conducted during the summer of 1960 by Accurate Exploration Ltd. using converted landing crafts and local schooners. This operation consisted of roughly 450 kilometres per year until and including 1964. However, full-scale exploration did not commence until 1968 (Table 5.2; Fig. 5.3), when Digicon's **M V Pacific Seal**, Dresser Olympic's **Campeche Seal** and the Geophysical Services Incorporated (GSI) **M V Grebe** combined to shoot 3970 kilometres of reflection seismic. The following year Pallister and Associates (Kenting) initiated its Arcticquest subscription program, employing GSI's **M V Grebe** while Digicon once again returned with the **M V Pacific Seal.**

In 1970 the Arcticquest survey was completed with the **M V Theron,** while GSI returned once again with the **M V Grebe** and Digicon as well as Olympic also made appearances with, respectively, the **M V Foja D'Oro** and **M V American Olympic.** The following year, however, most of the contractors deserted the Beaufort, leaving only GSI and the **M V Grebe.**

The first of a series of innovative approaches to exploration occurred in 1972 with the introduction of the **M V GSI Mariner**, which was built in Edmonton and assembled at Hay River. A combination of smaller dimensions and shallow draft made this vessel well suited for operations in Mackenzie Bay and the Beaufort Sea.

Another innovation which made its debut in 1972 was Pan Canadian Petroleum's utilization of an SRN-6 air-cushion vehicle in the western fringes of the Mackenzie delta. However, the stop-and-go method of shooting resulted in an average production of approximately 13 kilometres per day, insufficient to justify a continuation of operations the following year.

In 1973 GSI was the sole operator in the Beaufort Sea, with the **M V GSI Mariner** completing the bulk of the program. Also contributing to the season total was a GSI experimental adventure involving six jet boats off the southeast shore of Mackenzie Bay. Two boats were used to lay and retrieve geophones and sonobuoys, while the others acted as shooting, recording and survey vessels, with one spare boat being kept at the base camp. Unfortunately the high winds in the Beaufort severely hindered operations so that only about 480 kilometres of an anticipated 800 kilometres of seismic were actually obtained.

In 1974, the Toronto-based Arctic Canadian Continental Shelf Exploration Services Limited proposed a unique approach to marine seismic. The company planned to utilize the **Narwhal II,** a 14-metre single-crew all electric submersible, in conjunction with an on-ice support crew. However, the high logistical costs coupled with the potential danger to the submarine crew made this operation impractical. Consequently, GSI was once again the sole contractor in the Beaufort Sea, in the most unproductive year since 1969.

Since 1974 the total yearly kilometres shot has shown a continual increase, in conjunction with improved drilling success. Esso's original oil and gas discovery well Adgo F-28 of 1974 was followed in 1976 by Netserk F-40, in 1977 by Nektoralik K-59 and Ukalerk C-50, in 1978 by Ukalerk 2C-50 and most recently by Isserk E-27, Tarsuit A-25 and Kopanoar M-13.

The **M V GSI Mariner** remained the lone deep water seismic vessel in the Beaufort Sea from 1974 until August of 1978, when the Esso-leased **Arctic Surveyor** entered the area. In 1980 the **M V GSI Mariner** and **Arctic Surveyor** were joined by a second GSI vessel, the class 1 icebreaker **M V Edward O. Vetter.** While the **M V GSI Mariner** continued shooting standard marine seismic for various clients, the **M V Edward O. Vetter** carried out the first three-dimensional survey in the Arctic.

The desire to identify and delineate the size of the "elephant structures" of the Beaufort Sea will doubtlessly result in a continued high level of geophysical activity. In particular, the quantity of three-dimensional seismic in this region is anticipated to increase as companies attempt to determine optimal drilling locations. However, as in other areas, restrictions on pipeline construction and the natural gas export regulations have had a pernicious effect on the exploration potential of the Beaufort Sea.

### Arctic Archipelago

While Prudhoe Bay provided the general incentive for Arctic exploration, it was Panarctic's 1969 gas discovery at Drake Point on Melville Island which directed attention to the archipelago. Kenting responded in 1970 (Table 5.2; Fig. 5.4) by initiating "Polarquest", a subscription program utilizing the **M V Theron.** Polarquest was continued the following year with the addition of the **M V Theta.** Kenting's program was completed in 1972 with the **M V Theron,** and GSI continued to shoot non-exclusive survey with the **M V Hans Egede.** The level of activity increased once again in 1973 as Compagnie Générale de Géophysique (CGG) joined a GSI vessel.

Perhaps the most exciting exploration year in the Arctic Islands occurred in 1974 when GSI's **M S Arctic Explorer** and **M V Carino** combined to shoot an extensive survey. During the course of this program the **M S Arctic Explorer** ventured into the previously unnavigated channel between Melville and Prince Patrick islands, while the **M V Carino** became the first vessel to traverse the Northwest Passage through M'Clure Strait. CGG was also active in 1974, performing a survey with the **M V Orion Arctic.**

Marine operations in subsequent years were characterized by a general decrease in production, as GSI was left as the sole operator in the area.

The final year of true marine seismic in the Arctic Archipelago was 1977, as natural gas export limitations has tended to dampen exploration enthusiasm.

### Baffin Bay/Davis Strait

Exploration of Baffin Bay and Davis Strait commenced in 1971 (Table 5.2; Fig. 5.5) with Kenting's "Baffinquest". The **M V Theta** and **M V Theron** combined to acquire in excess of 2400 kilometres of reflection seismic for the program, while also performing exclusive surveys for Shell and Gulf. CGG also made an appearance in the region, with the **M V Orion Arctic,** conducting operations for Aquitaine. GSI entered the area the same year with the **M V J E Jonsson.**

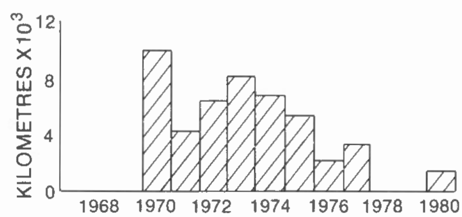



***Figure 5.4.*** *Geophysical activity, Arctic Archipelago (actual kilometres of reflection and refraction) 1970-80.*

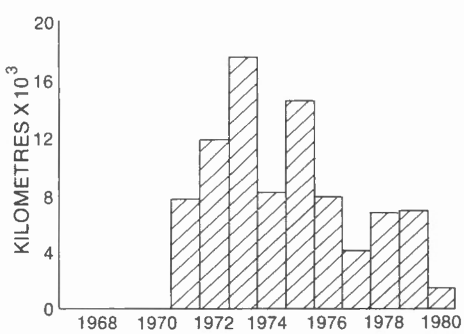



***Figure 5.5.*** *Geophysical activity, Baffin Bay/Davis Strait (actual kilometres of reflection and refraction) 1971-80.*

Activities in this area peaked in 1973 when GSI's **M V Hans Egede** and **M V J E Jonsson** combined with Petty-Ray's **M V American Robray II**, CGG's **M V Orion Arctic** and **M V Andromede** to collect 17 834 seismic kilometres. Operations slumped in 1974, when only GSI's **M V Carino** and **M S Arctic Explorer**, as well as CGG's **M V Orion Arctic** were active. There was, however, a considerable resurgence the following year, when CGG's **M V Polar Bjoern** and the GSI staffed **M V Indian Seal** made their debut.

Since 1975 there has been a considerable downward trend in kilometres collected and, when CGG abandoned the area in 1976, GSI was left as the sole contractor. In subsequent years GSI was joined by Petty-Ray, for an Esso program in 1977, and by the Esso vessels **R V Kirsten Bravo** and **R V Olga Bravo** in 1978 and 1979, respectively.

Marine seismic reached its lowest point in 1980 when only GSI's **M S Arctic Explorer** was active, accumulating a total of an estimated 1502 kilometres. The volume of activity is likely to increase somewhat in 1981; however, no large scale exploration programs are to be expected until the southern basins are more fully evaluated or drilling results in Davis Strait or Lancaster Sound lend encouragement.

### *Western Canada*

#### Introduction

The first large scale marine exploration program in Canada was performed offshore of British Columbia in 1959. However, due to a government imposed moratorium no exploration has been conducted since 1974. This paper will deal with west coast exploration in the past, as well as its future prospects.

#### West Coast

Seismic exploration offshore of British Columbia commenced in 1959 (Table 5.2; Fig. 5.6), in response to previous discoveries along the Pacific Margin of California. This original survey was performed by Western Geophysical Company and Geophysical Service Inc. for Richfield Oil Corporation, in the Hecate Strait. An upsurge in marine exploration commenced in 1962 when Shell mounted a large scale seismic investigation.

Following interpretation of data, Shell embarked on an extensive drilling venture in 1967. This two year program was concentrated in Hecate Strait and Queen Charlotte Sound, as well as along the western fringes of Vancouver Island. Fourteen wells were drilled in total by Shell, all of which were dry, prompting the company to abandon the west coast for other areas.

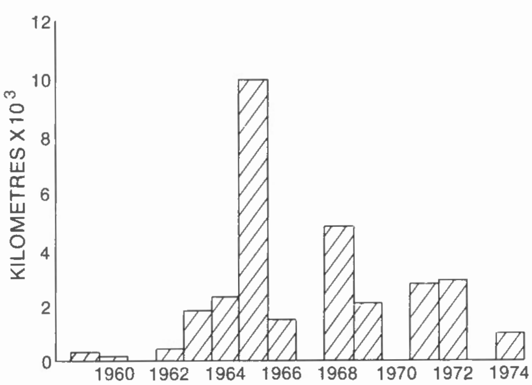



**Figure 5.6.** *Geophysical activity, West Coast offshore (actual kilometres of reflection and refraction) 1959-80.*

Since 1969, other companies have shown some interest in the potential of the British Columbia offshore. In 1971 and 1972 Chevron financed marine surveys by GSI's **M V Westwind** and Dresser Olympics' **M V Canadian Olympic.** Texaco also carried out a program in 1972, along the western coast of Queen Charlotte Islands, utilizing the **M V Caribbean Seal.** The final marine survey along the west coast was performed during 1974 in Hecate Strait by Gulf, with its own **M S Hollis Hedberg.**

While Shell's disappointing results did much to dampen enthusiasm, it was government regulations which eventually terminated west coast operations. Following the discovery at Prudhoe Bay and the ensuing discussion of the possibility of tanker transportation, there was an accompanying tightening of environmental regulations. In 1971 seismic exploration in the Strait of Georgia was banned by Federal Fisheries and Forestry Minister Jack Davis.

Subsequently, a rather vague moratorium was imposed with the Federal Government continuing to renew single-year land permits under the provision that no drilling be undertaken. However, with the apparent resolution of the transportation question in favour of tankers, it is anticipated that the moratorium will be lifted in the near future.

### *Central Canada*

#### Introduction

In the context of this discussion, the offshore regions of central Canada are divided into the Great Lakes and the vast area including Hudson Bay and James Bay as well as Hudson Strait. As a consequence of the Great Lakes Water Agreement, exploration in the first region is permitted only on Lake Erie. To date marine exploration in the second region has been confined mainly to Hudson Bay, with some minor work in Hudson Strait.

