Bedford Institute of Oceanography

BIO REVIEW '85

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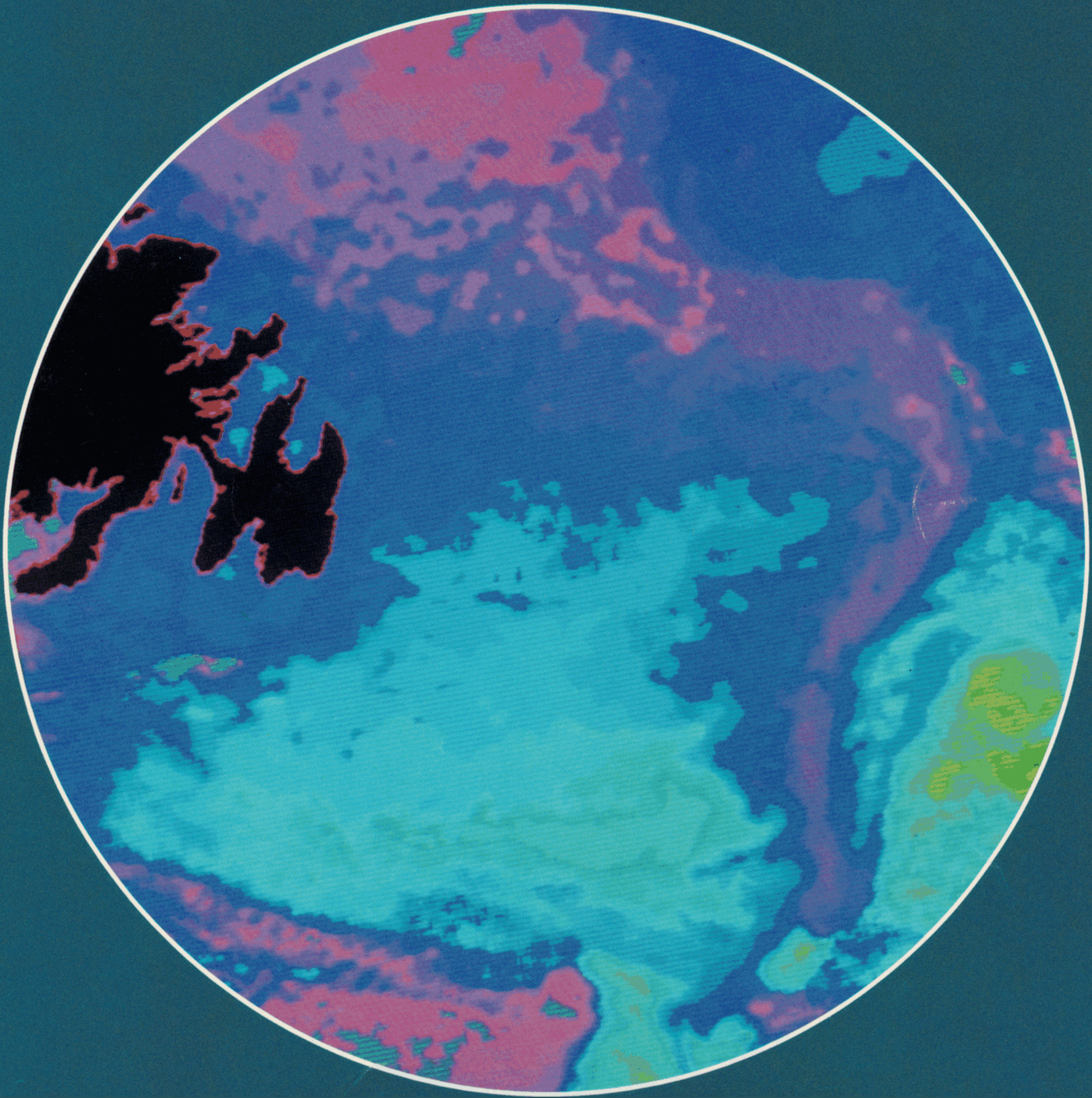

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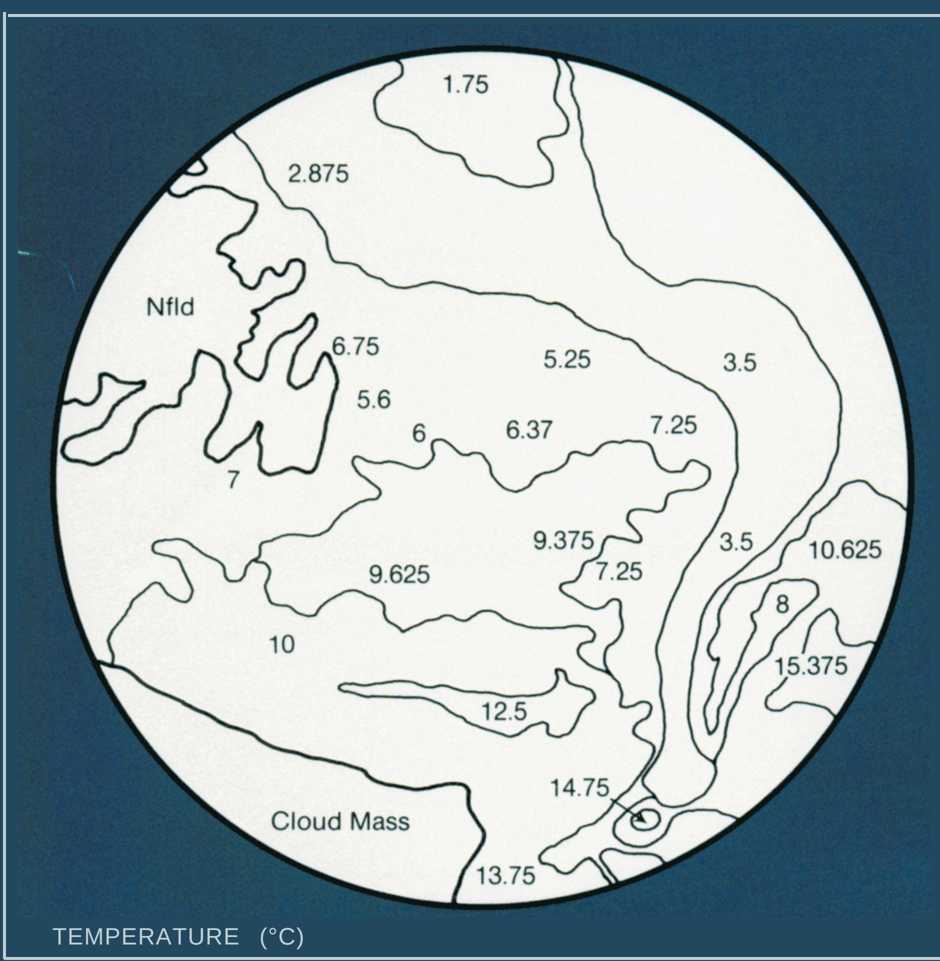

On the cover:

A satellite infrared image that depicts the sea-surface temperature (SST) over the Grand Banks of Newfoundland: it was taken on 31 October 1984 by a NOAA-7 satellite from an altitude of 833 km. The magnetic tape of infrared data was processed and enhanced for SST by Kevin Reid at the image processing facility located at BIO. The BIO facility was configured by Perceptron Computing Inc. of Toronto: the analysis software used to process and enhance the cover illustration was provided by the Rosenstiel School of Marine and Atmospheric Sciences.

The image nicely illustrate several features of the oceanography of the region. The Labrador Current is shown as the broad band of cold water (1.0 - 3.5°C) in the upper third of the image that narrows markedly between 49° and 48°N at the northern shoulder of the Grand Banks. It follows the outer edge of the Banks along a path parallel to the 200 m isobath. The shelf edge of the Labrador Current is highly variable with waters of about 3°C interspersed with waters of about 7°C. At 44°N, 49° W the variability on the temperature front is quite regular and wavelike. Near the Tail of the Banks, the Current is broken up by a blob of warmer water with central temperatures of about 15°C. Note that the reddish area in the southwest (bottom left) portion of the image is cloud cover and not a part of the Labrador Current.

The inshore branch of the Labrador Current can be seen as a cooler (5 - 7°C) region in Avalon Channel. Along 47°N and southwestward towards Whale Bank and Haddock Channel. the seaward boundary of the cooler water corresponds to the 100 m isobath.

The central portion of the Grand Banks feature warmer waters with SST increasing to a maximum of about l2.5°C at Southeast Shoal (near 44°20’S. 50°20’W). This warmer body of water situated on the Shoal is another well known phenomenon of the Grand Banks: it is currently being studied by DFO scientistsat the Norrhwest Atlantic Fisheries Centre in St. John’s, Newfoundland, and at BIO.

Regional oceanography: The Grand Banks of Newfoundland

For a thousand years or more, the Grand Banks have been a nursery of seamanship, a source of great wealth for some but of hard-wrung small returns for many, and a most dangerous region lying athwart the sea-lanes to North America from the older countries. The Grand Banks in the eighties of this century are a challenge for Canadian fisheries development, and the site of a great engineering adventure. Truly, the Grand Banks is a place we need to know more about: this issue of *BIO Review* records how federal oceanographers and hydrographers in eastern Canada are working to this end.

The earliest probings of the Norsemen from their settlements in southwest Greenland certainly covered the northern Grand Banks, on their way to their settlement in northern Newfoundland, and perhaps areas further south to Cape Cod and westward to the Great Lakes. These early explorers must have been very familiar with the special problems of ice, fog, offshore shoals, and the teeming seabirds, fish, and whales that attracted later voyagers. After Giovanni Cabotti's enthusiastic reports of his landing on Newfoundland in 1497, fishermen from England, France, northern Spain, and Portugal poured across the Atlantic for the dried cod and whale oil trades. This traffic led to several bitter little wars and to the 'French Shore' issue of northern Newfoundland in the 19th century; the matter was only finally resolved in 1977 with the Canadian declaration of our 200-mile fisheries management zone, which covers much of the Grand Banks.

As late as the 1960s, Portuguese schooners with fleets of tiny wooden dories had been taking cod with handlines on the Grand Banks, continuing a centuries-old technology. During all this period, one of the reasons why European and North American governments stood behind their fishermen on the Grand Banks was to support a nursery of seamanship to feed sailors to their navies in time of war: the ability of Newfoundlanders to handle small boats in great seas must have saved countless lives in distant oceans over the years. The legendary fog that so often shrouds the Grand Banks and the pack-ice and icebergs drifted down from the eastern Arctic brought the voyages of many ships, including the *Titanic*, to an abrupt and tragic end over the centuries, and progressively sharpened seamanship and the techniques of navigation. The terrible night of February 15, 1982, when a bitter winter storm took the lives of all 84 crew of the *Ocean Ranger* drilling rig and of 33 of the 37 seamen from the Soviet cargo vessel that attempted their rescue, will ironically further sharpen our skills.

You may ask, what has all this got to do with ocean science and the BIO? As we hope to show in this issue of our *Review*, the twin issues of Canadian responsibility for Grand Banks fisheries, and the possibility that production from the Grand Banks Hibernia field will finally end our dependence on oil imports to fuel eastern Canada, both require heavy scientific input, much of which has come from BIO over the last several years.

As for climate research, the subject of *BIO Review '84*, the reader will quickly discover that our work on the Grand Banks is not organized into a formal, single project with this title; rather, our individual research and survey divisions are responsible for many individual projects of which some are dedicated solely to a Grand Banks problem, while some will produce general results applicable everywhere off eastern Canada, including the Grand Banks. Because what happens on the Grand Banks is driven by oceanographic processes and events in the Atlantic Ocean and Labrador Sea far from the Banks themselves, we include relevant research of this kind in our review. It is not easy (or useful) to put an accurate estimate on the costs of all these projects, but they comprise approximately 20% of the DFO expenditure at BIO, totalling about $7.9 million. It should be noted that the component of fisheries management scientists housed at BIO does not have responsibilities for research off Newfoundland: this is done by scientists of DFO's Northwest Atlantic Fisheries Centre at St. John's, Newfoundland, with whom oceanographers at BIO collaborate in many projects. To recognize this, we have included in this

The historical photographs at left (circa 1911) depict "flying sets ", dories towed astern a schooner then dropped off one by one to fish. This centuries-old method was in use on the Grand Banks of Newfoundland until as late as the 1960s. The work was hard and dangerous, particularly as sudden summer fogs and storms often set down. In angry winds and waters, dories strayed from their parent vessels and, by one estimation, more fishermen were lost in this manner than in shipwreck. *(Courtesy of the Maritime Museum of the Atlantic, the F. W. Wallace Collection)*

edition a special guest article by Larry Coady and Scott Akenhead of St. John's

As the reader will discover in this *Review,* our research in support of fisheries management and oil exploration on the Grand Banks takes many forms and covers all oceanographic disciplines. Some projects are done directly at the request of the offshore industry who must have the best possible advice and data on conditions in the offshore: bathymetry of outports and large bays, wave climate, ice behaviour, currents and current surges, sediment bedload strength and the statistics of continental shelf earthquakes, the statistics and mechanics of iceberg scouring, and many other topics. Some projects are done because only thus can we, or various sectors of the industry, understand variability of fog, ice, and currents on the Grand Banks: the between-year variations in the Labrador Current and the interaction between the Gulf Stream and the topography of the Grand Banks, for example. Some projects are done because study of the unique features of the Grand Banks produces results of wide relevance: the structural history of the continental margin, and the great transform fault that forms the southern flank of the Grand Banks. Finally, some are done to back up the more direct investigations of fisheries biology and marine pollution done by the St. John's fisheries scientists: the influence of Hudson Strait outflow on fisheries production, the modelling of the effects of pollution on fish stocks, the processes controlling biological production on the Banks.

As well as discussing some of the ways in which BIO is addressing these problems, this issue of the *Review* contains our now-familiar guide to BIO organization, projects, voyages, and output of papers, reports, and charts. We hope it continues to be useful to you.

- *A.R. Longhurst*
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Contents

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chapter 1

Science and surveys on the Grand Banks: Government and industry

As a major centre for oceanographic research and hydrographic surveys in Canada, the Bedford Institute of Oceanography provides services, advice, and research expertise in support of a variety of national needs. In keeping with the federal government's economic thrust to promote and support technological development in Canada, a key strategy of Institute programs is to undertake work relevant to industry's needs. This paper explains how the Institute endeavours to meet the needs of three clients in one geographic region, the Grand Banks, and examines the associated institute-industry interfaces and interactions.

BIO has four objectives:

(1) To perform fundamental long-term research in all fields of the marine sciences, and to act as a major Canadian repository of expertise.

(2) To perform shorter term applied research in response to present national needs, and to advise on the management of our marine environment, including its fisheries and offshore hydrocarbon resources.

(3) To perform necessary surveys and cartographic work to ensure a supply of navigation charts of the required accuracy for the region from Georges Bank to the high Canadian Arctic.

(4) To respond with all relevant expertise and assistance to any major marine emergency within the same region.

Most interaction with industry occurs in the areas of applied research and hydrography. The level of effort in 1984/85 for applied research pertaining to the Grand Banks, including funds from all sources and overhead and support costs, is $6.4 million (or 16%); for hydrographic surveys and chart production, the corresponding figure is $4.8 million (or 30%). However, one should not lose sight of the importance of fundamental long-term research in meeting industry's needs. In science, basic research inevitably becomes the cornerstone of applied research, and what seems lacking in immediate application today may be of great importance a decade hence. This seems especially true in oceanography, and much of the knowledge now being applied to some of the most urgent problems of the marine environment stems from the basic research of years past. The provision of advice to industry today is possible because of the basic research that was undertaken five or ten years previously.

BIO programs provide support to various industries active on the Grand Banks, chief of these being the fishing industry, shipping, and the offshore oil industry. It should be noted at the outset, however, that few of the Institute's programs are focused on a single geographic region such as the Grand Banks; the majority have a much wider range of application. Thus, while some of the studies described here are specific to the Grand Banks, others are applicable to the Canadian east coast offshore generally including the Banks. Similarly, very few projects are directed at a single customer.

Institute programs have as one of their objectives support for the development of a stand-alone Canadian ocean industry, both manufacturing and contract R&D. Such an industry is of course not specific to any one geographic region, but this article will make reference to some of the firms involved with BIO on the Grand Banks.

Fishing industry

The support of the fisheries of Atlantic Canada, including the Grand Banks, has been a longstanding priority of Institute programs. There are four main thrusts:

- providing technical developments to assist in fish finding and stock assessment;
- providing a better understanding of the causes of variability in fish stocks;
- evaluating the consequences of industrial activity on the fisheries; and
- investigating how changes in the atmosphere/ocean climate machine affect fishing.

These involve varying degrees of interaction with the industry. Most of the Institute's research in support of the long-term renewal of fish stocks, for example, is an underpinning in oceanography and ecology for the work of the fisheries laboratories of the Department of Fisheries and Oceans, while the research pertaining to atmosphere/ocean climate is fundamental long-term research to address a major national issue. In both cases

Newfoundland fishing villages such as this one in the Ramea Islands off the rugged south coast rely exclusively on water transportation. In one example of efforts to improve the charts that fishermen use, radio-navigation grids that are corrected for distortion near coasts are now included.

the fishing industry is not the immediate customer.

Fishing profitability through technical inputs

The fishing industry itself is not as large a consumer of scientific products as the offshore oil industry; the technical problems of industrial fishing have largely been solved by the industry itself. Nevertheless, this situation is continually monitored so that we can match potential new ocean data services with what can actually be used by the industry.

Special navigation charts, tailored to meet the needs of fishermen in that they provide information about the seafloor, are now available for the Grand Banks and other regions as a result of a co-operative arrangement between BIO and a Newfoundland company, NORDCO. Prior to these charts, information on seafloor geology was provided on an ad hoc basis in answer to requests from individual fishermen. NORDCO submitted an Unsolicited Proposal[(1)], which was supported by the Institute. This was followed-up by other contracts and the transfer of Institute data. The company is now marketing the charts as a commercial venture.

Attention has been paid to the needs of small fishing vessels for access to radio navigation systems available more easily to larger ships. In particular, the way in which radio navigation grids are distorted near coasts and islands has been measured and the resulting correction included in charts that fishermen are likely to use, including the charts referred to above.

Physical oceanographers are co-operating with Atmospheric Environment Service meteorologists in a project designed to improve the detailed predictions of conditions within storms at sea; inferior predictions not only risk lives at sea, but also the unnecessary loss of productive fishing time if the storm proves to be less violent than predicted (refer to the section on the offshore oil industry below for further information on this project, known as the Canadian Atlantic Storm Project, CASP).

Research into acoustic fish-finding technology at the Institute has resulted in a much-improved system for groundfish detection by which not only abundance but also individual fish size can be measured. It is intended that this will be available commercially with as little delay as possible and discussions are underway with prospective manufacturers.

Consequences of industrial activity for fisheries

It is the responsibility of the Institute to apply its wide range of expertise in evaluating the consequences of proposed industrial developments. Part of this responsibility is discharged by aiding the drafting of guidelines for proponents' studies needed to back up Environmental Impact Statements, and the subsequent review of the statements within the Environmental Assessment and Review and other formal processes. Another part is the review of oil industry contingency plans for all exploratory wells, while a third aspect requires scientists to perform some related research because BIO may be the chief location of relevant expertise in Canada, or because it is essential for our scientists to be fully up-to-speed in the problems on which they must pass judgement.

The Grand Banks has been an extremely busy region for the Institute with respect to evaluating the consequences of industrial activity for fisheries, as well as for other concerns.

[(1)]*The Unsolicited Proposal (UP) Program* is an adjunct to the federal government's Contracting-out Policy in Science and Technology; it provides the Canadian private sector and commercial industry the opportunity to submit, on their own initiative, proposals for scientific work. Its aim is to encourage industry's contribution to government objectives and to increase government appreciation of Canadian industrial capabilities. The work is funded by the federal government.

An example of this activity is illustrated by the Hibernia Environmental Impact Statement (EIS). With the filing of the EIS on May 15, 1985, Mobil Oil Canada started along the regulatory road that could lead to production approval for this discovery. A joint Canada-Newfoundland review panel was established; their report is due at year-end. At the time of writing (June/July 1985), Institute staff are engaged in the technical review of the four-volume EIS and its many supporting documents. Departmental (DEMR and DFO) positions will be established based in part on the Institute reviews, and Institute staff will attend the public hearings to provide expert advice.

Researchers of the Marine Ecology Laboratory (MEL) at BIO are engaged in a project to model the possible effects of oil spills on the Grand Banks ecosystem. The project is funded by the Department of Energy, Mines, and Resources through the Panel on Energy Research and Development, PERD[(2)]. It is hoped that this modelling effort will go beyond traditional methods of impact assessment and will, in addition, provide a basis for the consolidation of information on the Grand Banks ecosystem. The project is of significance because it addresses the requirement for an ecosystems approach to environmental impact assessment as recommended in a recent Federal Environmental Assessment and Review Office (FEARO) report (Beanlands and Duinker, 1983). A major component of the project is the use of interactive modelling workshops involving scientists active in the field. Dutch and German scientists who have developed similar models have been consulted. The interactive modelling system is based on a microcomputer system that has been developed at MEL for the purpose of this project. The work is organized in three phases:

(a) development of a highly aggregated model representing the dynamics and major trophic pathways of the Grand Banks ecosystem;
(b) identification and modelling of the significant interactions through which oil spills could affect the biota on the Grand Banks; and
(c) elaboration of the model for predictive modelling of the effects of oil spills.

The first phase of the project was completed in June 1985 and has resulted in the preparation of a working model of the Grand Banks ecosystem and preliminary identification of ways in which the system is most likely to be impacted by oil in the event of a spill. To furnish critical data, it was necessary to run three major voyages to the Grand Banks to investigate the distribution and growth dynamics of microplankton communities. Developmental work is now continuing into phase (b), with increased emphasis on the toxicological aspects.

Offshore Petroleum and the Fisheries

What impact will recovering the hydrocarbon reserves off eastern Canada have on offshore fish stocks and fishing operations? Much misinformation existed when BIO hosted a two-day scientific consultation on this widely discussed subject in October 1980. The objective was to draft a scientific opinion on the probable consequences of the additional oil contamination to be anticipated as a result of offshore hydrocarbon production at Sable Island and on the Grand Banks. The consultation was organized by the Marine Environment and Ecosystems Subcommittee of CAFSAC (the Canadian Atlantic Fisheries Scientific Advisory Committee), so that a consensus might be expressed by at least one segment of the scientific community on the most probable consequences.

Recognizing that the problem is a complex one, it was decided to limit the focus of the two-day consultation. The panel of experts were each given a question in advance and asked to address it at the consultation prior to in-depth discussion. A very limited set of questions was used:

(1) What are the likely scales and frequency of accidental release of hydrocarbons from foreseeable developments off the Canadian east coast?
(2) What levels of oil contamination may be expected in water and sediments, and what would be the physiological consequences for biota?
(3) What kind of observational programs would be required to detect the effects on biota?
(4) What is the likelihood that such effects would impair recruitment and that such impaired recruitment would be separable from natural variation?
(5) What consequences for offshore fishing operations may be expected?
(6) What will be the effects, if any, of countermeasures?

Discussion did not cover coastal fisheries, recreational beaches, ports, harbours, or wildlife because it was felt that the very important inshore problems were much better understood than the offshore consequences. Views expressed were personal and not the position of any organization. The Consultation did not consider any program requirements for the future to solve uncertainties that were exposed and it was recognized that the output would not represent or substitute for a detailed study of the same problems more formally undertaken over a longer period. Lastly, no formal recommendations were made, or would they have been appropriate, as a result of the Consultation.

Notwithstanding the caveats noted above, the Consultation achieved its aims. For those interested in the details of the consensus replies to the questions, the following report may be consulted:

Longhurst, A. (Editor). 1982. Consultation on the consequences of offshore oil production on offshore fish stocks and fishing operations. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1096: 95 p.

[(2)] *The Panel on Energy R&D (PERD)* is an interdepartmental committee of Assistant Deputy Ministers representing some 23 federal departments, agencies, and crown corporations, who are responsible for reviewing, co-ordinating and recommending on priorities and funding for federal energy research and development. The *Office of Energy R&D (OERD)* of the Department of Energy, Mines, and Resources serves as the secretariat. Funding for this program is provided through the Department of Energy, Mines and Resources.

Interaction with industry takes place in two ways. Firstly, the periodic review by the funding agency (PERD) involves a committee comprising both government and oil company members. Secondly, much of the work on the project (54% of total resources) is contracted out to industry, primarily in Atlantic Canada. Significant proportions of the majority of PERD-funded projects are contracted out.

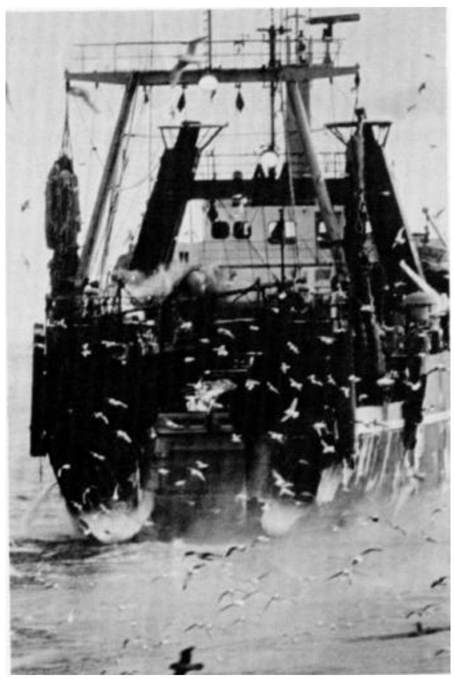
In another BIO project directly relevant to the consequences of industrial activity for fisheries on the Canadian east coast including the Grand Banks, research is being undertaken into surface current prediction, which is relevant to a number of applied problems such as oil spill trajectory modelling. The project involves joint participation of several government agencies, universities, and the oil industry (Esso, Dome, Petro-Canada, and Mobil). In the modelling work there is close co-operation with a Canadian company that is active in this field, Meteorological and Environmental Planning Ltd. of Markham, Ontario. Much of the data analysis and field work is carried out on contract by firms such as MacLaren Plansearch of Halifax, N.S. The work is funded by BIO, PERD, the Natural Sciences and Engineering Research Council (NSERC), and Mobil Oil Canada Ltd.

Shipping on the Grand Banks

According to the Charts and Publications Regulations of the Canada Shipping Act, all ships (both Canadian and foreign) are required to carry Canadian charts in Canadian waters. It is the responsibility of the Canadian Hydrographic Service (CHS) to provide these charts and associated publications such as Tide Tables and Sailing Directions.

In the case of the Grand Banks and its associated coastal waters, the CHS component at BIO is responsible for the upkeep of eight existing charts. In addition it is currently producing three new offshore charts for this region, two of which pertain to St. Pierre Bank off southern Newfoundland at the western edge of the Grand Banks. All three charts are being produced on contract (by Terra Surveys Ltd. of Ottawa), which is in itself a relatively new departure.

Large portions of the coast of Newfoundland are poorly charted. Knowledge of the bathymetry is scant with many parts of the coastline poorly delineated. The geographic position is, in places, several miles out of position. This state of affairs presents an obvious hazard to shipping, particularly since large vessels are now venturing into some of the harbours. As an example (and close to the Grand Banks), Notre Dame Bay in northeast Newfoundland is one such area where the existing charts are primarily British Admiralty reproductions dating back to the last century. Lewisporte, situated within Notre Dame Bay, is but one of several active ports in the area. It is the terminus for the Labrador ferry and a receiving depot for fuel oils for the central part of Newfoundland. Botwood, near Lewisporte, is the major shipping port for the Abitibi-Price paper mill at Grand Falls and has been used as a supply base for drilling in the Labrador Sea. Not only are existing charts here very old, but this area of the coast is very rugged and complex with numerous islands, rocks, and shoals. In 1984, BIO mounted a major hydrographic effort in Notre Dame Bay. Part of the work was undertaken by contract (Terra Surveys of Ottawa was contracted to survey Lewisporte and its approaches, and also Loon Bay), while part of the work was undertaken by BIO hydrographers working from CSS *Baffin*. To provide detailed shoreline plots for these and associated surveys, and later to facilitate the construction of the charts, another contract was let for photogrammetric mapping. The results of these various surveys will contribute data towards a set of new charts for the Notre Dame Bay area.



An offshore fishing trawler on the Grand Banks of Newfoundland.
(Courtesy of the North west Atlantic Fisheries Centre)

Another field in which there is significant interaction with the shipping industry is that of radio-navigation aids, such as Loran-C. Recently a new Loran-C transmitter was established by Transport Canada at Fox Harbour, Labrador, thereby extending the coverage of this state-of-the-art system to include the Grand Banks. A transmitter such as this cannot be used effectively without the updating of existing charts to include Loran-C technical data (lattices). In response to this need, CHS at BIO embarked on a major new program. The work, which will take several years to complete, is still underway. Much of it is being done on contract by such firms as Atlantic Air Surveys of Dartmouth, N.S. and Kenting of Ottawa. Loran-C provides fishing vessels and supply boats for offshore drilling platforms with an aid that contributes to more efficient and safer vessel operations. Helicopters servicing drilling platforms also utilize the revised charts in their offshore flights. The interaction with industry includes the training of vessel operators in the use of the revised charts.

Services such as the above must be responsive to the changing practices and demands of the industry. This is ensured through regular interaction with shipping interests in such fora as the Newfoundland Shipowners Association and the Atlantic Pilotage Authority, the Regional Director of Hydrography at BIO being a member of both organizations.

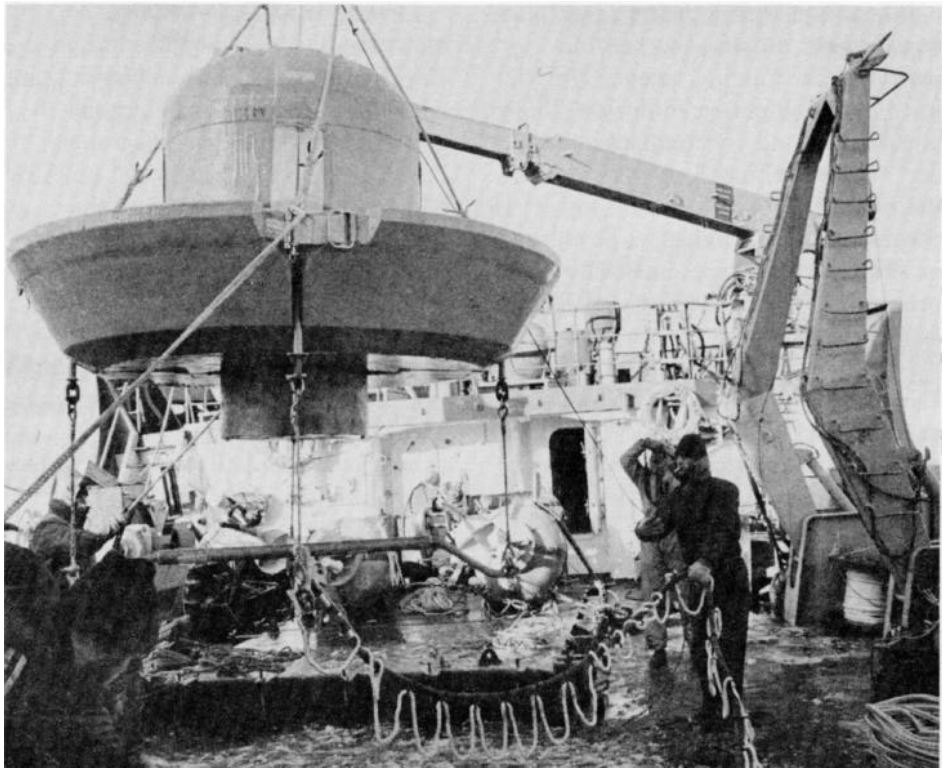
Also relevant to shipping is the research being undertaken at BIO on waves and sea ice (including icebergs). This work is considered under the section on the offshore oil industry since much of it is funded via the Energy

R&D Program (PERD). Of particular interest is the recently established Canadian Atlantic Storm Project (CASP) that will look in detail at the large and small features of severe and unpredictable winter storms that lash the Canadian east coast. Such storms are a threat to ships at sea and can cause millions of dollars of damage to vessels in small harbours, to wharves, and to private property.

Oil industry

Offshore regions are believed to contain Canada's largest remaining untapped reserves of oil and gas. Of these, the Hibernia field on the Grand Banks, discovered in 1979, is regarded as one of the best prospects. Mr. Paul Tellier, Deputy Minister, Federal Department of Energy, Mines and Resources, appearing before the Standing Committee of the Senate of Canada on Energy and Natural Resources in April 1984 said of the Hibernia field that it is "a very major oilfield on a world scale" (Tellier, 1984). Despite the high costs and risks, exploration on the Grand Banks has continued since the first well was drilled in 1966. In 1984, for example, seven exploratory wells and three delineation wells were drilled, resulting in one oil discovery, two gas-and-oil discoveries, and one gas-condensate find. In 1985, as previously stated, Mobil released its Environmental Impact Statement for the Hibernia field, and production from this source is now confidently expected during the next five years. As well as requiring new engineering solutions, Hibernia has been characterized by a great demand for scientific information about the environment in which it must operate, while for the Grand Banks as a whole there is the need to provide improved understanding of petroleum reservoirs. This has meant an unprecedented demand for scientific services from the federal government to which BIO has responded by making major changes in its research and survey programmes.

BIO research pertaining to offshore oil and gas may be classified under the following categories: geoscience considerations; effects of the ocean environment on offshore structures; and offshore geotechnics. Note that



Moorings about to be deployed from CSS Dawson *in November 1985. These directional wave buoys are being used in the Canadian Atlantic Storm Project to measure wave height, and the direction of propagation. of surface waters.*

the effects of oil and gas developments on the marine environment are considered under the section on the fishing industry.

Geoscience considerations

The objective of research in this field is to provide improved understanding of petroleum reservoirs and the geological hazards faced in hydrocarbon developments, e.g. seabed instability.

The geological setting of the Grand Banks was established by industry and government scientists in the 1970s, with the Atlantic Geoscience Centre (AGC) playing a major role. These studies, which continue, involve close co-operation between AGC and oil company scientists; the results make a direct contribution to the assessment of oil and gas reserves. As an example of more recent work, an agreement was struck in 1985 between the Geological Survey of Canada and a group of oil companies headed by Chevron to proceed jointly with a major aeromagnetic survey in an area covering the northeastern Grand Banks and the Orphan Basin. The objective was to delineate in greater detail than presently available a number of sedimentary basins that are potential sources of hydrocarbons. AGC will be playing a major role in this project. Field operations are scheduled for the summer of 1985. AGC will incorporate the data obtained with seismic information acquired through other contracts to establish the deep structure of the continental margin across the eastern Grand Banks and delineate the sedimentary basins that have developed during its formation.

The continental margin off Newfoundland is part of one of the world's classic transform-faulted margins. This region, which includes the Grand Banks, is a key target for seismic reflection experiments designed to acquire information on the geology deep within the earth's crust. The Frontier Geoscience Program[3] is funding the Atlantic Geoscience Centre

[3] *The Frontier Geoscience Program* is designed to gather data, provide analysis, and synthesize and disseminate information relating to the geology of the frontier areas. The focus is on the geology and evolution of sedimentary basins, the processes governing the generation, accumulation, and preservation of hydrocarbons, and the identification and analysis of constraints to their development.

Only two semi-submersible oil-drilling rigs of this type exist. This one was used on the Grand Banks of Newfoundland.

to do this. One of the objects of such work is to obtain an understanding of the fundamental controls on the development of the sedimentary basins that are known to contain hydrocarbon resources. The acquisition of the deep crustal marine seismic reflection data along the northeast coast of Newfoundland and across Orphan Basin and the adjacent continental margin was undertaken on contract by Geophysical Services Incorporated of Calgary in 1984, and further work is currently underway. Results off northeast Newfoundland will be made available to industry and others as part of the national Lithoprobe Program.[(4)]

Seabed instability resulting from earthquakes has been investigated by the Institute in the vicinity of the 1929 earthquake on the Grand Banks. The work has shown that surficial slumping is widespread on the continental slope within 50 km of the epicentre, and that the turbidity current generated was 300 m thick and sufficiently powerful to sweep seabed gravel into waves. Such information is useful in the preparation of standards by the Canadian Standards Association on the design of offshore structures. A significant part of this research was funded by PERD.

Effects of the ocean environment on offshore structures

The objective of research in this field is to improve the safety of marine hydrocarbon exploration and production systems. Rig operators need to know the statistics of wave conditions and currents (including the probable extreme wave heights and current surges), the statistics of ice and freezing spray conditions, and how to predict the drift of observed pack ice and icebergs approaching a rig.

In 1981 the Resource Management Branch of the Department of Energy, Mines and Resources (which subsequently became part of the Canada Oil and Gas Lands Administration, COGLA) asked the Atlantic Oceanographic Laboratory at BIO to provide an overview of oceanographic conditions for the Newfoundland Shelf and the Hibernia area in particular. This was done, and was followed by a workshop with industry, government, and university participation. Based on the recommendations of the workshop a steering group was formed involving the above groups (specifically Mobil, Petro-Canada, Dalhousie University, and AOL) to arrange and co-ordinate a joint program of analysis, modelling, and observation of currents on the Grand Banks. As an example of the work undertaken, current meter data collected by Mobil and satellite-tracked drifting buoy tracks resulting from Petro-Canada and International Ice Patrol work have been analyzed by AOL and utilized in a statistical iceberg-drift prediction model developed by Dalhousie University. Other oil companies, such as Husky-Bow Valley and Esso, are also involved, and significant parts of the program are undertaken on contract by consultants (e.g., Dobrocky Seatech has provided the consulting support for a study of pressure gauges). Funding is from PERD, the oil industry (who also provide ship time), and AOL.

The heavy ice conditions experienced over the Grand Banks in recent years have highlighted the need for better ice forecasting. One of the objectives of the Atlantic Oceanographic Laboratory's sea ice research program is to improve the models presently being used for operational forecasting by both the Atmospheric Environment Service and private industry. A major thrust in the work is to elucidate the respective roles of meteorological and oceanographic factors in determining the large-scale distribution of pack ice.

Icebergs represent one of the major hazards and impediments to Grand Banks hydrocarbon development. A major objective of AOL iceberg research is to develop models that will provide accurate predictions of iceberg drift in the short term (1 to 3 days over a range of 10 to 50 km) in order to assist industry in making decisions on the need to tow icebergs and/or to vacate the rig. In 1983, 1984, and 1985 AOL organized a voyage to the Grand Banks to monitor the trajectory of icebergs and to measure the associated currents and winds. Among the contractors involved in this project are Ice Engineering Ltd. of St. John's, Newfoundland, and Seimac Ltd. of Bedford, N.S.

A major thrust of the program of the Atlantic Oceanographic Laboratory is wave studies. Relevant to shipping and coastal engineering as well as to the offshore oil industry, the AOL program has two main components. One is the presentation of statistical data on ocean wave fields over many years in the form of wave climate charts. The other is research aimed at understanding how waves form, propagate, and eventually decay and at improving numerical wave-hindcast models. One recent example of external interaction with reference to the Grand Banks is in connection with the *Ocean Ranger* incident. While this interaction is not on a one-to-one basis with the industry, it obviously has important implications to them. The

[(4)] *The Lithoprobe Program* is a national, collaborative, multi-year, multidisciplinary, geoscientific research program for investigating fundamental questions concerning the nature and evolution of the rigid outer shell of the earth (the lithosphere) beneath Canada's landmass and surrounding oceans. It involves the effective integration of modern geophysical, geological, and geochemical concepts and technology to extend knowledge of the lithosphere in various key areas in Canada into the third dimension - depth.

Ocean Ranger sank during a storm in February 1982, and Institute staff provided expert advice on factors such as waves at the Royal Commission that was established to investigate the incident. One example of how the Institute assisted (in response to a specific request of the Commission) was to develop and build a three-dimensional model of the energies measured at the *Zapata Ugland* rig, some 30 km north of the *Ocean Ranger* site. The model depicted the period from 1430 h local time on February 14 through 0330 h on February 15 when the storm reached its peak and eventually the *Ocean Ranger* sank.

The Canadian Atlantic Storm Project (CASP), referred to previously, is a multi-year joint meteorological and oceanographic research project whose objective is advancing the understanding of Canadian east coast storms and the effects of such storms on the oceans, e.g. in the generation of waves. As such it is of relevance to oil and gas development because such storms are a threat to offshore drilling platforms. The meteorological aspect is the responsibility of the Atmospheric Environment Service, while the oceanographic component is the responsibility of the Atlantic Oceanographic Laboratory at BIO. Initiated in 1984/85, the main field work is to be undertaken in 1985/86 off Nova Scotia and on the Grand Banks using buoys and moored instruments. While the oceanographic field work is essentially confined to the Scotian Shelf, the results will be applicable to the east coast offshore generally. The project, estimated to cost about $3 million, is primarily funded through PERD. The CASP management committee includes oil industry members as well as, of course, BIO and Atmospheric Environment Service representatives.

Offshore geotechnics

The objective of this area of activity is to improve knowledge of seabed conditions on the Grand Banks for both development and regulation purposes. The Atlantic Geoscience Centre is conducting various projects, many funded by PERD, on topics such as seabed stability, soil properties, sediment dynamics, and iceberg scouring.

With the step-up in engineering activity and offshore development in ice-infested waters, it is becoming increasingly important to understand ice scouring processes and to predict the frequency and depth of seafloor disruption by iceberg and sea-ice scouring. At risk are seabed components of hydrocarbon production systems such as wellheads, flowlines, gathering lines, and production manifolds. Advice has been provided to Mobil, based on surveys undertaken by AGC, on the distribution and age of iceberg scours on the Grand Banks. Other BIO research in this field is concerned with iceberg grounding, scour formation and degradation, and the development of techniques for predicting scour frequency and depth. Iceberg scour is monitored using submersibles and side-scan sonar, and other techniques are being developed. The work is funded to a large extent by PERD and the Environmental Studies Revolving Fund (ESRF)[5]; much of it is done on contract by companies such as Geonautics Ltd. of St. John's, Newfoundland. An example of one of the ESRF-funded studies is the Dynamics of Iceberg Grounding and Scouring experiment (DIGS); this project involves the voyage of the charter vessel *Polar Circle* to offshore Labrador (where it is somewhat easier to study iceberg grounding and scour) in the summer of 1985.

One of the major programs of the Atlantic Geoscience Centre is the systematic mapping of the sediments and bedrock of the seafloor off eastern Canada. Over the years this activity has resulted in the accumulation of a considerable body of knowledge on regions such as the Grand Banks. This information is of interest to the oil industry. One of the first examples of interaction with industry occurred in the 1960s and early 1970s when exploratory work first got underway on the Grand Banks. Industry approached BIO for information on the characteristics of the seafloor in order to ascertain foundation conditions for anchoring drilling rigs. Following the discovery of oil at Hibernia in 1980, Mobil investigated the possibility of transporting oil ashore by pipeline. The company wanted to know if seafloor conditions were such that a relatively direct pipeline could be constructed between Hibernia and St. John's. AGC was approached. The advice provided was that while such a direct route was not feasible, a more southerly route might be possible. As is now (i.e., July 1985) known, Mobil subsequently decided against the pipeline option. In the interim, however, AGC provided information pertaining to foundation characteristics for pipelines to contractors working for Mobil, e.g., Lavalin Ltd. In a somewhat related example of the use of this type of geological data to industry, advice was provided to a salvage company in connection with the recovery operation for an expensive anchor chain that was lost overboard from a supply vessel on the Grand Banks.

In other geotechnics work in support of the Hibernia development, studies of sediment dynamics, soil properties, and seabed dynamics are all underway and are funded via PERD or the Frontier Geoscience Program. In connection with the first type, results suggest that sand ridge bodies near Hibernia are less relict than previously thought and appear to have developed during the last 8000 y; an inventory of offshore geotechnical boreholes, including industry boreholes, is currently underway, while in the seabed stability work a surficial features map has been compiled for the Hibernia area.

Marine information and advice

In addition to the many contracts and joint programs with industry pertaining to the Grand Banks, there is considerable interaction through the provision of advice, interpretation, and data. Much of this occurs on an ad hoc basis through informal channels on a one-to-one basis, but in

[5] *The Environmental Studies Revolving Fund (ESRF)* is administered jointly by COGLA and the Northern Affairs Program of the Department of Indian Affairs and Northern Development. It was established to finance environmental and social studies needed to assist decision making on oil and gas activity in the Canada Lands. The studies are financed by means of levies on the oil and gas industry and cover a broad range of scientific disciplines in the physical, biological, and social sciences.

addition certain formal mechanisms have been established to facilitate the transfer. An example of the latter is the Institute's marine advisory and industrial liaison office, BIOMAIL. The functions of this office are:

- to facilitate the dissemination and interpretation of information and data on all appropriate aspects of the oceans to industrial users and other government departments;
- to encourage the transfer of technology to Canadian industry and the healthy growth of ocean industry especially in Atlantic Canada;
- to facilitate contractual relations for all aspects of ocean R & D between Canadian industry and the Bedford Institute of Oceanography;
- to co-ordinate the review of unsolicited proposals; and
- to advise industry on federal funding for technology transfer (PILP, COPI, IRAP, etc.).

Data banks have been established at the Institute for records from current meters, tide gauges, wave measuring buoys, ocean bottom seismometers, and other instruments. Other data are supplied to national data centres such as MEDS (Marine Environmental Data Service). The Atlantic Geoscience Centre maintains an extensive open-file system for geoscience data, while marine geological samples from regions such as the Grand Banks are housed in a special Institute Curation facility. Bathymetric data, in the form of digitized field-sheets, are maintained to supplement the information recorded on published charts. These are accessed routinely by industry and others working on Grand Banks problems. In addition, the BIO Library maintains a special collection of environmental assessment literature covering offshore regions such as the Grand Banks. This collection, probably the most complete set of such documents available in Canada in the public domain, is used extensively by industry.

Formal links with industry are also achieved through various committees and other bodies. One such committee on which the Institute is represented is the Environmental Advisory Committee on Newfoundland and Labrador Marine Transportation. Its purpose is to provide information and advice to the Coast Guard Control Authority on those aspects of the environment and natural resources that may be affected by shipping routes and ship movement. Appropriate industry representatives, e.g. Dome Petroleum in connection with the shipping of oil from the Arctic to southern ports, serve on the committee. As another example, BIO staff are active on several of the Environmental Studies Revolving Fund committees that are relevant to the Grand Banks. These committees, which comprise government, industry, and university members, identify research priorities, review research proposals, and appoint scientific authorities for specific projects. Institute staff serve (or have served) on the following ESRF committees relevant to the Grand Banks: bottom sediment transport; effects monitoring; icebergs; and sea bottom ice scour.

Brian Nicholls.

Further reading

In addition to this issue of the BIO Review, two earlier issues should be consulted: *BIO Review '81*, which discusses how Institute programs respond to the marine issues facing Canada, and how the priorities of the programs are influenced by evolving national needs for information about the ocean; and *BIO Review '83*, which is devoted to "surveys and services". Geological Survey of Canada Paper No. 81-6, "Part I, Marine Geoscience in Canada; A Status Report" provides the background to some of the earlier geological work on the Grand Banks, while the annual reports of the Canadian Hydrographic Service provide information on surveys and charting pertaining to the Grand Banks.

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chapter 2

Geoscience

The Grand Banks of Newfoundland extend to the east and southeast of the Island of Newfoundland and cover an area 2.5 times the size of the Island. They are the most extensive shallow feature on the continental shelf of eastern Canada. Because of its geomorphological significance and the potential resources hidden beneath it, the region has been the scene of continuous marine geophysical and geological investigations since surveys in offshore eastern Canada were initiated in the mid sixties. In our understanding of the formation and development of the North Atlantic Ocean, the margins of the Grand Banks provide a unique record of the continental break-up of North America, Africa, and Europe 100-l80 million years ago. As the location of significant sedimentary basins formed during the break-up of the ancient continent of Pangea, the Grand Banks provide us with a record of basin evolution and the potential for substantial hydrocarbon resources. As a shallow bank presenting a physical barrier to the southward flow of large icebergs calving off the glaciers of Greenland, the area provides a major challenge to the exploitation of resources beneath the surface of the Banks. Extension of exploration across the steep margins of the Banks, and future exploitation of any resources found in these deeper water areas, faces the added concerns of stability of seabed sediments in these deeper water regions and the possibility of submarine landslides such as those triggered by the 1929 earthquake on the continental slope off the southwestern Grand Banks.

The Chevron *et al.* discovery of oil at Hibernia P-l5 in 1979 provided a new impetus to hydrocarbon exploration at a time when industry interest in the area had waned considerably after 38 dry holes had been drilled. A total of 13 discoveries have now been made in the Jeanne d'Arc Basin located on the northeast margin of the Banks. The major oil play in this region, estimated to contain nearly 75% of the oil potential, relates to the trans-basin fault zone, which extends from Hibernia to Ben Nevis. Currently there are seven significant discoveries on this trend. A recent hydrocarbon assessment of the East Newfoundland Shelf (Proctor *et al.*, 1984), based on all available well, seismic, and geochemical data, indicated a 50% probability of more than 8.4 billion barrels of oil and 12.2 trillion cubic feet of gas, including the 1.3 billion barrels and more than 2 trillion cubic feet of resources already discovered. Although the Hibernia field is in the "giant" class, the engineering constraints to developing the field are considerable and must be carefully assessed before development.

The increase in industry activity on the Grand Banks since 1979 has resulted in an acceleration of the activities of the Atlantic Geoscience Centre in the area and the initiation of a number of studies directed specifically to problems associated with the development of oil and gas from the Hibernia field. Many of these new studies are being carried out as short-term research projects funded by the Office of Energy Research and Development or the Environmental Studies Revolving Fund. Such research studies build on the Centre's broad geological understanding of the region and form part of the ongoing research carried out at the Atlantic Geoscience Centre. This work is now co-ordinated within the East Coast Task of the Frontier Geoscience Program, which provides a unified geoscience approach to the study of frontier resource areas such as the Grand Banks by integrating deep crustal studies relating to the origins of sedimentary basins with detailed studies of the internal geology of these basins and the generation, accumulation, and entrapment of hydrocarbons, and those studies of present-day processes that constrain the potential development of these resources.

The program of the Atlantic Geoscience Centre covers all facets of frontier geoscience research in the east coast and Arctic offshore areas. Much of the research is using state-of-the-art technology, either developed in house for specific research, or more often through co-operative R&D projects with industry. Research into the geology of the offshore requires scientists to be at the forefront of technology in both the acquisition and interpretation of new information. This in turn requires close co-operation between government, university, and industry scientists. The Atlantic Geoscience Centre is continually seeking opportunities for more effective co-operative programs with these other sectors of our society.

The papers included in this chapter of the *BIO Review* summarize some of this research as it applies to the Grand Banks and adjacent continental margins. As well as increasing our fundamental knowledge of this important part of Canada's landmass, the results of these studies are directly applicable to the safe exploration and exploitation of the mineral and energy resources so important to Canada's resource-based economy.

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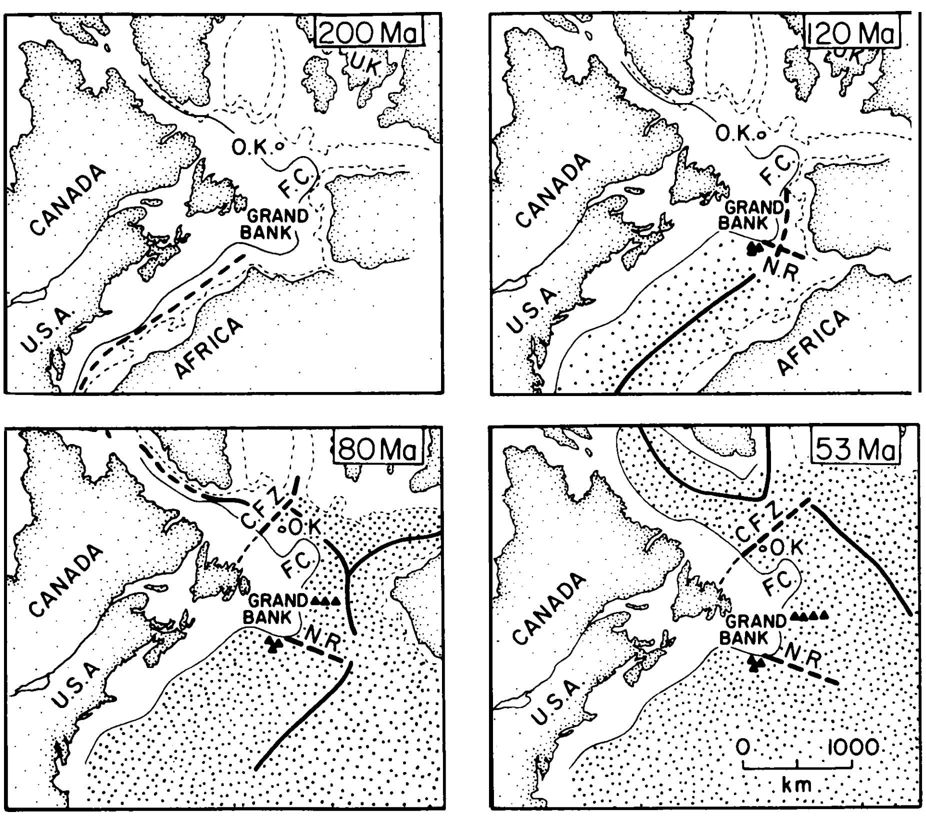
Passive margins: The Grand Banks example

C.E. Keen

The continental margins encircling the Grand Banks were formed by the break-up and drift of the North American, African, and European continents over a period of about 80 million years. As a result, passive margins of varying age border the southern, eastern, and northeastern Grand Banks. Each of these margin segments exhibits characteristics that depend primarily on the timing of continental break-up and the geometry of the initial plate motions between the separating continents.

These plate-tectonic events are illustrated in the first figure (see also Le Pichon *et al.*, 1977; Haworth and Jacobi, 1981). The margin south of the Grand Banks formed first as Africa and North America separated. This margin is one of the world's best examples of a transform margin along which the initial continental motions were strike-slip. Analogues are the more common transform faults and fracture zones in the ocean basins that initially offset segments of the mid-ocean ridges. This shearing between the two continental blocks was not an instantaneous event but started more than 175 million years ago and continued until complete separation of the continents occurred about 100 million years ago. The margin becomes progressively younger to the southeast.

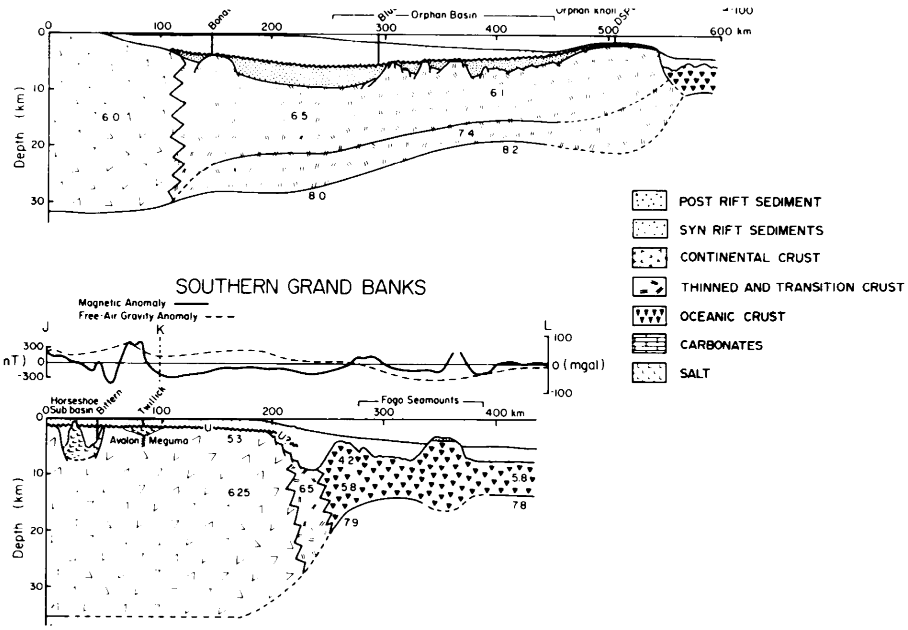


1. The various stages of continental break-up around the Grand Banks are depicted. Dotted regions are areas of oceanic crust formed by seafloor spreading as the continents separated: solid lines are the positions of active mid-ocean ridges: dashed lines represent the positions of incipient ridges and major fracture zones. Times are given in the upper right hand corner of each panel. (O. K. = Orphan Knoll; F.C. = Flemish Cap; N.R. = Southeast Newfoundland Ridge; C.F.Z. = Charlie Fracture Zone.)

The passive margin east of the Grand Banks was formed by the pull-apart motions between the Grand Banks and the Iberian Peninsula (see first figure), which began about 120 million years ago. This margin is therefore primarily a rifted as opposed to a transform margin. It is bounded to the south by the Southeast Newfoundland Ridge and to the north by Flemish Cap. The former feature may represent a leaky transform fault in oceanic crust, a seaward prolongation of the transform margin. In contrast, Flemish Cap is a continental fragment, pulled away from the continent proper during rifting. The significance of these rather striking features in the evolution of the margins is unclear and their nature is the subject of continuing controversy.

The northeastern Grand Banks is bounded by the Orphan Basin, a wide, deep basin underlain by continental crust. The ocean-continent transition is northeast of Orphan Knoll, a high standing continental remnant similar in some respects to Flemish Cap. This continental margin was formed by rifting between the Grand Banks and western Europe with final continental break-up probably occurring about 90 to 100 million years ago. The margin north of Orphan Basin is another transform margin, the landward prolongation of the Charlie Fracture Zone.

In all of these margin segments, the plate tectonic history has been deciphered largely from the record of marine magnetic anomalies, which allows us to date the oldest seafloor and the geometry of the earliest seafloor spreading under certain circumstances. Reconstructions of the positions of the continents that match pre-break-up features are also an important geometrical constraint. Other geophysical data such as gravity anomalies and seismic data define the position of the ocean-continent boundary approximately. Geological data such as the depositional environment and stratigraphy of sediments in deep exploratory boreholes indicate the vertical motions that accompany and follow break-up. Thus a full understanding of the formation of these margins requires the integration of many types



2. Two crustal cross-sections across the margins of the Grand Banks; lines GHI and JKL are shown in the third figure. The numbers are seismic velocities in kilometres per second. The gravity and magnetic anomalies along track are shown above each cross-section. Sediments are divided into two groups: post-rift, which were deposited after rifting stopped, and syn-rift, deposited during rifting. These are shown separated by a wavy line. This is an unconformity which suggests uplift between the rift and post-rift stages of margin development. It is common on many (but not all) passive margins. Deep exploratory wells are indicated by vertical lines into the sediments above which are the corresponding well names.

of information.

So far we have described only the timing and geometry of plate motions that provides a partial explanation of where and when the passive margins formed. We still do not have a good understanding of the forces deep in the mantle that drive the plates and cause continental break-up. While there is agreement that some form of convection probably occurs beneath the plates and provides the ultimate driving force, the interaction between convection and continental break-up is not clear.

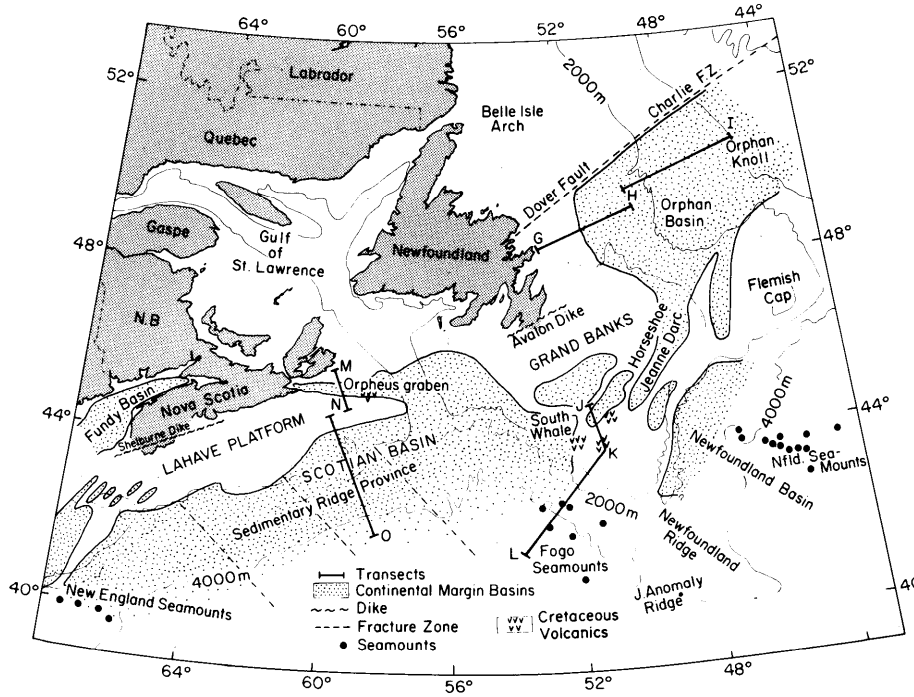
Two main theories are currently being championed (Sengor and Burke, 1978; McKenzie, 1978; Keen, 1985). The first holds that an upwelling limb of a convection cell acts on the bottom of the lithosphere or plate, and provides thermal and mechanical energy that thins the lithosphere from below. If thinning is sufficiently drastic, continental break-up will occur. The second theory proposes that the lithosphere itself is stretched, perhaps in response to distant changes in plate motions or to extensional forces created by uplift of the continental lithosphere. Extension of the lithosphere would be accompanied by lithospheric thinning, and possibly continental breakup.

Observations appear to support the extensional model, but the critical distinguishing tests have not yet been devised. What is clear, however, is that extension and thinning do occur in the crust, even though the underlying driving mechanism for this is not known. Stretching has been documented by seismic mapping of extensional faults in the basement rocks on many margins, including those bordering the Grand Banks. Furthermore, seismic refraction measurements made by the Atlantic Geoscience Centre show that the entire continental crust thins as the ocean-continent boundary is approached to less than half its thickness under the continents proper (Keen and Hyndman, 1979).

In general terms, the consequences of continental break-up and the development of passive margins are accompanied by the creation of oceanic lithosphere adjacent to the continent, and by the creation of sedimentary basins. The latter are the focus of recent exploration for petroleum.

The creation of new oceanic lithosphere and the development of the ocean-continent transition have inevitably led to the search for that often elusive boundary between ocean and continent. The nature and development of this boundary or transition zone could contribute to our understanding of the process of continental break-up. The Grand Banks region provides many opportunities to study this feature across a variety of different margins. Two examples of the results of such studies are shown in the second figure. The southern transform margin exhibits a fairly sharp break between oceanic and continental crust, as might be expected from a sheared margin. In contrast, the margin northeast of Newfoundland is characterized by a broad zone over which the continental crust may have been stretched and thinned, before oceanic crust is reached. This margin may exhibit a fairly sharp transition from thinned continental to oceanic crust just seaward of Orphan Knoll as shown in the second figure. The region requires more detailed study to confirm this interpretation.

An understanding of the development of sedimentary basins on passive margins is another area of research currently underway at AGC (see for example, Beaumont *et al.,* 1982; Royden and Keen, 1980; Keen, 1979). The Grand Banks is an interesting region in this respect as well because of the diverse styles and geometries of the basins that occur there (see third figure). These basins are elongate narrow half grabens (from the German for ditch) separated from each other by basement highs covered by relatively little sediment. They trend roughly northeast across the Grand Banks and are filled with sediment as old as the beginning of rifting between the African and North American plates, about 200 million years ago. This suggests that their development was concurrent with the development of the transform margin, but their evolution continued after the formation of that margin. We may not have



3. Location of cross sections shown in the second figure and distribution of the major sedimentary basins (stippled regions) around the Grand Banks.

defined all of these basins yet: others may occur in deep water, at the foot of the continental slopes. Flemish Pass is an example of such a basin; it has received little sediment and therefore is partly filled with water instead of sediment.

In contrast to the narrow half grabens that occur to the south, the northeastern region of the Grand Banks is occupied by the deep, broad Orphan Basin. One interesting question, particularly in view of petroleum exploration, is whether the Jeanne d'Arc Basin (that contains the Hibernia oil field) continues into the Orphan Basin region. If not, what is the nature of its northern termination? In co-operation with several oil companies, we are currently conducting high-resolution mapping of magnetic anomalies in the area to answer these questions.

How does the crust (and deeper lithosphere) behave beneath these basins? The basins themselves are simply holes into which sediment can be deposited. One must look deeper for clues to the processes that formed them. We have shown that the whole crust thins beneath the basins, but the measurements have not allowed us to examine how this thinning occurs. Two possible models are shown in the fourth figure (after Wernicke, 1985). The models differ significantly in the vertical motions they would produce, and therefore in the history of sedimentation and basin subsidence. The subsidence history is closely related to the ability of sediments of a given age to produce petroleum, so this is not only of academic interest.

In order to investigate the validity of these and other models for the development of the basins on the Grand Banks, we have started the collection of deep crustal seismic reflection data. Such data give a detailed cross-section through the earth's crust, down to depths of 30-40 km or more. Other countries - the U.S., Britain, France, West Germany, and Australia - are involved in similar studies, but until 1984 no studies of this kind had been initiated in Canada. Preliminary results across the Orphan Basin suggest that faulting occurs only in the upper 10 km of the crust; below this depth crustal thinning must occur by ductile deformation (see fourth figure).

More data of this kind are currently being collected across the other basins on the Grand Banks for there may be more than one kind of deformational style. Data are also being collected across the ocean-continent boundaries to provide better resolution of these important features. These will provide us we hope with some clues on how the Grand Banks basins developed. In turn the information will be relevant to petroleum exploration on the one hand and to an understanding of the forces driving continental break-up on the other.

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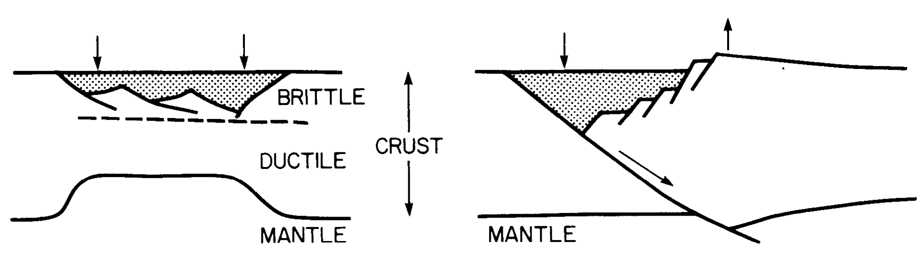

4. Schematic illustration of two models of extension in the crust and lithosphere. The stippled areas are the sediments. Note that the two models produce different basin shapes. The arrows indicate the direction of rift-stage vertical motions, which also differ in the two examples. After Wernicke (1985).

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Surficial and bedrock geology of the Grand Banks

G.B.J. Fader

To geologists, the Grand Banks of Newfoundland are unique in several ways. They bar the southward flow of large icebergs from Greenland and their northern flank is in fact riddled with furrows or scours, and pits formed by grounding icebergs. In the subsurface below that northern flank lies the Hibernia Oil Field, now estimated to hold 500 to 800 million barrels of recoverable oil (Mobil Oil, 1985). To anchor and fix oil production structures safely in this offshore region and to construct and operate flow lines and gathering lines, all while avoiding collision with icebergs, poses special engineering problems. Yet another part of the uniqueness of the Banks is their sand and gravel sea beds, which hold promise as a large source of aggregate for the construction industry.

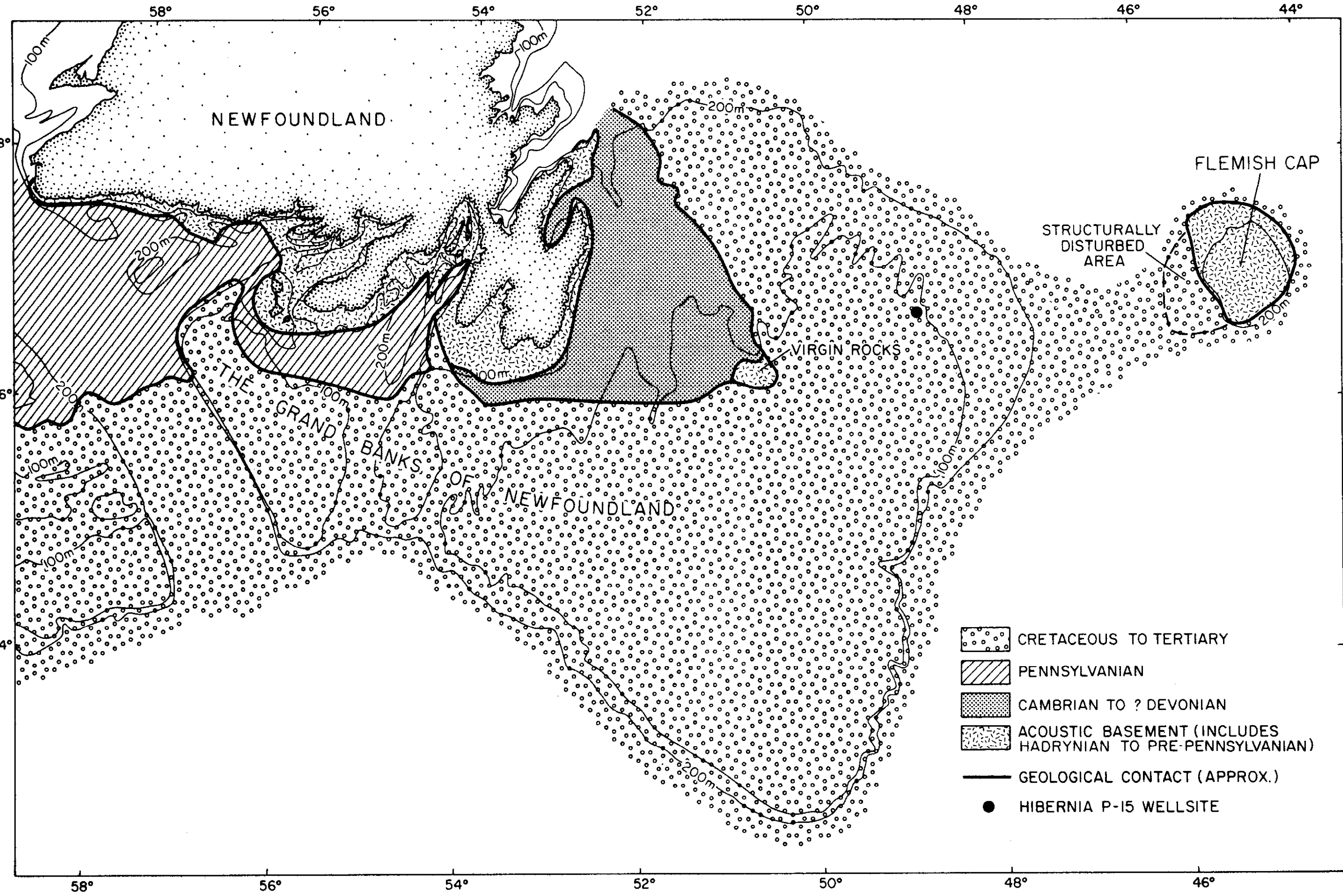
The Geological Survey of Canada's Atlantic Geoscience Centre has been systematically studying the surficial and bedrock geology of the east coast continental shelf for 20 y. Research was extended to the Grand Banks in the early seventies, and the Scotian Shelf to the southwest is now largely completed from a reconnaissance perspective. Most current efforts on the Grand Banks are concentrated on the eastern and northern portions because of the complex nature of geological conditions in the area and the more immediate needs of government and industry to assess conditions for hydrocarbon exploration and development at Hibernia.

Major regional geological voyages to the Grand Banks were conducted in 1972, 1975, 1980, and 1985 to collect seismic reflection, sidescan sonar, and magnetic survey data as well as bedrock and surficial samples, and to conduct submersible observations. From this data base we are preparing detailed surficial and bedrock geology maps and analyzing major processes such as iceberg grounding, sediment dynamics, and seafloor and subsurface stability. During this period as well, we have provided advice to industry on the suitability and routing of offshore pipelines, on the construction of offshore islands, and on geological hazards in the Grand Banks region. Some of the unique geological characteristics of the Grand Banks that contrast it from the Scotian Shelf to the southwest and the Labrador Shelf to the north are discussed below.

A most important bedrock geological characteristic of the Grand Banks is the distribution of Tertiary "semi-consolidated" bedrock and the landforms it creates (see first figure, the bedrock map). All of the major banks - St. Pierre, Green, Whale, and Grand - are underlain by shallow Tertiary rock. With the exception of some heavily channeled areas underlying Green and Whale banks, most other areas have only a thin layer of surficial sediment and in many places Tertiary rocks outcrop at the seabed (Fader and King, 1981). This means that suitable stable foundations for offshore exploration and development platforms are available in contrast to the Scotian Shelf near Sable Island where thick, dynamic (moving) sediments form the seabed.

The inner shelf of the Grand Banks is also unique in that the thickness of overlying glacial materials is very thin (less than 2 m on average) over an area extending from the Avalon Peninsula to the inner edge of Grand Bank. Here the bedrock consists of well-indurated Paleozoic sedimentary rocks, which have been extensively sampled with the BIO-designed electric rock core drill. This area is also heavily scoured by icebergs and the resulting furrows at the seabed are considered to be a combination of very old (greater than 15,000 y B.P.) and modern furrows. The exposed bedrock and the density of iceberg furrows has precluded the use of a direct-route pipeline to Newfoundland from the Hibernia oil fields (King and Fader, 1981). Existing pipeline-burial technology cannot cross and trench the hard bottom in a cost effective manner. A southern "Tertiary bedrock" route, although very long, is geologically more favourable.