#### Great Lakes

Although the first North American offshore well was drilled in Lake Erie during 1913, large scale marine seismic exploration did not commence until 1968 (Table 5.2; Fig. 5.7). Atlas Lake Erie No. 1 and other drilling successes in 1967 provided the stimulus for marine activities in Ontario. During the initial year of operation, a survey was carried out for Amerada Petroleum Corporation by Geoprospectors Inc. while Geophysical Service Inc. utilized its **M V Eugene McDermott** in programs for Shell Canada Limited and Pan American Petroleum Corporation.

During the interim period to the present, surveys have been financed by Consumers' Gas Company of Toronto, Anschutz (Canada) Exploration Limited of Calgary and Canadian Superior. The contractors involved with these operations have been Kenting Exploration Services, Petty Ray Geophysical and Geophysical Service Inc. In general, some type of local barge has usually been employed in these surveys as in the case of the R & L No. 1 used by GSI in 1980.

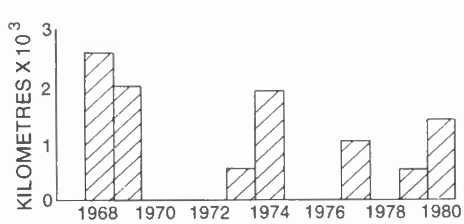



**Figure 5.7.** *Geophysical activity, Lake Erie (actual kilometres of reflection and refraction) 1968-80.*

It is not foreseen that activities on Lake Erie will change drastically in the foreseeable future. However, the attractive geology of nearby Lake St. Clair and Lake Huron coupled with a good record concerning potential problems of pollution in Lake Erie, will in all likelihood result in legislation permitting limited expansion of offshore exploration sometime in the future.

### Hudson Bay/Hudson Strait

Operations commenced in this region in 1965 (Table 5.2; Fig. 5.8), when Richfield Oil contracted GSI to perform a seismic survey in Hudson Bay. In 1968 and again in 1970 Arco and Aquitaine joined to finance an extensive reflection and refraction survey by CGG. In 1971 the French company returned once again to perform reflection and refraction surveys for several different clients.

No marine seismic operations were carried out in 1972; however, 1973 saw the debut of Kenting in the area with the **M V Thorarinn.** Activities peaked in this region during the 1974 season as CGG's **Orion Arctic**, Kenting's **M V Thorarinn** and GSI's **M V Hans Egede** combined to shoot 8853 kilometres of reflection and refraction seismic. This year also saw the first drilling venture in the region as Aquitaine commenced the Narwhal well with a drillship from Louisiana. Adverse ice and storm conditions conspired to terminate activities prematurely and the 517 foot unplugged hole was abandoned.

The following year Aquitaine returned with the drillship **Pentagon P-82** and drilled the Hudson Walrus and Polar Bear wells to basement. Results from these wells were very disappointing, discouraging further activity in the area. The last seismic survey was carried out in 1975 by GSI's **M V Carino**, operating for Mobil.

Recently some interest has been shown in Hudson Bay, as Chevron requested the 30.6 million hectares of territory to be posted for sale. While no bids were made during the November 17, 1980 sale, a Canadian company is reported to be formulating an offer to submit to the Minister of Energy, Mines and Resources. The exploration commitment would include approximately 4500 kilometres of seismic over three years, an environmental study during the fourth year, as well as a drilling program of at least two wells in the fifth year.

## *Eastern Canada*

### Introduction

Offshore Eastern Canada has been by far the most active region for marine seismic exploration. From the initial season of 1960 interest increased throughout the ensuing decade to peak in 1971 at nearly 80 000 kilometres acquired. Subsequent years were characterized by a decline in kilometres collected, reaching a minimum in 1979 with less than 10 000 kilometres, while 1980 was a year of recovery as over 30 000 kilometres were obtained. This discussion will outline the trends in marine seismic exploration in relation to drilling success during the last two decades.

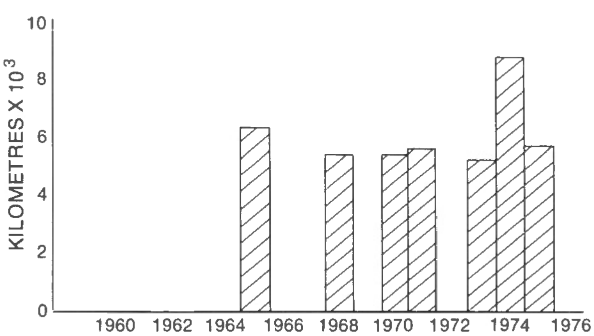



***Figure 5.8.*** *Geophysical activity, Hudson Bay/Hudson Strait (actual kilometres of reflection and refraction) 1965-80.*

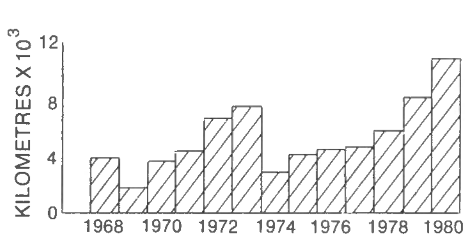



***Figure 5.9.*** *Geophysical activity, East Coast offshore (actual kilometres of reflection and refraction) 1960-80.*

### East Coast

Offshore seismic exploration along Canada's east coast commenced in 1960 (Table 5.2; Fig. 5.9) as GSI performed a reflection and refraction survey for Mobil. The marine vessels **Minna** and **Titus** were employed as the shooting and recording vessels respectively, in a 1406 kilometre program in the Sable Island area. After a lull of two years seismic exploration resumed once again in 1963 as Shell commenced its extensive program offshore of Nova Scotia. GSI performed this original survey utilizing the **North Star IV** for recording and the **Minna** as the shooting vessel. A major increase in geophysical marine activity occurred in 1964 as GSI completed an expanded program for Shell, using the **North Star IV** for recording and the **Lady Johnson** and **Polar Star** as shooting vessels. The following year saw a further increase in kilometres acquired as GSI completed the Shell program and conducted additional surveys for Humble Oil and Texaco.

The volume of activity dropped somewhat in 1966 with GSI again working for various clients, while Mobil carried out a survey with its own **M V Pegasus.** A significant renascence in geophysical marine operations occurred in 1967 as Western Geophysical's **Smitlloyd II** and **Devora** were involved in a major exploration venture by Pan American and Imperial. Also making a debut this season was the French company CGG, performing a survey for Petrosar. This year also saw Mobil Sable Island C-67 become Canada's first continental offshore natural gas discovery, stimulating increased interest in the east coast.

The upsurge in marine exploration continued in 1968 with GSI regaining shooting programs for Pan American and Shell. CGG also returned, shooting a program for Elf Oil, while Mobil carried out an extensive survey in the Sable-Banquereau-Grand Banks region with its own **Fred H. Moore.** In 1969 activities once again exceeded the previous year's total, with more than 34 000 kilometres being collected. Mobil continued to utilize its own vessel, Teledyne Exploration Co. was contracted by Shell, Catalina Exploration and Development carried out a participation program, and CGG performed surveys for various clients. Optimistic drilling results were also obtained in 1969 as Shell completed its first well on the Scotian Shelf, Onondaga E-84, a natural gas discovery with noncommercial flows.

Interest in the east coast continued to increase in 1970, as programs were financed by Shell, Mobil, Amoco, Imperial, Texaco, Murphy, Husky, Tenneco, Elf, Chevron and others. These surveys were carried out by CGG, Western, Delta, and Catalina Exploration. Despite the lack of a major oil and gas discovery in 1970, operations experienced a considerable increase in 1971 to a total of nearly 80 000 kilometres. Numerous clients were involved in the surveys performed by three GSI vessels, two CGG and Delta vessels, and single

Olympic and Western vessels. GSI and Delta also completed an extensive participation survey that season in excess of 16 000 kilometres. A significant drilling result also occurred in 1971, as Mobil Tetco Sable Island E-48 gave an indication that commercial reserves might be found under the Scotian Shelf.

Although activities decreased in 1972 from the peak of the previous year, the total kilometres acquired remained at a high level. The major contractors were present once again as CGG operated two vessels, as did Western and Seiscan-Delta, while single vessels were employed by GSI, Digicon, Delta and Petty-Ray. A company vessel was also active this season as Shell's **R V Niobe** completed a survey. Some encouraging drilling news was obtained as Shell Primrose N-50 identified thick pay zones, while Mobil Tetco Thebaud P-84 became the first truly commercial discovery on the Scotian Shelf. These two successes were, however, insufficient to significantly alter the generally dismal exploration record of the east coast. Consequently 1973 saw a slight decrease in marine seismic exploration, although kilometres once again remained high. Numerous companies financed surveys this season, including, Imperial, Mobil, Shell, Texaco, Chevron, Gulf, Amoco and others. The contractors involved with these programs were GSI, CGG and Kenting, while Shell and Gulf utilized their own vessels. There were no major drilling successes in 1973, although Mobil-Gulf-Adolphus 2K-41 hinted at possible oil-bearing structures in the Grand Banks area, while Bjarni H-81 suggested some potential in the Labrador basin.

The generally disappointing drilling record compiled by Shell, Mobil and others contributed to a plunge in geophysical activities in 1974 of more than 50 per cent from the previous year. GSI was the major contractor this season operating the **M V J E Jonsson**, **M S Arctic Explorer** and **M V Carino** in surveys for various companies. Also returning was CGG in a program for Eastcan with its **M V Orion Arctic** and Digicon's **M V Gulf Seal** in a participation survey on George's Bank. The sole drilling success of 1974 was Mobil Tetco Texaco Citnalta I-59, a noncommercial gas well which did little to dispel the growing pessimism surrounding east coast exploration. In 1975 a moderate reduction in the volume of operations occurred with GSI utilizing the **M V J E Jonsson, M S Arctic Explorer**, **M V Carino** and **M V Indian Seal**. Also active that season was Digicon with the **M V Atlantic Seal** and **M V Gulf Seal**, as well as CGG, with the **M V Dauphin de Cherbourg** while Esso used its own **R V Kirsten Bravo**. The absence of any drilling successes in 1975 further contributed to the decline in east coast marine geophysics.

A substantial decrease of almost 50 per cent in activities to less than 16 000 kilometres acquired occurred in 1976, as activities reached their lowest level since 1966. GSI's **M S Arctic Explorer** and **M V Carino** performed surveys for various clients including, Eastcan, Esso and Shell, while CGG's **Polar Berg** was engaged along the Labrador coast. Also present was the company boat **R V Kirsten Bravo** for an Esso program. The 1977 season saw a continuation of the downward trend in exploration, as the mounting total of noncommercial wells continued its debasing effect. GSI's vessels were active once more as was Esso's company vessel. Once again, however, no encouragement was provided by drilling results during the 1977 season.

In 1978 the meagre survey programs were performed by GSI's **M S Arctic Explorer** and **M V Carino**, CGG's **Polar Bjoern** and Petty-Ray's **M V Deep Sea Explorer**. Drilling activities along the Scotian Shelf were rewarded this year by the Mobil Texaco PEX Venture D-23, a prolific gas discovery. However, the implications of this discovery were insufficient to prevent a further decline in total production to below 10 000 kilometres in 1979. GSI, the sole contractor that season, utilized the **M S Arctic Explorer** for a variety of surveys. Two company vessels were also active; the **R V Olga Bravo** for Esso and the **M V T W Nelson** for Mobil. Unquestionably the most significant event in the scenario of east coast exploration was the discovery of commercial reserves of oil with Hibernia P-15. The ramifications of this occurrence filtered throughout the entire oil industry as companies prepared for a major exploration campaign.

For the marine geophysical industry, 1980 was the year of the phoenix as the optimism surrounding Hibernia was the catalyst to a resurgence of activities from the disappointments of the seventies. Two major innovations for the east coast were implemented this season as GSI carried out the first three-dimensional marine survey in Canada, while its three vessels: **M S Arctic Explorer, M V Fred J. Agnich** and **M V Bering Seal** continued operating during the winter. The GSI vessels combined to obtain 17 890 of the total of 30 163 kilometres collected in 1980. Western Geophysical was also active completing 5112 kilometres of program for Chevron and Gulf with the **Western Narrows.** Geoterrex was the only other contractor present on the east coast in 1980, collecting 300 km of data for the Cape Breton Development Corporation. Two company vessels also carried out surveys with Mobil's **T W Nelson** acquiring 1928 kilometres while Esso's **Olga Bravo** collected 4933 kilometres.

The level of seismic activity in offshore eastern Canada can be expected to continue its increase in light of the success of the Hibernia delineation program. However, as is the case in the other offshore regions of Canada, export regulations coupled with the federal-provincial conflict have inhibited a full realization, in a timely fashion, of the offshore potential of eastern Canada.

## THE ROLE OF MARINE GEOSCIENCE IN PETROLEUM EXPLORATION AND DEVELOPMENT, 1980-2000

– R. Meneley and F. Rayer

Expansion of exploration frontiers into Canada's offshore basins led to the development of modern marine geoscience during the 1960s and 70s. The major oil discovery at Hibernia together with other significant hydrocarbon recoveries in exploratory wells drilled offshore of Labrador, in Scotian Shelf, Beaufort Sea, and offshore Arctic Islands during the past five years have set the stage for an unparalleled acceleration of offshore activity during the 1980s and 90s. We can safely assume an accompanying significant increase in petroleum-related marine geoscience to support offshore exploration and production during the next two decades. Numerous comparisons have been made between the projected level of offshore Canadian drilling activity and that of the North Sea during the years following the first major Viking-Graben oil discovery. Despite the lower drilling requirements on offshore Canadian permits, continued success in Canada's offshore basins, particularly the east coast basins, will lead to rapid increases in both capital and personnel requirements for increased multichannel marine seismic and offshore drilling activity. The most dramatic increase will be in the east coast offshore (Fig. 5.10), extending throughout the Scotian Basin, east Newfoundland basins, and the Labrador Shelf to Davis Strait. Continued offshore activity is anticipated for the Beaufort Sea and the Sverdrup Basin, while significant offshore activity is projected to commence in northern Baffin Bay-Lancaster Sound and to be resumed in basins off Canada's west coast, later in the decade.

During the next twenty years, emphasis will be on traditional marine geoscience as well as on the development of new marine geotechnology. Future developments will involve interdisciplinary teams consisting of experienced geologists, geophysicists, oceanographers, geochemists, and

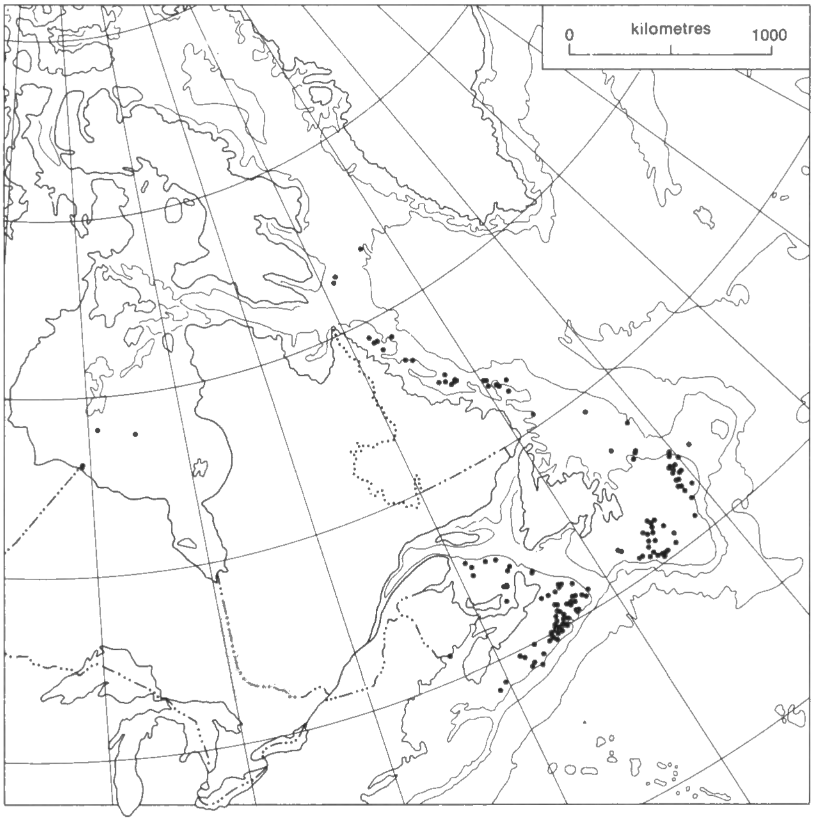



*Figure 5.10.* *Wells offshore eastern Canada and in Hudson Bay, 1962-1981.*

geotechnical engineers to deal with increasingly diverse, yet interrelated problems associated with the cold marine environment to design efficient production and transportation systems, pipeline and terminal facilities and to support exploratory drilling activity in a variety of seabottom environments and increasing water depths. Expanded marine geoscience research and development will be required for environmental marine geology; coastal, shelf and slope, shallow to deep water geology and geotechnology; and in geophysical seabed to crustal studies. Considerable effort will be needed to learn the most effective methods for dealing with ice, including icebergs, pack-ice and associated pressure ridges as well as ice-land and ice-seabed interfaces.

Co-operative research in marine geoscience by industry, government institutions, and universities will be required in the next two decades to handle projects in both traditional and new petroleum exploration and production related geoscience fields. An increase in the number of trained professionals in marine geoscience will be required and will result from the increased focus on marine geoscience at Canadian universities. An increase in research and development from the traditional low level of Canadian earth science research, as well as an increase in Canadian professional content is anticipated in the 1980s and 90s.

During the next twenty years, specific new developments in marine geotechnology should occur in:

a. collection and synthesis of data from high resolution geophysical surveys,

b. in situ offshore measurement of sediment properties,

c. improved sampling and laboratory measurement and testing of sediments,

d. improved field instrumentation for sediment and water measurement on the seabed.

Coastal mapping will be expanded to develop an integrated multiparameter atlas covering Canada's coastal areas to improve our regional understanding of coastal processes so that effective oil spill counter-measures can be designed for both environmental conservation and restoration. More systematic mapping of environmental marine geology will be conducted jointly by industry and government organizations. Multidisciplinary marine geoscience involving physical oceanography, geochemistry, biology, ecology, biostratigraphy, sedimentology, and geophysics will be undertaken initially in localized areas, but ultimately, systematically tied regionally, to extend over the bulk of Canada's coastal areas. New technology will also be needed to monitor underwater and under ice, thaw-freezeback conditions and to record changes throughout various seasonal climatic regimes. New computer techniques must be developed to better handle and display large volumes of surficial, nearshore, and deeper water seabed data.

In the east coast offshore, a significant growth in petroleum-related marine geotechnology of the deeper water continental shelves will occur. Joint industry, government and university research will be conducted on ice scouring, primarily a Canadian problem. A better understanding of the frequency, age, and duration of ice scouring will be needed to effectively design offshore production systems and nearshore terminal and pipeline facilities. New studies in biostratigraphy and isotope analysis will be required to determine the age of ice scours and to unravel the multiple generation history of scouring during various Quaternary glaciation stages involving the continental shelf. Concurrent studies of sediment dynamics, including sediment transport, sedimentary fill in ice scours, and sediment stability, will also gain considerable attention. New technology to monitor and measure sediment dynamics in the offshore marine regime will also be required.

Evaluation of site-specific foundation response to slumping, slope movement or creep, wave loading, and permafrost to further understand shelf and slope stability will be undertaken. Improved technology for mapping the seabed, including refinements to the "deep-tow" system, and in high resolution subbottom profiling will be necessary to provide a better inventory of the geological conditions on the continental shelves. Improvements can also be anticipated in both piston and vibracore technology in order to sample the seabed and underlying lithologies. Trenching technology will also receive considerable attention in the next two decades. Monitoring of iceberg grounding and experimental work in berm design will be required in order to learn how to isolate or shield terminal and production facilities from moving ice in shallow water coastal regimes. Additional effort will be focused on sidescan sonar survey techniques and interpretation to provide mosaic coverage for seabed and ice scour mapping. Repeated surveys over selected profiles, transects and specific areas will allow geoscientists a better understanding of the changing morphology of the offshore environments within nearshore and deeper water shelves as well as on the deep water continental shelves, rises, and in deep ocean basins beyond the shelves.

The Canadian offshore regions will receive increasing emphasis on geophysical research related to deep crustal studies, and in high resolution seabed profiling. Deep investigations involving gravity, magnetics, refraction and long-line reflection surveys will provide a better understanding of the regional framework of the Canadian continental shelves and rises, and of the relationship of continental-oceanic crust boundaries to hydrocarbon occurrence in a global tectonic context. Co-operative work by Canadian and international research groups should be encouraged for joint investigation of the Atlantic and Pacific margins. Continued work on thermal modelling of subsiding continental margins may reveal new, direct criteria for predicting areas of optimum thermal maturation in specific offshore basins and basin types.

Marine geoscience in the Arctic offshore is on the threshold of new discoveries. The current international projects, Fram and Cesar, involving geological, geophysical, and oceanographic investigations of the Arctic and Polar ridges will provide fundamental new data on crustal processes. Results of these projects over the next twenty years will allow geoscientists to resolve the poorly understood plate tectonic regimes north of the Canadian mainland, beyond the Arctic Archipelago.

Marine geoscience activity will continue in the Beaufort Sea and the Arctic interisland regions. Coastal and seabed mapping will continue in the Beaufort; however, because of the different conditions, emphasis will be on understanding the effects of permafrost and its distribution on the continental shelf. Research will be directed to studies of the effect of permafrost on resolution of seismic data, consequently dramatic improvements in seismic data quality in permafrost areas can be expected. Additional geoscience studies on permafrost creep, and on sediment dynamics or soil foundation relationships in permafrost areas will be continued. The effects of shallow gas and gas hydrates on seabed stability will also receive considerable attention. Investigations of ice scouring, particularly involving the dynamics of pressure ridges will gain increasing attention in the next two decades. A better understanding of geopressured zones and the thermal-lithologic conditions of the near seafloor sediment layer in cold-shallow water regimes will result, and experimental work with differential permafrost to stabilize earth-filled structures to optimize seafloor production systems will receive considerable attention over the next two decades.