The Virgin Rocks - Eastern Shoals area of the Banks is very shallow (about 4 m water depth), elevated, and rugged. Here, very hard pink and white quartzite, tillite, and volcanic rock protrude up to 40 m above the

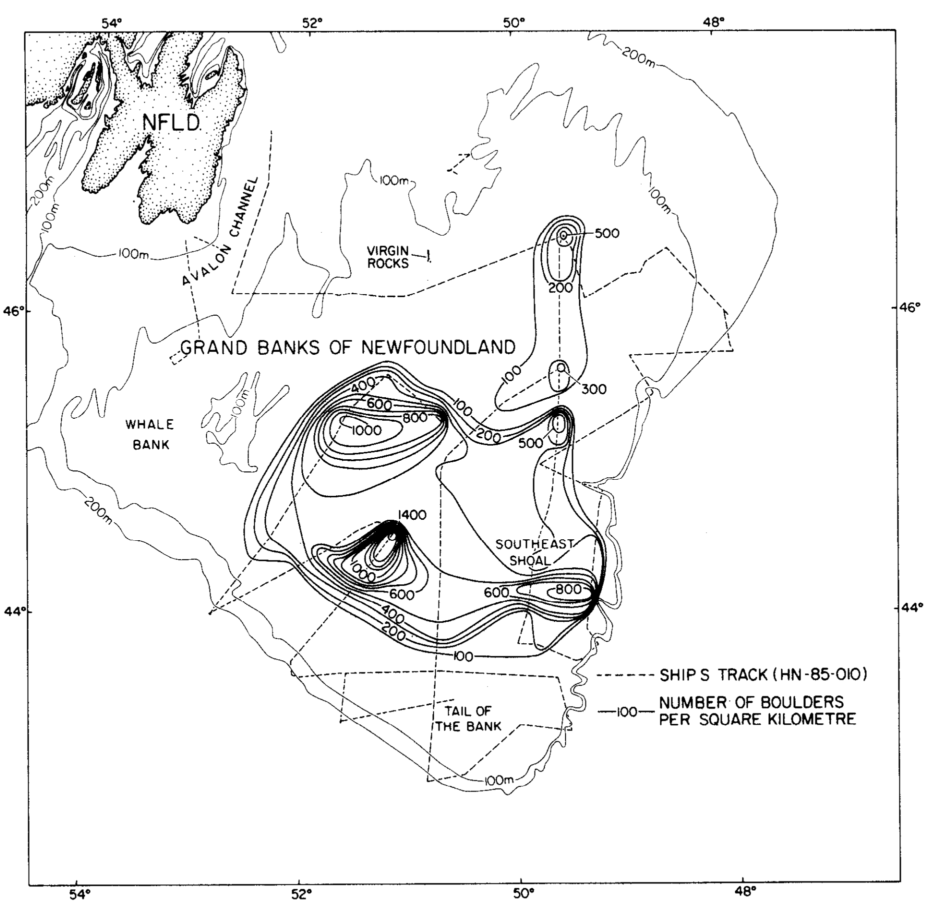


1. Generalized regional bedrock geology of the Grand Banks of Newfoundl and interpreted from seismic reflection profiles and analyses of electric rock core drill samples.

surrounding sandy seabed of the Grand Banks. The area has long been considered potentially suitable as a base for construction of platforms for navigation, search and rescue, and hydrocarbon development-related facilities.

To the west, south of Newfoundland, the bedrock consists of coal-bearing Pennsylvanian sandstone of the Sydney Basin, which extends from the on-land coalfields of Nova Scotia to within a few kilometres of the southern coast of Newfoundland. These rocks occur beneath Rose Blanche and Burgeo banks and floor the bottom of Placentia Bay.

The distribution of the surficial sediments on the Grand Banks of

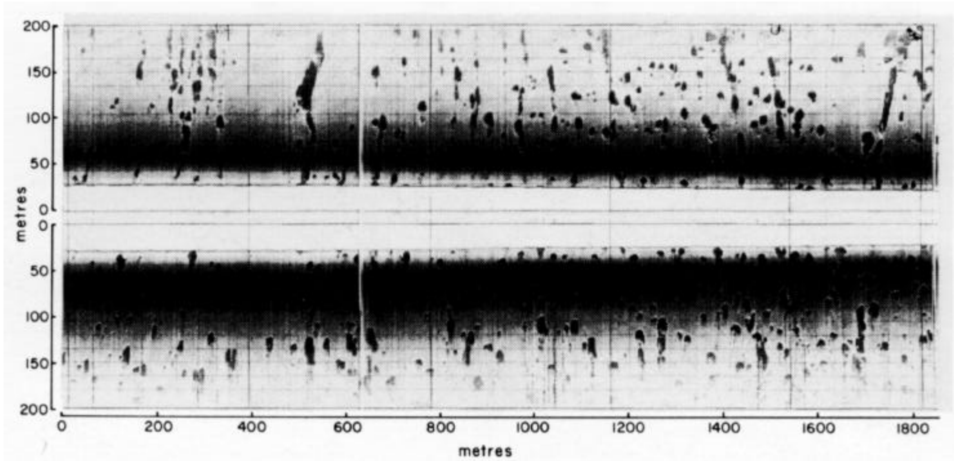


2. Distribution of boulders larger than approximately 0.5 m, interpreted on the basis of 100 kHz side-scan sonograms. The distribution portrayed is confined to water depths above 150 m on the Grand Banks. The boulders are up to 7 m in diameter.

Newfoundland is controlled to a large degree by the glaciers that crossed the Banks and the lowest stand of postglacial sea level and its subsequent rises. From a wide variety of data sources, this lowest sea level is interpreted to be at a present depth of approximately 100 m. Warping of the sea-level terrace may occur from the southern Tail of the Banks to the nearshore area of the Grand Banks possibly because late glacial ice delayed rebound of the land surface in the Tail of the Banks area.

The low sea-level stand and its subsequent rise or transgression gave most of the surficial sediments their present distribution and character. Vast areas of the Grand Banks were above water as large islands before sea level began to rise in early postglacial times. During this phase, the sample data suggest that the Grand Banks supported tundra vegetation. Sea-level transgression very effectively reworked the surface of the Banks: previously deposited glacial sediments were largely reworked, sorted, and eroded except for deposits preserved in buried channels or protected depressions. In this way, the Bank areas developed their "beach" character of sand and gravel. The largest of the sand bodies are called sand ridges; they are up to 10 m thick and have wavelengths of over 3 km. These features dominate the surface of Grand Bank. In the troughs of the sand ridges and also at the seafloor near the Hibernia area are zones of gravel seabed with large boulders up to 7 m in diameter (see second figure). These have been observed on submersible dives across the Grand Banks. The glacial and postglacial muddy sediments are confined to the deeper areas not transgressed of the inner-shelf such as Downing Basin, Avalon Channel, and Whale Deep whereas the shallow bank areas consist of vast deposits of sorted and clean sand and gravel.

A wide variety of other seabed features occur across the Grand Banks. Shell beds, localized circular patches of dense shells, occur on Southeast Shoal (see third figure). They are acoustically unique and easily identified on sidescan sonograms: it has not been determined whether they are living or dead accumulations of shellfish. In Downing Basin, an active gas seep has been found at the seabed. Bottom photographs show mounding and cracking of the sediments with bubbles escaping from the seabed and much particulate matter suspended in the water column. In Placentia Bay, a new bedform "megaflute" has been identified and mapped: these very large current scour features are several hundred metres long and up to 10 m deep. Through the process of megaflute erosion, over 3 km^3 of sediment have been eroded from a narrow 4 x 75 km zone along the eastern flank of Placentia Bay.

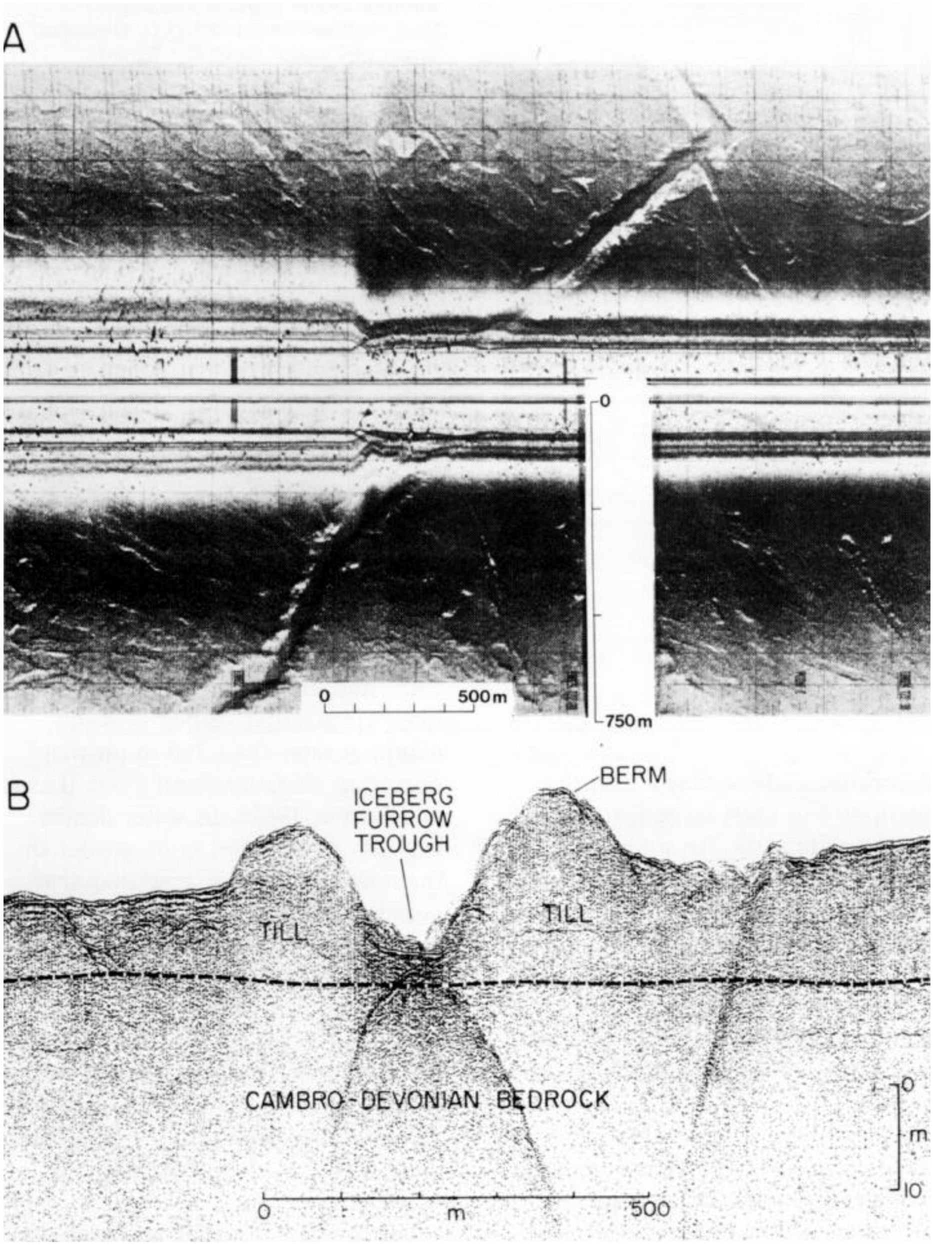


3. Sidescan sonogram across the Southeast Shoal on the Grand Banks showing a light-toned, sandy seabed with numerous dark patches interpreted as "shell beds". Some of the shell beds appear to be aligned in a bead-like fashion: this may result from control on their distribution by low relief bedforms.

A major question within the geological community studying the Grand Banks is to what extent glaciations affected the area. Answering this question will tell us what the source of the present day sediment was at the seabed, help us understand the processes that have affected the Grand Banks, and shed light on the geotechnical properties of the seabed and subsurface that are of concern for hydrocarbon development. The western Grand Banks was covered by glacial ice (Rose Blanche - Whale Banks) as evidenced by (1) the presence of till directly deposited from ice and interbedded glaciomarine sediments, which indicate grounded ice-sheet and floating ice-shelf environments, (2) the environmental indicators of glacial conditions as recorded in sediment cores, and (3) the presence of glacial erratics derived from the province of Newfoundland across the area (Fader *et al.,* 1982). This ice advance represents the last or Wisconsinan glaciation of the area. In contrast, the question of ice extension across the eastern Grand Banks is not entirely resolved as the late Pleistocene-Holocene sea-level transgressions removed most of the glacial evidence. However, glaciomarine sediments in buried channels south of Hibernia, together with coarse gravel and boulders (up to 1500 per square kilometre) of Newfoundland provenance over much of Grand Bank were probably deposited by glacial ice.

The Grand Banks is the area of transition between modern iceberg furrowing by Greenland-generated icebergs and a relict population of iceberg scours on the Scotian Shelf and adjacent areas from late Wisconsinan, locally generated icebergs. A detailed discussion of iceberg furrowing is presented elsewhere (see article by D.I. Ross and M. Lewis in this chapter). Icebergs grounding on the Grand Banks create linear scours and isolated pits (Fader and King, 1981). The largest iceberg furrow (known as superfurrow) occurs in the Avalon Channel and is 12.5 m from the top of the berm to the trough (fourth figure). The berms consist of a large pile of boulders with numerous sponges on their surface. Isolated pits, a special type of iceberg scour, are less common. In the Hibernia area some reach a maximum depth of over 10 m and are 100 m in diameter (fifth figure). These are interpreted to result from erosion by grounded icebergs together with slumping, current scour, and soil failure.

While surveying the southern Grand Banks with the submersible *Pisces IV,* areas of the seabed were observed to be covered with white filamentous material. These patches also occur off the east coast of the United States in the Gulf of Mexico and off Baffin Island in areas of active hydrocarbon gas or oil seeps (B. MacLean, personal communication). The term "white slime" has been proposed for these type of deposits (Bright and Rezak, 1977), which are bacteria mats that live on the methane or waxy residues from hydrocarbon venting. To further support the gas venting origin for the "white slime" deposits, subsurface seismic reflection profiles from the Tail of the Banks area show large acoustic anomalies (about 300 m deep), interpreted as gas-charged sediments. This gas may eventually migrate through the rocks and be vented from the seabed. In any case, the gas-charged sediments represent a potential shallow hazard to hydrocarbon exploration in the Tail of the Banks area. In the same area, the "shell beds" described earlier are found. From studies of gas venting off the coast of Norway (M. Hovelin, personal communication), large populations of shellfish were found living and feeding on similar bacteria, which in turn fed on the hydrocarbon products escaping from the seabed. Further research on the presumed relationship between venting hydrocarbons, bacteria, and shellfish is necessary to confirm the validity of the idea. If true, this would possibly explain why dense shellfish populations exist on the southern Grand Banks and on other areas of the continental shelf.



4. A 70 kHz sidescan sonogram (A) and high-resolution seismic reflection profile (B) of "super furrow", one of the largest iceberg furrows from the Grand Banks of Newfoundland, which occurs in the Avalon Channel east of the Avalon Peninsula. Its height from the top of the berm to the trough is 12.5 m. The iceberg that formed "superfurrow" is believed to have scoured the seabed through to the bedrock surface, and may be more than 20,000 y old. Note the rapid change in direction of the furrow in the upper sonogram (A). (Sonogram courtesy of C.F.M. Lewis.)

The systematic mapping of the surficial geology of the Grand Banks will continue producing a suite of maps and reports. Because of an immediate need for this type of information at the Hibernia oil field area of the Grand Banks, the mapping program has been accelerated and a new style of surficial geology map has been prepared (Fader *et al.,* 1985). The map displays surficial sediment distribution, seabed hazards, iceberg furrow densities, bedform distributions, and other relevant geological information to assist geologists, engineers, environmentalists, and industry in the safe and timely development of resources in the area. Through this combination of long term systematic regional mapping, together with site specific, detailed, multiparameter mapping, a balanced surficial geological program can respond to the governmental and industrial needs on the Grand Banks.

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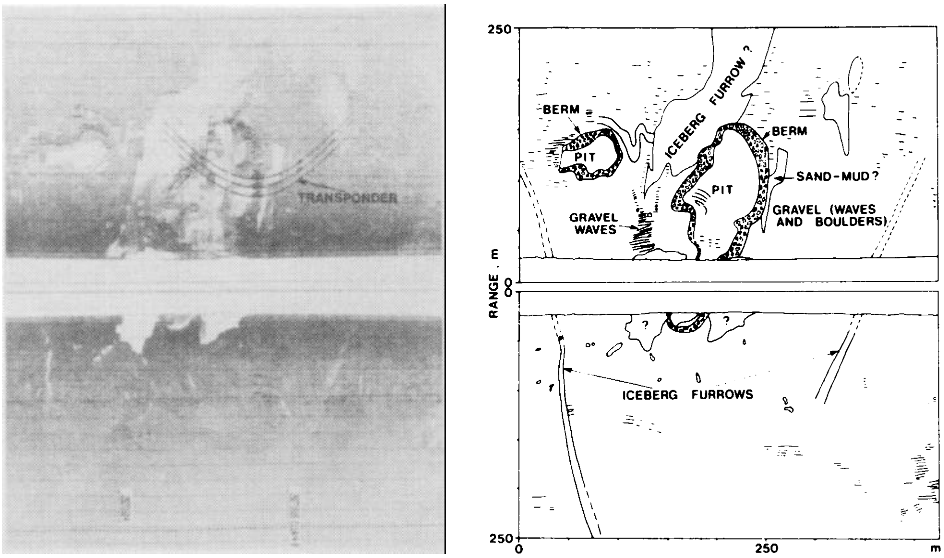

5. A 100 kHz sonogram of an iceberg pit located 100 km east-southeast of the Hibernia P-15 well site at a depth of 87 m. The seabed and subsurface sediments may have been deformed as much as 100 m from the pit itself as indicated by areas of seabed outside the pit berm, which appear as white patches (areas of low reflectivity) on the sonogram. Note the smaller pit to the left of the large pit on the upper sonogram.

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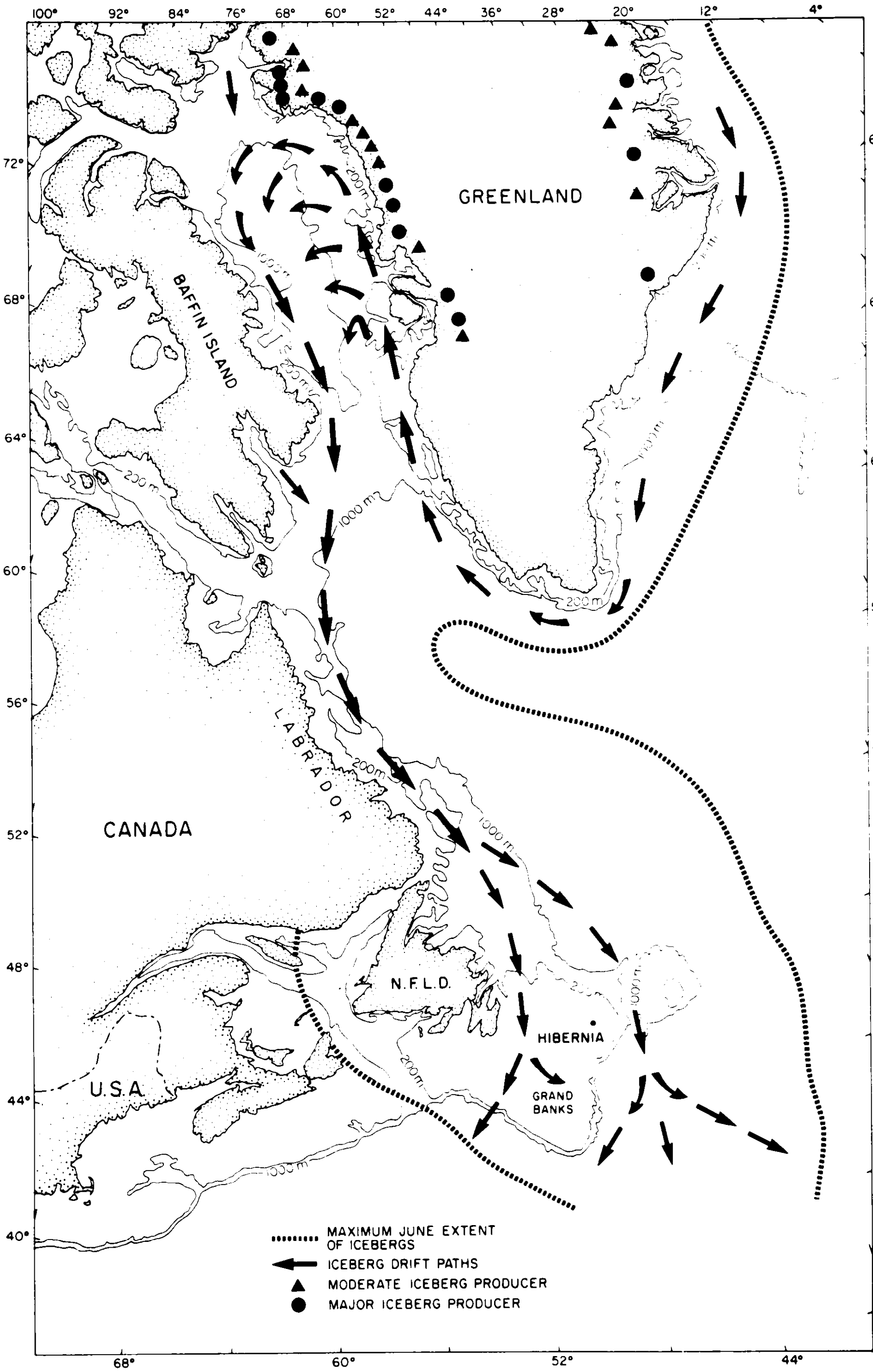
Iceberg-scour features on the Grand Banks

D.I. Ross and M. Lewis

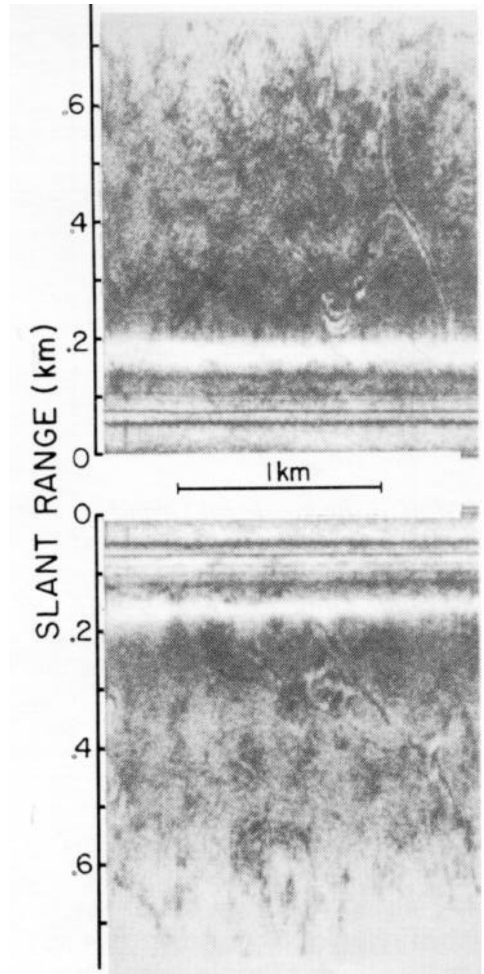
Icebergs calved from Greenland's glaciers are carried south along the Labrador coast by the Labrador Current and across the northern margin of the Grand Banks of Newfoundland. On reaching the Grand Banks, the Labrador Current bifurcates carrying the icebergs with it along one of two paths. One path follows the Avalon Channel along the eastern shore of the Avalon Peninsula of Newfoundland while the other crosses the northern margin of the Banks and travels south along their eastern margin through the Flemish Pass (first figure). The latter path carries the icebergs through the primary exploration area of the Hibernia field on the northeastern edge of the Grand Banks. As they cross the shallower areas of the Banks, many of these icebergs trail their keels across the seabed, scouring the seafloor to depths of a few metres. In some cases they ground, creating depressions where they sit on the seafloor and exert large forces on the seabed sediments. An understanding of the frequency of impact of icebergs with the seabed and of the forces to which the seabed is subjected during impact is needed to design seafloor installations for the production of oil and gas from the Hibernia and adjacent fields. This understanding starts with identification of iceberg-impact features in the area, evaluation of these features in the light of present-day iceberg statistics, measurement of seabed sediment properties, and accurate modelling of the iceberg-seabed interactions that occur.

Two distinct populations of iceberg scours have been described on the northeast Grand Banks (Fader and King, 1981; Lewis and Barrie, 1981). A late Wisconsinan relict iceberg population in water depths greater than 110 m appears as a dense pattern of discontinuous lineations that are believed to represent partially buried iceberg scours beneath a thin sand veneer (Fader and King, 1981). This characteristic pattern is continuous with, and grades into, a well-defined intensely scoured seabed in water depths greater than 200 m on the northeast Newfoundland Shelf (Lewis and Barrie, 1981). In water depths between 60 and 160 m or greater on the northeast Banks, a second sparse population of fresh-looking ice-scour marks is superimposed over the older pattern of partially buried scour marks (second figure). These well-defined scour marks appear as elongated linear to curvilinear features that are believed to represent the current episode of ice scouring that began on the Banks after the rise in sea level approximately 10,000 y ago.

Using sidescan sonar and high-resolution seismic profiler data, the morphology of the scour marks that form the modern Holocene population has been well documented and incorporated into a regional ice scour data base (d'Apollonia and Lewis, 1981; Geonautics, in preparation). These geophysical mapping tools, coupled with direct observations of scour



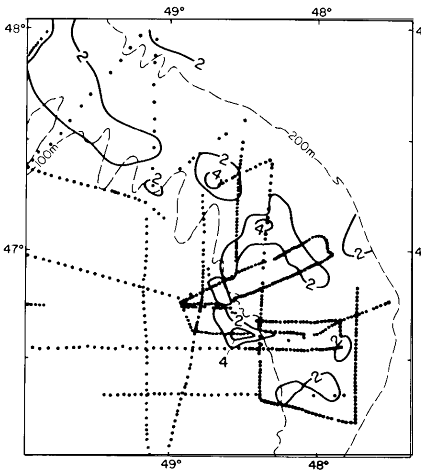
1. Map showing tidewater glaciers and drift paths of icebergs onto the Grand Banks of Newfoundland. (From Mobil Oil Canada Ltd., 1980, after Robe 1980.)



2. A sidescan sonograph of the Grand Banks seabed (at 133-m water depth) showing two populations of iceberg scour marks: a younger set of narrow continuous features superimposed on a degraded, discontinuous net work of older scour berms (ridges).

marks from manned submersibles, have enabled scientists to develop an in-depth understanding of the characteristics of iceberg scours and the physical processes creating them.

Regional analyses show that the average density of the observable Holocene scour population on the northeast Grand Banks ranges from 0-4 scours per square kilometre (third figure) with the highest scour concentrations occurring in water depths of 130 to 160 m (d'Apollonia and Lewis, in preparation). Scours measured from sidescan sonar records are from 10 to 100 m wide with the average maximum width increasing from 24 m in water depths of 60-80 m to 43 m in depths of 140-160 m. Scour depth can be measured from heave compensated Huntec deep tow seismic records. In the northeast Grand Banks, average scour depth varies from 0.5 m in water depths of 60-80 m to 1.2 m in depths of 140-160 m (Lewis and Barrie, 1981). Scour orientations on the top of the Banks change direction frequently whereas those in deeper water tend to be more linear. This trend is believed to reflect an increase in the control of ocean currents on iceberg drift patterns in deeper water (King and Gillespie, in press). The



3. Map of the northeast Grand Banks showing the distribution of iceberg-scour mark density in scours per square kilometre (heavy contours). Tracks of sidescan sonar are shown by the. . . symbol: bathymetry is in metres (the dashed contours).

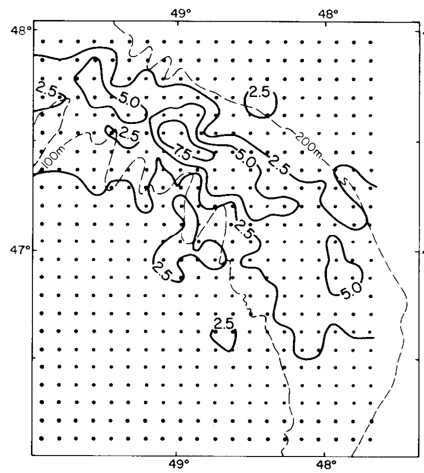
deepest measured scour (9 m) occurs on the edge of the Avalon Channel (d'Apollonia and Lewis, 1981). The deepest recorded scour feature (5.4 m) is in the greater Hibernia area (Lewis and Barrie, 1981), but some circular depressions now believed to have been formed by icebergs have depths exceeding 10 m (Barrie *et al.*, in press).

Direct observation of iceberg scours as they are preserved on the seafloor today gives little indication of their age, the number of icebergs that scour the seafloor in any given year, or in fact the physical parameters of the scours at the time of formation. Infilling of a scour with sediment or by other processes of degradation can significantly modify scour appearance over time. Some indication of the relative age of scours can be obtained in areas of fairly dense scouring when cross-cutting of older scours by more recent features occurs. Repeat surveys of a specific area over a period of several years can be used to identify new scours and to evaluate the rate of degradation of existing scours. In an area where scour density is low, however, it may take many years using such a method to obtain a sufficient population of scours for the analysis to be statistically significant.

A method of modelling the scour population and the rate of scour additions is therefore required to provide an input into risk analyses leading to the design of oilfield transmission lines and other seabed installations. Such a model should provide statistical information on the number of icebergs impacting a particular area over a period of time and the depth of scour to be expected from these impacts, because it is this information that is of most relevance in the protection of a seafloor system.

Two approaches have been used to develop grounding models. The first (Gaskill *et al.*, 1985) assumes a relationship between scour formation and scour degradation and uses observed iceberg scour data with reasonable values for sediment infilling to relate the observed scour parameters to those at the time of formation. In this way measurements on the scours as they are now observed on the seabed can be used to determine the distribution of initial scour depths (i.e., depth at time of formation) as well as the frequency at which scouring has occurred over a particular period. The second model (d'Apollonia and Lewis, in press), uses measured information on iceberg flux and draft together with bathymetry to calculate directly the number of iceberg groundings in each of a number of cells in the area. This model has yielded results (fourth figure) in which the spatial pattern of modelled groundings in the northeast Grand Banks is visually similar to the pattern of mapped iceberg scour marks on the seabed (third figure).

Both mapped scour marks (third figure) and modelled groundings (fourth figure) are most abundant between the 100 m and 200 m isobaths and decline in density both upslope and downslope. The density ridge of scour marks (and groundings) between 100 and 200 m is interpreted to reflect the route by which most icebergs pass through the region via the Labrador Current. The upslope decrease may signify a lesser flow of water and ice onto the Banks relative to the core of the Current - hence, fewer groundings. The downslope decrease in scour mark density is interpreted as the limiting zone in which even the deepest iceberg keels contact the seabed infrequently. Other influences, not yet modelled or corrected, such as incomplete scour detection, preferential scour obliterations by waves and currents, and variations in iceberg draught, flux, or trajectories, etc., may account for the differences between the third and fourth figures.



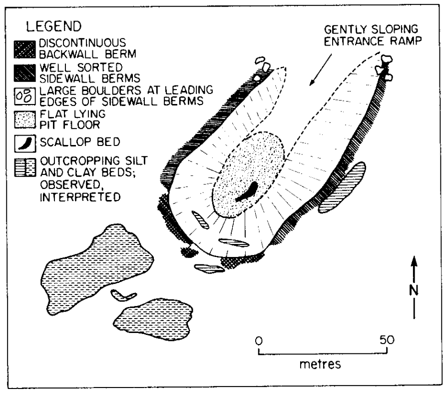
4. An example of a modelled output showing the number of calculated iceberg groundings per square kilometre (heavy contours) for a 1000-y period given the present mean iceberg flux and draught distribution onto the northeast Grands Banks. Centres of model cells are shown by the . . . symbol: bathymetry is in metres (the dashed contours).

Pits or circular depressions in the seafloor have a similar density of distribution to those of modern iceberg scours and were first defined by Fader and King (1981) as "iceberg pits" because of their often close association with linear iceberg scours. King and Gillespie (in press) note that short scours and pits are commonly observed in a relatively narrow zone at the Banks' edge wherever the break in slope is sharp. The maximum reported penetration of all measured iceberg pits into the underlying sediments on the Grand Banks of Newfoundland is 8 m (Mobil Oil Canada Ltd., 1985). (Pits can be up to seven times deeper than the deepest iceberg scour within the 80 to 120 m bathymetric corridor).

Depressions or pits in the seabed have been documented in numerous site specific and regional geological and geophysical survey lines on the Grand Banks of Newfoundland (Amos and Barrie, 1980; Fader and King, 1981; Lewis and Barrie, 1981; Fader *et al.*, 1985; Barrie *et al.*, in press). These features range in width from 30 to 350 m and in depth from 0.5 to 8.0 m with an average depth of 3.0 m (Mobil Oil Canada Ltd., 1985). Based on observations by manned submersible, the pits are elliptical to circular in shape.

The origin of these iceberg pits has been a subject of controversy. The profiles show a low amplitude berm, which is commonly associated with iceberg scouring mechanisms. It has also been suggested that these features could be "pockmarks" originating from the erosion of underlying clays initiated by the ascension of gas or water (gasturbation) (e.g. King and MacLean, 1970; Josenhans *et al.*, 1979; Hovland, 1981). However there has been no shallow gas detected in the Hibernia area (Mobil Oil Canada Ltd., 1985). Another possible mechanism suggested has been related to thermokarst (Mobil Oil Canada Ltd., 1985), but there is no evidence to support this interpretation.

In October 1984 and August 1985, scientists from the Centre for Cold Ocean Resources Engineering of Memorial University, Atlantic Geoscience Centre, Mobil Oil Canada Ltd., and the Biology Department of Memorial University participated in an investigation of a circular 100-m-wide depression located 11 km east-southeast of the Hibernia P-15 discovery well. The investigation used the Canadian Navy's SDL-1 submersible and its support vessel HMCS *Cormorant* to visually supplement sidescan sonar and subbottom profiler measurements of the pit's size and shape (Barrie *et al.*, in press). The results of these observations, illustrated in the fifth figure, strongly indicate that the elongated depressions up to 10 m deep found on the northeastern Grand Banks are iceberg-formed pits, where the iceberg loading on the seabed results in a bearing capacity failure and subsequent pit overdeepening. The particular depression investigated occurred at a depth of 87 m and was 10 m deep. From observations of sediment in the pit, it is considered to have been formed within the last 100 y. The recent occurrence of these overdeepened iceberg pits and the process of sediment failure causing the overdeepening are clearly important when considering the design of gravity-based platforms for the development of the Hibernia field.



5. Schematic plan view of a 10-m deep iceberg pit on the northeast Grand Banks based on submersible observations. See previous article (fifth figure) for an interpretation of the same feature.