Marine geoscience related to Canada's offshore west coast will become increasingly important as petroleum exploration resumes with termination of the existing moratorium. Geological, geophysical and oceanographic studies for resource exploration and production will accelerate in the mid to late 1980s. Additional research can be anticipated related to the plate tectonic subduction-convection model for evaluation of toxic waste disposal areas.

During the next decade use of the **Glomar Explorer**, in the second generation Deep Sea Drilling Project, will provide an increasing amount of data worldwide which will significantly alter our understanding of plate tectonics, stratigraphy and geochemistry of the deeper water continental shelf, rise and deep ocean basin regimes. Paralleling these improvements in marine geoscience will be dramatic improvements in new drilling technology and rock engineering to allow resource exploitation in increasingly deep water environments.

In summary, considerably more effort will be directed in the next two decades to marine geoscience, on new technology to acquire, monitor and evaluate offshore data, and on multidisciplinary interpretations of marine earth science data. A significant increase in Canadian specialists as well as an increase in the co-operative joint project work of industry, government and universities is anticipated. The next two decades will represent a new era in marine geoscience; one that will produce results in many related fields which will dramatically alter existing geoscience concepts. The activity will expand in many areas ranging from recent, shallow water to nearshore, shelf and deep water processes of the continental shelves, to the deeper water slopes, rises, and deep ocean basins associated with the continental margins and beyond. While we can safely predict an increased effort in these multidisciplinary fields, the magnitude of the effort in any one of them will depend on the degree to which the results impact on Canadian offshore resources development.

## MINING AND DREDGING – D. Pasho

### *Western Canada*

At the present time, mining and dredging in marine areas offshore in British Columbia are being carried out on a continuing basis by only one company, Rivtow Straits Ltd. This sand and gravel dredging operation is based in Prince Rupert where land-based sources are too distant to be economic. All of the actively worked lease areas lie within 15 km of Prince Rupert in inshore waters, generally adjacent to shoals, at depths of less than 10 m. At present approximately 225 000 tonnes of fill and road base material for use in the Prince Rupert area are dredged annually. Better quality sand needed for construction in Prince Rupert is barged from the Vancouver pits of Rivtow Straits. Demand for sand and gravel in Prince Rupert is expected to increase in the future with the anticipated major expansion of port facilities.

### *Central Canada*

Three operations are currently licensed by Ontario Ministry of Natural Resources to dredge material from the Great Lakes. They recover a combined total of nearly 600 000 tonnes per year of sand fill and some sand size aggregate for the construction industry. Organic contaminants and limited natural sorting preclude the use of much of the material as aggregate. Protection of natural shorelines, beaches and fish-breeding grounds, the capital investment required for dredging equipment, and the relatively poor quality of available material are deterrents for expansion of the industry. There is little likelihood of recovery of metallic minerals from Hudson Bay, James Bay or the Great Lakes, with possibly one minor exception, viz. the mining of a high grade vein-type silver deposit via a shaft from Silver Islet, Lake Superior.

There is apparently minimal involvement by industry earth scientists in exploration for offshore resources in central Canada.

### *Eastern Canada*

At present it appears that no mining activity is being conducted on the continental shelf off eastern Canada either for minerals or aggregate. However, mining of optical quality silica sand from the Gulf of St. Lawrence is anticipated. During the 1960s prospecting for placer gold occurred off the south coast of Nova Scotia and it is possible that a mining operation may be undertaken in the future.

As the demand increased for construction materials through possible engineering projects such as Fundy Tidal Power, Hibernia oil field development, and hydrocarbon storage facilities, offshore deposits of sand and gravel may be utilized. The Geological Survey of Canada has been systematically mapping the surficial sediments on the continental shelves of eastern Canada and these maps will form the basis for aggregate exploration. High resolution seismic reflection studies and subsurface samples would be necessary to delineate in detail the size of the deposits.

### *Northern Canada*

With the exception of bottom materials recovered for the construction of artificial islands, no mining or dredging of offshore resources is carried out or anticipated in northern Canada. To date, seventeen man-made islands have been constructed in the Beaufort Sea to provide offshore drill sites for oil and gas exploration. Possibly six additional islands will be built in the next three years. Where freezing to bottom is encountered, nearshore islands are constructed by transporting land-acquired fill over the ice. In deeper water, fill is dredged; a prototype "production-scale" island near the edge of shore-fast ice in 20 m of water will require 2 500 000 $m^3$ of fill and aggregate. It will encompass a berm area of 25 hectares and will require a "borrow pit" of 60 hectares to supply the material. Aggregate obtained from the dredged material will be used for concrete capping of the structure.

Earth science personnel are involved with sea ice movement and ice scour, permafrost, environmental studies, soil mechanics, and design engineering of the structure. Specialists exist within the major oil companies but use is also made of consultants with expertise in these fields.

Acknowledgments: Information supplied by J. Masham, Ontario Ministery of Natural Resources (Central Canada), A.H. Jones, Department of Indian Affairs and Northern Development (Northern Canada).

## MINERALS – D. Pasho

Industry activities related to minerals other than petroleum in Canada's offshore have, in the past, been limited to sporadic investigations of heavy or precious metals and occasional inquiries concerning offshore sources of sand and gravel. This general lack of interest does not necessarily reflect a negative attitude towards the possibility of developing offshore minerals, but rather reflects the perceptions of higher costs and greater difficulty associated with offshore exploration and mining as compared with

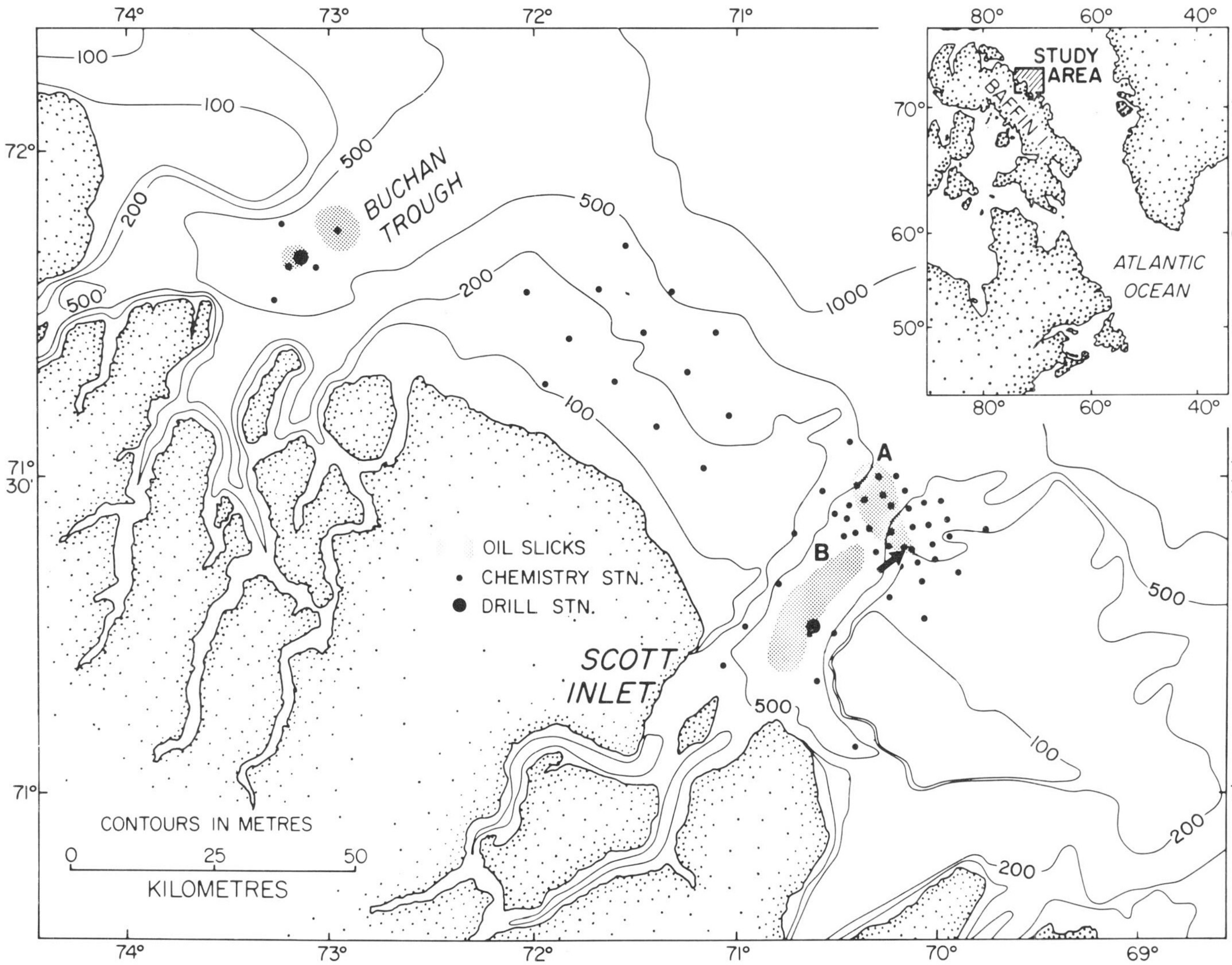



*Figure 5.11. Natural hydrocarbon seepage at Scott Inlet and Buchan Gulf, Baffin Island Shelf. The figure shows the area where surface slicks were observed in 1980, and sampling sites. The arrow indicates the locality in the Outer Scott Trough where oil droplets and bubbles were erupting at the sea surface. Petroliferous rocks were observed on the seafloor from the submersible **Pisces IV** in 1981 (from Levy, E.M. and Maclean, B., 1981, Geological Survey of Canada, Paper 81-1A, p. 401-403).*

relatively abundant onshore Canadian sources or low cost imports. In recent years, however, a number of changing circumstances are increasing the likelihood that offshore minerals in Canada will receive more attention in the future.

Firstly, in the case of such industrial minerals as sand and gravel, and silica sands, it is increasingly difficult to maintain low cost, dependable sources of supply in some Canadian locations. Depletion of local onshore deposits or high transportation costs of both have led some companies to evaluate seriously the possibility of developing offshore deposits. Over the longer term, such situations are likely to increase and should stimulate further interest in offshore sources.

Secondly, activities related to offshore mineral deposits being carried out by the Department of Energy, Mines and Resources are now co-ordinated through the Working Groups of the Department's Co-ordinating Committee on Ocean Mining. The Shelf Working Group, which draws upon a broad pool of expertise and information in Canada Oil and Gas Lands Administration, Geological Survey of Canada, Canada Centre for Mineral Technology (CANMET) and Mineral Policy Sector is, at present, compiling a Canadian offshore minerals resource inventory. The inventory will, in part, identify types of deposits and delineate offshore target areas within which mineral deposits may exist and are most likely exploitable within the foreseeable future. The Deep Ocean Working Group of the Committee is studying the potential of polymetallic sulphide occurrences on the Juan de Fuca ridge as well as assessing the possibility that recent discoveries of these deposits may prove valuable in the interpretation of some Canadian sulphide deposits. They are also continuing their study of the potential for deep seabed recovery of manganese nodules. This type of information will provide industry with an idea of what commodities might be available from the Canadian offshore and where exploitable deposits are most likely to occur.

Thirdly, work is underway within the Department of Energy, Mines and Resources to design and formulate a resource management regime specifically dealing with the development of offshore minerals other than petroleum within Canada's area of jurisdiction. There are, at present, no appropriate Canadian acts or regulations applicable to offshore mining.