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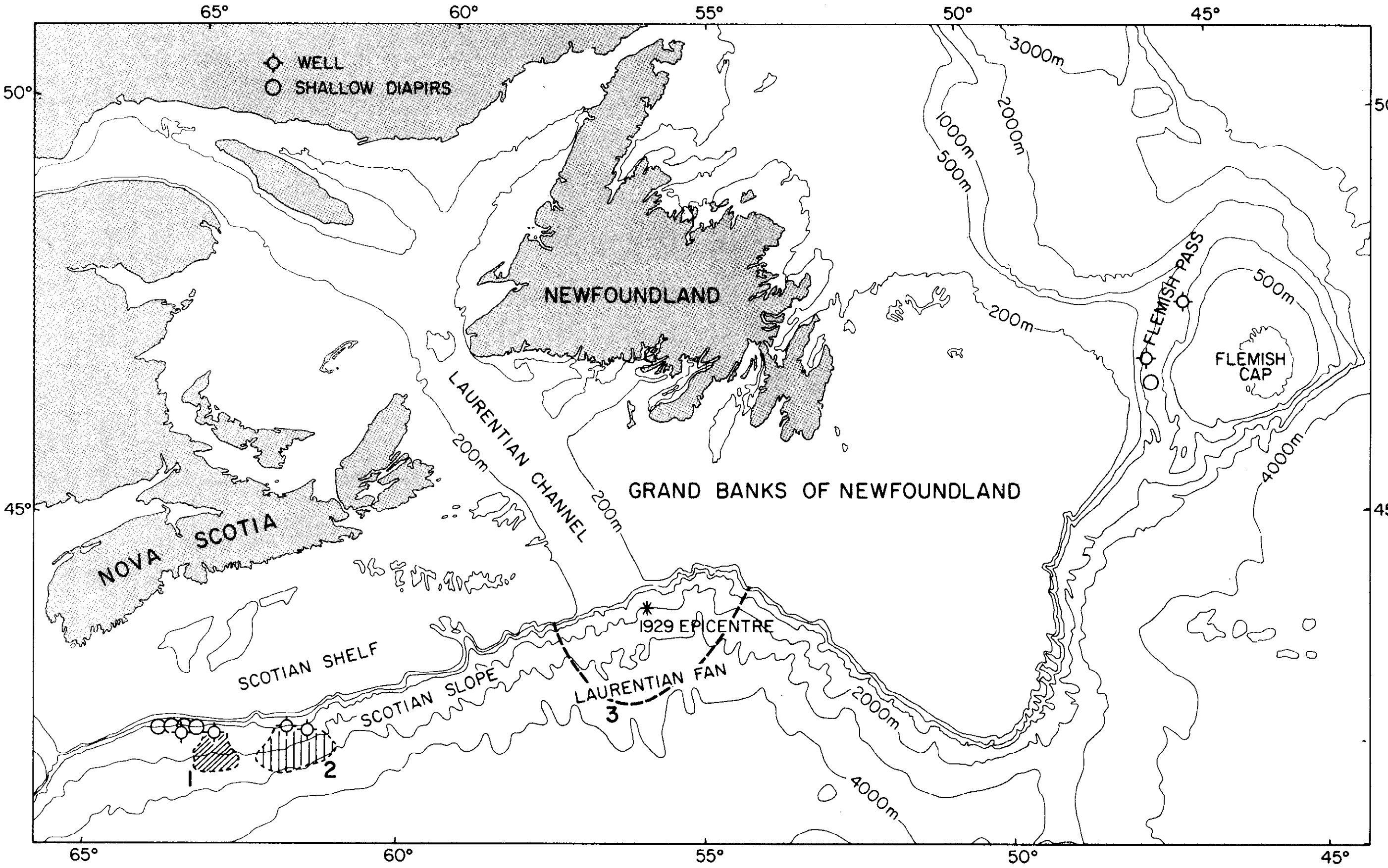
Seabed stability on the continental slope adjacent to the Grand Banks

D.J.W. Piper

On November 18, 1929, a large (magnitude 7) earthquake occurred on the continental slope off the southwest Grand Banks. Twenty eight lives were lost in southern Newfoundland as a result of coastal inundation by the tsunami produced by the earthquake (Doxsee, 1948). Submarine landslides were triggered on the continental slope within 100 km of the epicentre (Piper *et al.*, 1985) and about 200 km^2 of gravel, sand, and mud were transported many hundreds of kilometres in a powerful turbidity current. Deep-sea telegraph cables were cut almost instanteously by landsliding near the epicentre, and by the turbidity current at progressively later times away from



1. Location of deep water wells and sediment instability features on the eastern continental margin of Canada. Area (1) has abundant surface and subsurface flows: area (2) contains surface features associated with the earthquake 15,000y ago; and area (3) contains surface features associated with the earthquake of 1929.

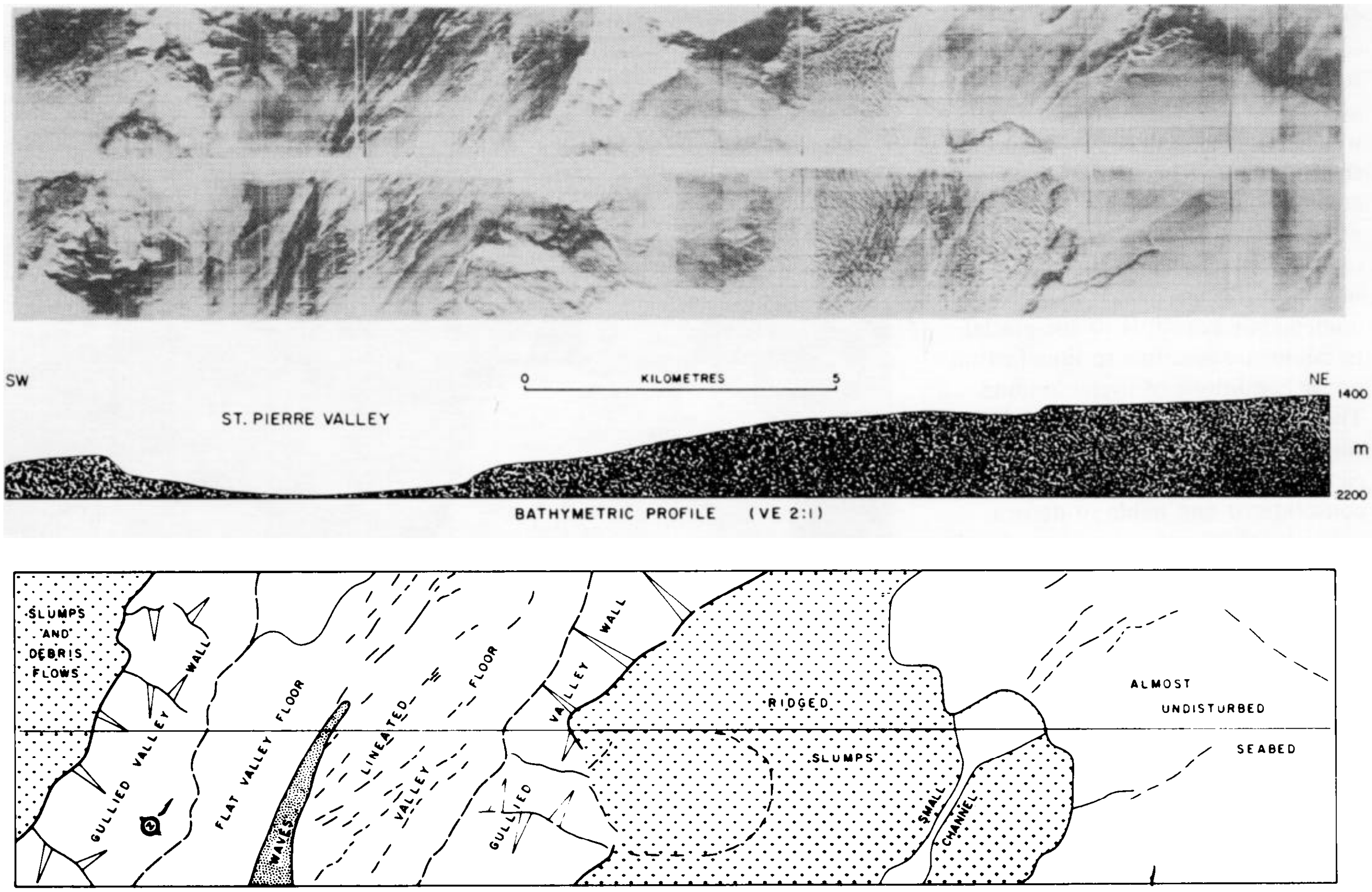
the epicentre. The last was cut 13 h after the earthquake. These more distant cables were presumably cut by the turbidity current, and allow us to estimate velocities for the turbidity current of up to 65 km/h on the 2.5° slopes.

There are a number of immediate questions that the 1929 earthquake raises concerning hydrocarbon development on the Grand Banks. Is another earthquake likely in the same area or elsewhere on the Grand Banks? What would be the effect of such an earthquake on engineering structures on the Grand Banks? How stable is seabed sediment on the steep continental slope in areas such as Flemish Pass and the Scotian Slope where exploration is now taking place?

The probability of future earthquakes of a given magnitude (but not their precise timing) can be estimated where there is good historic data on past earthquake activity. The Earth Physics Branch of the Department of Energy, Mines, and Resources in Ottawa is the agency responsible for this work: its results are available as a seismic zoning map in the National Building Code. Unfortunately, because of the distant offshore location of the Grand Banks and the small number of seismographs at adjacent land stations, our knowledge of the distribution of past earthquakes is inadequate for accurate prediction of earthquake risk on the outer part of the Grand Banks (Basham *et al.,* 1983).

Research at BIO has been contributing in two ways to a better understanding of earthquake activity in this area. Ocean bottom seismometers developed at the Institute have been deployed on the seabed for two months in the vicinity of the 1929 earthquake epicentre to try to detect very small modern earthquakes in this area: only two local quakes within the detection limits of the equipment were monitored.

The other technique has been to use new, deep-towed, geophysical techniques such as sidescan sonar and seismic reflection profiling to try to locate the sites of large earthquakes that occurred in the past. This is done by recognizing landslides and other features similar to those produced in 1929 that formed during earlier earthquakes and have subsequently been buried by younger sediment. This younger sediment, if dated, provides an estimate of the age of the earthquake activity. This type of work shows that large earthquakes of the size of the 1929 event are rare on the eastern Canadian continental margin: there was probably one south of Halifax some 15,000 y ago (Piper *et al.,* in press), and one twice as old as that in Flemish Pass (Pereira *et al.,* 1985). The 1929 earthquake was probably the only such event in as many as 100,000 y in that area off the southern Grand Banks. Although our studies are not yet complete, and the data base is still inadequate, there is good geological evi-

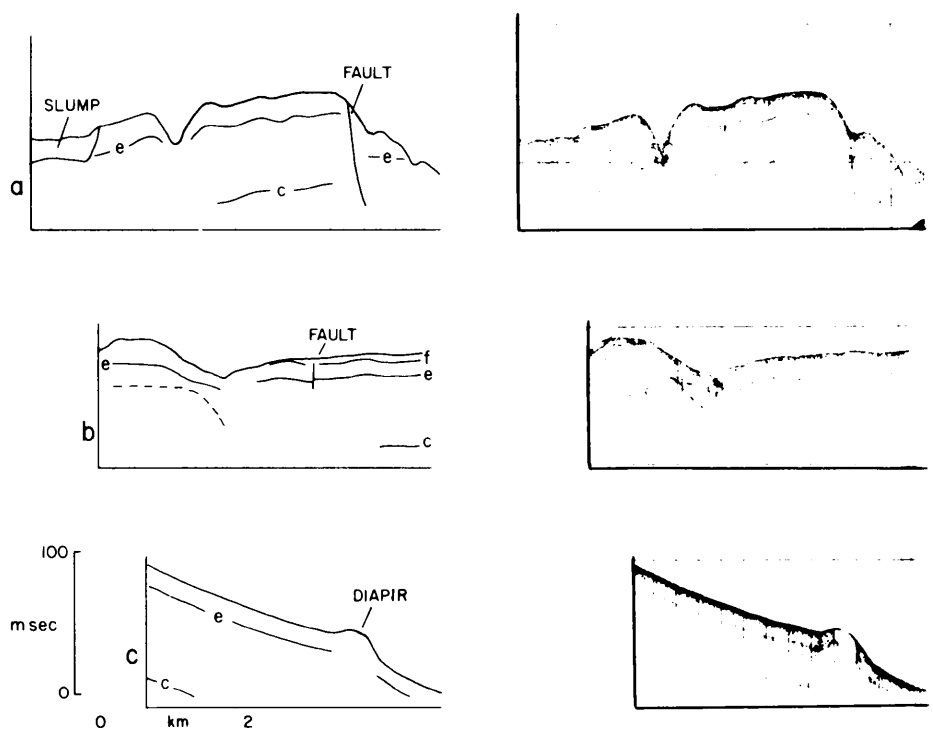


2. Seismic reflection profiles showing shallowing diapirism and faulting on the Scotian Slope.

dence that large earthquakes occur very infrequently around the Grand Banks. It seems likely that for producing hydrocarbon fields on the continental shelf, the forces on structures due to icebergs and waves will be greater than those likely from any earthquake activity.

On the steep continental slope, beyond the edge of the continental shelf, there may be a greater risk of seabed landsliding, triggered either by earthquakes or by other geological processes such as slope oversteepening as a result of valley erosion, or overloading by rapid sediment deposition. The geological conditions on the continental slope off eastern Canada are different from those on most other slopes where hydrocarbon exploration has taken place, such as in the Gulf of Mexico, so that there is a lack of prior experience for analyzing slope stability in the east coast offshore.

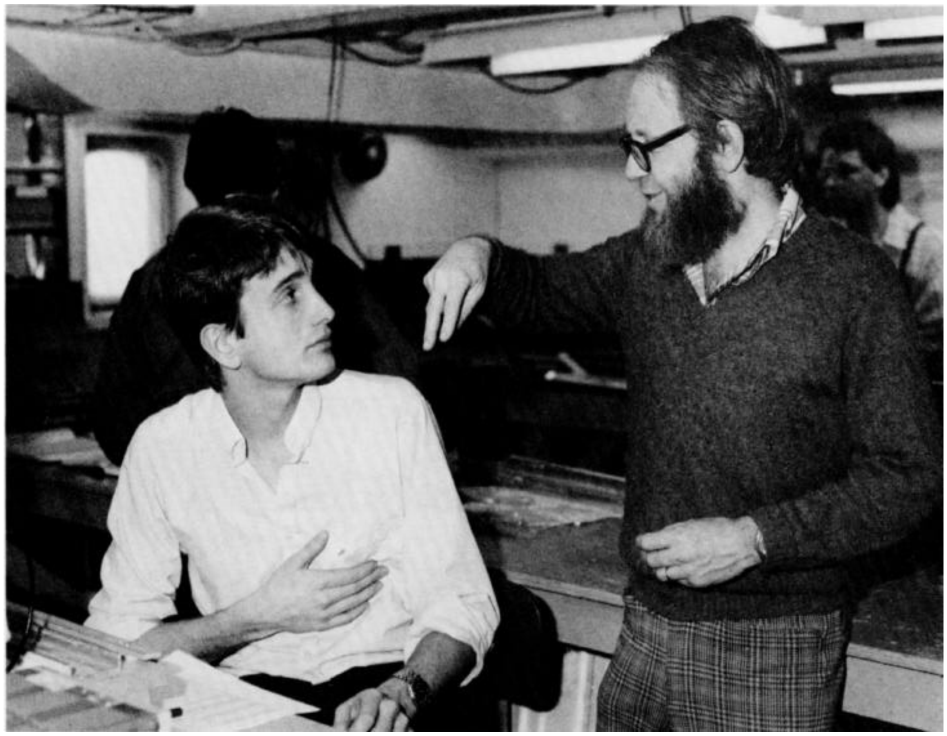
Our studies of submarine landslides around the 1929 earthquake epicentre



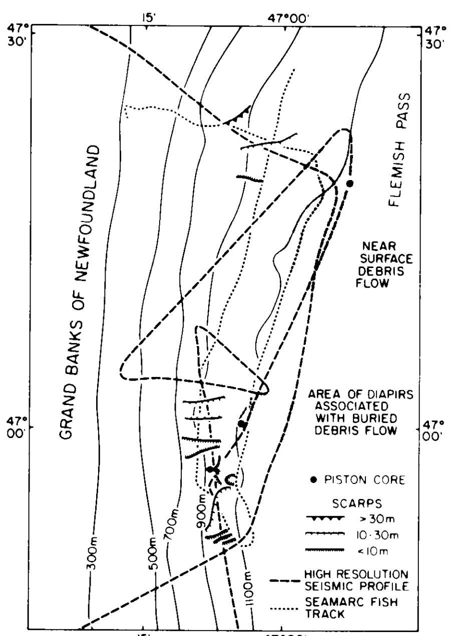
3. SeaMARC sidescan sonograph showing results of rotational slumping triggered by the 1929 Grand Banks earthquake.

and on the Scotian Slope show that sediment instability is closely related to sedimentation that occurred 50,000 y ago when large continental ice sheets were grounded across the continental shelf (King and Fader, 1985). In many areas this grounded ice extended to water depths of about 500 m at the top of the continental slope. The fine sand and silty sediments deposited immediately seawards of the glacial terminus are sensitive to liquefaction under conditions of cyclic loading. The finer muds deposited rapidly from suspension further away from the glacier margin may in places be underconsolidated and liable to deform either by slow surface creep or by the upward movement of subsurface masses of mud in shallow diapirs.

In order to better understand the potential problems posed by sediment instability on the continental slope, a program of geotechnical sampling and testing is being carried out, partly under contract and partly in co-operation with the Technical University of Nova Scotia and the National Research Council of Canada, and in a new geotechnical research laboratory at the Atlantic Geoscience Centre. This program has required new sampling and measurement techniques, which are being developed through the international Long Coring Facility co-ordinated by the University of Rhode Island, and through projects under the National Research Council's PILP program with Huntec (Seabed II project) and NORDCO (tripod mounted cone penetrometer).



John Hughes Clarke and David Piper in C.S.S. Hudson's general-purpose laboratory.



4. Interpretative map of seabed instability features in Flemish Pass.

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chapter 3

Physical and chemical oceanography

The Grand Banks is the most popularly known of the Canadian continental shelves due to its important economic role in Canadian history from the early activities of European fishermen through to the present day interest in the Hibernia oil field. From an oceanographic perspective, it is part of the continuous complex of prominent continental shelves found along the east coast of Canada, shelves that because of their extent have physical and chemical processes and water characteristics of their own. In this respect the Grand Banks is no exception. It is the meeting ground of the major surface currents of the western North Atlantic: the Labrador Current, the Gulf Stream, and the Gulf of St. Lawrence outflow. It is also the southern boundary of the Labrador ice sheet and melting ground for most east-coast icebergs. The Labrador Current with its various branches following through the Strait of Belle Isle, the Avalon Channel, and the eastern continental slope interacts and mingles with the waters of the Gulf Stream along the southern edges of the Banks and with the estuarine waters of the Gulf of St. Lawrence to the west. The meeting and mixing of these various waters in and around the Banks create a relatively complex and challenging area for physical and chemical oceanographic research.

The Atlantic Oceanographic Laboratory (AOL) with its expertise in physics, chemistry, and metrology, has over the past two decades made a significant effort to improve the description and understanding of the Banks. As will be apparent in the following articles, the majority of these studies are multidisciplinary for success in one discipline today is often critically dependent upon results or technology available from another. An excellent example of this is our recent enhancement of sea ice and iceberg studies. We have undertaken to develop models suitable for routine seasonal and interannual forecasting of ice extent near the Hibernia oil field. The models of ice distribution require both a prediction of growth and decay locally and of advection under the influence of wind and currents. As indicated above, these major current systems can influence water motion and properties (temperature) over the area of the Banks and each of these may be influenced by larger-scale oceanic or global processes. As such, this ice program is heavily dependent upon the measurements and models of currents, winds, and water properties throughout the east coast system. To monitor ice extent and movement we utilize recently available satellite imagery and analysis systems and location beacons that communicate via satellite. Our numerical modelling requires the power of our largest computers. Without the broad-based expertise and technology available within the Laboratory, tackling this difficult problem and many of the others described in this section would not be possible.

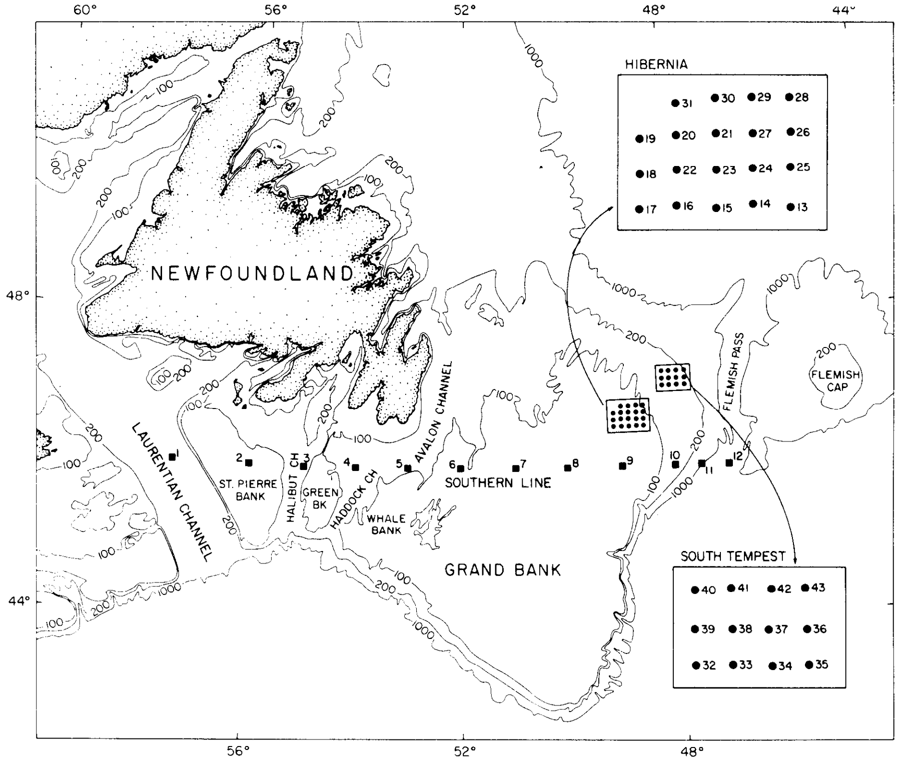
- J.A. Elliott
Director
Atlantic Oceanographic Laboratory

Background levels of petroleum residues and their origin on the Grand Banks

E.M. Levy

Eric Levy.

The Grand Banks region, long one of the most important fisheries of the North Atlantic, has recently been shown to hold one of the largest reserves of petroleum in the western world. As most of the area is contained within the 200-mile territorial limit, Canada has been confronted with the dilemma of obtaining the maximum benefit from the petroleum resource without unduly jeopardizing the fishery. The most obvious threat to living resources is, of course, a major spill associated with blowouts such as those that have occurred in the Gulf of Mexico and the North Sea. The *Ocean Ranger* disaster has already emphasized the hazard inherent in petroleum exploration and production in the very hostile environment of the Grand Banks. Less dramatic, but no less damaging environmentally, are the cumulative effects of the day-to-day losses that are incurred during normal operations. To maximize the benefits from the resources of the region, it is clear that an “early warning” is needed to signal when damage to renewable living resources is imminent and corrective action must be taken. Because an essential first component of the required monitoring program is an assessment of the background levels of volatile hydrocarbons and petroleum residues in the region before any production of crude oil commences, a study of the region was carried out from CSS *Dawson* in April 1981 (Levy, 1983). The study included examination of background levels of particulate petroleum residues floating on the sea surface, of volatile hydrocarbons and of dissolved/dispersed petroleum residues in the sea-surface microlayer and throughout the water column, and of petroleum residues in the surficial bottom sediments along a line of stations extending from the Laurentian Channel across the Grand Banks to Flemish Pass and at the Hibernia and South Tempest sites where exploratory drilling was in progress. In addition, ancillary chemical analyses were carried out to identify the origin of the material responsible for the existing background level.

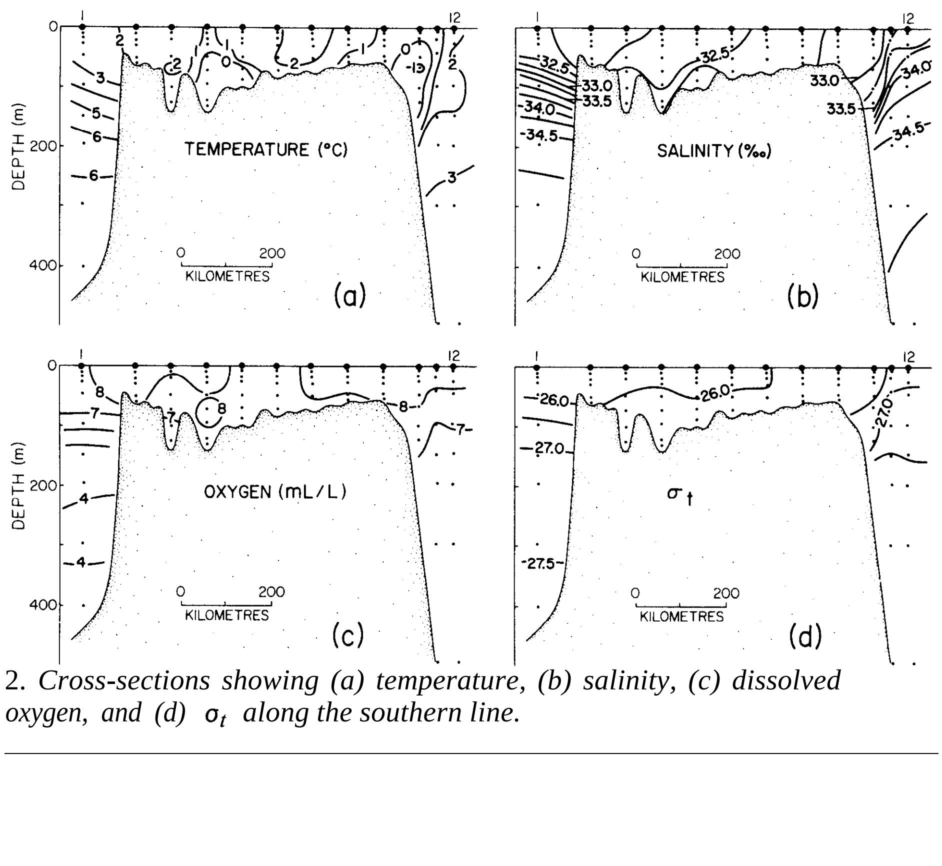


1. *General bathymetry of Grand Banks area and the locations of stations at which sampling was carried out (April 7- 17, 1981).*

Hydrochemistry and general circulation

The waters of the Grand Banks are dominated by the inshore portion of the Labrador Current, which flows onto the northern portion of the Banks and then spreads southward in a complex system of seasonally and locally variable currents. In spring, the upper layers of this water are modified by the annual influx of cold, low salinity water from melting sea ice and of freshwater from run-off along the Newfoundland and Labrador coasts. Warmer and more saline water present along the continental slope occasionally intrudes onto the Banks in response to meteorological conditions. Mixing of these waters in conjunction with seasonal warming accounts for the chemical and physical properties of the water in each of the areas studied and is a major consideration in interpreting the observed distribution of petroleum-related substances.

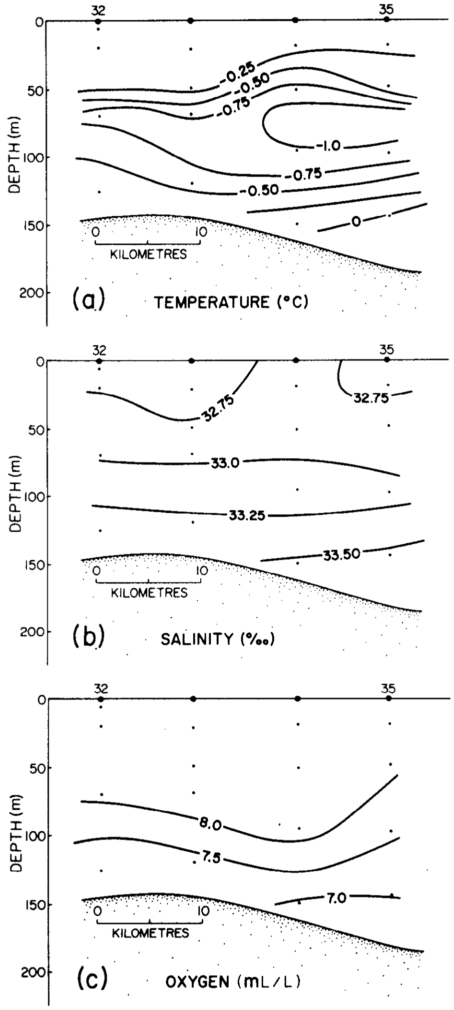
The hydrochemistry of the Grand Banks region at the time of the study is illustrated by the second figure. Slope water (>5.0°, >34.5°/$_{oo}$, 5.1 ml/l) was present below about 150 m in the Laurentian Channel and



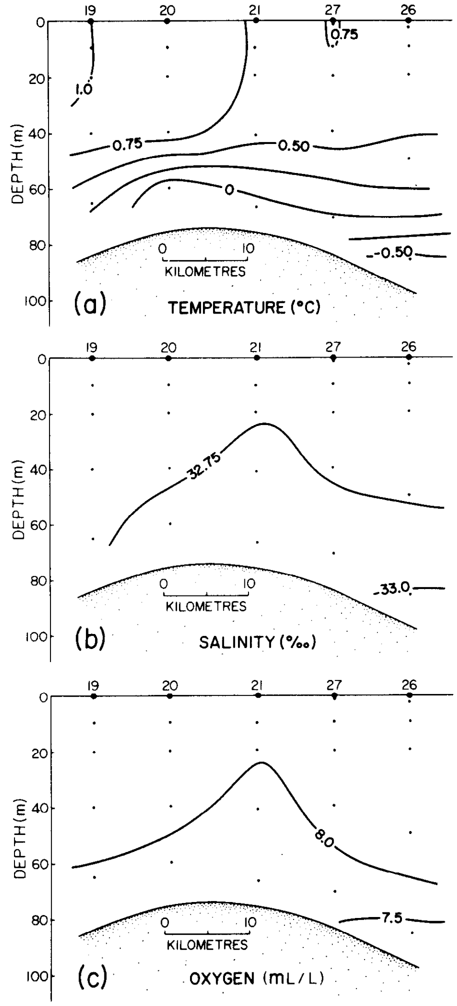
2. *Cross-sections showing (a) temperature, (b) salinity, (c) dissolved oxygen, and (d)* σ_t *along the southern line.*

along the western slope of the Banks whereas a core of Labrador Current water, which gave rise to the low temperatures throughout the water column at stations 10 and 11 and near the bottom at station 8, was found along the seaward slope of the Banks. Over the Grand Bank (stations 5-8), temperature, salinity, and dissolved oxygen concentrations were very uniform (1.5 ± 0.5°C, 32 ± 0.25°/oo, 8.0 ml/l, while the small differences in the properties of the water east to west over Grand, Green, and St. Pierre banks reflected the admixture of differing proportions of modified Labrador Current water and slope water. For example, at station 4, which was directly in the flow of modified Labrador Current water through the Avalon and Haddock channels, temperatures were lower and salinities and dissolved oxygen concentrations higher than at the neighbouring stations on the slope of Green Bank (station 3) and on the slope of Whale Bank (station 5). Conversely, the higher temperatures at station 7 indicate an intrusion of slope water onto the bank. Throughout the region, vertical mixing from the storms of late winter and early spring resulted in temperatures and salinities that were almost uniform, concentrations of dissolved oxygen that exceeded the saturation value, and densities that were almost invariant throughout the upper 50-60 m at each station. Below this homogeneous layer, the density of the water over the Banks increased to the bottom because of the increasing salinity and decreasing temperature, and there was a slight decrease in density in the east to west direction across the Banks.

At the South Tempest grid (third figure), temperatures throughout the water column were below 0°C except at the bottom, and a temperature minimum layer with values as low as - 1.32°C was present at 80-120 m. Dissolved oxygen concentrations were 7.5 - 8.2 ml/l within the layer, >8 ml/l above it, and <7 ml/l below it. The temperature-minimum layer presumably was a remnant of the previous winter's cooling, while the water above this was Labrador Current water modified by meltwater and



3. *Representative cross-sections showing (a) temperature, (b) salinity, and (c) dissolved oxygen data for the South Tempest grid.*



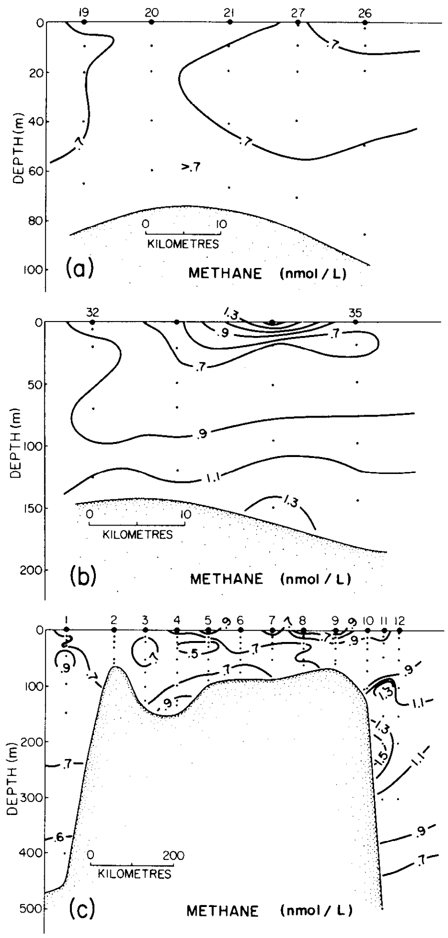
4. *Representative cross-sections showing (a) temperature, (b) salinity, and (c) dissolved oxygen data for the Hibernia grid.*

slight seasonal warming; the water below the layer was relatively unmodified Labrador Current water. At the Hibernia grid (fourth figure), which was farther from the edge of the continental shelf and where water depths were considerably less, the unmodified Labrador Current water was less prominent. The general temperature level was appreciably higher because of the more advanced seasonal warming at the lower latitude, and temperatures increased in the north to south and east to west directions. Negative temperatures were present near the bottom on the two northern lines but, with the exception of station 25, not on the two southern lines. The properties of the deeper water in this area were very similar to those at the same depths at the South Tempest grid, although there was no indication of a temperature minimum layer. In both areas, the upper 50 m was homogeneously mixed by the stormy conditions that prevailed at the time.

Volatile hydrocarbons

Water Column - Methane was the only volatile hydrocarbon present (detection limit 0.02 nmol/l) in all but only a very few of the 234 water samples collected on the Grand Banks. In the rare cases when ethane, propane, and higher molecular weight volatile hydrocarbons were detected, their concentrations were never more than a few per cent of that of methane, which suggests that the methane was predominatly of recent biological origin rather than from natural seepage or other escape of volatile hydrocarbons from the seabed.

Concentrations of methane ranged from 0.41 to 1.8 nmol/l, with the vast majority of the values in the 0.45 to 0.90 nmol/l range. Such highly skewed data sets are best analyzed by lognormal statistics, and the geometric mean of 0.74 nmol/l is an appropriate measure of the general background level for the region as a whole. When sorted geographically, the backgrounds for the Southern Banks, Hibernia, South Tempest, Flemish Pass, and Laurentian Channel areas were 0.70, 0.68, 0.86, 0.90, and 0.65 nmol/l, respectively. At the Hibernia area, methane concentrations were remarkably uniform, with 92% of the values in the range of 0.69 ± 0.09 nmol/l (fifth figure, part A), reflecting the high degree of mixing that was occurring throughout the water column at the time. All the values exceeding this interval were encountered at the eastern and southeastern portion of the grid and seem to be a feature of the relatively unmodified component of Labrador Current water. This was also suggested by the higher general background level of methane at the South Tempest grid (fifth figure, part B) where the Labrador Current water modified by the meltwater dominated and by the higher concentrations of methane at stations 8-11 on the southern line (fifth figure, part C) where there was a strong component of Labrador Current water. At the South Tempest grid, the methane distribution in the water column was more complex in keeping with the more heterogeneous character of the water. At this site the range of concentrations was greater (0.59-1.75 nmol/l), and concentrations increased with depth. Along the southern line (fifth figure, part C), concentrations of methane in the upper 100 m were, for the most part, between 0.45 and 0.90 nmol/l. At stations 8-11, however, a patch of water contained concentrations of 0.90-1.35 nmol/l. This was in the core of Labrador Current water, and therefore, its methane concentration was more in keeping with that at the South Tempest grid than those elsewhere on the Southern Banks and Hibernia grid.



5. *Representative cross-sections showing methane concentrations at the (a) Hibernia grid, (b) South Tempest grid, and (c) southern line.*

Again, it would seem that the slightly higher methane concentrations in the water over the edges of the banks were the consequence of enhanced biological processes.

The background level of volatile hydrocarbons in the water of the Grand Banks at this time was only 25% of the concentrations reported by Lamontagne *et al.* (1973) in the surface waters of the Norwegian Sea (2.3-3.5 nmol/l) and the Greenland Sea (3.3-5.1 nmol/l) and of those reported by Scranton and Brewer (1977) in the western subtropical North Atlantic (1.5-5.7 nmol/l. This, presumably, was a reflection of low rates of biological activity on the Grand Banks during early spring when water temperatures and light levels were low.

Surficial Bottom Sediments - Total concentrations of volatile hydrocarbons in surficial bottom sediments along the southern line and on the Hibernia grid ranged from 0.05 to 0.41 mmol/l and from 0.81 to 3.2 mmol/l while those of methane ranged from 0.45 to 2.19 nmol/l (sixth figure). Sediments from the former area varied widely in grain size and texture and, at some locations, were devoid of volatile hydrocarbons. Those collected at the Hibernia grid were much more uniform and the contour plots indicated that the highest concentratons were on the western portion of the grid. It is tempting to surmise that this might be indicative of underlying gas and oil, and some credence to this hypothesis is provided by the presence of appreciable amounts of ethane, propane, and butane. Indeed, the ratios of the concentrations of methane to the combined concentrations of ethane and propane were well within the range (0- 10) commonly accepted as indicative of gas of fossil origin as opposed to gases of recent biogenic origin, which typically have ratios of 10^{-3} to 10^{-4} (Bernard *et al.,* 1977).