Over the next five to ten years, these three factors should act to encourage the development of Canada's offshore minerals other than petroleum. Early operations will likely involve the recovery of industrial minerals (construction aggregates, refractory sand, etc.) from shallow water areas and will service local or regional markets accessible by water transport. If initial offshore mining ventures are competitive, additional interest would likely be generated in the development of offshore sources of other industrial minerals and, possibly, in the exploration for heavy minerals and placers.

As compared with most industrial minerals, resource potential in the offshore areas of Canada for heavy minerals and placers seems much more limited, and exploration is more complex and risky. Therefore, commercial offshore activities related to their development are likely to wait until data from government or academic institutions strongly indicate the likelihood of their occurrence in specific areas. It might be expected that over the next five or ten years, there will be little exploration for such deposits unless it is directed towards the very few offshore areas where present information suggests some likelihood of existence.

When considering the requirements for Canadian geoscientists specializing in offshore minerals, it must be borne in mind that the industry is likely to be modest in size and will develop slowly. In general, geologists with a background in areas such as marine geology or sediment dynamics, can, with some study and involvement, adequately meet most of the routine needs of government and industry. While specific offshore exploration or development programs may be facilitated by drawing on specialized expertise, few companies will be able to justify such inhouse capability. Thus, although there will be a need and a demand for experts specializing in offshore minerals, it will be limited. It seems likely that with the exception of a very few experts in industry and government, marine consulting firms will be the most likely place for such individuals.

## AIRBORNE GEOPHYSICS INDUSTRY – N.R. Paterson

### *Introduction*

### Activity

Industry in general recognizes the contribution that airborne geophysics (principally the airborne magnetometer) can make to offshore exploration in the start-up phase of the program. For this reason airborne magnetometer surveys were conducted over large areas of Canada's continental shelf and adjacent areas in the late 1960s and early 1970s. By 1975 most of the marine areas surrounding Canada, both territorial and international, had been covered by industry or government. A large proportion of the industry work was done on a nonexclusive basis, thereby allowing a number of interested companies to benefit from the information at a very modest cost. Interpretations of much of the work have been carried out on an exclusive or nonexclusive basis by several consulting organizations. In many cases the airborne data have been integrated with available marine gravity and magnetic data obtained by the Federal Government. Index maps of available aeromagnetic coverage and interpretive reports are available from the following contractors and consultants:

1. Terra Surveys Limited/Geoterrex Limited, Ottawa
2. Questor Surveys Limited, Toronto
3. Aqua-Terra Consultants Limited, Calgary

Because aeromagnetic data are perceived by industry to provide mainly regional scale geological information, the method has been applied only sparingly in the later phases of offshore exploration programs. Contractors report very little activity in the period 1977-1980, such work being limited to private surveys on the west coast and on small acreages in the Arctic.

There has been no reported activity in airborne gravity surveying in offshore Canada, though industry is said to have conducted some trials of a helicopter gravity system during the 1970s. The work would be similar to that conducted in 1977 off the coast of Virginia and, earlier, on the north slope of Alaska.

In addition to the above petroleum-directed activities, small coastal areas have been surveyed with the objective of prospecting for metallic or non-metallic minerals or both. These programs are normally extensions of similar work carried out on the adjacent land. Methods used are, similarly, an extension of the onshore techniques and include magnetometer, audio-frequency or transient electromagnetometer, and VLF electromagnetometer. The last two techniques are rendered virtually ineffective by the salt water environment, including the tidal area. The magnetometer has produced useful information in coastal areas of British Columbia, Newfoundland, Baffin Island, Nova Scotia, Hudson Bay, the Great Lakes, and many other parts of Canada. Such surveys are usually confined to a coastal strip not more than 1-2 km wide. As such, they hardly qualify under the present definition of "marine geosciences".

## The Industry

The Canadian airborne geophysical industry is dominated by three principal contractors, located in Ottawa and Toronto. In addition, there are three or four smaller contractors willing and able to conduct marine surveys and also located in eastern Canada. In all, some 15-20 licensed survey aircraft are available in Canada for airborne geophysical surveys. Of these, roughly 75 per cent represent the capability of the three major organizations. In addition, several American contractors continue to carry out surveys in Canada, mainly for U.S.-based petroleum clients.

Offshore aeromagnetic surveying accounts for only a small fraction of the annual domestic aeromagnetic business. It is estimated that of at least 500 000 line km of magnetics and combined electromagnetics/magnetics flown annually in Canada, less than 10 per cent takes place over water. In terms of magnetics only, the offshore fraction could be as high as 15-20 per cent and is probably increasing.

Canadian airborne geophysical contractors have traditionally played an important role in the international scene, probably accounting for at least one-third of the international market. The Canadian federal-provincial aeromagnetic program has been instrumental in sustaining a strong airborne geophysical capability in Canada. Canadian International Development Agency (CIDA) programs have provided valuable international (including offshore) experience. The international petroleum corporations, however, with roots mainly in the United States and Europe, and the Canadian subsidiaries of these organizations, have been slow to develop ties with Canadian industry. An exception is the working relationship between the French petroleum companies and Geoterrex Limited of Ottawa, which is itself French controlled. The major Calgary-based American subsidiaries have a tradition of drawing on parent company expertise in the planning, supervision and interpretation of aeromagnetic surveys, with the result that a significant proportion of their work is farmed out to American contractors and consultants and is managed by American specialists. Currently a trend appears to be developing towards the establishment of a nucleus of magnetics/gravity specialists in the Calgary offices of the major petroleum companies. It is hoped that this trend will continue.

## The Future

The perception of airborne geophysics as solely a reconnaissance tool in petroleum exploration is challenged by many geophysicists. Recent advances in both instrumentation and interpretation techniques have opened up new applications for high sensitivity aeromagnetics and aeromagnetic gradiometry. Improved methods of flight path recovery and altitude control have contributed significantly to the usefulness of magnetic data. Despite the lack of airborne geophysical activity in offshore Canada in recent years, it is not unlikely that, political-economic factors permitting, there will be a renewed emphasis on aeromagnetic surveys in the 1980s. These will probably take the form of relatively detailed (e.g. one-half to one kilometre line spacing) surveys with high sensitivity magnetometer, possibly with gradiometer. Airborne gravity surveys are likely to be of a similarly detailed nature.

### *Technical Developments and Limitations*

Since about 1970 most aeromagnetic surveying done by industry in Canada has been based on the relatively high sensitivity family of optical pumping magnetometers. These instruments are capable of a resolution of 1/100th gamma or better, as compared with the 1/10th to 1 gamma resolution common with proton precession magnetometers. Limited use has also been made in Canada of a relatively high sensitivity version of the fluxgate magnetometer (resolution of the order of 1/20th gamma). Vertical aeromagnetic gradiometers have been employed sparingly in offshore Canada but one fairly extensive survey was conducted in the Beaufort Sea at the beginning of the decade. The system employed two optical pumping magnetometers separated vertically by about 50 metres.

There have been relatively few significant developments in magnetometer instrumentation in the past few years, but there has been a major improvement in the areas of digital data acquisition, quality control, real-time and post-flight verification and editing, and subsequent processing. These procedures, including the continuous recording of fourth differences of the magnetic values, have led to a significantly improved end product. The availability of reliable digital data, recorded at an appropriately short sample time, has allowed the geophysicist to extract meaningful information from data of quite low magnetic relief. For example, the signatures of some weakly magnetic sedimentary beds may have an activity of barely 1 gamma. The sensing and resolution of such signatures can aid importantly in the mapping of stratigraphy and interpreting structure.

Although the value of high sensitivity data is seldom apparent on the total intensity contour map, it is readily seen in computer processed maps such as residuals, downward continuations and derivatives. Such processes have benefited from the availability of accurate and reliable digital data, but they have also undergone significant advances through the advent of new computer technology. One very important area is quantitative analysis. Major advances have been made in this area in the past ten years. Several semiautomatic procedures have been developed for the calculation of depth and geometry, based on the fitting of simple models to the magnetic profiles. Other procedures operate on the fourier components of the anomalies in two dimensions. A recent development is the adaptation of the Marquardt (viz. W.W. Johnson, Geophysics, 1969) algorithm to semiautomatic computer modelling. By this process simple magnetic models are optimally fitted to selected anomalies on the digital magnetic profiles. The geophysicist is required only to input the fiducial numbers at the start and end of the anomaly and the azimuth of the anomaly's longer axis. The computer varies up to seven parameters of the body in order to obtain the best least-squares fit, and lists the final values along with the observed and fitted magnetic profile values and the standard deviation of the fit. After the geophysicist is satisfied with the fitting process the bodies are drawn by machine plotter, together with their essential geometric and magnetic parameters, on the flight path or magnetic contour map.

Another equally important area of development, applying primarily to marine surveys, is navigation and path recovery. Traditionally aeromagnetic surveys over the sea have relied on shore-based radio antennae or transponders for position control. During the 1970s there has been an increasing use of INS (Inertial Navigation Systems) such as the Litton LTDN-51. Contractors have also experimented with passive VLF systems, recording up to 5 channels simultaneously. Since the INS requires periodic updating and because VLF lacks the accuracy required for most aeromagnetic surveys, ancillary radio or radar systems are simultaneously employed. Where Decca is available, this is the preferred ancillary system; Loran C, Argo DM-54, Motorola Mini-Ranger and other radio and radar positioning aids have also been employed successfully. Doppler is commonly used as a further aid in navigation and as a supplementary technique in the path recovery process.