Petroleum residues

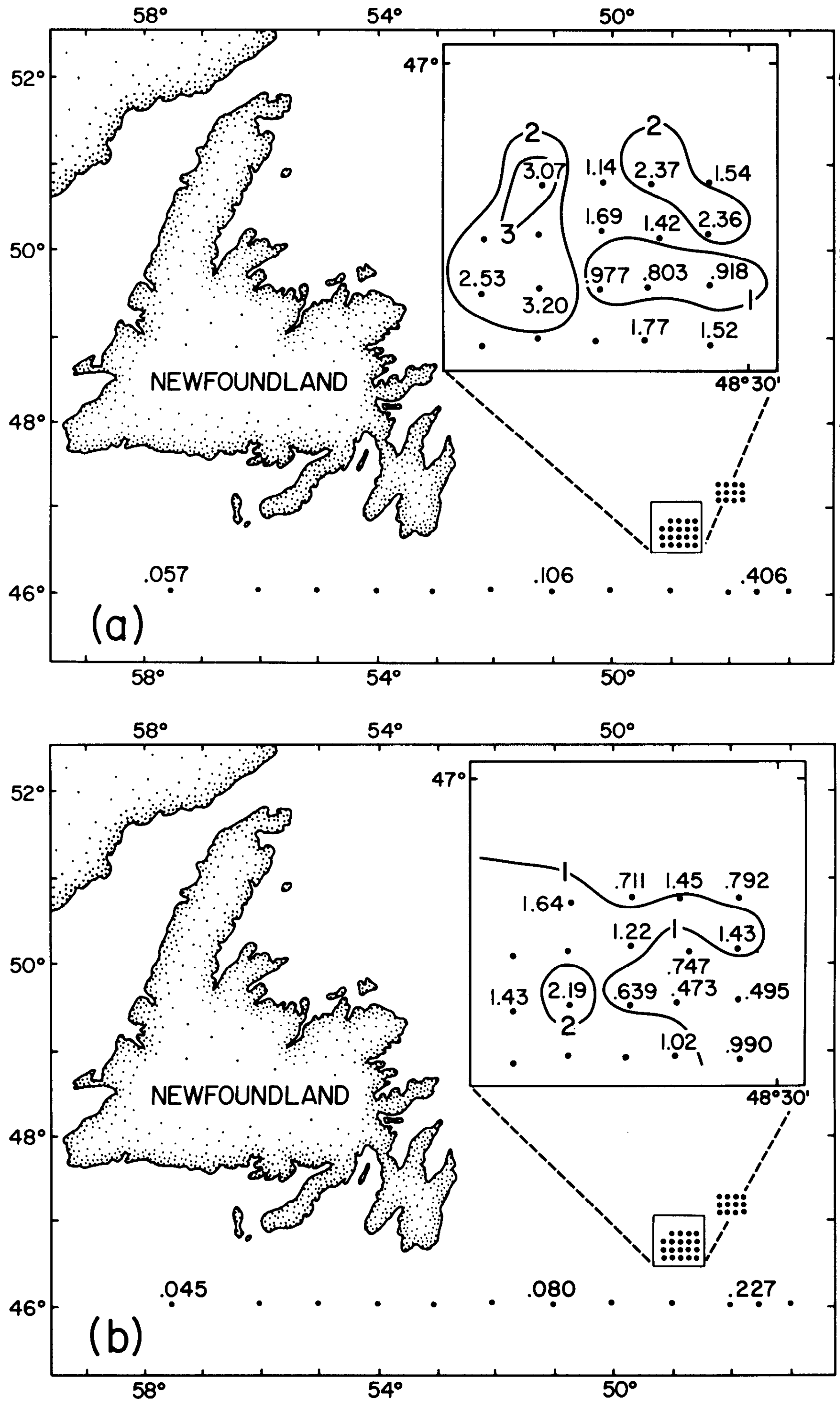
Surface Slicks - Visual observations of the sea surface failed to detect any oil in the form of slicks along the southern line (stations 1-12), although meteorological and oceanographic conditions were favourable for their formation and detection. During the remainder of the cruise, high winds and rough seas would have prevented the formation of slicks even if oil had been present.

Floating Particulate Petroleum - Samples for the estimation of floating particulate petroleum residues were collected at the first 27 stations after which it became too rough to deploy the sampler. Concentrations of floating tar ranged from 0 to 85 µg/m^2 (seventh figure), although almost two-thirds of the samples contained no evidence of tar. Analysis by gas chromatography suggested that all samples were the weathered remains of oil discharged from ships.

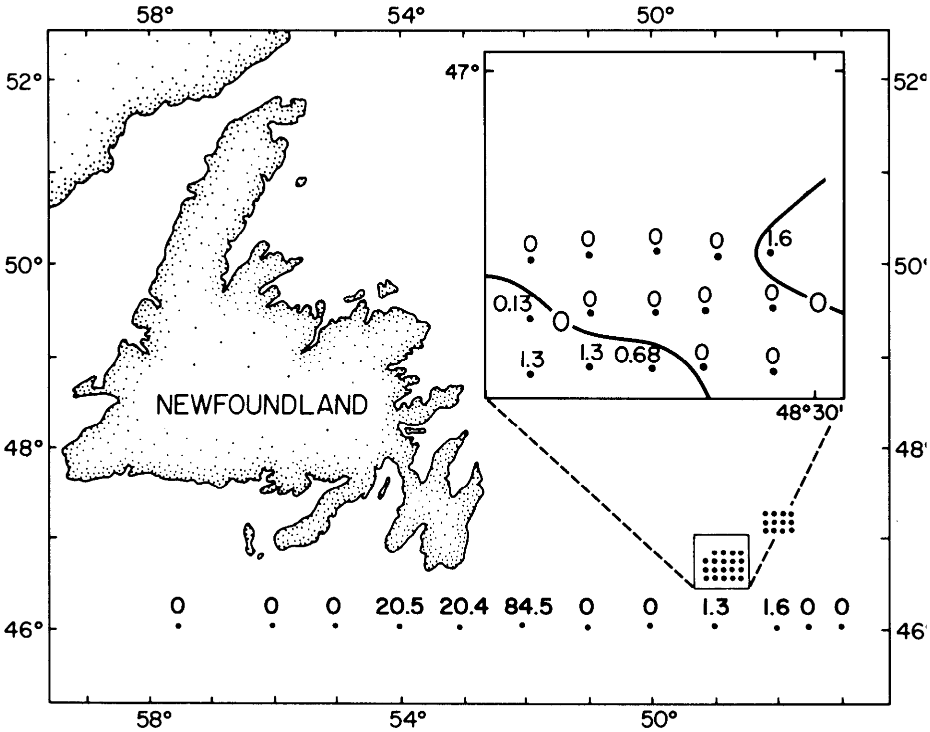
Although there were too few data to estimate the background level, data collected for the northwest Atlantic between 1971 and 1974 suggested that the background level at that time was less than 10 µg/m^2 (Levy and Walton, 1976). Since tar concentrations increased abruptly in waters dominated by the Gulf Stream and were virtually zero to the north, it would seem that the tar found at stations 4, 5, and 6 had been carried there from the south. Thus, the values for the other stations were probably more representative of the general conditions on the Grand Banks and indicated that the southward flow of unpolluted Labrador Current Water was continuing to maintain relatively pristine conditions insofar as floating tar was concerned.

Dissolved/Dispersed Petroleum Residues - Concentrations of dissolved/dispersed petroleum residues in the *sea surface microlayer* of the Grand Banks during April 1981 ranged from 14 to 440 µg/l, although most of the values were in the range of 25-50 µg/l. The general level of contamination as indicated by the geometric mean was 28.9 µg/l, considerably higher than the level of 7.5 µg/l observed in Baffin Bay in 1977 (Levy, 1980). This was probably a direct consequence of the higher level of human activity in the area. Further, as shown by the contour plot (eighth figure), a contaminated area was present at the Hibernia site "downstream" from the drill rig *Ocean Ranger* and within the zone of its support vessels. Thus, there was a strong implication that the elevated concentrations (up to 440 µg/l) in this area were a direct consequence of their activities and, with this as the main source, the observed distribution of the surface contamination was readily attributable to the south-southwesterly flow of surface water. It is apparent, therefore, that the oil industry, even at the level of its operations in April 1981 was already having a detectable effect on the concentration of dissolved/dispersed petroleum residues in the surface microlayer.

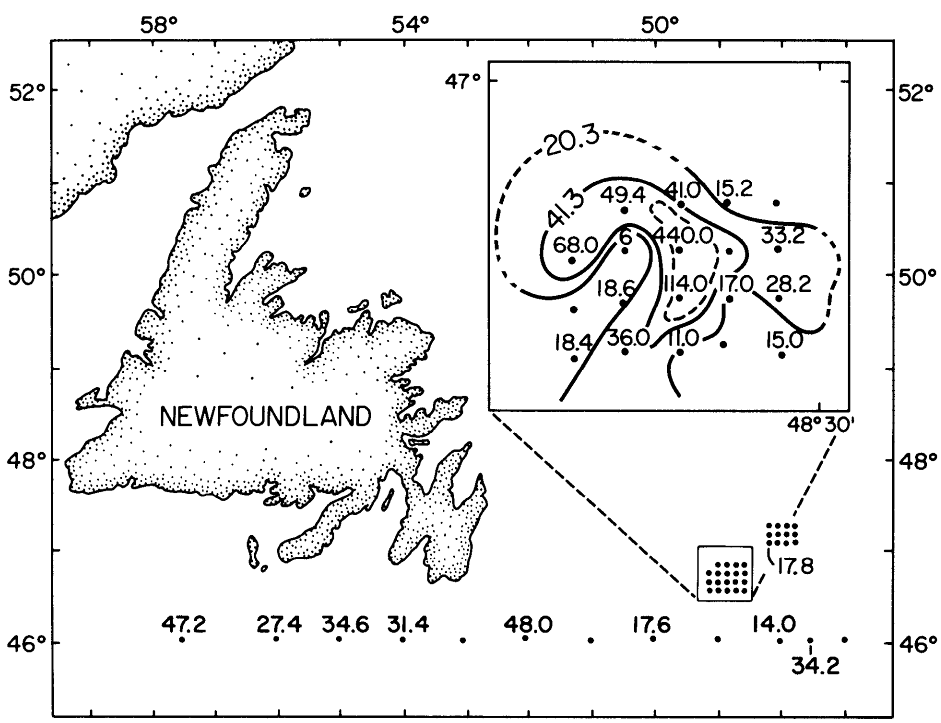
Concentrations of dissolved/dispersed petroleum residues in the *water column* ranged from 0.05 (detection limit 0.01) to 4.05 µg/l with most of the values near the lower end of the range (only 10 of the 234 values exceeded 1 µg/l. Most of the higher values were encountered along the southern line and most, but not all, were in the upper 20 m. The background levels calculated for the various areas suggested that that for the southern Banks was somewhat higher than those at the Hibernia and South Tempest areas, but the differences were so small as to be of no significance in terms of environmental quality. Thus, the overall background level for the water column of the Grand Banks was 0.18 µg/l. This is the lowest level found so far in the waters of any region of eastern



6. Area plots showing concentrations (millimolesper litre) of (a) total volatile hydrocarbons and (b) methane in surficial sediments from the Grand Banks area.



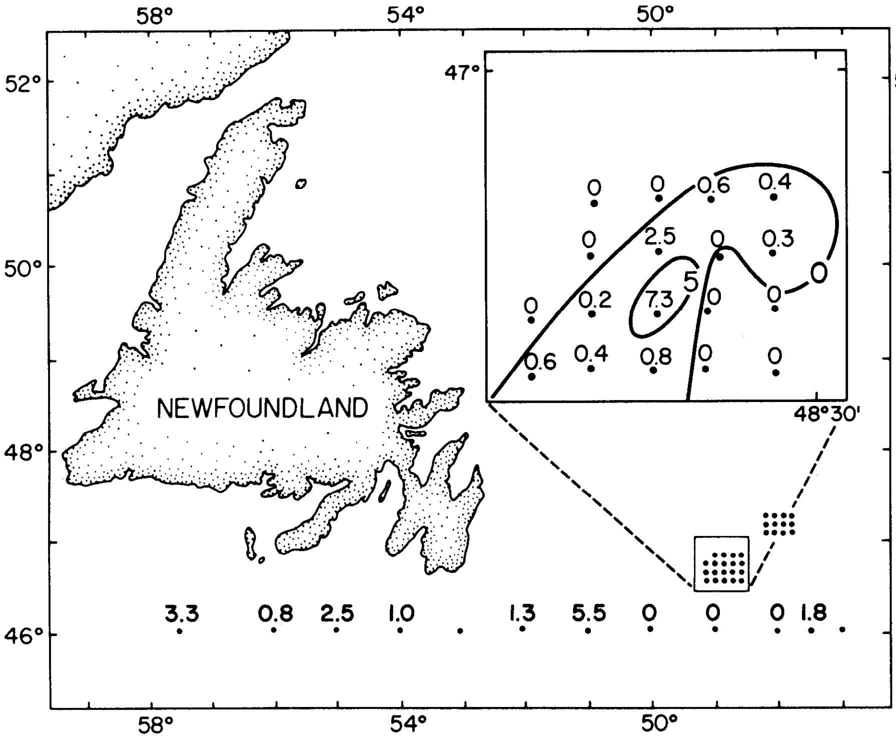
7. *Area plot showing concentrations (micrograms per square metre) of floating particulate petroleum residues in the Grand Banks area.*



8. *Area plot showing concentrations (micrograms per litre) of dissolved/dispersed petroleum residues in the sea surface microlayer in the Grand Banks area.*

Canada; for example, the general background level for the Gulf of St. Lawrence is presently about 0.35 µg/l (Levy, 1985), for the Labrador Shelf about 0.50 µg/l (Levy, In press), for Hudson Bay about 0.45 µg/l (Levy, In press), and for the Baffin Island Shelf, 0.48 µg/l (Levy, 1980). Because the background levels over such a broad geographical region are so similar, it is currently thought that the major input to the remote areas is a diffuse source, most probably fallout from the atmosphere of polynuclear aromatic hydrocarbons derived from the high-temperature combustion of organic materials. In more accessible areas, localized inputs of oily substances from shipping and other human activities may be superimposed on this diffuse background and give rise to greater variability in the data. Thus, the existing background level of dissolved/dispersed petroleum residues in the water column of the Grand Banks appears to be derived primarily from diffuse sources such as atmospheric fallout, and the oil industry's activities have not, as yet, had sufficient impact on the background level to be detected.

Surficial Bottom Sediments - Concentrations of petroleum residues in the surficial bottom sediments ranged from 0 to 5.5 µg/g along the southern line and from 0 to 7.25 µg/g on the Hibernia grid (ninth figure). By way of comparison, concentrations in sediments from the continental shelf and the deep areas of Baffin Bay in 1978 were 0-2.5 and 0-7.5 µg/g (Levy, 1980) and 0-7.5 and 0-40 µg/g in sediments from Hudson Strait and the Labrador Shelf (Levy, In press). Although sediment types varied so widely along the southern line that comparisons were not meaningful, those at the Hibernia area were much less varied. Concentrations were highest at stations 23 and 21, decreasing outwards from this area, and in the northwest and southwest portions of the area petroleum residues were not detected. Since the *Ocean Ranger* was operating just north of station 21 and the prevailing current was southwestward, this distribution pattern was a strong implication that the sediments in this area were receiving oily substances from this exploratory activity.



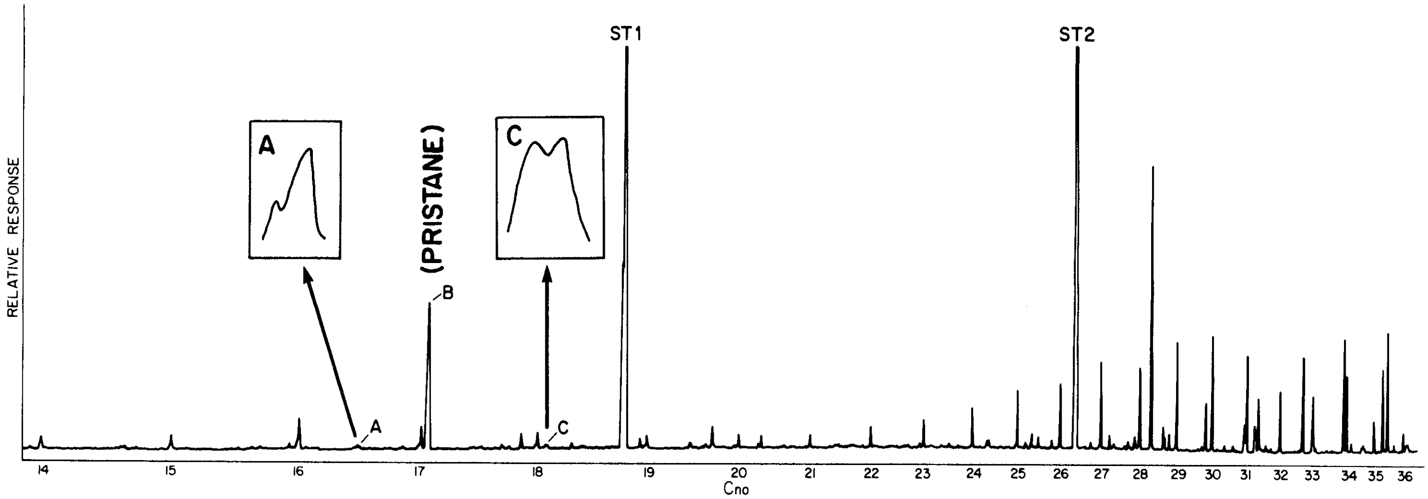
9. Area plot showing concentrations (micrograms per gram) of petroleum residues in the surficial bottom sediments of the Grand Banks area.

Identity of background material

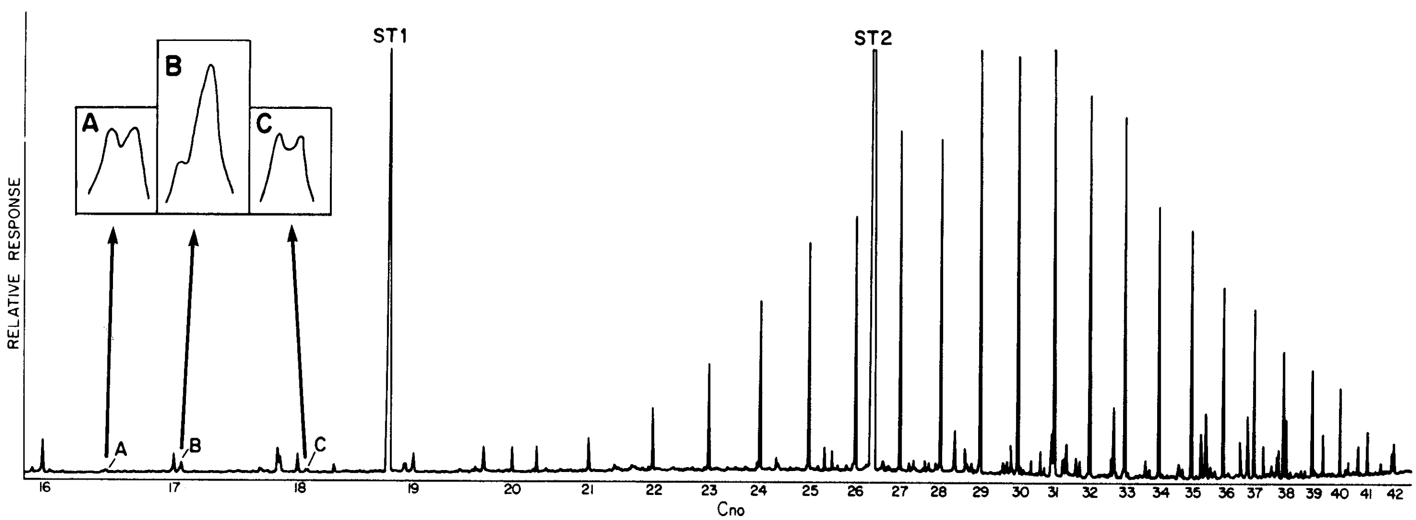
Hydrocarbons in marine waters and sediments are of two general categories; namely, those of "recent" origin, which have only recently been synthesized by naturally occurring biochemical processes, and those of "fossil" origin, which were synthesized by biochemical processes occurring in the geological past and have since undergone substantial change in chemical composition. Recently biosynthesized hydrocarbons comprise a relatively narrow range of n-alkanes, generally between n-C_{15} to n-C_{21}, in which the concentrations of compounds having an odd number of carbon atoms greatly exceed those with an even number. Pristane, an isoprenoid hydrocarbon, is common and abundant and there are usually significant amounts of olefinic but virtually no aromatic compounds. Fossil or petroleum-related hydrocarbons, on the other hand, contain a very broad homologous series of n-alkanes extending beyond n-C_{40} without an odd to even carbon preference, homologous series of isoprenoid and naphthenic hydrocarbons, series of alkylated aromatic and polyaromatic compounds, and heterocyclic compounds containing sulfur, nitrogen, and oxygen. In addition, there are hydrocarbons derived from the combustion of fossil fuels and other organic materials. These contain polynuclear aromatic compounds with 2 to 6 rings, and the unsubstituted compounds are far more abundant than the alkylated derivatives. Hydrocarbons from all these sources contribute in varying relative proportions to the mixture that is present in the marine environment, and its composition is further complicated through chemical alteration by weathering processes. Since the analytical procedure used to measure background levels of "petroleum residues" is based on the total concentration of non-polar aromatic material and because these, rather than the n-alkanes, are the compounds of environmental importance, the procedure provides a good measure of environmental quality. However, except for deductions based on the interpretation of excitation and emission spectra and on the distributions of the total concentrations of aromatic materials and their variability, unequivocal identification of the source of the "petroleum residues" is not possible. For this purpose, the composition of the aliphatic fraction of the non-polar substances extracted from marine samples often contains useful information.

Capillary-gas chromatographic analyses were done (Gassman and Pocklington, 1984) of the aliphatic hydrocarbons present in water samples collected at 1 m depth in the Laurentian Channel (station 1) and at the Hibernia site (station 13). In both cases, the chromatograms (tenth figure) show the virtual absence of n-C_{15} and n-C_{17} alkanes, which are characteristic of marine algae, indicating that there was little direct input of hydrocarbons from recent primary production. In the n-C_{21} to n-C_{42} range, the distribution of peaks resembled those typical of "petroleum residues"; that is, all members of the series were present and there was no prominent odd to even preference in the carbon numbers.

A particularly useful feature for the purpose of source identification is the nature of the peaks corresponding to the isoprenoid hydrocarbons (i.e., norpristane, pristane, and phytane). These compounds are derived from phytol which, in turn, is derived from chlorophyll. Because of the high specificity of biosynthetic pathways, the chromatograms of the recently biosynthesized compounds contain a single peak corresponding to a single isomer of each of the substances. However, this stereospecificity is lost through geologic maturation and the various diastereoisomers (i.e., compounds having the same structural formulae but with the atoms arranged somewhat differently in space) of the compounds are formed. Although these isomers have very slightly different physical properties, even with the best gas chromatographic techniques only partial separation is possible, and each of the isoprenoid peaks displays a doublet corresponding to two groups of the partially separated diastereoisomers. In this case (tenth and eleventh figures), the peaks corresponding to norpristane and phytane at both the Laurentian Channel and Hibernia locations displayed the doublets typical of fossil isoprenoid hydrocarbons. Since the heights of the doublets are the same, the norpristane and phytane



10. Gas chromatograph (GC) trace of Laurentian Channel saturated hydrocarbons. Insert shows stereoisomers of (a) norpristane and (c) phytane. ST1 and ST2 are two internal standards (1-chlorohexadecane and methyl tricosanoate). GC conditions were the following: 20-m column (0.14 mm i.d., 0.125 µm film thickness of 0V T3) of Duran glass. Injection splitless with a splitless period of 2 minutes. Temperature program was 50°C at 1°C/minute to 160°C and then 2°C/minute to 340°C.



11. Gas chromatographic (GC) trace of Hibernia-site saturated hydrocarbons. Inserts show stereoisomers of (a) norpristane, (b) pristane, and (c) phytane. GC conditions as for tenth figure.

are considered to have been derived solely from the diagenesis of the biogenic precursor material with no detectable contribution from recently synthesized biogenic material. However, in the case of pristane, the height of the second member of the doublet greatly exceeded that of the first. This excess is interpreted as representing the recent biogenic component as derived from the secretion from herbivorous zooplankton (i.e., the digestive by-product of the chlorophyll molecules contained in phytoplankton). Thus, there is clear evidence of the presence of contamination from fossil hydrocarbons at both the Laurentian Channel and Hibernia sites, and the "excess" pristane indicates the contribution of biogenic hydrocarbons to the total hydrocarbon "pool" in both locations.

By considering the total concentrations of branched and cyclic alkanes (represented by the small peaks interspersed between those of the n-alkane), the total concentration of n-C_{15} - n-C_{20} and n-C_{21}, - n-C_{34} alkanes, the isoprenoids, and polyunsaturated hydrocarbons, Gassman and Pocklington (1984) attributed the hydrocarbons in these samples according to their definite and probable fossil fuel or biogenic source. Although the total concentration of hydrocarbons at the Hibernia site was about twice that at the Laurentian Channel, slightly more than one third of the total at the former and slightly less than one third at the latter was thought to be of fossil origin. The "definite" fossil component, however, greatly exceeded the "definite" biogenic component at the Hibernia site whereas the reverse was the case at the Laurentian Channel site.

Concluding remarks

The results of this study demonstrated that the background level of petroleum-related substances, both low-molecular weight volatile hydrocarbons and the higher molecular weight aliphatic and aromatic hydrocarbons, in the waters and sediments of the Grand Banks area in 1981 were among the lowest found anywhere in eastern Canada including remote regions of the Arctic. However, the results also provided clear evidence, both qualitative and quantitative, that the petroleum industry was already having a detectable, albeit small, impact on the existing low background levels of petroleum residues in the surface microlayer, water column, and bottom sediments of the area. Although this is, as yet, no cause for environmental alarm, it is a portent of what can be expected in the future. In view of the existing pristine nature of the area, continued exploration and eventual production, even in the absence of the inevitable mishap, can only lead to future increases in the level of contamination in this area. This poses no small challenge to governments, regulatory agencies, and the oil industry if recovery of the petroleum resources of the Grand Banks is to proceed in such a manner that the environment is not altered to the extent that the fishery is eventually placed in jeopardy.

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Sea ice and iceberg movement

S.D. Smith and G. Symonds

The past three years (1983-1985) have been heavy ice years. Ice and icebergs have impeded the progress of petroleum exploration on the Grand Banks and Newfoundland continental shelf and highlighted the need for improved forecasts to make offshore operations in these waters safer and more efficient. A broad range of forecasts is needed covering periods from a few hours to several months with applications ranging from an individual iceberg and its projected path to the formation, movement, and deformation of sea ice over the entire northeast Newfoundland shelf. Numerical models being developed by the Atlantic Oceanographic Laboratory will play an important role in meeting these forecasting needs.

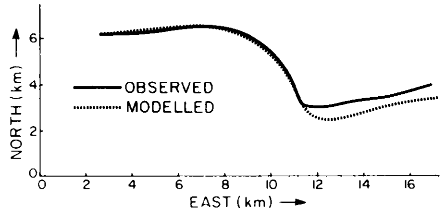
Iceberg drift models can follow two possible approaches: the statistical approach applies a general (statistical) knowledge of the drift characteristics of icebergs in the area; the dynamic approach calculates the balance of forces acting on an iceberg and the acceleration, which is integrated twice to obtain the velocity and position. However, each of these approaches has its limitations. The statistical approach (e.g., Garrett, 1984) does not attempt to forecast variations in currents and winds, and so the effects of these variations are not included in the model output except as statistically predictable uncertainty in the drift rate and position. Dynamic models, however, rely on a detailed knowledge of the variations of winds and currents and of the draft and cross-sectional area of an iceberg, information not available in most operational situations.

Equilibrium drift models might be considered to be a third category. An iceberg is assumed to follow the current plus a certain fraction of the wind speed, with a Coriolis deflection to the right of the wind direction. The results equal those of dynamic models if the iceberg's response to changes in currents and winds is fast enough to make the transient response to these changes insignificant. The computation time required to estimate equilibrium drift rates is much less than for dynamic modelling. Therefore, in dynamic modelling it is instructive to investigate response times to identify the range of circumstances in which using an equilibrium drift model would suffice.

A dynamic iceberg drift model (Smith and Banke, 1983) has been developed at BIO and tested in a hindcast mode (i.e., on known events) using currents, winds, and iceberg-drift tracks reported from Canadian east coast drilling rigs. This model calculates water and wind drag, applies a Coriolis force and a gravitational force due to geostrophic sea-surface tilt, and adjusts the air-drag and water-drag coefficients to obtain a best (leastsquares) fit of the modelled track to the observed drift track. Banke and Smith (1984) have applied this model to a large quantity of drilling rig data and have reached conclusions regarding the time of response to changes in wind (less than one hour in most cases) and the values of drag coefficients required to obtain a best fit of the modelled and observed tracks. The consequences of not towing icebergs were investigated by first modelling the tracks of 12 icebergs towed during part of their tracking periods, and then removing towing forces from the model to simulate the track that the iceberg would have followed without towing. In two of the cases, it appeared that the drill rig would have had to move to avoid a collision, but in nearly half of the cases it appeared that the iceberg would have approached less closely had it not been towed.

The data on currents taken at a drill rig have two major deficiencies for modelling of iceberg tracks. Firstly, simultaneous tracks of more than one iceberg show significant differences, presumably due to variations in currents, when separations are greater than about 10 km (Garrett *et al.,* 1985). Secondly, the available data were taken at only one or two levels and the variation of currents with depth could not be properly accounted for in computing water-drag forces. The lack of high-quality data on current profiles in the vicinity of icebergs has limited the development of dynamic iceberg drift models, although Sodhi and El-Tahan (1980) successfully modelled an iceberg trajectory using current profiles based on data from a nearby current-meter mooring.

With support from the Office of Energy Research and Development (OERD), an experimental program has been carried out during three voyages (83-018, 84-023, and 85-008) of CSS *Dawson.* We have gathered data on the drift of ten icebergs of widely different shapes and sizes. Current profiles were measured in detail using newly acquired Ametek doppler acoustic current-profilers, with CSS *Dawson* holding station 1 to 2 km from the iceberg. This process provides unprecedented detail about variation of current with depth, and a preliminary look at the data clearly shows the

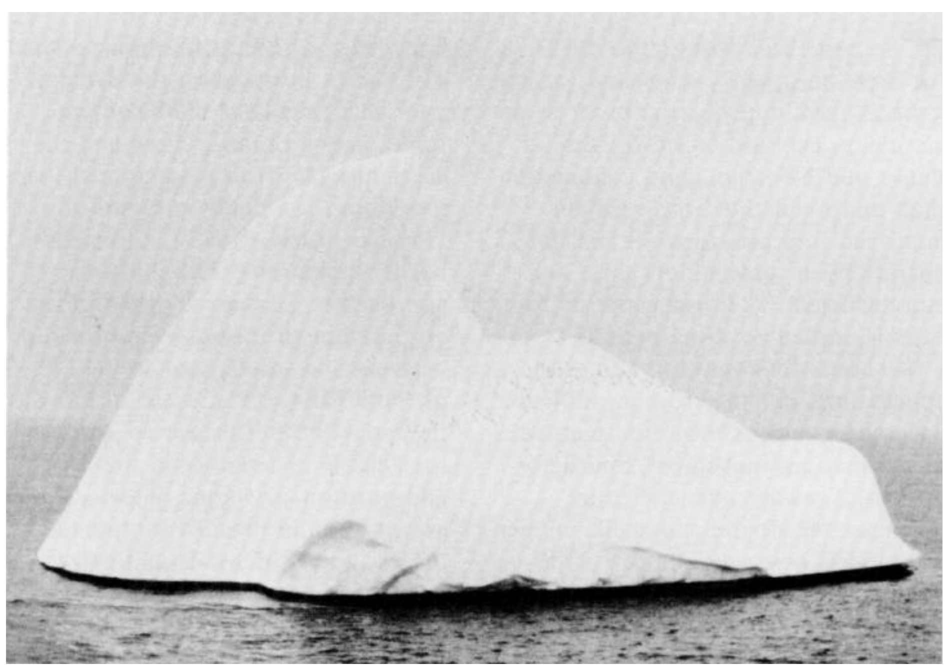


1. Observed and modelled hourly positions of a small, pinnacled iceberg in the Strait of Belle Isle from 0500 to 1700 GMT on June 24, 1983. Iceberg travelledfrom left to right (i.e., to the east).

inadequacy of using measured currents taken at only one or two levels.

A multilayer version of our dynamic iceberg model has been developed and tested using some of the data obtained in 1983. The first figure shows an observed and modelled track for a small iceberg; the iceberg is shown in the second figure. The iceberg drifted 15 km during this period and the model was able to reproduce the observed track with a root-mean-square error of 0.5 km. The 1984 and 1985 voyage data are now being analyzed (September 1985), and further development of the drift hindcast model is in progress. When site-specific current forecasts are available, it will be possible to apply this model in a forecast mode. Eventually a hybrid dynamic/statistical model may be developed, in which those terms not amenable to dynamic modelling can be handled statistically.

Whereas iceberg forecasting focuses on predicting the motion of individual icebergs, sea-ice forecasts are concerned with a field of pack ice composed of a large number of ice floes of various shapes and sizes. The motion of an individual floe is only important insomuch as it reflects the motion of the entire pack. For this reason, modelling the motion of sea ice differs from iceberg modelling in two ways. Firstly, in addition to winds and currents, sea ice motion is modified by stresses within the ice pack itself due to floe-floe interactions. For example, sea ice resists compression through the process of ridging, which creates thicker, stronger ice that will resist further compression. Alternatively, open water leads may form when ice diverges. Secondly, thermodynamic forcing is an important factor in determining the mass balance and thickness distribution of the pack-ice field. Atmospheric cooling in winter creates new ice in leads between floes or on the underside of existing floes, while oceanic heat flux and atmos-

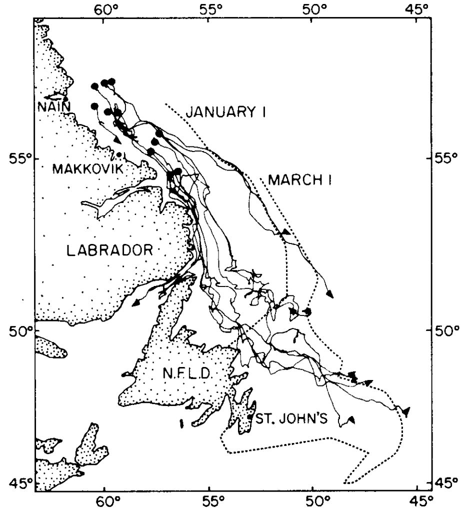


2. A small iceberg tracked in the Strait of Belle Isle, June 24, 1983. Mass is 85,000 tonnes, height 19 m above waterline, length 66 m, draft 54 m.

pheric warming in spring and summer provide heat to melt the ice.

Both statistical and dynamical approaches to sea ice modelling are being pursued within the sea-ice program of the Atlantic Oceanographic Laboratory (AOL). A statistical model of sea ice motion was described by Colony and Thorndike (1985) in which the trajectory of an individual floe was modelled as a "random walk". The ensemble of all possible trajectories allows one to answer variations of the question: "If a particle occupies region R at time t, what is the probability that it will occupy region R 'at time t' "? This same model was applied to modelling sea ice trajectories through the Greenland Sea (Colony *et al.,* 1985), a situation which in many respects is similar to the northeast Newfoundland shelf where too few data presently exist to provide the necessary input for the model. The model has an advantage over dynamic models in that medium- to long-range forecasts can be given in terms of a probability with a known error. A disadvantage, in terms of operational forecasts, is that the natural variability of the trajectories leads to a spreading of the probability distribution over a broad region after only a few time steps (1 month).

Shown in the third figure are the trajectories of satellite-tracked buoys placed on the ice off Nain and Makkovik, Labrador, during January and February 1985. The positions of these buoys are obtained via satellite approximately ten times per day. During the course of the winter the buoys show a mean longshore drift of 20 cm/s. Of the 11 buoys deployed, 2 drifted out of the main pack into the Labrador Sea where the ice would melt rapidly, one went through the Strait of Belle Isle into the Gulf of St. Lawrence, one grounded on an island off Nain, and the remainder drifted south toward the Grand Banks and eventually into open water east and northeast of the Grand Banks. Although these data are insufficient to obtain statistically reliable estimates, they do serve to illustrate the mean and variability of ice-floe trajectories over the northeast Newfoundland shelf. This program is expected to continue over the next few years to obtain



3. Sea ice trajectories from January to April 1985. Solid circles show the starting locations and arrows indicate direction of motion at the end of each trajectory. Plotted lines indicate ice extent on January 1 and March 1.

statistically reliable estimates of the mean and variance of ice drift throughout the region shown in the figure.

The spreading of the probability distribution can be reduced by introducing a known component of the variability that may be predicted in a deterministic manner. For example, the tidal component of the variability could be predicted and removed from the random fluctuations. Over a two-day period, deterministic models of ice motion can provide forecasts that are at best as good as the data input to obtain them. Over longer periods of time, the deterministic models can be used in a hindcast mode to aid in identifying the major factors contributing to the variability in ice motion. A dynamic/thermodynamic model described by Hibler (1979) has been applied to the northeast Newfoundland shelf with the aim of modelling the seasonal advance and retreat cycles of sea ice. In particular, we would like to be able to identify the major factors that determine whether any given year will experience a heavy or light ice season. Thermodynamic forcing is particularly important since in our study area all of the ice eventually melts each year. Models of the radiation balance at the atmosphere-ice interface provide estimates of the growth and decay rates of sea ice due to atmospheric cooling and heating. In our study area, the thermodynamic processes are complicated by spatial variations in thermal forcing and by advection of ice between regions with greatly differing heat and mass budgets. Of the trajectories shown in the first figure, two were advected into the Labrador Sea where warmer ocean temperatures rapidly melted the ice. Finally, ice growth and heat exchange are strongly influenced by ice thickness, which is affected by strain due to spatial variations in the ice velocity field that in turn forms ridges and leads.

To provide reliable forecasts, a coupled atmosphere-ice-ocean model is required and, as with iceberg modelling, a dynamic/statistical model may provide the optimum forecasting tool. Much more data on the formation, movement, and deformation of sea ice are required both for model verification and also to provide input for forecasting models. The reliability of any forecast is often only as good as the input data, and a detailed monitoring network will have to be maintained to provide the necessary atmosphere, ice, and ocean information.

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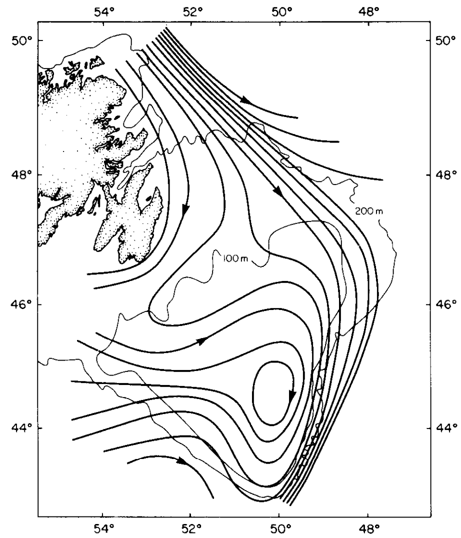
Mean and variable currents over the Grand Banks

B.D. Petrie

On April 14, 1912, the ocean liner *Titanic* struck an iceberg south of the Grand Banks of Newfoundland and sank with the loss of 1513 lives. This incident prompted the formation of the International Ice Patrol to provide better protection for trans-Atlantic steamers against the menace of Arctic ice and icebergs. This was to be accomplished through iceberg observation reports and studies of the oceanography and meteorology of Baffin Bay, the Labrador Sea, and the continental shelves off the Canadian east coast. Of particular interest was the Labrador Current in the vicinity of the Grand Banks of Newfoundland.

D.J. Matthews, on the steamship *Scotia,* carried out the first systematic investigation of the waters of the Grand Banks and adjacent areas in 1913. Some of the main results of Matthew's study were: (1) the Labrador current splits into three parts on the northern edge of the Grand Banks: the westerly branch flows through Avalon Channel and around Cape Race; the middle and most important arm follows the eastern edge of the Grand Banks; the eastern arm flows eastward to the north of Flemish Cap; (2) the Grand Banks themselves are not dominated by a single definite current, the general tendency of the circulation appearing to be a slow southeastwardly drift; and (3) the velocities of the Labrador Current are as a rule relatively weak.

Smith *et al.* (1937) expanded and quantified this earlier work and produced a map (first figure) of the primary circulation over the Grand Banks based on an interpretation of temperature and salinity observations. The western branch of the current moves through Avalon Cannel and turns westward following the coastline. In the vicinity of 55° W, the flow turns eastward moving toward the stronger branch along the eastern edge of the shelf. On meeting this branch, the current over the shelf first moves southward then west along the shelf break creating a clockwise gyre over the southeast Grand Banks centered at 44°30'N, 50°W. Smith *et al.* estimated a water transport of 0.4 x 10^6 m^3/s for the inshore (western) branch of the Labrador Current and equal transports of 2 x 10^6 m^3/s through Flemish Pass and north of Flemish Cap. All flows were subject to considerable variability.

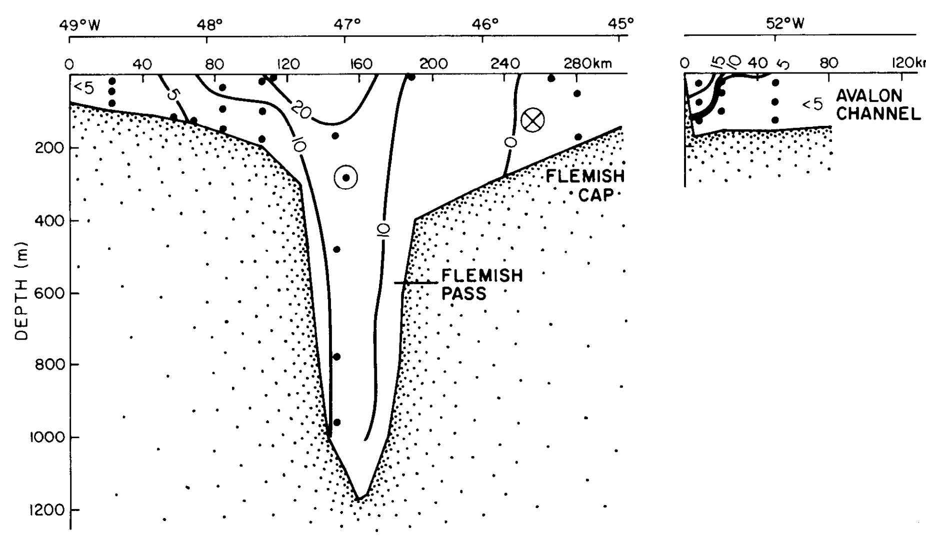


1. Primary circulation over the Grand Banks as depicted by Smith et al. (1937).

The work of Smith *et al.* remains the standard reference frame for any programs to collect physical oceanographic data in the area. It is particularly useful for studies addressing the mean circulation of the Grand Banks, less useful for programs dealing with variable currents.

Recent measurements of the mean circulation

Since 1937 the International Ice Patrol has continued to gather hydrographic data in the Grand Banks region with particular emphasis on the offshore Labrador Current. Their recent efforts as well as those of oil companies, universities, and government agencies have involved the use of satellite-tracked drifting buoys and current meters (Petrie and Anderson, 1983). The buoys are fitted with a large drogue so that they will move with the currents in the upper 20 m of the water column. The current meters are moored at fixed locations and can measure current speed, direction, temperature, and salinity. However, the Grand Banks are so large that, to date, only a small portion of them has been surveyed with these instruments.

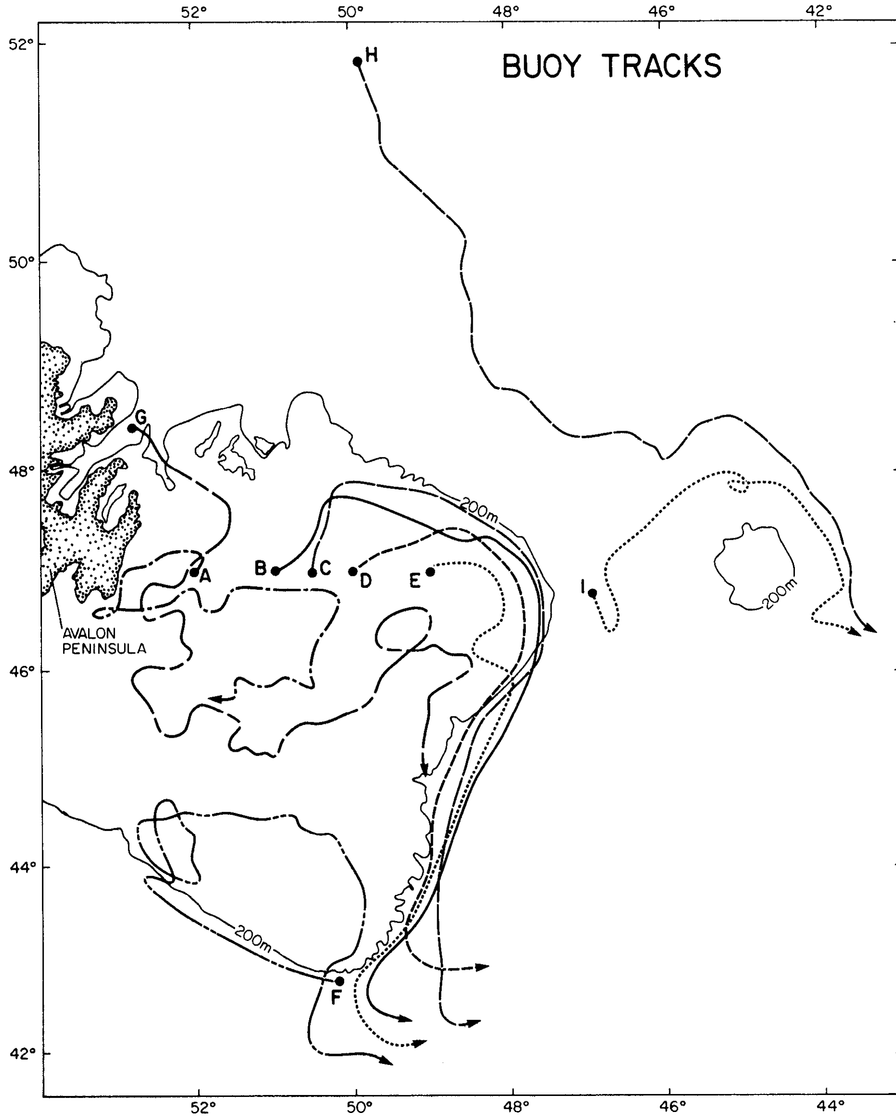


2. Contours of the current through Flemish Cap and the Avalon Channel derived from archived current meter and drifting buoy data. The dot within a circle represents flows toward the reader (i.e., out of the page) while the x within a circle represents currents away from the reader (i.e., into the page).

The major deployment of moorings so far has taken place roughly along 47°N in Flemish Pass and off St. John's in the Avalon Channel. The over 200 km in between have not been sampled nor has much of the rest of the Banks.

The second figure shows a composite picture of current-meter observations and drifting-buoy-derived currents for the branches of the Labrador Current in Flemish Pass (offshore) and Avalon Channel (inshore). The former branch obviously transports significantly more water than does the latter. The core of the offshore branch is located above the steep topography of the continental slope and not over the 100 m isobath as depicted by Smith *et al.* Countless hydrographic surveys and numerous drifting-buoy tracks help to confirm this. Another mooring to the south on the 490-m isobath showed a mean velocity of 46 cm/s at the 110 m depth over 80 days. Furthermore, while the average speed calculated from all drifter tracks of the near surface flow along the eastern outer edge of the Grand Banks is about 30 cm/s, individual buoys have averaged 85 cm/s along this length. This would not be considered a relatively weak flow as described by Matthews. The figure also shows a northward flow on the western side of Flemish Pass - a feature of the region that has become known since Smith *et al.* did their work. The inshore branch of the Labrador Current appears to be confined tightly to the coast.

A large number of fixed-point moorings would be necessary to show the circulation patterns on the Grand Banks. On the other hand, we can get an idea of the spatial variability by plotting the paths taken by satellite-tracked drifting buoys. They might describe the routes followed by parcels of water. In the third figure, selected buoy tracks from 1984-85 are shown. They do point out some of the features noted by Smith *et al.* For example, the branches of the Labrador Current through Flemish Pass and north of the Cap are depicted by tracks B-E, H, and I. Perhaps drifter F captures some of the clockwise flow around the southeastern Grand Banks. It is also one of the few examples of drifters

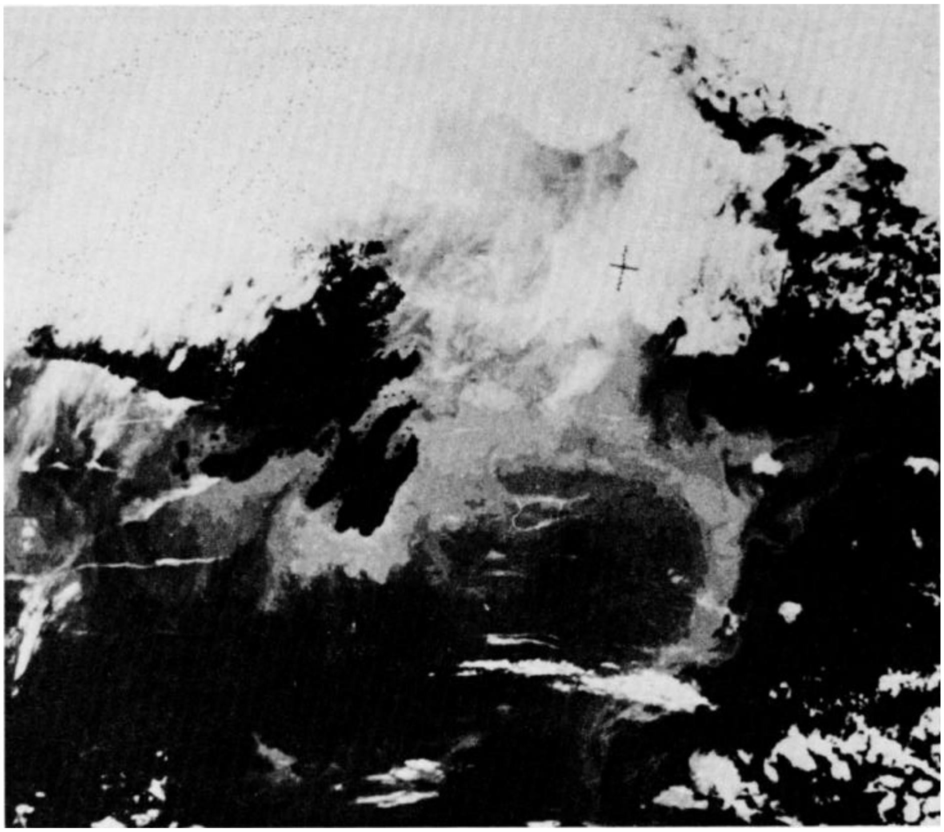


3. The curves correspond to the path of nine satellite-tracked drifting buoys on the Grand Banks.

that have moved westwards after reaching the Tail of the Banks; most are deflected to the east. However, there does not appear to be a well defined inshore branch of the Current and the details of the movement of drifters on the Banks often oppose the Smith *et al.* view. In general, the mean currents on the Banks are quite small, amounting to a few centimetres per second. Drifters tend to remain in the area for a long time; one lasted for 205 days before being entrained in the offshore branch of the Labrador Current.

Variable flows

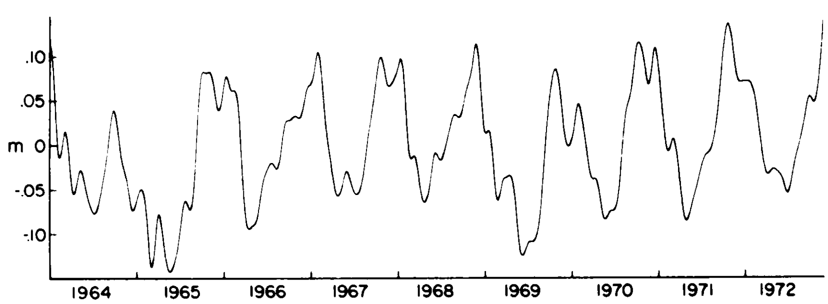
Some of the complexity of the movement of drifting buoys on the Grand Banks can be accounted for by the time-varying currents. Processes that could contribute to the variability include changes of the circulation due to the freshwater run-off cycle, seasonal changes in weather, storms, instabilities in the various branches of the Labrador Current, and tides. Perhaps several of these processes acted together to produce the complex temperature structure seen in the infrared picture shown in the fourth figure. This image from April 1983 shows an offshore Labrador Current with some evident splitting around Flemish Cap. The Current also has smaller scale spatial variability (eddies), which could be associated with instabilities in the mean flow. The inshore branch also possesses evident variability similar to that of the offshore branch. The two branches appear to surround the Grand Banks. Perhaps these eddies



4. This satellite infrared image of the Grand Banks region depicts the sea surface temperature with lighter areas corresponding to cooler temperatures.

are one of the mechanisms whereby water is exchanged between the shelf and the slope areas. In fact, a recent study of the salinity budget and iceberg populations of the Grand Banks and the Labrador Current does point to eddy-induced exchange as an important process contributing to the distribution of those properties.

Wind can also have a marked effect on the currents over the Grand Banks through direct forcing in the energetic 3-10 day "storm" band and through the generation of inertial-period (about 16 h on the Grand Banks) motions. A comparison of the mean and variable flows over the Banks based on satellite drifting buoy data indicates that the variable currents generally exceed the mean by a factor of three. At the Hibernia oil exploration site, the factor can be as great as 10. Thus, if for example you need to predict the path of an iceberg for the next several days, it may be more important to be able to predict the time-varying flow than to know the mean. However, to forecast wind driven currents there first must be a good prediction of winds, a difficult and at times uncertain task in itself. At present, hindcast wind-driven current models are being considered.



5. The figure shows annual and interannual variability of adjusted sea level at St. John's, Newfoundland.

These allow for model verification and examination of worst-case storms that can be applied to offshore development problems.

Tidal currents are generated by the action of well-known gravitational forces on the ocean and so can be predicted more confidently. The efforts of oil companies and the BIO in the past several years have produced accurate tidal models for the waters of the Grand Banks.

The variability considered so far has been of the short-term variety. There is convincing evidence that seasonal and interannual variability significantly affect the water properties of the Grand Banks. One manifestation of this is in the low-frequency fluctuations of sea level at St. John's shown in the fifth figure. Over the 9-y span in the diagram, the eye can easily pick out the consistent variation over a year and changes from one year to another. These variations have been linked to the annual freshwater discharge mainly from Labrador and the Canadian Arctic. Measurements in Avalon Channel (see second figure for the mean) have shown that the transport changes from about 0.3 x 10^6 m^3/s in July and August to about 0.6 x 10^6 m^3/s after the arrival of the main part of the discharge in September and October. These measurements were made for only one cycle however and do show significant variability; consequently the transport increase must be taken with a grain of salt.

The mean and time-varying currents over the Grand Banks are the result of many processes acting together to produce a complicated spatial and temporal structure. In recent years the deployment of new oceanographic instruments has led to an improved picture of the mean flow and an appreciation of the processes responsible for the variable currents. Considerable progress has been made in the understanding of the latter and efforts to improve the state of understanding are continuing.

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chapter 4

Biology

It is clear that the Grand Banks are a rich source of both renewable and non-renewable resources. The richness of the fishery has long been a matter of comment, and the potential for extraction of fossil fuel has recently been convincingly demonstrated. All are concerned that Canadians should be able to extract maximum benefit from both types of resource, while managing the fishery effectively and extracting the hydrocarbons without damage to the environment.

Direct investigation of the details of the fish stocks, their sizes, seasonal migrations, and interactions with each other is the responsibility of the Northwest Atlantic Fisheries Centre in St. John's, Newfoundland, and we are pleased to include in this chapter an account of that work by two scientists from the Centre. The particular concern of the Marine Ecology Laboratory at BIO is with the interacting web of natural events that leads to fish production: the utilization of solar energy by the phytoplankton, the transport of fertilizing nutrients to the surface waters, and the passage of energy-rich organic compounds through all the steps in the food web until they arrive at fish, birds, and mammals of economic importance.

With financial assistance from the Office of Energy Research and Development (OERD), the Marine Ecology Laboratory undertook to examine closely the question of how oil accidentally released into the marine environment might affect this complex natural fish-producing mechanism. Others had already examined the direct effects of oil on fish, but MEL staff now wished to look more deeply at indirect effects of oil on the total ecosystem. Viewing the food web as a complex mechanism, they asked: How does this mechanism work, and what would be the effect of oil on its functioning?

As the article by K.F. Drinkwater shows, it is necessary to look far beyond the boundaries of the Grand Banks to understand what makes them so productive. They are strongly under the influence of the Labrador Current from the north, and the chemical and biological constituents of this Current are in turn strongly influenced by the amount of fresh water entering and leaving Hudson's Bay. Surprising as it may seem, fish production on the Grand Banks is influenced by the amount of precipitation in the northern regions of Manitoba, Ontario, and Quebec. The unravelling of this story requires expertise in physical, chemical, and biological oceanography, and integration of all three disciplines is the hallmark of the work of the Marine Ecology Laboratory. The ability to make long-term predictions about trends in the fish stocks would undoubtedly benefit the fishing industry, and it is now clear that an important term in the equation is year-to-year variability in the freshwater run-off of the Hudson Bay catchment area, although more work is needed to fill in the details.

One way of finding out whether we have sufficient understanding of an ecosystem is to attempt to reproduce its chief features in a computer model. Not only can the performance of the natural system be modelled, but existing knowledge of the effect of oil on bacteria, phytoplankton, zooplankton, or benthos can be incorporated as perturbations of the natural system, giving at least an indication of probable effects in nature. The section on modelling by W. Silvert should be read in conjunction with that on heterotrophic activity on the Grand Banks by M.A. Paranjape and R.E.H. Smith. Early in the attempt to model the Grand Banks ecosystem, it became apparent that there were serious doubts whether the conventional wisdom of biological oceanography (that primary production is mainly by diatoms and secondary production is mainly by copepods) could be applied to the Grand Banks. With assistance from OERD a second project was launched to investigate the biological submodel. The results of several major voyages to the Grand Banks clearly showed that the diatom-copepod paradigm applies only to a short period in spring. For the remainder of the year production is dominated by small phytoplankton cells, which in turn are grazed by microzooplankton. Large amounts of phytoplankton production are released into the water in soluble form and taken up by bacteria that are in turn consumed by small animals and used to support the food web leading to fish.

This new understanding of the Grand Banks ecosystem permits MEL scientists to proceed with more confidence to the construction and testing of an ecosystem model. Meantime, those whose job it is to make environmental impact assessments have shown a keen interest in ecosystem modelling as a technique for integrating the diverse and disparate evidence brought forward during environmental impact hearings, and for considering whether a number of small impacts on different parts of an ecosystem might amount to a significant perturbation of the total fish-producing system.

R.G.B. Brown of the Seabird Research Unit (DOE at BIO) has contributed yet another biological perspective on the Grand Banks ecosystem. Not only does he report the basic data about what species of birds are present, and what are their seasonal migrations, so that we may understand the risks to the bird flocks of a potential oil spill, but he suggests interesting ways in which bird distributions may give us clues to ecosystem functioning. For example, oceanographic zones characterized by upwelling of nutrient-rich water tend to be frequented by flocks of dovekies. These birds feed on zooplankton. Is the zooplankton there because the nutrient upwelling sets off a highly productive food chain, or does the upwelling simply force the zooplankton from deeper water to congregate near the surface?

In this chapter we are reminded once again that while we may frame simple questions like "Is hydrocarbon extraction harmful to Grand Banks fisheries?", the answers are never simple and straightforward. We can test the toxicity of oil for fish and come up with an answer of sorts, but as soon as we dig beneath the surface of the problem we come across areas of very fundamental uncertainty. Answering outstanding questions involves theoretical modelling, field investigations, and a thorough familiarity with the latest ideas and techniques in the worldwide scientific community.

— *K.H. Mann*
Director
Marine Ecology Laboratory

Stock assessment and related fisheries research on the Grand Banks

L. W. Coady and S. A. Akenhead

We are very pleased to include this guest article in our issue of BIO Review devoted to the Grand Banks. Within our Department of Fisheries and Oceans, the mandate to provide effective management of the fisheries resources of Atlantic Canada is handled by various decentralized establishments with specific regional responsibilities. It is the Newfoundland Region of the Atlantic Fisheries Service that is responsible for those resources on the Grand Banks. BIO regularly undertakes scientific investigations in co-operation with the Newfoundland Region as it does in other locations with the Quebec, Gulf, and Scotia-Fundy regions of the Fisheries Service. Part of the latter region is, in fact, housed at BIO and is routinely represented in the pages of the Review.

The Newfoundland Region's research facilities are at the North west Atlantic Fisheries Centre on the White Hills overlooking St. John's. With a professional and technical staff of about 160 and access to three DFO research vessels (Wilfred Templeman, Shamook, *and* Marinus) *as well as the chartered* Gadus Atlantica, *they conduct a diverse program of research. Here, the authors have provided an overview of their Centre's current efforts that demonstrates the diversity of biological problems faced by fisheries scientists in the Grand Banks area.*

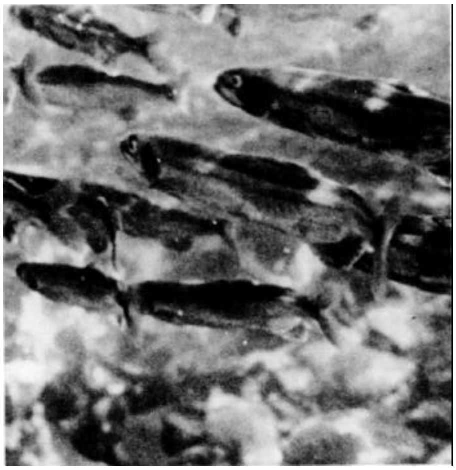
Fisheries research on the Grand Banks addresses several related questions: How large are the fish populations? Where do they spawn? Where do they migrate? How do they interact with other species? What factors affect their growth and survival? The fundamental aim of the research is the provision of advice for use in the development of fishing plans, quotas, and other management strategies that will ensure the conservation of marine resources. For that reason, 80% of research activities in the Newfoundland Region are tied to the population dynamics of commercial fish stocks and the effects of present and projected exploitation rates.

Detailed observations on groundfish stocks and their environment are recorded during regular research-vessel trawling surveys that utilize commercial gear modified to sample pre-recruit abundance. These are supplemented by regular studies at principal landing ports of catches by commercial fisheries as well as commercial sampling of foreign and Canadian vessels at sea. Regular stock inventories are taken to produce the best current estimates of stock abundance for prediction of yields and for annual quota adjustments.

Fisheries management is an actively developing field and the stock assessment procedures of 1985 are much more sophisticated than those of ten years ago. Recent analyses consider mixed-species catches and species interactions. Fishing-effort and catch-rate indices are now derived from mixtures of boat sizes and gear types and consider a wide variety of fish abundance estimates, all of them 'noisy' from a statistical standpoint.

The development of statistical models underlying stock assessment analyses presently involves, at St. John's, exploring predictors of recruitment distributions that avoid parameter-fitting approaches. In addition, life history-strategy theory is being used to estimate the natural mortality rate of fishes (an important input to management models) from the schedules of growth and reproduction through the life of a fish species.

In evaluating a total allowable catch, an accurate assessment is needed of the number of young fish that will recruit to the fishery in the year for which the TAC is being set. Juvenile flatfish, for instance, pose special sampling problems and a #41.5 Yankee shrimp trawl has been selected to evaluate their distribution and abundance. An attempt is now being made to develop an index of year-class strength (from research surveys) at some age before recruitment to the fishery occurs. In the course of these



Capelin in fish tanks. (Courtesy of the Centre)

studies, valuable information is being collected on the general biology and dynamics of juvenile flat fish: length-at-age, weight-at-age, distribution as it relates to the adult population, maturity, feeding behaviour, and predation by other species.

The general question of how many fish? is being considered in the context of seasonal distributions. In the past, all fish stocks under quota control were subject to a stratified random trawl-survey once a year and such snapshots provided little information on seasonal variability. A project was mounted in 1984 to quantify the effect of seasonal variability (in distribution and abundance) on biomass estimates of the major groundfish species in the northern Grand Bank area (Div. 3L). The project will also address temporal variability in biological parameters. To ensure adequate survey coverage and to encompass all important groundfish species in the area, approximately 300 random-stratified stations are surveyed over a 6-week period in each quarter of the year.

Understanding year-class strength and recruitment processes in marine fishes remains the outstanding research priority in fisheries science. The physical transport of nutrients from the deeps east of the Grand Bank up onto the shallow sunlit waters of the Southeast Shoal controls the production of food and planktonic predators of larval fish, and ultimately controls the survival of fish eggs into demersal juveniles. Lessons learned from early-life history studies of cod and redfish on the Flemish Cap have been put to good use in production studies of the Southeast Shoal. Present work is designed to reveal the processes determining the early-life history of the larval yellowtail flounder *(Limanda ferruginea)* and the stock's subsequent year-class strength. This involves determining growth, feeding, distribution, and abundance relative to biological and physical oceanographic conditions.

The patterns of nutrients and water density revealed in the Southeast Shoal cruises provided several surprises. Nutrient levels were much higher than predicted by early versions of a Grand Banks model (see article by Silvert, this chapter). It also seems that chlorophyll levels near the shelf break are high year round due to the buoyancy and turbulence of the Labrador Current. Patterns of community ecology are clearly organized by the striking frontal features of the area. And . . . yes, the production is sustaining larval fish!

The Southeast Shoal is visited by spectacular hordes of whales, seabirds,

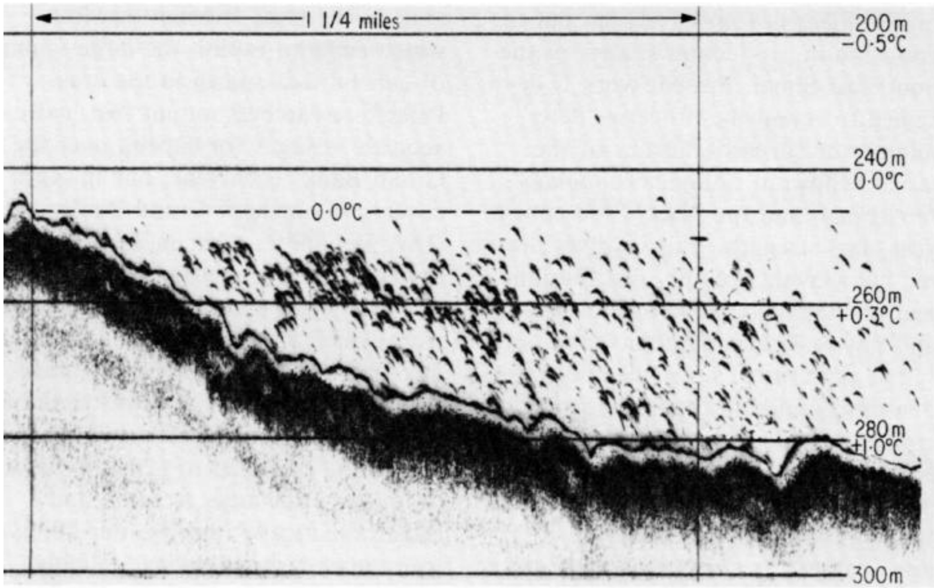
Technicians from the North west Atlantic Fisheries Centre sample a trawl catch of fish aboard a research vessel. (Courtesy of the Centre)

and, in the past, Russian trawlers, which came to exploit the large schools of capelin that spawn in the area. Pelagic researchers mount two hydroacoustic voyages for capelin over the Grand Banks each year: one in April covers the northern Grand Banks (Div. 3L) and another in June covers the entire area (i.e., Div. 3LNO). These voyages provide a reliable basis from which we can identify and predict fluctuations in population abundance and predict relative distributions. A modified dual-beam transducer is now being prepared to generate data on in-situ fish target strength and thus dramatically improve our ability to estimate fish abundance reliably.

The success of capelin studies has led to research on recruitment prediction. In a collaborative effort with McGill University, the ecology of capelin early-life history on the Grand Bank is being investigated by considering, among other hypotheses, how large waves might mix the shallow Southeast Shoal waters to the bottom, resuspending the sediments and freeing capelin larvae that hatched in those sediments. In co-operation with BIO, the submersible *Pisces* was deployed in the area in 1985 to investigate larval capelin dynamics and examine tilt angles of adult capelin (an important consideration in hydroacoustic research).

While biologists are aware that cod concentrate on offshore spawning grounds in the spring, very little is known about how they disperse after spawning and how they move inshore. Commencing in 1983, cod schools were followed inshore from offshore spawning sites on the northern Grand Banks. Research vessels equipped with high-powered sonar are able to locate cod and capelin and follow them for several days (see first figure). While the picture is not completely clear, it seems that cod move inshore along the bottom. The cod move shoreward at depths between 250 m and the shallower cold (0 to - 1.7°C) waters of the Labrador Current. These migrating cod tend to remain where the temperature is around 0°C to 3°C although occasionally they may be found in waters as cold as -0.5°C.

Cod-tagging studies conducted since the late seventies have answered



1. Acoustic tracing of cod migrating inshore to reach the warmer bottom waters of the Grand Banks. (Courtesy of W.H. Lear, unpublished data)

several key questions dealing with the seasonal movements of cod. Adult cod tagged on spawning grounds on the northern slope of the Grand Banks are sometimes recaptured in the inshore fishery in the same year, and provide estimates of the proportions of cod taken in the inshore fishery. Tagging efforts, concentrated on the northern Grand Bank component of the northern cod stock complex, have revealed that only 2-3% of this component is actually harvested inshore. The cod inhabiting the southern slopes of the Grand Bank (Div. 3NO) in winter are considered a separate stock. Generally, these cod remain on the bank throughout the year and, while they disperse northward across the surface of the Bank in spring, there is very little movement westward and the 3NO stock does not contribute significantly to the Newfoundland inshore cod fishery.

In the summer and fall, adult and juvenile cod have also been tagged in inshore areas. Recaptures by the offshore fleet provide information on the migrations of cod returning to spawning areas. Cod clearly home to nearly the same areas as they were spawned, much like salmon returning to home rivers.

Predatory fishes compete with fishermen! When one commercial species such as cod eats other commercial species such as capelin, shrimp, or snow crab, there is an interest in the effect increasing numbers of one will have on the other. Cod feeding is studied by examining stomach contents, whose interpretation requires an understanding of selection, digestion, and the partitioning of food energy into growth, activity, and reproduction. Very few measurements of fish bioenergetics have been carried out at the - 1.0 to 3.0°C temperatures that are typical of the Grand Banks cod habitat. Feeding studies using modern computers and analyses can be very revealing. A statistical clustering approach has been developed to analyze stomach contents and identify diet types more accurately than old-fashioned groupings by length or trawl sample could. Cod-diet preferences can now be sorted out and prey abundance, as perceived by cod, mapped for the Grand Bank area.

Predators can also be viewed as collecting tools. Although the view they provide is distorted the information that can be gained about the distribution, relative abundance, and sizes of prey can be very useful, especially in an area as poorly studied as the Grand Banks. For example, large quantities of euphausiids were found in cod stomachs in the area of the Virgin Rocks in the spring of 1979. Concentrations of euphausiids have not previously been reported in this area, and their presence in large quantities in even large cod suggests high productivity in this area.

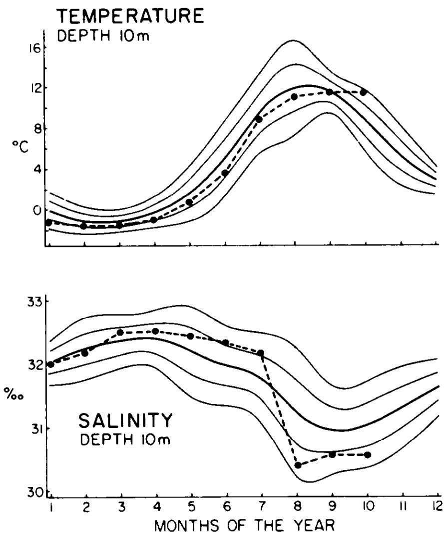
Previous studies (Lear, 1976) indicated the presence of Atlantic salmon *(Salmo salar)* in the area of the Grand Bank of Newfoundland and their possible relationship to inshore fisheries in Canada. In the spring of 1979 and again in 1980, locations thought suitable for salmon were fished. In total, 341 salmon were caught over the southern end of the Grand Bank and to the east of the Bank beyond the 200 m isobath. The distribution of tag returns indicated that some of these salmon were from rivers in the Maritimes and Maine, USA. The condition of gonads indicated that some of the fish would have matured as grilse having spent only one winter at sea. This is the first recorded capture in the Northwest Atlantic (other than in coastal fisheries) of l-sea-winter salmon that would eventually mature as grilse. More work is planned. The biology, ecology, and population dynamics of snow crab on the Grand Banks is being studied. Crab fishermen have extended operations out to 60-120 miles eastward and northward to southern Labrador. Since 1982, snow crab landings on the northern Grand Bank (Div. 3L) have declined precipitously. Size-frequency and shell-condition analyses from spring research cruises have shown that recruitment into the crab fishery virtually ceased after 1981. Bottom temperatures from Station 27, near the commercial crab grounds, show a severe lowering of water temperatures beginning in 1982 and continuing to the present. It appears that these cold temperatures (below - 1.0°C) interrupted the moult cycle of snow crab causing the failure of the fishery after the standing stock of legal-sized animals was depleted.