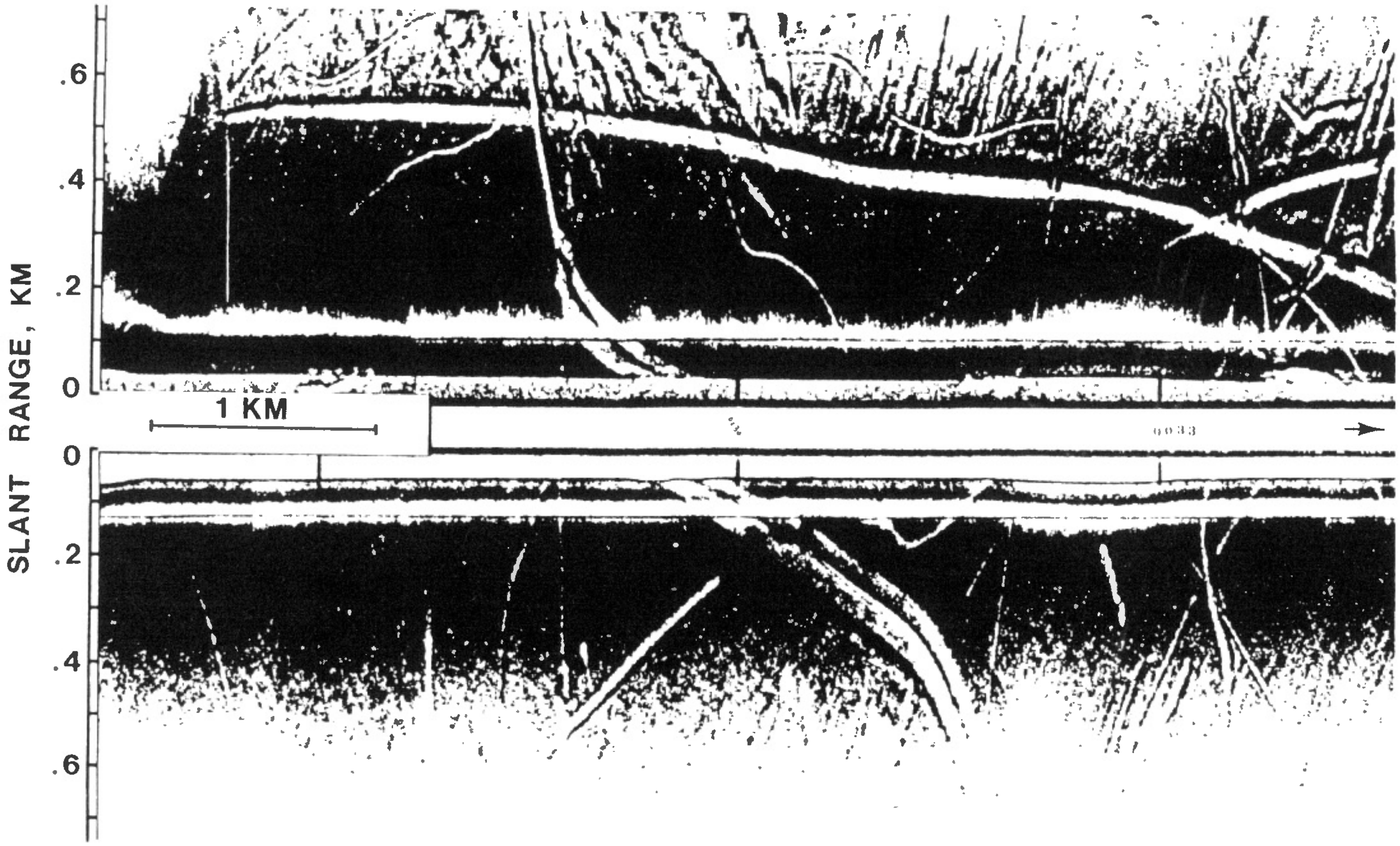



*Figure 5.12.* *Iceberg furrows seen on a sidescan record in 190 m water off Labrador. Random, well defined straight to curvilinear scouring on uniform fine grained sediments. The double-track scour visible crossing the central part of the area is approaching 200 m in width. A channel-like, natural depression crosses the ship's track in the lower part of the area. Note the narrowing of the longest scour as it crosses the deeper water in the channel in the right lower part of the area (source: C.F.M. Lewis).*

Advances in INS and VLF in the 1970s have significantly affected aeromagnetic survey effectiveness in the far offshore areas. Attention is being given currently to SATNAV (satellite navigation), both as a means of calibrating INS and as a navigation system of its own.

Precise navigation control is essential in high sensitivity aeromagnetic surveying because of the effect of aircraft movements in the earth's magnetic field. To make use of magnetic data recorded at an accuracy of better than 1/20th gamma, aircraft position must be known at all times within limits of about 10-20 metres. Such an accuracy is usually achievable in the vertical sense by the use of simultaneous radar and barometric digitally recording altimeters. These procedures are now standard in offshore surveying. Lateral control within these tight limits has rarely been achieved but seems to be within reach of the newer INS instruments.

Technical developments in airborne gravity surveying have not yet found application in Canada where fairly widespread marine gravity networks are already available. The airborne magnetometer is not only more accurate but is vastly less expensive than its marine counterpart. The same cannot be said for gravity, and this situation is unlikely to change in the near future.

### *Operations*

#### Central Canada

No commercial airborne geophysical surveys have been reported in central Canada in the past four years. In the mid-1970s medium-sensitivity aeromagnetic profiles were flown in east-west strips from the east shore of Hudson Bay from Akimiski Island in the south to Cape Smith in the north. These profiles extended the existing aeromagnetic coverage of Hudson Bay obtained privately in the late 1960s. Similar profile surveys were flown in the area of Southampton, Coates and Mansel islands in the early 1970s. Network surveys were conducted in Hudson Strait, Richmond Gulf and the Cape Tatnam areas in the period 1966-1972. All of these surveys employed medium-sensitivity fluxgate or proton magnetometers.

A variety of navigation systems were employed, including the Federal Government Decca network, when available, VLF and doppler. Principal flying bases were Churchill, Coral Harbour, Great Whale River and Moosonee.

The results of all of these surveys have been interpreted by several specialist groups and integrated with the available Federal Government marine magnetics network.

Little, if any, aeromagnetic activity is reported over the Great Lakes, with the exception of mineral surveys along the fringes of Lake Superior and Lake Huron's Georgian Bay.

Combined airborne electromagnetic (INPUT) and magnetometer surveys have been flown over parts of other major lake systems, including Reindeer Lake, Wollaston Lake, Lake Athabasca, Great Slave Lake and Great Bear Lake. In 1979 some 8000-12 000 line km of combined INPUT magnetometer surveying was done over Lake Athabasca to search for structures favourable for uranium accumulation. These surveys were controlled for the most part by Motorola Mini-Ranger.

**Western Canada**

Little commercial activity has been reported in western Canada, other than an aeromagnetic survey of approximately 50 000 line km off the British Columbia coast in 1980. It is understood that this was a high sensitivity survey employing INS, doppler and Decca for navigation and path recovery.

Prior aeromagnetic work in the area included a petroleum survey with fluxgate magnetometer in 1973 and a number of extensions to land surveys flown over Vancouver Island and the Queen Charlotte Islands. The latter surveys were probably carried out in the search for minerals rather than petroleum.

**Atlantic Canada**

No airborne geophysical surveys have been reported in Atlantic Canada since 1975. Prior to that date extensive high sensitivity aeromagnetic surveying was conducted in the Labrador Sea and Davis Strait. With the exception of some relatively small blocks, the Labrador Sea survey, totalling about 18 500 line km, was flown on a relatively loose grid of profiles spaced 16 km by 32 km apart. In Davis Strait roughly 35 000 line km were surveyed at profile spacings of 5 km by 12 km or less. All of the surveys have been interpreted and are believed to be available publicly from the survey sponsors.

These surveys were conducted using a variety of aircraft and navigation systems. Principal flying bases were Churchill, Fort Chimo and Frobisher Bay. The magnetometer employed was of the caesium vapour, optical pumping type.

The only other reported surveying for petroleum in Atlantic Canada is a fluxgate survey in the Grand Banks area of Newfoundland in 1973. This survey employed a combination of VLF (3-channels) and doppler for navigation and path recovery.

Mineral surveys have been flown in numerous coastal areas around Newfoundland, Nova Scotia, etc., including surveys in St. George's Bay and Notre Dame Bay. In 1979 high sensitivity aeromagnetic surveys were flown for the Nova Scotia Government over the northern half of Cape Breton Island using precise vertical and horizontal control. These surveys covered a strip approximately 4 km wide over the surrounding coast.

**Northern Canada**

The only airborne geophysics reported in northern Canada in recent years consists of two small, high sensitivity aeromagnetic surveys flown for petroleum companies in the Labrador Sea and Davis Strait in 1980. These surveys employed stringer-mounted helium vapour magnetometers on a DC-3 aircraft, operating out of Frobisher Bay. Position control was by a combination of radio positioning (Argo DM-54) and doppler.

Prior to 1975 a large part of the Arctic Islands and adjacent waters were covered by systematic regional aeromagnetic surveys. These commenced in the Mackenzie Delta and Beaufort Sea areas in the late 1960s and extended northward to Banks Island and the Sverdrup Basin in the early 1970s. The northwest passage (Parry Channel), Jones Sound, and Axel Heiberg and western Ellesmere islands were also covered in the early 1970s.

More than 150 000 line km of compiled aeromagnetic maps are available in these areas from the survey sponsors. The work was mainly medium sensitivity, using a variety of magnetometers, aircraft and navigation systems. The Federal Government Decca Lambda system was used extensively. Line spacing varied from 1.6 km to more than 24 km, the closer interval applying generally to the island areas where visual path recovery was possible.

A program of high sensitivity airborne magnetometer and vertical gradiometer surveying was conducted in the late 1960s in the Beaufort Sea consisting of profiles extending northwards from the mainland. The system used double caesium vapour magnetometers in a towed bird gradiometer configuration. Access to these results and their interpretation is possible through the survey sponsors.

The widespread aeromagnetic coverage in the Arctic Islands (the above industry surveys are generally contiguous with or overlap Federal Government aeromagnetic coverage) has allowed various organizations to carry out regional interpretations. However, vastly more information could be derived, of direct exploration importance, from more closely spaced, high sensitivity digital magnetic coverage. A second phase of medium scale aeromagnetic surveying appears to be underway with this in mind. There are few areas in the world where the airborne magnetometer enjoys as many advantages. The extremely high cost and technical limitations of seismic surveying in the Arctic are strong incentives in favour of continued aeromagnetic surveying.

## COLD REGIONS CONTRACTING AND CONSULTING – J.I. Clark

An insight into the activities of the contracting and consulting component of industry is provided by the Inventory of Canadian Research and Development Capabilities for Engineering in Cold Regions, prepared by Acres Consulting Services Limited for the National Research Council of Canada, 1978.

The inventory contains 313 listings. Of these, 230 are industries and the remainder are in government or universities. This assessment relates only to the industry component and includes contractors, consultants and producers. The criteria for inclusion in the directory were:

- a demonstrated research and development capability specific or complementary to engineering work in cold regions
- an existing business address in Canada

Cold regions are defined as those areas north of the southern limit of discontinuous permafrost, including the Arctic Islands and the water between, and the ice affected water off the east coast of Canada. Thus the inventory reflects activities in most of Canada's marine environment.

The inventory is classified by subject, organization and geographic listings. There are 12 subject areas identified, one of which is ocean engineering. Of the six subclassifications, within the subject area of ocean engineering, four can be identified as having a major component directed towards marine geosciences. Although the inventory would not adequately reflect marine geoscience activities for the west coast, it is a good indication of the number of performers, the level of effort and the source of funding (i.e. by contract or in-house). Specific information related to ocean engineering is presented for the year 1977. General trends are indicated by a summary of total level of effort for the five years, 1973 to 1977 inclusive.

### *Atlantic Canada*

Within the Atlantic Region nine performers in ocean engineering were indicated for the industry sector, six in Nova Scotia and three in Newfoundland. Only four of these organizations were involved with work related to marine geoscience. The level of effort is summarized below:

| Province | Total Cold Regions* R & D Person Years | Total Ocean Eng. R & D Person Years | Related to Geoscience Person Years | Per cent of Total R & D | Per cent of Oceans Eng. R & D |
|---|---|---|---|---|---|
| Newfoundland | 6.1 | 0 | 0 | - | - |
| Nova Scotia | 17.3 | 7.1 (41%) | 2.0 | 11.5 | 28 |
| Total | 23.4 | 7.1 (30%) | 2.0 | 8.5 | 28 |

*Includes only those performers indicating ocean engineering as part of cold regions R and D capability.

The inventory attempted to include all performers in cold regions research and development. Although NORDCO and C-CORE have very active programs, they are included in the government and university sectors and are therefore not reflected in the above data.