The short-finned squid *(Illex illecebrosus)* is a seasonal migrant to the Newfoundland area. Incidental catches have been made during May-July groundfish surveys on the Grand Bank. In July to November, squid may support a lucrative inshore fishery. Some years, squid are numerous and profitable; other years they are scarce. Over the past few years the inshore abundance of squid at Newfoundland has been successfully forecast for the fishing industry. Midwater trawl and plankton surveys (February-March) were undertaken within the Gulf Stream System in the area between the Grand Bank and Scotian Shelf, as an index of the relative abundance of pre-recruit (larval and juvenile) *Illex.* In June, stratified random surveys on the southwest slope of the Grand Bank provide further information on the relationships between catch rate, hydrography, and inshore squid abundance in the coming months.

The ocean climate for the region north of the Laurentian Channel is known mainly from Station 27, an oceanographic station near Cape Spear, the most easterly point of North America. Attempts to start a time series for ocean climate correlations in the thirties (following Hjort's advice) were unsuccessful but, since Newfoundland joined Canada in 1949, voluntary occupation of Station 27 by research vessels entering and leaving St. John's has provided 20 to 40 observations each year, more than enough to track the interannual swings in salt and heat content of the Labrador Current (see second figure).

Among the fisheries ecology projects that have used the Station 27 data set are a successful analysis of the northern cod year-class strength (Sutcliffe *et al.,* 1983), of inshore cod catches (Akenhead *et al.,* 1981; Lear *et al.,* In press), and of the collapse of the snow crab fishery on the Grand Bank (Taylor *et al.,* In press). Ocean climate information is particularly useful in this region, because many Grand Bank species are at the edge of their temperature range in this transition zone from boreal to arctic conditions. Haddock, yellowtail flounder, cod, and other resident species survive through the winter off Newfoundland only by avoiding the freezing waters. Many commercially important species (squid, mackerel) temporarily migrate into the region in summer, in abundances that vary according to ocean climate conditions as well as absolute abundance.

High technology offers new tools to make exploring the marine biology of the vast Grand Banks less costly and time-consuming, especially remote sensing through satellite sensors. While few satellites offer data valuable to

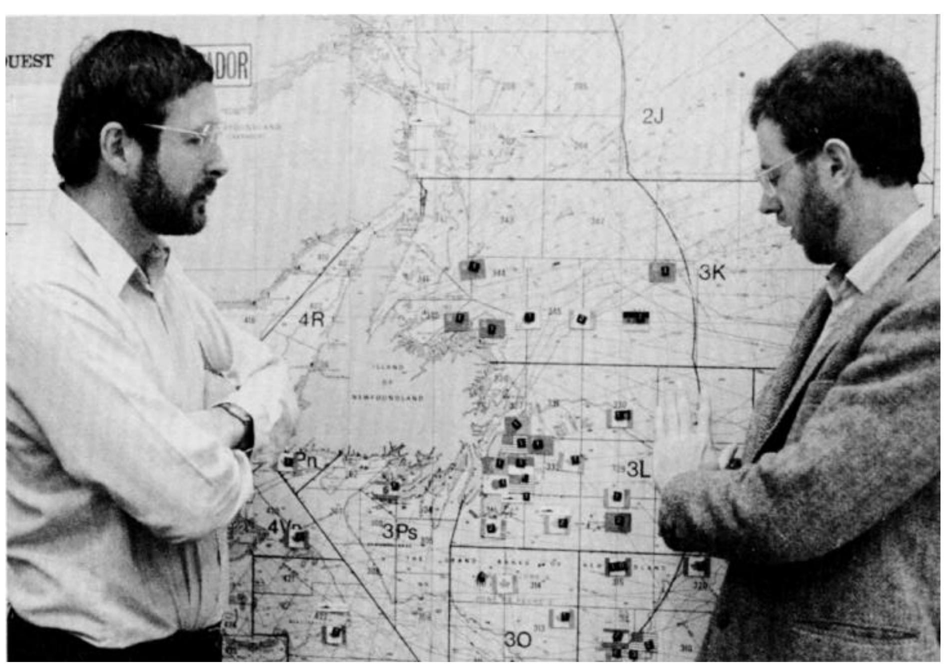


2. The 10-m mean salinity and temperature for each month at Station 27 (St. John's) is compared to the long term mean (centre of 5 solid lines). Plus and minus 1 and 25 standard deviation lines indicate how unusual each month's departure from the mean is. About 16% of observations will be more than one standard deviation higher than the mean, but only 2.3% of monthly means are expected to be more than two standard deviations from the long- term mean.

marine biologists (ocean physicists are better served), sea-surface-colour data are slowly becoming available from NASA archives. Researchers studying the Grand Bank are fortunate that a large ground-truth data base exists from the expeditions that Mobil Oil Corporation supported in 1980. In a co-operative project with the Institute of Ocean Sciences in British Columbia, we are comparing the chlorophyll and primary production data from 1980 to the digital data of nine sea-surface colour images from the Nimbus 7 satellite.

It may be that satellite images can be analyzed to reveal relative primary production in spite of being unable to map subsurface chlorophyll. The ability to map regions of high primary productivity would be a valuable step forward in understanding the biology of the Grand Banks. As an example, the satellite coverage will refine the current estimates of annual primary production on the Grand Bank (175 g C/m^2/year), and thus set important constraints upon the expectations of maximal yield for the fisheries there.

Some research is aimed at theoretical multispecies or ecosystem considerations. Two examples are the examination of trophic dynamics in multispecies marine systems, and the relationship of the structure of marine trophic webs to the relative degree of stability or chaotic behaviour of the



Larry Coady and Scott Akenhead.

systems. A more practical approach uses the extensive research vessel data base, obtained since the mid-forties, to document changes in fish distribution and community structure on the Grand Bank.

Scientists at the Northwest Atlantic Fisheries Centre and BIO have pioneered the development of a biochemical technique - the so-called mixed function oxygenase (MFO) enzyme system - which can be used as a sensitive monitoring tool for petroleum pollution when development begins on the Grand Banks of Newfoundland (see article by Paranjape and Smith). The earliest field studies demonstrating an association between MFO enzyme induction in fish and hydrocarbon pollution were carried out in Newfoundland in the early 1970s. During the last decade other field studies investigating the relationship between MFO enzyme induction and sources of petroleum or mixed-organic pollution have been carried out in the North Sea, the mid-Atlantic, the Pacific, the Adriatic Sea, and the Great Lakes. In addition to such supporting field studies, investigators from laboratories both in St. John's and Dartmouth have studied induction potentials in a variety of fish species common to this area of the Northwest Atlantic.

Fisheries scientists have been involved in the Hibernia Development Project's environmental impact assessment and in the review of the many supporting documents. Evaluating the effects of hydrocarbon development on the fisheries is one of the chief aims of fish habitat research at the Northwest Atlantic Fisheries Center. For example, a mixed-function oxidase enzyme may indicate exposure to hydrocarbons of fish at the Hibernia site. Researchers are also exploring the suite of hydrocarbon metabolites in fish gall bladders as an indicator of exposure of wild stocks of hydrocarbons.

Future research, in keeping with the trend toward ecosystem management, will emphasize co-ordination among specializations. Efforts will be accelerated to improve the precision of estimates of total allowable catch, catch rates, stock forecasts, and other outputs from stock assessment. The expected development of the Hibernia oil field will create added pressures to examine baseline environmental conditions and to ensure that the interests of the fishing industry are protected.

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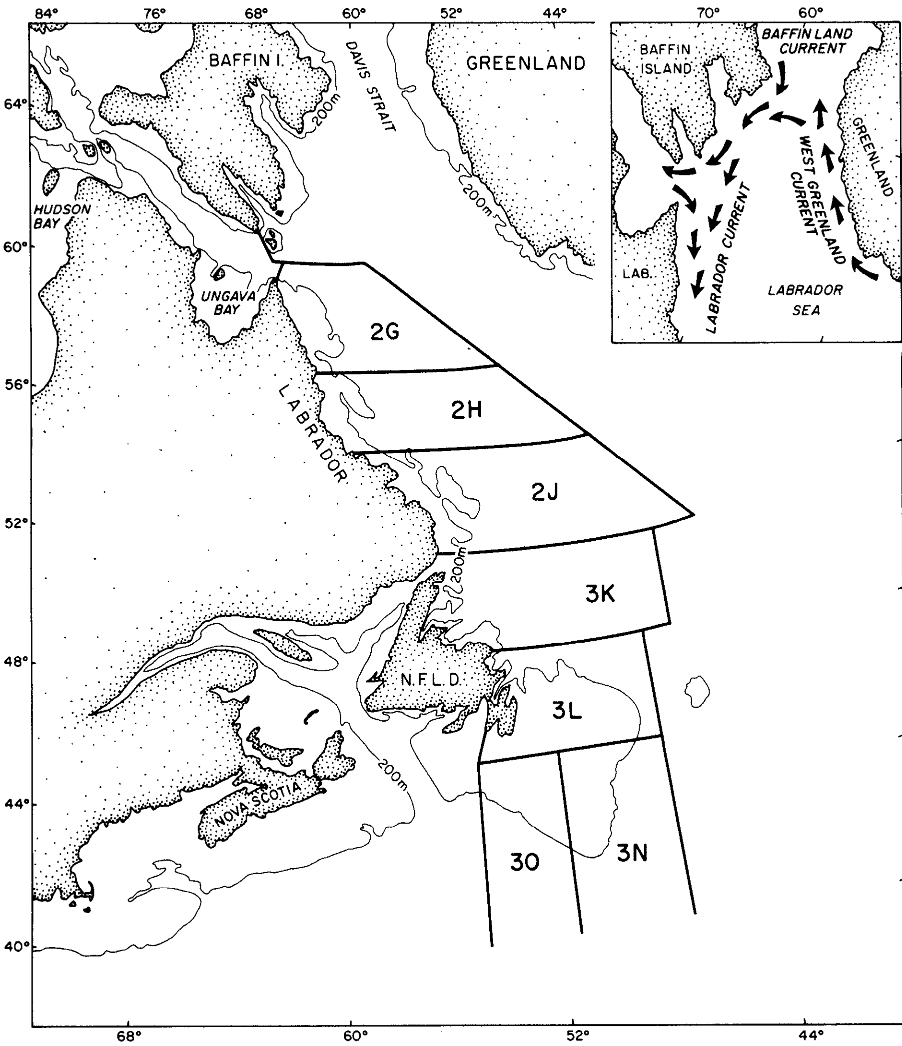
How the Labrador Current and Hudson Bay run-off affect the ecology of the Grand Banks

K.F. Drinkwater

The Labrador Current has a profound influence on the Grand Banks of Newfoundland. Entering this region from the north, the current carries cold, low salinity water. The chilled and often ice-infested waters off Newfoundland are strong testimony to the Current's influence on the physical environment. Less known and understood is the effect of the Current on the biology of the Grand Banks. Studies conducted by Soviet scientists in the early sixties show clearly that cod larvae spawned on the southern Labrador Shelf are transported by the Current into the Grand Banks region. Recent studies by scientists from the Marine Ecology Laboratory have probed further into the effects of the Labrador Current on the biological production of the Labrador Shelf and the distribution of fish there, and on the biological consequences of these effects on the Grand Banks.

The journey begins over 1000 km north of the Grand Banks in the Hudson Strait and Ungava Bay area (see first figure). Owing to the size, shape, and bathymetry of Ungava Bay, resonance occurs there at tidal frequencies and creates high tidal ranges, strong tidal currents, and intense vertical mixing. The latter process produces a water mass that is an admixture of three water masses entering the area: (1) cold (less than 0°C) water of polar origin, which flows southward along eastern Baffin Island; (2) relatively warm (approximately 4°C) water from the Labrador Sea; and (3) low salinity water flowing out from Hudson Bay (Dunbar, 1951;

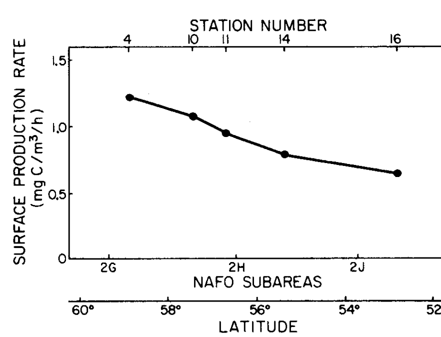


1. The Grand Banks and Labrador Shelf showing the North west Atlantic Fisheries Organization (NAFO) Subarea boundaries. The insert shows the major surface ocean currents in the northern region.

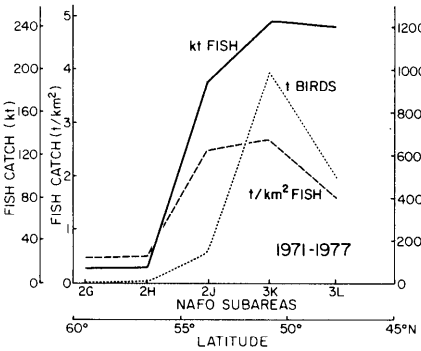
Kollmeyer *et al.*, 1967). The resultant mixture is transported by the residual circulation onto the northern end of the Labrador Shelf and then southward by the Labrador Current. The temperature and salinity characteristics undergo only slight modifications en route to the southern Labrador continental shelf (Lazier, 1982), which suggests that mixing is weak over the shelf. Hudson Strait, therefore, has been termed the birthplace of the Labrador shelf waters (Dunbar, 1951).

The intense mixing in the vicinity of eastern Hudson Strait also has important biological effects, because it produces nutrient-enriched surface waters (Kollmeyer *et al.*, 1967). The uptake of nutrients from sea water is an essential requirement for primary production. At most Arctic or temperate latitudes, depletion of the available nutrients by phytoplankton during the spring or early summer bloom usually limits algal growth through the summer and fall unless new sources of nutrients arise. Sutcliffe *et al.* (1983) argued that the high surface nutrients from Hudson Strait are advected onto the Labrador shelf and represent the primary source of new nutrients onto the shelf in summer. The nutrient flux from Hudson Strait to the Labrador shelf is relatively continuous. Sutcliffe and his co-workers also formed the hypothesis that a food chain develops on the Labrador shelf progressively 'downstream' from this nutrient source during the time required for development, and with the southward advection by the Labrador Current. They suggested that the estimated two months necessary for water to travel from Hudson Strait to the Grand Banks would be sufficient for development from phytoplankton to large zooplankton and small fish. The transit speed of approximately 20 km per day is consistent with measured currents over the shelf.

If the Sutcliffe *et al.* (1983) hypothesis is correct and the primary source of new nutrients to the Labrador shelf enters from the north, a southward decrease in primary production can be expected. Available surface-production data from Irwin *et al.* (1978), although limited in both spatial and temporal coverage, do show decreased production towards the south (see second figure). The hypothesis also predicts increasing abundance of zooplankton and fish to the south. Qualitative zooplankton data with which to test the hypothesis are unavailable; however, fisheries data do exist. The mean catch of the major commercial species, expressed as either weight or weight per unit area, increases dramatically in southern Labrador with catches remaining high through to the Grand Banks (see third figure). The dominant commercial species is Atlantic cod. It is possible that such a representation using catch statistics is misleading because it may reflect only fishing effort. This is especially true in the northern Labrador regions where the local population is small and the distance to the home port of any commercial fishing fleet is long. For this reason Sutcliffe *et al.* (1983) examined seabird abundance along the coast.



2. Surface production rate as a function of longitudinal distance along the Labrador Shelf.

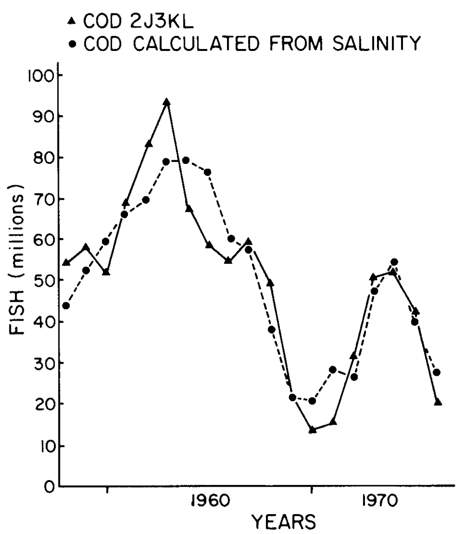


3. Fish catch, fish catch per unit area, and bird abundance as a function of longitudinal distance along the Labrador-Newfoundland Shelf.

The seabirds nest at the shore and feed upon small fish, thereby, requiring for at least a short time a dependable supply of food. The parallel between the abundance of bird and fish catch is striking (see third figure). It is not a reflection of available nesting sites, inclement weather, or existing ice conditions. The interpretation is that there is a scarcity of small fish in the northern Labrador shelf for the birds to feed upon.

The hypothesis of Sutcliffe *et al.* (1983) further suggests that the size of zooplankton increases to the south. Again, qualitative zooplankton data are lacking, but indirect evidence is available. Prey size is known to be a key factor in determining the maximum size attained by fish (Kerr, 1979). On the Labrador shelf and Grand Banks, cod length (at 'largest size') increases to the south, with cod on the northern Labrador shelf being little more than 60% of the size of those on the southern shelf and on the Grand Banks (May *et al.*, 1965).

Phytoplankton production, fish abundance, fish size, and bird abundance along the Labrador shelf all support the hypothesis that nutrients from Hudson Strait initiate a chain of events that culminates in higher fish production on the southern shelf and off northern Newfoundland. Extending the hypothesis further one might expect that interannual fluctuations in nutrient supply may produce year-to-year changes in fish production. Unfortunately, nutrient data for Hudson Strait and the Labrador Shelf are not available over a long time-series. However, more-abundant nutrients are associated with high salinity water and salinity records are available. Data have been collected at Station 27, 4 km off St. John's, Newfoundland, on a regular basis since the early fifties. While the station is located further south than desired, no long-term salinity measurements are available on the Labrador Shelf. Comparison of Station 27 upper-layer salinities with annual estimates of age-four cod abundance in the offshore of southern Labrador and northern Newfoundland and the Grand Banks is revealing (see fourth figure). Eighty per cent of the variance in cod abundance from 1958-1976 can be explained by the summer-time salinity levels during the first three years of a cod's life. In years of higher salinity (and therefore higher nutrients), cod abundance increases.



4. Measured abundance of Atlantic cod in the southern Labrador-northern Newfoundland Shelf area and abundance calculated from correlations with salinities.

The low salinity outflow from Hudson Bay, one of the three main constituents of the Labrador shelf water, also affects the biology of the Labrador shelf. Monthly mean freshwater discharge into the Bay shows an inverse relationship with the seasonal upper layer salinities off St. John's, given an appropriate lag time for the water to travel from Hudson Bay to eastern Newfoundland. Assuming a similar inverse relationship exists between Hudson Bay run-off and salinity at interannual time scales, decreased cod catches will follow years of high run-off (that is low salinity and low nutrients). This is consistent with the salinity-cod relationship noted above. The proposed mechanism is that, in high discharge years, the increased stratification suppresses mixing of deeper water into the surface euphotic zone and thereby lowers nutrient concentrations. This reduces primary production and eventually lowers the amount of food available to the cod. Unfortunately, sufficient hydrological, meteorological, and oceanographic data are as yet unavailable to test this hypothesis.

In the late summer of 1985, a voyage on CSS *Hudson* was conducted to further test the validity of the Sutcliffe *et al.* (1983) hypothesis that a food chain develops downstream from Hudson Strait. Abundance and size data on the bacteria, phytoplankton, zooplankton, and fish over the Labrador shelf were collected and will be used to investigate the predicted longitudinal gradients. Comparisons will be made to determine the relative importance of the longitudinal gradients to the cross-shelf gradients and the difference between topographic features, such as those on the banks, in troughs, and along the continental slopes. Analysis of the data will be completed in the near future and should provide significant new insights into the impact of the Hudson Strait outflow and the Labrador Current on the biology of the Labrador shelf, and their possible effects on the Grand Banks.

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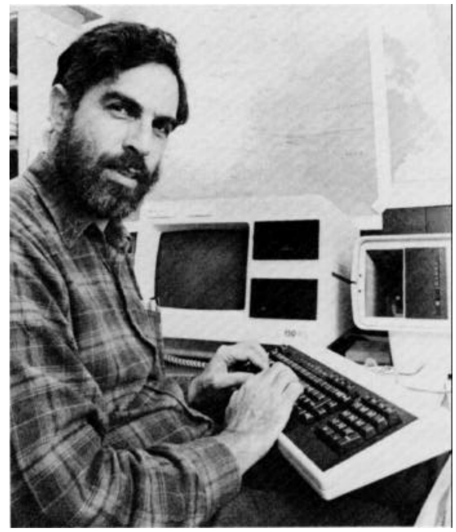
The Grand Banks modelling project

W. Silvert



Bill Silvert.

In 1983 the Marine Ecology Laboratory undertook to develop a model of the Grand Banks ecosystem that would assist in the evaluation of possible ecological risks associated with oil production on the Grand Banks, particularly at the Hibernia site. This project was funded by OERD and is one of several initiated at MEL to improve our understanding of the ecological implications of offshore energy developments on the Grand Banks and other shelf systems.

The Grand Banks modelling project is organized in three phases: (1) development of a highly aggregated model representing the dynamics and major trophic pathways of the Grand Banks ecosystem; (2) identification and modelling of the significant interactions through which oil spills could affect the biota on the Grand Banks; and (3) elaboration of the model for predictive modelling of the effects of oil spills, given uncertainties in the parameter estimates and the possibility that available data may not be sufficient to resolve the structure of all of the submodels. Phase (1) of the project was completed in 1985, and phase (2) should be completed in 1986.

Model development

The basic model structure was defined at a workshop at the Northwest Atlantic Fisheries Centre in April 1984. At this and later workshops, an effort was made to include individuals from many different areas of marine ecology, as well as physical oceanographers familiar with the transport properties of the area. A major function of a model like this is to facilitate communication between specialists; consequently, discussions were largely carried out in plenary sessions rather than in specialist working groups.

This planning workshop was followed by a full modelling workshop at Acadia University in July 1984. The main objective here was to develop a preliminary working model of the Grand Banks ecosystem that incorporated the concepts put forward by the participants and represented a realistic picture of the processes that govern the system. This included the identification of the major interactions, particularly nutrient flows (mainly carbon and nitrogen). It was also decided to use the model at an early stage for sensitivity analysis in order to identify the most critical parameter values for determining model performance.

General description

It was agreed at the April workshop to work with a highly aggregated model at the outset, and to adopt a more detailed structure only for those parts of the model for which it was clearly needed and supported by adequate data. This “top down” approach has been used for much of the ecosystem modelling work at MEL, and the workshop participants agreed that the data available on the Grand Banks ecosystem are such that a more detailed approach would probably not be fruitful.

In keeping with this philosophy, the model structure is built around three broad biological categories arrived at through a compromise between ecosystem considerations and the practical needs that a model of this type must address. One category consists of fish, macrobenthos, and their predators, including mammals, birds, and fishermen: another includes zooplankton (except for ichthyoplankton, which were grouped with fish) and meiobenthos: the third category consists of phytoplankton and bacteria.

Within each of these three general groups, the organisms are further classified by size. For the preliminary modelling stage we decided to use large size groupings covering a factor of 10 in linear dimension. Most particle size studies use a factor of 2 in equivalent spherical volume, which is an order of magnitude finer on a logarithmic scale: however, this would have meant using 20 to 30 size classes for the model, which was felt to be impractical. The decade scale corresponds roughly to functional groupings. For example, within the “fish” grouping, the size range from 1 mm to 1 cm consists mainly of ichthyoplankton, from 1 cm to 10 cm of small pelagic fish, and from 10 cm to 1 m of groundfish; (these are equivalent spherical diameters, not lengths). The

SIZE (m)	FISH	ZOOPLANKTON	PHYTOPLANKTON
10^{0}	DEMERSAL		
10^{-1}	PELAGIC		
10^{-2}	ICHTHYOPLANKTON	CARNIVORES	
10^{-3}		HERBIVORES	
10^{-4}		MICROPLANKTON	LARGE PHYTOPLANKTON
10^{-5}			SMALL PHYTOPLANKTON
10^{-6}			MICROBES
10^{-7}			

1. Size classes used in the workshop model.

scheme used is shown in the first figure.

Feeding behaviour is assumed to depend only on size, with each predator consuming organisms between 2 and 3 orders of magnitude smaller than itself. For example, pelagic fish feed on herbivores, microplankton, and large phytoplankton according to the size categories shown in the first figure. These descriptive terms are used only in a crude sense of course. Many trophic interactions do not fit into this simple scheme.

It was decided at the April workshop to use four spatial compartments, three on the Grand Bank itself and one corresponding to the eastern branch of the Labrador Current. The four main compartments are shown in the second figure, with the location of the boundary regions indicated. The boundary conditions actually correspond to water masses rather than specific geographic regions.

The structure of the model is as follows: the main subroutine calls a total of nine lower level subroutines, listed below:

INIT - Initialization routines called only at start of simulation.

PHYS - Calculation of water temperature and solar radiation at each time step.

SPILL - Calculation of oil distributions, based on different oil spill scenarios.

BOUNDS - Compute values of state variables in boundary compartments.

VERTMX - Compute vertical distribution of nitrate due to vertical mixing.

EXCHG - Compute advective and diffusive transport between compartments.

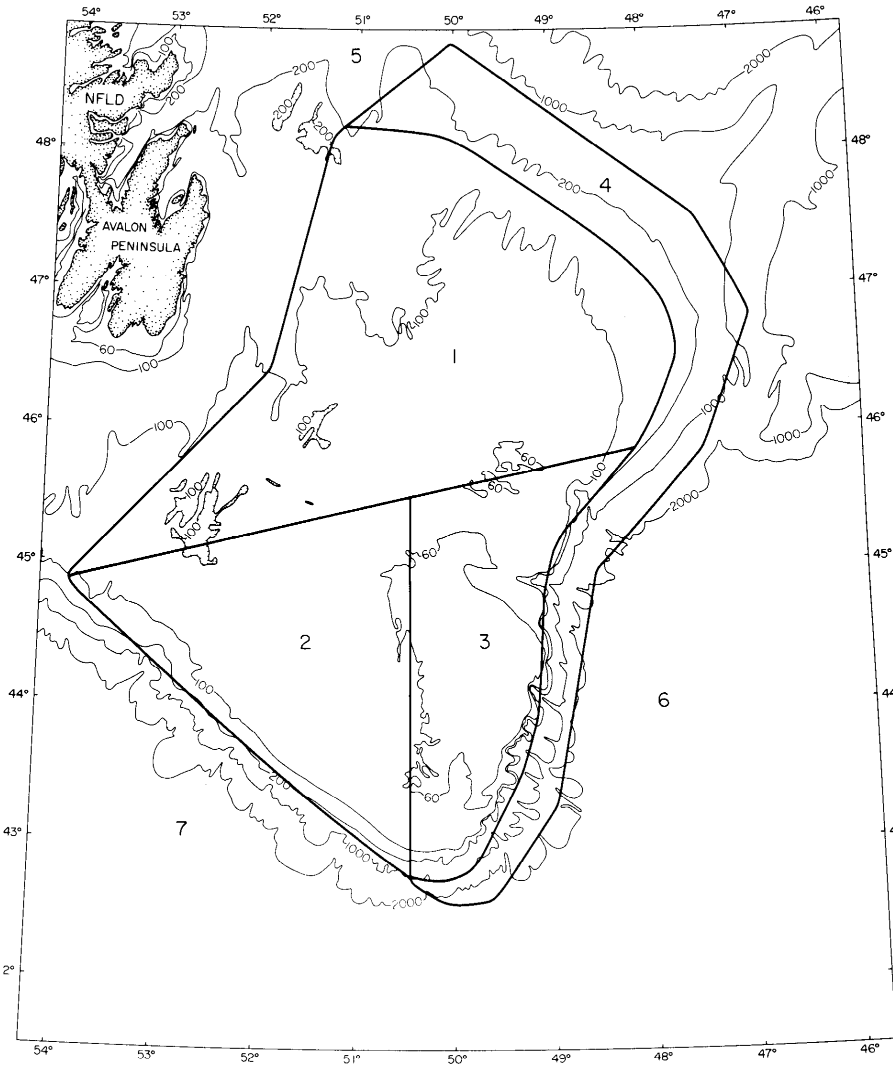
RECYCL - This subroutine handles the remineralization of nitrogen.

SRPHYT - Biological subroutine for microbes and phytoplankton.

SRZOOP - Biological subroutine for zooplankton and meiobenthos.

SRFISH - Biological subroutine for fish and marine mammals.

EXPORT - Loss of fish to the commercial fishing fleet, birds, etc.



2. Compartments (1-4) and boundaries (5-7) for the model as agreed on at the July 1984 workshop.

We have tried to keep the number of state variables in the model as small as possible. As mentioned above, the size classes are much broader than is usual in size-spectrum analysis. The model includes only 11 state variables, defined as follows (sizes refer to equivalent spherical diameters):

BACT - Microbes.

PHYT2 - Small phytoplankton, 1-10 μm.

PHYT3 - Larger phytoplankton, 10-100 μm.

ZOOP1 - Microzooplankton, 10-100 μm.

ZOOP2 - Mostly herbivorous zooplankton, 100 μm^{-1} mm.

ZOOP3 - Mostly carnivorous zooplankton, 1 mm^{-1} cm.

FISH1 - Ichthyoplankton.

FISH2 - Small fish, mostly pelagic.

FISH3 - Large fish (mostly demersal) and resident marine mammals.

ANTGN - Nitrogen in the mixed

layer (available to phytoplankton).

BNTGN - Nitrogen below the mixed layer, which is made available to phytoplankton only through vertical mixing.

The ZOOP and FISH variables also include benthic fauna. An additional state variable is currently being introduced to describe non-living organic material, which is a major source of carbon in marine ecosystems. There are of course many other variables used in the simulation, but these are the only ones modelled dynamically.

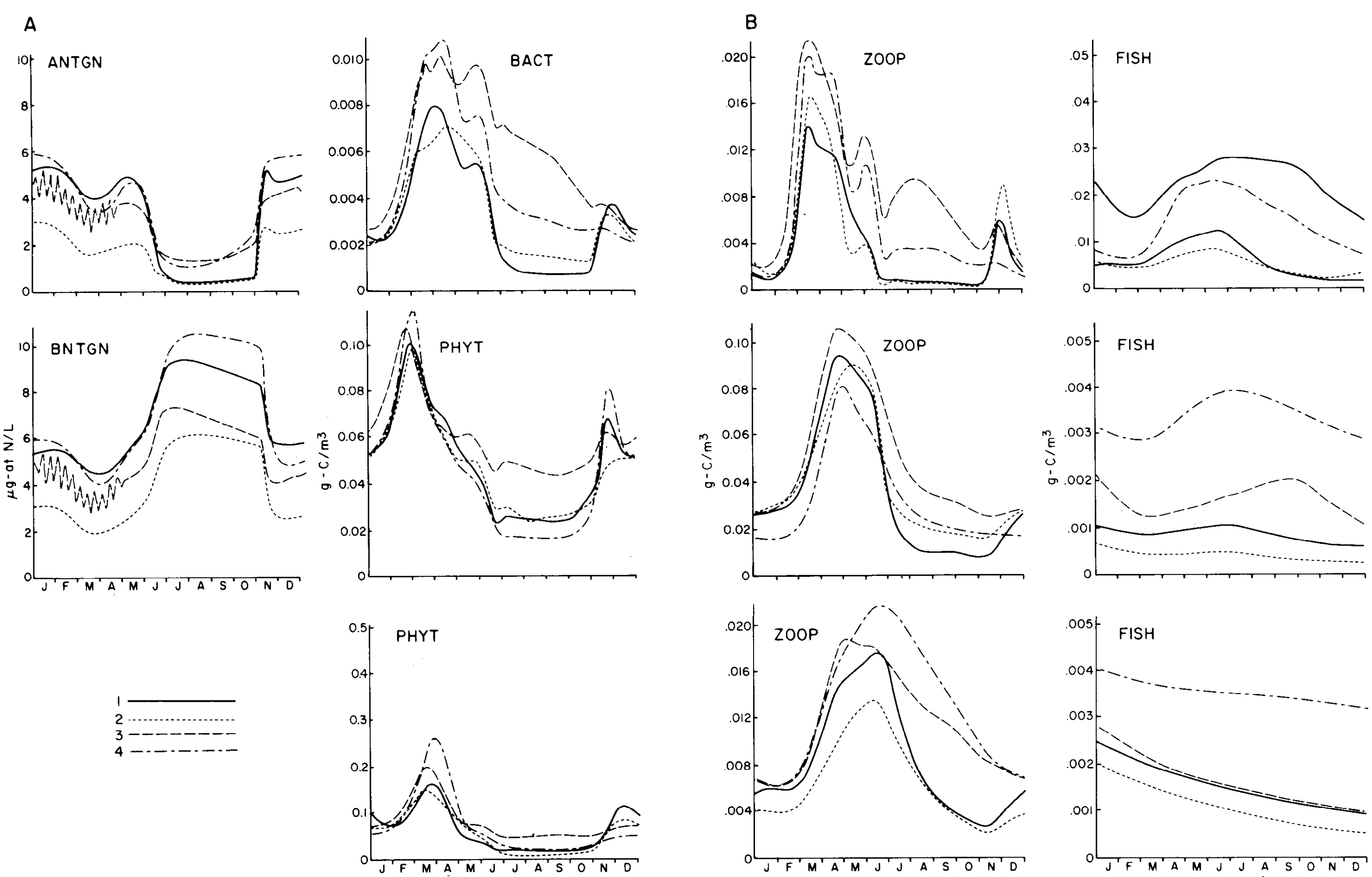
Results from the current model

The simulations shown in the third figure constitute a typical set of runs. Each plot covers one year, starting on March 1, with a standard set of initial conditions. Much of the behaviour of the system as described by these runs can easily be changed by small parameter changes in the model and, because no effort has yet been made to optimize the parameter estimates, quantitative assessment of these results is not meaningful now. Except for the nutrient curves, which are expressed in microgram-atoms of nitrogen per litre, all of the results are expressed as grams of carbon per cubic metre. Sizes are all expressed as equivalent spherical diameters (ESD).

Primary production and nutrients

Primary production, nutrients, and the benthic component appear to be the most critical parts of the model at present. The current submodel is very sensitive to environmental parameters, which makes the “tuning” of this part very important in determining the overall behaviour of the complete model. Examining the reasons for this has proven instructive, and we are pursuing this problem further in the coming year. Unfortunately there is little independent evidence on how robust the algal component of the seasonal cycle is, information that would be provided by interannual time series on primary production; thus, much of the information needed for validation of the predicted sensitivities must come from indirect evidence.

In the present version of the model there is no nutrient limitation during the winter, and the initiation of the spring bloom is caused by a combination of enhanced light and rising temperatures, both of which increase the growth rate. This means that the onset of the spring bloom is determined by the difference between gradually changing factors, so that the timing is very sensitive to small changes in environmental factors or grazing. Thus, in the simulations shown in the fourth figure, the bloom occurs too early. This can be corrected easily by making small changes in these driving variables or by tuning physiological parameters such as the dark respiration rate of phytoplankton, but we feel that it is important to determine whether the timing of the spring bloom really is so sensitive to these



3. Simulated results.

factors, or whether it is governed by changes more directly associated with stratification of the water column or some other dominant driving force. This determination is especially critical for a model that is to be used for predicting the effects of oil spills, because the effects of a spill, if it affects physiological parameters to which the system is very sensitive, could be greatly magnified.

It is commonly accepted that the spring bloom is associated with stabilization of the water column due to stratification. Detailed models of phytoplankton growth usually treat primary production as a balance between net growth in parts of the water column where both light and nutrient supplies are adequate, and losses due to grazing and respiration in the light- and nutrient-limited parts. This work involves modelling the vertical structure of the plankton in more detail than seemed feasible in the context of our present work, given the limited data base and the lack of detailed physical oceanographic information on vertical mixing processes throughout the year. At the July workshop, it was assumed that the reduction in vertical mixing in spring would increase the mean amount of light to which phytoplankters are exposed, but field measurements of chlorophyll concentrations suggest that the opposite occurs: in many parts of the Grand Banks the chlorophyll concentrations are found at depths greater than the mean mid-winter mixing depth. Various ways of relating the spring bloom to stratification in terms of aggregated variables have not convincingly resolved this problem, and it is likely that a more detailed submodel of algal growth and respiration throughout the diurnal cycle may be required to understand the processes involved.