### *Central Canada*

A total of twenty-nine industrial organizations indicate an ocean engineering capability in central Canada. Nine of these are located in Quebec and twenty in Ontario. Five of the Quebec organizations and seven in Ontario included work involving marine geosciences. The level of effort is summarized below:

| Province | Total Cold Regions* R & D Person Years | Total Ocean Eng. R & D Person Years | Related to Geoscience Person Years | Per cent of Total R & D | Per cent of Oceans Eng. R & D |
|---|---|---|---|---|---|
| Quebec | 103 | 5.5 (5.3%) | 5.0 | 4.8 | 95 |
| Ontario | 298 | 30 (10%) | 20 | 6.7 | 66 |
| Total | 401 | 35.5 (8.8%) | 25 | 6.2 | 70 |

### *Western Canada*

One organization in Manitoba and one in Saskatchewan indicated research and development capability for ocean engineering but neither was involved with marine geoscience. The predominant activity is in Alberta and British Columbia but the British Columbia involvement is probably understated because of the cold region orientation of the inventory. Most of the activity is indicated to be in Alberta with twenty-six organizations indicating research and development capability in ocean engineering of which sixteen are involved in marine geoscience. Sixteen organizations indicate research and development capability in ocean engineering in British Columbia but only five of these are involved in activities related to marine geoscience. A summary follows:

| Province | Total Cold Regions* R & D Person Years | Total Ocean Eng. R & D Person Years | Related to Geoscience Person Years | Per cent of Total R & D | Per cent of Oceans Eng. R & D |
|---|---|---|---|---|---|
| Alberta | 284 | 47.5 (16.7%) | 38.2 | 13.4 | 81 |
| British Columbia | 65 | 5.8 (8.9%) | 1.5 | 2.3 | 26 |
| Total | 349 | 53.3 (15.2%) | 39.7 | 11.4 | 74 |

In summary, of the 230 industries in Canada surveyed, 84 indicated a research and development capability in ocean engineering and of these, 37 organizations were involved with activities directly related to marine geosciences. These activities required 67 person years of effort and over 90 per cent was funded by contracts. The level of effort directed to marine geoscience activities represents about 8.5 per cent of the total research and development effort of the 84 organizations with ocean engineering capability.

No data are available for 1978 to 1980 but there is no doubt that marine geoscience activity has increased. There is also no information on the marine geoscience activities of foreign organizations contracted for work in Canada. It is well known that foreign companies have been contracted to undertake seabottom investigations in the Beaufort Sea and off the east coast of Canada. These activities are sometimes carried out in concert with a Canadian organization with the intent of enhancing technology transfer to the Canadian organization. In the case of the Beaufort Sea, however, there is also a reverse technology transfer related to the substantial Canadian capability in permafrost technology. Thus, while an operator experienced in the Gulf of Mexico environment may provide some technology transfer in over water operations in the Arctic, he will enhance his own capability in cold regions activities and permafrost technology and reduce or eliminate the advantage that Canadian organizations might have had for exporting cold regions ocean engineering and geoscience technology to other countries.

The total technical manpower represented by the 230 organizations included in the survey is not indicated but is very likely in excess of 20 000. If the assumption is made that research and development capability is a reflection of the capability to investigate, analyze and design, the Canadian industry capability will be severely strained in meeting the challenge of the next two decades. The level of effort directed by industry towards marine geosciences research and development including geotechnical engineers, probably represents less than one-third of one per cent of the technical manpower of the organizations included in the inventory.

## CONTRACTING AND CONSULTING – WEST COAST – R. MacDonald

Projects in the offshore waters of western Canada requiring the services of people trained and experienced in the marine geosciences have not been numerous over the past several years. Almost all projects with funds available to contractors and consultants have been initiated by government and its agencies by direct action or regulation.

Western Canada produces and exports considerable quantities of wood products and ore concentrates. A majority of pulp mills are located on tidewater and dispose wastes into the sea. Several mines are also located on tidewater and have been allowed to dump tailings and waste rock into seawater. In both cases, government regulation has required these wastes to be piped to depths offshore before release, thereby either increasing dilution of fluids in the case of pulp mills or depositing solids into a more chemically stable environment than the subaerial in the case of mines. These pipeline projects have been a significant source of work even though somewhat sporadic. There is no increase foreseen in projects funded by local industry.

Two major projects, neither of which are complete, have been undertaken by B.C. Hydro, a provincial crown corporation. The power transmission group has let a contract to a consortium of STK (ITT-Norway) and Pirelli Cables (Italy) to lay two 500 kV circuits from the mainland to Vancouver Island. Exploratory route surveys have been carried out over the past six years. The final route engineering survey was recently completed in preparation for the civil work, which is to start in the summer of 1981. The cables will be laid in the fall of 1982 and the spring of 1983. The marine geology and geophysics was done by Thalassic Data Ltd.

The second large project being undertaken by B.C. Hydro involves the natural gas distribution group. Again, the object is to supply energy to Vancouver Island. Hydro's proposal is to lay a pipeline (or pipelines) across the southern Strait of Georgia, leaving the mainland from the Fraser Delta. The majority of the effort has been focussed on finding a route through the Gulf Islands. Possible problems with stability of the Fraser Delta foreset have yet to be addressed. Work to date has been carried out by several contractors including Montreal Engineering, Williams Bros., McElhanney Surveying and Engineering, Dobrocky Seatech and Atmex Geophysics. Recently, consulting services in marine geophysics have been supplied by Thalassic Data Ltd.

Two other large companies, Westcoast Transmission and Centennial Pipeline, were also contenders for the job, but a decision made just recently awarded the job to B.C. Hydro. Westcoast had done some fieldwork to outline the area of their proposed crossing from Powell River to a point on Vancouver Island just south of Comox. This work was done in 1980 by Can Dive Services Ltd. In so far as the marine portion of the pipeline is concerned, there may have been some advantages from a slope stability point of view to the more northerly crossing.

Another provincial crown corporation, the B.C. Ferry Corporation, has in the past awarded contracts to check proposed ferry routes for uncharted reefs and possible problems with sediment transport.

Government departments, through either lack of interest or activity, have not been significant sources of work in the marine geosciences on the west coast. Provincially, the Department of Highways has let a few contracts in the past. At the federal level, several large contracts have been let to study the impact of proposed encroachments on Fraser Delta wetlands in order to expand airport and shipping facilities. Little of this work has been of a geological or geophysical nature. Resource-based departments within the federal structure have let a few contracts of interest but the majority of work is done in-house. The one contract of note was an offshore gravity survey done by McElhanney Surveying and Engineering in 1975.

At the moment, there is enough work on the west coast to keep those who are presently involved in the marine geosciences active. However, when the B.C. Hydro projects are completed, there are no known projects of a similar magnitude being planned. A possibility for the future is renewed interest in offshore petroleum exploration and perhaps the requirement for marine geological and geophysical services in support of environmental monitoring and seafloor engineering. However, competition from companies already associated with the petroleum industry but not yet established on the west coast will be heavy. Federal Government contracts through resource based departments are unlikely to become significant to consultants in the marine geosciences unless there is a considerable change in attitudes and priorities.

There are numerous companies based in Vancouver with renowned expertise in land based geotechnical engineering. With increasing numbers of projects being situated on tidewater or offshore, their need for marine expertise is increasing. However, the higher costs of marine work and, in some cases, bad experiences in the past, are still keeping these companies wary. Technological developments have greatly enhanced the quality of geophysical data to the point where valuable information can be reliably obtained in most circumstances. Acceptance of the relatively junior companies specializing in marine geosciences by the established geotechnical community is happening and probably represents the best hope for the future.

The waters of the west coast of Canada offer a laboratory for marine research and development with little equal. Deltas of large rivers and deep waters protected by the steep sides of fiords, both being accessible and usable on a year round basis are two of the many features which could be used to advantage by industry. However, the marine geosciences from most points of view are in a decline on the west coast. A major study involving governments, industry and the universities may be a way of coming out of the doldrums. A nagging problem which presents itself in most offshore engineering projects is the stability of marine sediments. A study of this problem would involve all disciplines within the marine sciences and the results could be of major importance to several ongoing or planned large scale projects.

**ENGINEERING AND DESIGN** – J.I. Clark

The marine geoscience disciplines have an important role in the development of viable engineering designs for marine environments. An understanding of the geological processes and a knowledge of the significant engineering properties (strength and deformation characteristics, permeability, consolidation) of the seabottom materials is essential to the design of marine structures and facilities.

Current projects in the planning stage, or in some cases already under development, include bottom founded exploration and production platforms, subbottom pipelines, tunnels, storage caverns and artificial islands. These installations may be required in several of the marine areas of Canada where geological conditions are complex and where properties of the material, with respect to design, are largely unknown. Permafrost and the presence of gas hydrates in the Beaufort Sea add to the complexity of that environment. The location and properties of seabottom granular materials that can be used for construction purposes is not available except for very localized areas.

One of the major stumbling blocks to obtaining detailed subbottom material properties is the exceptionally high cost of exploratory programs. This has necessitated very limited exploratory programs when compared with the intensity of investigation for similar projects on land. At best this leads to costly overdesign to accommodate variations in soil profile and properties which may not have been detected by the field exploration work or at worst, designs which are not compatible with actual conditions. At the same time it provides a powerful incentive to be able to extract meaningful engineering properties from other geoscience activities such as geophysical surveys and to develop more efficient and informative geotechnical exploration tools.

A review of other sections of this document indicates that various government agencies have developed very good interdepartmental working relationships and have defined areas of responsibility necessary for co-ordinated marine geoscience activities in all of Canada's marine environments. It would appear from these reports that a substantial body of data and experience exists and that the structure to control and regulate industrial activities and to provide scientific baseline data in the marine environment is in place. What is missing is the geotechnical data base required to develop or assess specific designs. Industry has carried out site specific studies related to specific projects, such as artificial islands in the Beaufort Sea. There is, however, no model nor are data available to develop a model relating the existing geoscience data base to significant geotechnical design parameters.

If the level of research and development effort by Canadian industry is accepted as an indication of the capability to undertake and implement engineering design in Canadian marine environments, the technical manpower would appear to be insufficient to meet the demands of projects currently in the planning stage. The total level of research and development effort related to marine geosciences was estimated to be 67 person years in 1977, as reported for the industry sector in the report on the Inventory of Cold Regions research and development as referenced in the next section. Thus, the capability to regulate and control development in the Canadian marine environment and to be able to provide baseline scientific data, as reflected by the activities and interrelationships of various government departments, is substantially greater than our capability to develop a geotechnical data base to couple with the marine geoscience data base so that it can be applied to solving engineering design problems, it may not be possible to achieve the objectives for projects currently in the planning stage. This effort would involve: development of techniques to enhance existing marine geoscience data, such as the derivation of significant engineering properties from existing geophysical survey data; the development of geological/geotechnical models for different marine geological settings; improvement in sampling and in situ testing techniques to become more cost effective and an accelerated program of geotechnical investigations in the areas most promising for development. Implementation of the required program would require significant new funding by both government and industry*. This funding will be required to support the gathering of essential marine geoscience data but it must also expand the data base for geotechnical engineering and design. Many of the scientific programs carried out can be incrementally expanded to provide hard geotechnical data at comparatively little extra cost. Examples of the type of geotechnical data required and the application of these data to engineering design are included in the Proceedings of the First Canadian Conference on Marine Geotechnical Engineering held in Calgary in April, 1979, available through the Canadian Geotechnical Society.

In February 1981, the Subcommittee on Soil and Rock Engineering of the Associate Committee on Geotechnical Research of the National Research Countil presented a report to the Associate Committee which contained a report prepared by the Task Force on Marine Geotechnology in Canada. The Task Force established by the Subcommittee was chaired by Dr. P.G. Sly (Environment Canada). The report identifies important research and development needs in the field of marine geotechnology and discusses alternative research and development strategies that could be adopted to enhance the research and development effort in Canada. The report proposes that consideration be given to the formation of an independent corporation supported jointly by industry and government in which there would also be an important contribution from the university community. Such an undertaking would appear to fit with the research and development policy as stated by the Ministry of State for Science and Technology, and might well serve as the vehicle for the geotechnical research and development thrust required to support Canadian marine activities in the coming decades.

| | Sources of Funding | | Performers of Research | |
|---|---|---|---|---|
| | Present (1979) (%) | By 1985 (%) | Present (%) | By 1985 (%) |
| Industry | 35.8 | 50.0 | 44.2 | 63.0 |
| Federal Govt. | 38.9 | 33.3 | 25.5 | 15.6 |
| Provincial Govt. | 6.9 | 6.6 | 3.6 | 2.5 |
| Universities | 4.4 | 2.5 | 0.8 | 0.5 |
| Total | $ 2.5 billion | $ 7.6 billion | | |

No indication is given for target expenditures by application area for 1985. The current science and technology expenditures for research and development indicate that about 2.5 per cent is allocated to "Oceans".

**THE SEABED PROJECT** – R.W. Hutchins

**Editorial Note**

This project has been referred to by several contributors to this report. It is an outstanding example (and one of very few) of what can be done, and should be done, in the way of government – industry – university liaison. As a consequence, the editors felt that details of this project would be of considerable interest to readers of this report.

***The Project***

The Seabed Project is a multidisciplinary, mission directed, research and development program. It was begun in 1974, to develop a more cost effective methodology of making superior quality high-resolution maps of the first 200 metres of the seafloor, under the kinds of weather and sea conditions generally found over Canada's continental shelves and margins. The project is based on concepts put forward by Huntec ('70) Limited under an unsolicited proposal, and has been carried out by project teams of scientists and engineers from Huntec, from Memorial and other universities, from the Atlantic Oceanographic Laboratory, Defence Research Establishment Atlantic and the National Research Council, Division of Electrical Engineering.

Scientific direction for the project and the core research group, consists of user scientists led by L.H. King, of the Atlantic Geoscience Centre of EMR, and scientists and engineers from Huntec ('70) Limited based at BIO and at Toronto. A resident researcher from IKU (Institutt for Kontinentalsokkelundersokelser – continental shelf Institute), Norway, joined L.H. King's group at AGC for one year.

The project is particularly noteworthy due to its success in bringing together and obtaining the ongoing commitment of individuals with different institutional affiliations to contribute towards a common objective. During the program an estimated 70 000 kilometres of data on the Canadian shelf has been acquired under the Regional Geological Mapping Program conducted by AGC. Funding for the program has been provided by Departments of Energy,

* Author's addendum: In January 1981, the Ministry of State for Science and Technology reaffirmed the governments national target for research and development at 1.5 per cent of GNP and indicated a framework that will see major shifts in sources of funds and performers of research as well as a substantial increase in funding level. Both sources of funding and performers of research are to change as indicated in the following tables.

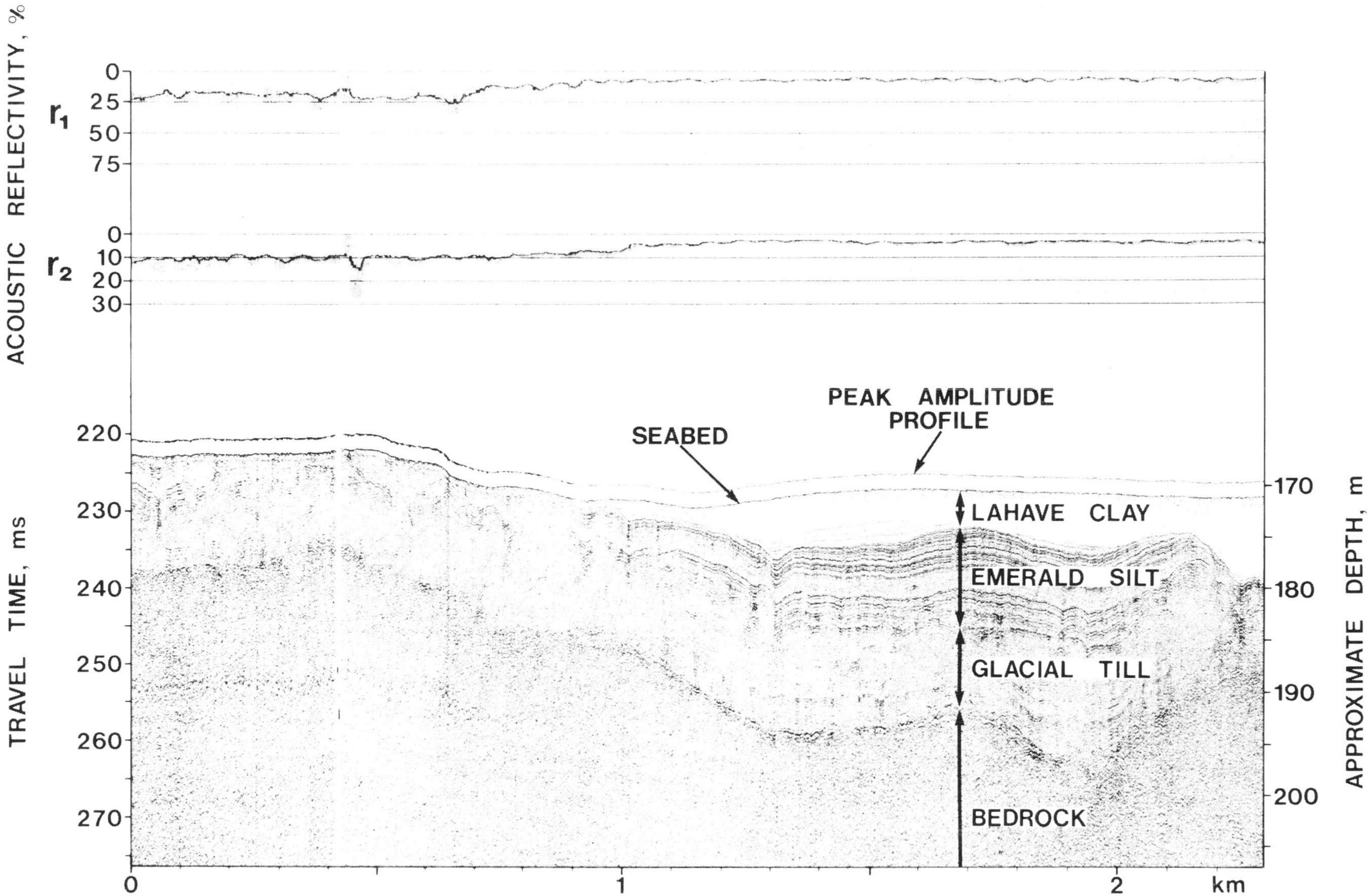



**Figure 5.13.** *Processed data from Huntec's Deep Tow Seismic System showing acoustic reflectives ($r_1$, $r_2$) peak amplitude profile, and enhanced seismic section, over outcrops of Emerald Silt to the left and La Have Clay to the right, with a contact at 0.9 km distance (from Parrott, D.R., Dodds, D.J., King, L.H. and Simpkin, P.G., 1980, Canadian Journal of Earth Sciences, v. 17, p. 722–737).*

Mines and Resources; Fisheries and Oceans; National Defence; Supply and Services through the Unsolicited Proposal Fund and from the National Research Council. The work at Memorial University was funded by subcontract through Huntec and by a Strategic Grant of the Natural Sciences and Engineering Research Council.

### *Quantitative Acoustic Remote Sensing of the Seafloor*

Digital signal processing applied to the inversion of multichannel seismic data to produce frequency depth spectra, velocity depth spectra, and other geological parameters is a well established and highly developed methodology for deep seismic exploration. More recently the method is used for intermediate penetration high resolution multichannel systems.

The research described below has applied digital signal processing at sampling rates up to 50 kilohertz, to inversion of very high resolution seismic data, to estimate the parameters of geoacoustic scattering models – known as reflectivity metrics.

Reflectively metrics produced in real time together with the graphic recordings are effective in identifying lithostratigraphic boundaries; for studying the hardness, variability, stability, depth and type of overburden on the seafloor and for mapping the acoustic properties of sediments at depth. Reflectivity metrics have also been used as the parameters in forward modelling to determine the propagation of sound in the ocean.

This note describes new developments and current research in quantitative acoustic remote sensing of the seafloor and subbottom units carried out under the Seabed Project. The methodology utilizes specially designed seismic reflection profiling equipment deployed in an underwater tow fish and digital signal processing methods developed under the project over the last five years. During this time it has been used in conjunction with other methods as a lithostratigraphic mapping tool in support of studies of the surficial geology of the eastern Canadian shelf[1 2 3]. The technology provides the seafloor engineer and marine geologist with relevant information not available from other underway methods. In addition, it has a large potential for further improvement through continued research. The method is based upon the inversion of single-channel seismic data to produce "reflectivity metrics" along the line of advance of the tow fish[4 5 6 7]. A reflectivity metric is the measure of a particular parameter of a geoacoustic model, for example a semi-infinite two layer model. Examples of reflectivity metrics are the water depth; the acoustic impedance through measurement of reflectivity; small scale bottom roughness through measurement of scattered energy; depth and reflectivity of the first subbottom layer and frequency dependent acoustic attenuation within the overburden material. Each reflectivity metric is calculated from the reflection time series; the source function which is a mathematical description of the spatial time distribution of the acoustic wavelet produced by the source; and the depth, attitude and vertical velocity of the tow fish obtained from a sensor package in the tow fish[8].

Each reflectivity metric is sensitive to a particular feature or characteristic of the seafloor, and thus, may be used directly for preparation of maps for specialized purposes. The statistical properties of the reflectivity metrics are in themselves a measure of the degree of variability, and have proved particularly useful in the design of more effective sampling programs, resulting in substantial savings in the overall cost and time required to complete the survey of an area. Reflectivity metrics, combined in a prescribed way, form a feature vector, which through the use of pattern recognition methods, is used to discriminate between the different lithological units identified through a sampling program[9].

Finally, reflectivity metrics obtained by inversion are being used as the parameters for forward modelling, to predict the propagation pattern of sound in the ocean for a variety of defence purposes[10 11].

At the present state of development, some reflectivity metrics are calculated on line and displayed alongside the graphic recordings of the seismic section[4]. Work is underway to develop improved software for online calculation and display of those reflectivity metrics which at present must be computed from tape recorded data as an offline operation, and to extend the technique to multichannel data to estimate sound speed depth spectra using wide angle reflection.

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