The model does not include several of the threshold effects commonly used in models of this type, but for which empirical evidence is weak. Some of the workshop participants recommended that various thresholds on nutrient uptake and grazing rates be incorporated, and it has been established that these could stabilize the model and could also be used effectively for tuning it. It is likely that several control features of this type will be incorporated into the model during the coming year, but because of the lack of detailed information about threshold behaviour in nature and doubts that such behaviour can be reliably duplicated under laboratory conditions, we feel that it is necessary to study the behaviour of the system without this regulatory feature first. Thresholds may also be especially sensitive to the effects of oil contamination, which would weaken the predictive power of any model in which they played a major role.

According to the Mobil Oil Canada study and work on similar ecosystems, the end of the spring bloom corresponds with the exhaustion of available nitrate in the water column, and during the summer the levels in the surface waters fall below the minimum measurable value of about 0.1 µg-at N/l. Field data show that there is still some nitrate present at depth, and at the July workshop it was agreed to divide the nitrogen variable into two components: ANTGN available for plant growth, and a bottom component, BNTGN, which cannot be utilized by algae but can be converted into ANTGN by vertical mixing. It was assumed that the dividing line between these strata was at the pycnocline, and again the problem arises that the chlorophyll maximum in summer frequently falls below the pycnocline: except for the southern transect (44°N) there is generally enough nitrate available at depths where chlorophyll is available to support primary production. This indicates that the cells found at depth may be moribund, and that production is occurring only in the surface waters. If so, then the producing cells may have to be more efficient at scavenging nutrients from the water column than the Michaelis-Menton kinetics now used in the model predict. It has been hypothesized that, under oligotrophic conditions, algae can exploit small pockets of excreta in the wake of swimming zooplankters even when the mean nutrient concentrations in the water are effectively zero, and it may be that nutrient uptake should be modelled in this way, rather than in terms of the observed nutrient concentrations.

The phytoplankton biomass curves, PHYT2 and PHYT3, show a small autumn bloom. Because there was no October voyage in the Mobil study, it is not certain whether this bloom commonly occurs. However, the existence of the bloom in the model depends on the timing of the breakdown of stratification in the fall, as a rapid breakdown quickly introduces a large quantity of nutrients into the surface water, which causes a strong bloom, while a slow breakdown gives the smaller herbivores time to consume the bloom as it develops.

In the simulation shown in the fourth figure, the ANTGN levels do not fall below about 0.5 µg-at N/l, owing mainly to the use of uptake thresholds to stabilize the runs. The phytoplankton biomass tends to die off too early in the summer, and there are spurious oscillations in the ANTGN and BNTGN levels for Compartment 3 in late winter due to the fact that the BNTGN variable is very small and turns over in less than a day. These numerical problems further complicate the analysis, but it appears that the modelling of nutrients and primary production is central to understanding the workings of the Grand Banks ecosystem and will have to receive very careful attention before this part of the ecosystem can be adequately incorporated in the model.

Zooplankton and fish

As should be expected in a size-structured model, the three zooplankton classes differ in their rates of response to the dominant forcing effect during the year, which is the spring bloom. Only the smallest size class exhibits any structure in this response. It is however noteworthy that the middle class, ZOOP2, has a biomass 4-5 times higher than each of the other two classes. This probably reflects a feeding advantage, since ZOOP2 can eat both size classes of phytoplankton.

The adult fish classes, FISH2 and FISH3, are the only components of the model that have not come close to equilibrating during the second year simulation shown in the fourth figure. While the values in Compartment 4 (Labrador Current) remain fairly high, the other values continue to drop rapidly. It appears that the Grand Bank itself does not produce enough energy to support fish populations at observed levels of abundance, although the relative ordering of the levels is consistent with observation: Compartment 2 (SW slope) is least productive, and FISH2, which is mostly small pelagic fish like capelin, is fairly high in Compartment 3 (Southeast Shoal). However, this simulation does not include migration, and it has been suggested that some of the fish and zooplankton populations on the Grand Banks overwinter in the richer waters of the Labrador Current. These simulation results, while tentative and not quantitatively reliable, may lend support to this hypothesis, a factor to be considered in future model development.

If migration between Compartment 4 and the other compartments plays a significant role in determining the productivity of the Grand Banks, then the potential impact of an oil spill at the Hibernia site, located as it is close to the centre of the hypothesized migrations, could be increased.

Summary of model results

Several areas of the present model must be analyzed before appropriate submodels can be constructed. The interplay between nutrient dynamics and primary production, particularly the role played by microbes, is not well understood and will be a major focus for attention. The linking between the pelagic component of the ecosystem and benthic organisms is another area where much information is lacking, and this is reflected in uncertainty on how best to model the interaction. A third critical area is the modelling of feeding rates: while these have been extensively studied in the laboratory and some *in situ* studies have been carried out, the role of patchiness in enhancing feeding efficiencies has received very little attention. One problem faced in dealing with these uncertainties is that all of these concerns could involve interactions that are potentially vulnerable to oil-spill impacts, and if they are incorrectly modelled one could arrive at incorrect conclusions about the vulnerability of the ecosystem, even if the resulting model gave good results when calibrated against existing time series.

Future research and applications

Bringing the model to its present stage of development has resulted in a greater understanding of the complexity of the forcing functions on continental shelf ecosystems. While it was apparent before this project started that data on the Grand Banks were scarce and incomplete, the modelling process has identified those gaps in the data most critical to our understanding of how the Grand Banks ecosystem functions. Further work with the model will help to identify more of these critical parameters and determine the accuracy with which they must be defined, thus providing direction to future research in the area. We hope that the model will eventually be adapted to other continental shelf ecosystems as a means of collating and synthesizing existing data and planning new fisheries related research.

Other federal government departments, who are responsible for the assessment of environmental impacts, have demonstrated an interest in the application of ecosystem modelling to the impact assessment process. Present methods of assessment are largely unstructured and do not consider impacts on the whole ecosystem resulting from a measurable impact on a small part of the ecosystem. The modelling approach is capable of integrating all of the potential impacts. It also provides a structure that can be built upon as understanding of the ecosystem grows and as the type and magnitude of perturbations caused by the development change. Assessment of the applicability of this ecosystem modelling approach to environmental impact assessment will begin in 1986. Perturbations will be input to the model based on the pollutant-input scenarios described in Mobil Oil Canada Ltd.'s Hibernia Development Project Environmental Impact Statement. Information obtained from the modelling process on potential impacts will be compared with the impact predictions.

Microheterotrophic activity on the Grand Banks: The biological submodel

M.A. Paranjape and R.E.H. Smith

Primary production by phytoplankton forms the basis of all major pelagic food webs. Organic carbon produced by the photosynthetic activity of phytoplankton is used by pelagic herbivores as a source of energy for growth and metabolism. Until lately, large phytoplankton and large crustacean herbivores were considered to be the major producers and consumers of organic carbon, but recent studies of the role played by bacteria and microzooplankton as consumers of organic carbon no longer support this traditional view. Scientists now believe that planktonic bacteria may consume one half or even more of the primary production in many areas. Similarly, the microzooplankton, by virtue of their small size, would be expected to have high rates of consumption to support their disproportionately high specific rates of growth and metabolism. If this is generally true, the activity of small consumers or microheterotrophs in the pelagic zone, with the apparent insertion of additional steps or side branches in the food chain, raises important questions about the overall trophodynamic efficiency of plankton production.

The microheterotrophic community includes bacteria and microzooplankton. Bacteria are usually less than 1 µm in size while microzooplankton are defined as animals that pass through a 200 µm mesh opening. These latter include a variety of ciliates, nanoflagellates, sarcodines, and larval stages of many metazoan phyla.

In the last 15 y, using new techniques of microscopy, combined with fluorescent stains to aid identification, estimates of bacterial abundance from many coastal and shelf waters have become much more precise. One million cells or more per millilitre of water are commonly measured. If natural bacterial populations as abundant as this have comparable metabolic activity to those observed in the laboratory cultures, then bacteria may well be a significant component of plankton secondary production. However, it has often been suggested that the metabolic rates of bacteria in nature are low because substrates for growth are scarce, and therefore most bacteria in the sea are metabolically dormant. This is still a much debated issue.

Many new techniques to measure bacterial activity have been developed in the last ten years. Some depend on measuring the rate of assimilation of a major constituent of the bacterial cell such as the DNA precursor, thymidine, or the substrate of dissolved organic carbon derived from algal cells. Other methods depend on measuring the frequency of division of bacterial cells or the specific measure of some metabolic index such as respiration. In many cases, the resulting estimates of bacterial activity are much larger than has been assumed historically.

The microzooplankton community is even more heterogeneous than the bacteria. As early as 1908, Hans Lohmann pointed out that microzooplankton are often dominant in the animal plankton, but for many decades his work was not followed up anywhere. Recently, however, more careful methods of collection, preservation, and enumeration have been employed to study the patterns of distribution and abundance. In the temperate waters, we now know that the microzooplankton often make up as much as 40% of the macrozooplankton biomass in the inshore as well as in the oceanic areas and at times can exceed it by an order of magnitude. Despite their obvious importance, microzooplankton have been little studied experimentally. Unfortunately, most are inconspicuous and too delicate to be manipulated successfully for laboratory experimentation. At any rate, they are so diverse in size, feeding habits, and reproductive patterns that the few laboratory-derived experimental results cannot be successfully applied to natural situations. As a result, the impact of the total microzooplankton community as potential grazers on small primary producers is usually estimated indirectly.

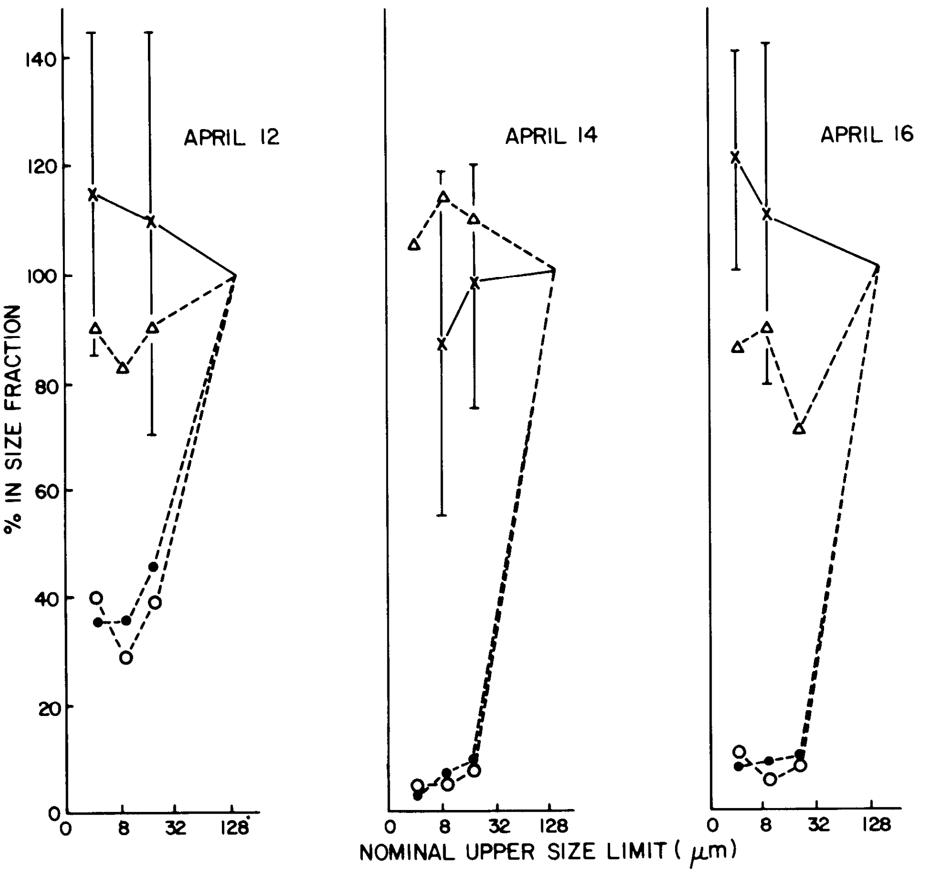
In our study of microheterotrophic activity on the Grand Banks, we used different approaches to separate the activities of the two components of the community. From our earlier measurements, we found that phytoplankton in the bacterial size-range are often active on the Grand Banks. We also found that active bacterial cells able to assimilate glucose and/or amino acids may comprise only a small fraction of the total bacterial population. Thus, we separated the bacteria from the rest of the plankton by screening water through filters of different defined porosities, and measured the rate of oxygen consumption in different size fractions. We simultaneously measured the photosynthetic activity as well as assimilation of glucose and amino acids in different size-fractions. In this way, we were able to discriminate the contribution of bacteria and other phytoplankton to the total community metabolism.

The oxygen uptake approach obviates the need to assume values for bacterial growth efficiency, the proportion of the population which is physiologically active, and the metabolic efficiencies of the bacteria. It returns an answer directly on the proportion of community metabolism due to bacteria. However, great analytical precision is required to measure the small oxygen changes caused by natural plankton communities. We solved this problem at BIO by constructing an advanced oxygen analysis system capable of delivering state-of-the-art precision. This instrument permitted us to measure oxygen consumption rates for the Grand Banks microplankton in incubations of 24 h or less, at the ambient temperature.

We were able to separate bacterial from phytoplankton metabolism clearly on many occasions. The first figure, for example, shows that virtually all metabolism during the late stages of the spring phytoplankton bloom was accomplished by organisms smaller than a 5 µm nominal dimension. This size range includes virtually all the bacterial activity, as evidenced by assimilation of glucose and amino acids in the dark, but very little of the phytoplankton activity, as evidenced by photosynthetic carbon assimilation. It is accordingly reasonable to attribute most of the community metabolism to bacteria rather than to phytoplankton or other relatively large organisms. Additional measurements in spring, summer, and fall showed that bacterial metabolism probably averaged about one half or more of total microplankton metabolism in the surface mixed layer, and a similar share of primary production appeared to be consumed by bacteria.

The other component of the microheterotrophic community is the microzooplankton, which feeds primarily on the small-sized phytoplankton. By feeding on that part of the biomass spectrum not utilized efficiently by the larger crustacean grazers, they make the production of nanoplankton (and probably picoplankton as well) accessible to the larger grazers such as copepods and larval fish.

To estimate the grazing impact of the total microzooplankton community on phytoplankton, we used a recently developed dilution method, which involved minimum handling of the prey and the predator components in the sea water. The method is elegant in its simplicity. Several dilutions of natural sea water prepared with filtered sea water are incubated at the ambient temperature and light-level, and changes in chlorophyll, as an index of phytoplankton biomass, are monitored. The dilution series reduces chances of predator-prey encounters between microzooplankton and phytoplankton populations as well as reducing competition for nutrients in the



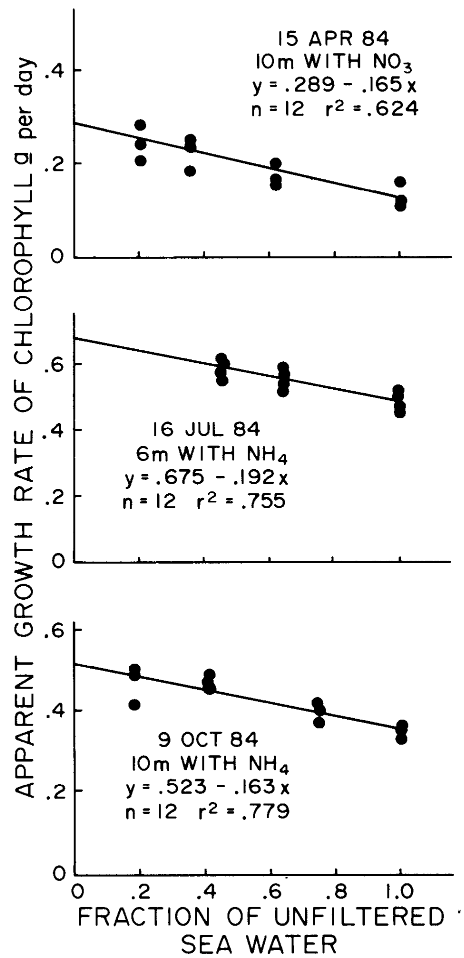
1. Cumulative size distributions of plankton biomass and activity in samples collected in April 1985 near the Southeast Shoal on the Grand Banks. Sizes are defined by the size of mesh through which the water was filtered before measurement of biomass of activity. By definition, the largest class (< 200 µm) contains 100% and the smaller classes (< 5, < 10, < 20 µm) some fraction of the total microplankton. The properties shown are dark O_2 consumption rates (x, with bars showing 95 % confidence interval), chlorophyll a concentrations (closed circles), ^{14}C - CO_2 assimilation (open circles), and bacterial biomass (triangles). When most of a property is due to the smallest organisms, then random statistical error can cause the amount in small-size fractions to appear greater than 100% at times (e.g., O_2 consumption for April 12).

phytoplankton population. Rates of phytoplankton growth and grazing mortality can then be calculated from the observed changes in the chlorophyll *a*, because the rates of change in chlorophyll at different dilutions are linearly related to the dilution factors. The negative slope of this relationship is the grazing coefficient for the microzooplankton and the y-axis intercept, where no grazing occurs, is the instantaneous growth rate of phytoplankton (see second figure). Both of these coefficients can be used further to calculate the grazing by the microzooplankton community on the initial standing stock and potential primary production of phytoplankton.

The results of the experiments performed on the Grand Banks are shown in the second figure. In spring, water-column stratification and increased light levels lead to an intense flowering of phytoplankton. Chlorophyll levels reach greater than 10 µg/l in the mixed layer. Boreal and arctic species of chain-forming diatoms dominate the phytoplankton. Almost 85% of the chlorophyll is found in the species greater than 20 µm in size. Most of it is not useful to microzooplankton because they cannot usually eat such large cells. However, they daily consumed about 25% of the standing stock and 60 to 80% of the production of phytoplankton of less than 20 µm size. Nevertheless, the grazing impact on the total phytoplankton community was only about 3% and 15% of the standing stock and production, respectively.

In summer and fall the situation was reversed. The phytoplankton biomass was generally less than one microgram of chlorophyll per litre, and the flagellates of less than 20 µm size were predominant. This is the preferred size range of food particles for microzooplankton. As a result, during these seasons, they consumed about 15% of the standing stock and 35% of the primary production daily.

Thus it appears that bacteria and



2. The relationship between the apparent growth rate of chlorophyll and the dilution factor is depicted. The experiments were performed in three different seasons. The negative slope defines the grazing coefficient for microzooplankton and the intercept gives the doubling time of the chlorophyll.

microzooplankton together could easily remove about one half of the standing stock and almost 60 to 70% of the production in spring and another 15 to 20% more in summer and fall.

We do not have estimates of what larger crustacean grazers on the Grand Banks might consume. Their biomass, however, appears to be low in most seasons. Consequently, their grazing impact on phytoplankton can probably be assumed to be low as well. It is now clear that the classical linear food-chain concept where large phytoplankton are the major producers and large grazers are the major consumers does not seem to apply to the Grand Banks ecosystem. Except in the few weeks of the spring months, small phytoplankters are the dominant producers and microheterotrophs are the major consumers. The pathway by which the secondary production of microheterotrophs becomes available to the higher trophic levels on the Grand Banks is not yet clear.

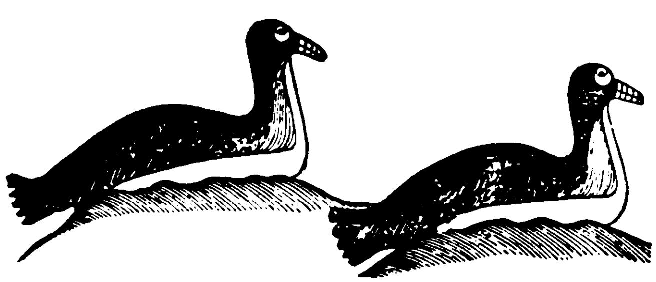
Seabirds and the Grand Banks

R.G.B. Brown

The abundant seabirds of the Grand Banks have been known to seamen and fishermen for centuries. The 1728 edition of the *English Pilot,* describing "Some Directions which ought to be taken Notice of by those sailing to *Newfoundland,"* says: "There is also another thing to be taken Notice of by which you may know when you are upon the | Grand | Bank. I have read an Author that says, in treating of this Coast, that you may know this by the great quantities of Fowls upon the Bank, *viz. Sheer-waters* | greater and sooty shearwaters *Puffinus gravis* and *P. griseus* |, *Willocks* | common and thick-billed murres *Uria aalge* and U. *lomvia* |, *Noddies* | northern fulmars *Fulmarus glacialis* |, Gulls | probably black-legged kittiwakes *Rissa tridactyla* | and Pengwins | great auks *Pinguinus impennis* |, &c. without making any Exceptions; which is a mistake, for I have seen these Fowls 100 Leag. off this Bank, the *Pengwins* excepted. It's true that all these Fowls are seen there in great quantities, but none are to be minded so much as the *Pengwin,* for these never go without |i.e. away from| the Bank as the others do, for they are always on it, or within it, several of them together . . ." The Great Auk has been extinct since 1844, but everything else still holds good today.

The fishermen of that period used to put the Grand Banks seabirds to a more immediate practical use, killing them for bait or for their own food. Captain J.W. Collins, a redoubtable Gloucester skipper, vividly describes the Banks schooners of the mid 19th century, their shrouds hung with row upon row of dead shearwaters, ready for the pot. (Discriminating Newfoundland gourmets, he says, preferred sooty to greater shearwaters.) Nowadays our concerns are more humane. We worry about the actual or potential effects of such man-made hazards as offshore oil spills, the massive drownings of alcids in gill-nets, and the competition between birds and fishermen for a common prey, the capelin *Mallotus villosus.*

The shortest distance between the western edge of the Grand Banks and the closest point of land is about 60 km, and this is probably outside the foraging range of most of the seabirds that breed in the very large colonies in eastern Newfoundland. The majority of the birds we see on the Banks are either non-breeding subadults, or adults outside the breeding season. Recoveries of banded birds, combined with taxonomic evidence, show that it is a catchment area not only for the colonies in Atlantic Canada, but also for populations breeding as far away as Greenland, Russia, and Antarctica. The greater and sooty shearwaters' and Wilson's storm-petrels *Oceanites oceanicus,* which swarm on the Grand Banks in summer, are emigrants from the southern hemisphere winter; they breed, respectively, in Tristan da Cunha, the Falklands, and Antarctica. Banding suggests that most of the newly fledged juvenile Atlantic puffins *Fratercula arctica* from southwest Iceland, the largest breeding centre for the species, migrate directly to Newfoundland waters. They presumably mingle there with puffins from the colonies in southeast Newfoundland. The kittiwakes that winter on the Banks include birds from west Greenland, Britain, Spitsbergen, and the western Russian Arctic. The dovekies *Alle alle* come from northwest Greenland and the thick-billed murres from colonies in Lancaster Sound, Hudson Strait, and west and east Greenland. These complex and far-ranging migrations have clear implications for seabird conservation and management in



Great Auks, which became extinct in 1844. (Sketchesfrom the English Pilot; The Fourth Book; Describing the West India Navigation, from Hudson's Bay to the River Amazones; London; 1767 or earlier.)

A Humpback whale on the Grand Banks; in the background are two of the many vessels that were in the area fishing capelin at that time.

Canadian waters. Any man-induced changes in the marine environment of the Grand Banks may affect populations that breed thousands of kilometres away.

Seabirds may only reliably be censused at their breeding sites, and it is hard to estimate the numbers of these non-breeding birds on the Banks. We can, however, make some order-of-magnitude guesses. The world population of greater shearwaters' and the northwest Greenland population of dovekies exceed, respectively, 5 million and 14 million birds; all of these probably visit the Grand Banks at one season or another. So do some 4 million thick-billed murres from colonies in the Arctic, as well as a proportion of the 1.5 million common murres and 0.8 million puffins from eastern Newfoundland. To judge from these incomplete figures, the total biomass of seabirds on the Grand Banks is at least 10,000 t. A preliminary calculation suggests that the fish-eating species take an annual total of 250,000 t, mainly capelin, from the Grand Banks and eastern Newfoundland waters combined. This is the same order of magnitude as the annual capelin consumption by both fin whales *Balaenoptera physalus* and harp seals *Pagophilus groenlandicus* in Newfoundland waters, and of the peak catch in the offshore capelin fishery of the 1970s. It is an order of magnitude less than the annual total taken by Atlantic cod *Gadus morhua.*

Seabirds occur everywhere on the Grand Banks, as the *English Pilot* pointed out. However, modern quantitative observations made from BIO and other research vessels show that their distributions are often very patchy. Dovekies, for example, are commonest along the eastern and southwest slopes, and are relatively scarce over the main 'plateau' of the Bank. When the greater shearwaters first arrive at the end of May, they form very large, local flocks on the Southeast Shoal, near the southern tip. On the other hand, murres, outside the breeding season, are spread fairly evenly across the whole 'plateau'. Evidently, so also were Great Auks.

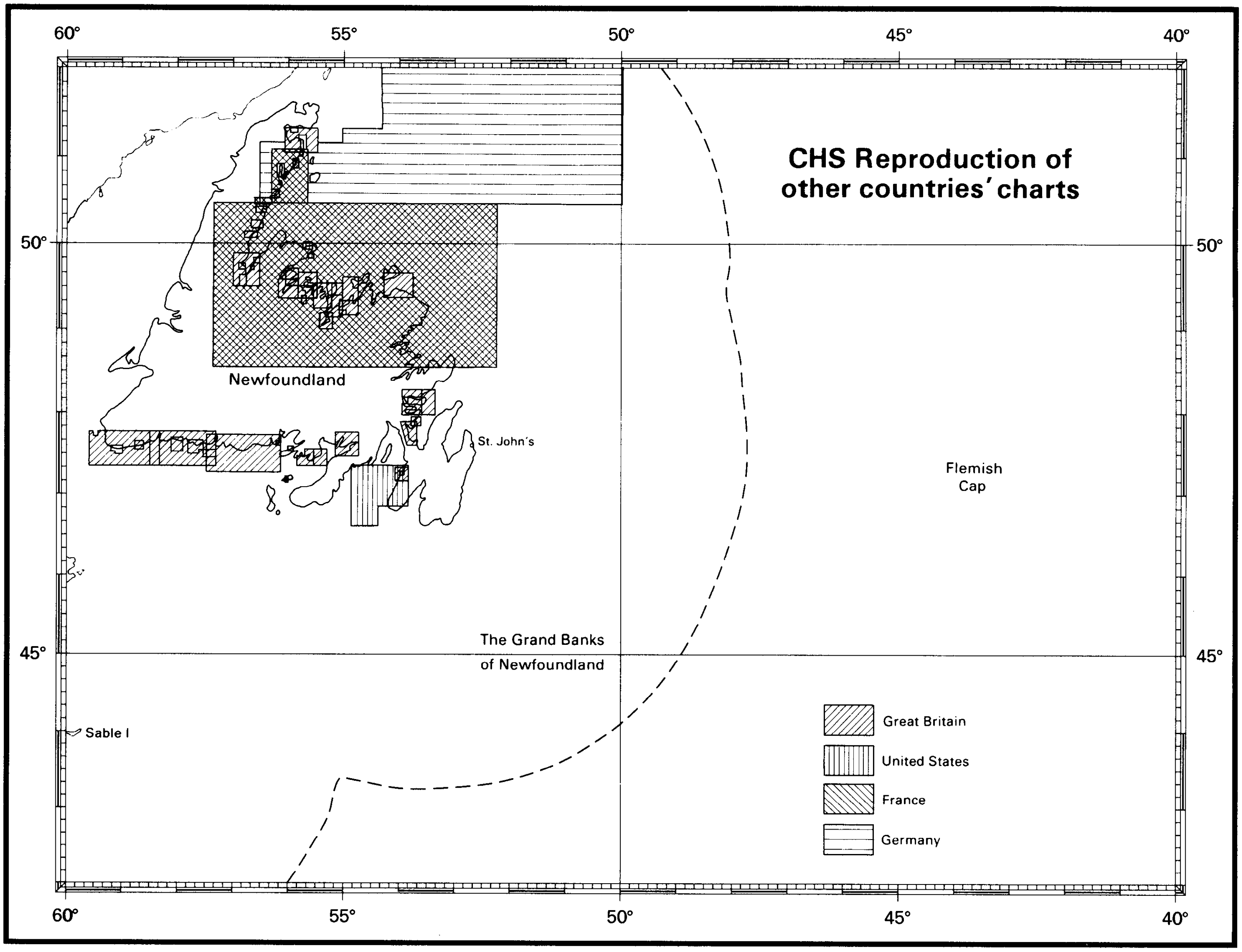
As one might expect, this patchiness reflects the distributions of the birds' prey and, at one or more removes, the underlying oceanographic and other factors that control them. At the simplest level, the distributions of the more generalized feeders, such as fulmars and kittiwakes, are largely determined by the operations of the fishing fleets from which they scavenge offal. Dovekies are more specialized seabirds; they feed on zooplankton fairly close to the surface. Their prey not only occurs at high densities at the edge of the Banks, but is apparently forced up into the surface layers, and concentrated there, by upwelling along the slope. The dovekies are presumably able to maximize their foraging efficiency by feeding in this zone. Shearwaters feed on fish, squid, and the larger zooplankton, but they are poorly adapted to diving; they can probably reach the bottom only in such shallow parts of the Bank as the Virgin Rocks and the Southeast Shoal. Specifically, their arrival at the Shoal appears timed to coincide with that of the very large schools of capelin that spawn there. The birds seem to use the fish as a superabundant food supply while they moult and build up the energy reserves depleted during their breeding season and their long migration up from the South Atlantic. Murres, by contrast, are proficient divers, able to reach depths of more than 100 m - the maximum depth of water over most of the 'plateau'. In theory, therefore, they are able to hunt for fish throughout the waters of the Grand Banks.

The ultimate aim of the Canadian Wildlife Service's research on the seabirds of the Grand Banks is to understand their place in the Grand Banks ecosystem as a whole. We have been accumulating quantitative data on their distributions there since 1969, and we may reasonably claim to know roughly where the birds are at any given season. But, as the essentially qualitative nature of the interpretations of these distributions shows, we have barely begun to understand their pelagic ecology. However, we can at least make some preliminary, testable predictions, and define problems for future research. There is, for example, the suggested association between dovekies and shelf-edge upwelling. These upwelling zones can be located by satellite imagery. Do they have quantitative or qualitative biological properties in common, such as a high local density of copepods, or a distinctive zooplankton species community? If so, how do these fit in with the quantitative and qualitative food requirements of the dovekies? Are dovekies invariably associated with these zones? It would be informative to compare the physical and biological characteristics of an upwelling that is used by dovekies, with one that is not. To what extent do seasonal variations in zooplankton distribution and biomass influence the timing of the birds' arrival on, and departure from, the Banks? We hope that the Grand Banks Ecosystems Modelling Project described earlier in this chapter and with which our seabird research is integrated will provide some of the answers to these questions.

chapter 5

Charting the Grand Banks and adjoining areas

Canada's history of hydrographic surveying and charting of the Grand Banks of Newfoundland and the island of Newfoundland is not very long. Apart from the Canadian Hydrographic Service's efforts during the Second World War, the island and its surrounding waters were not included in the Service's mandate until 1949 when Newfoundland became a province and its territorial waters became the eastern boundary of Canada. The charting of Newfoundland prior to this was done mostly by the British Admiralty. The coast was surveyed adequately enough to meet the needs of the commerce of the island, which was mostly waterborne



1. Charts of Newfoundland waters that were prepared by other countries and reproduced by the Canadian Hydrographic Service are denoted.

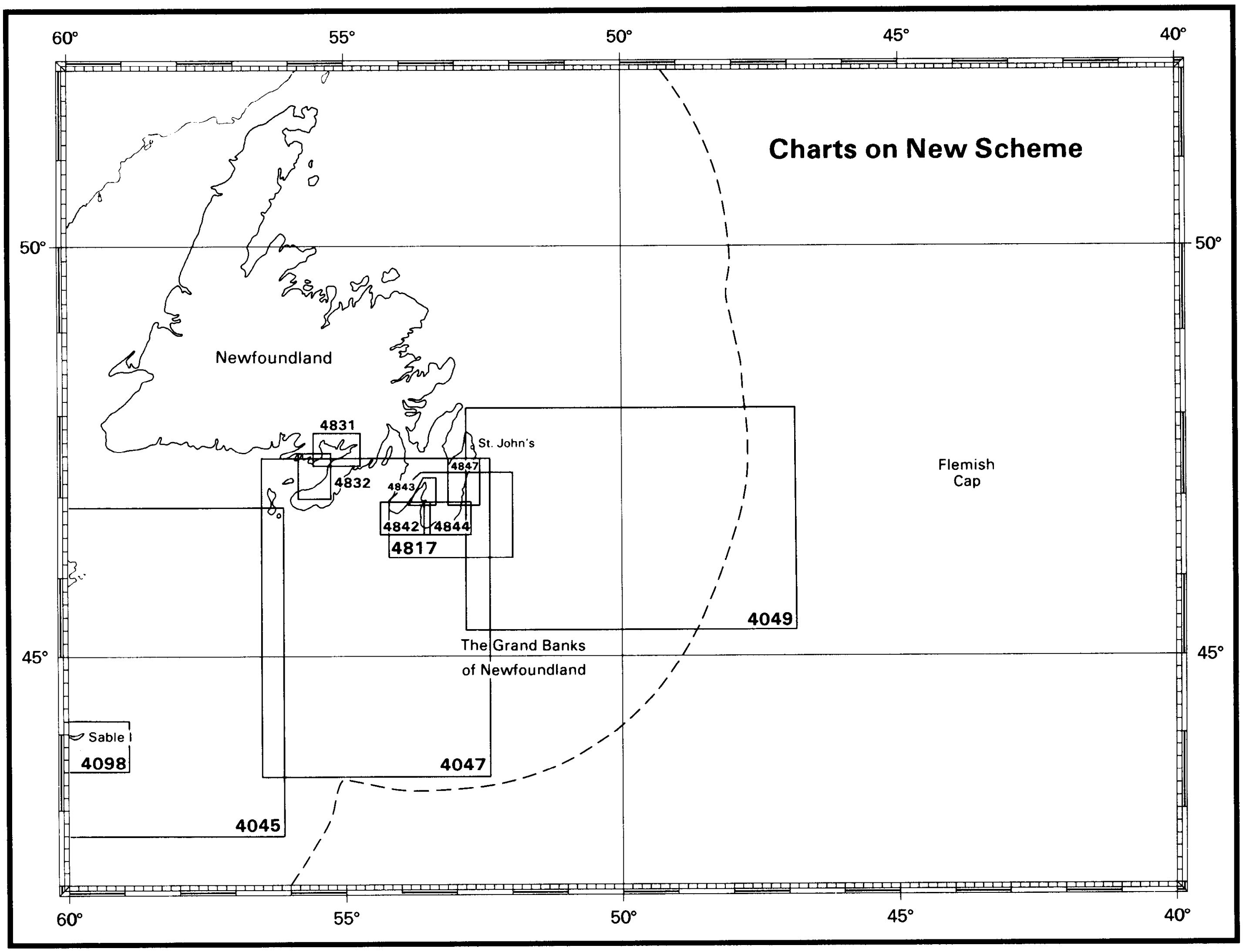
and supported by vessels much smaller than those of today. Although the Admiralty charts are remarkably accurate for their time, they do not meet the needs of today's marine community. During the 1950s, the CHS assumed responsibility to maintain these charts, which are now published as Canadian reproductions (see first figure).

The first Canadian chart of Newfoundland - Mortier Bay - was produced in 1941 from quickly collected survey results. At that time, the harbour was tentatively chosen as a meeting place for Prime Minister Churchill and President Roosevelt, and the Admiralty was concerned that the previous survey of 1876 was not adequate to allow for the entry of warships there. Other work by the CHS during World War II included surveys and charts of Bay Bulls (on the east coast of the Avalon Peninsula), where a marine slip had been built to serve Canadian warships, and of the active ports of St. John's, Harbour Grace, and Holyrood.

Newfoundland has undergone many changes since 1949. The fleets of fishing schooners known as saltbankers have been replaced by a modern trawler fleet, outports have been closed and roads built, and the economy has developed into a resource-export based one that has changed the pattern of shipping around the province. These and other changes have created a need to provide new, more accurate nautical charts that are based on recent hydrographic survey work (see second figure).

The development of the Hibernia oil fields will once again affect shipping patterns along the southeast coast of Newfoundland. St. John's has served as a focal point in the exploration for natural resources on the Grand Banks. During this time, its waterfront, which traditionally has supported foreign fishing fleets, has expanded to serve and supply drilling platforms and seismic survey vessels. During the development and production of the Hibernia fields, St. John's will remain at the centre of the activity.

A number of other natural ports in Placentia Bay have been proposed because of their location, deep water, and year-round access for use in the pre-production phase of the Hibernia fields. The Marystown Shipyard, located in Mortier Bay on the west



2. *Charts published by the Canadian Hydrographic Service based on a new scheme are available as indicated for the Grand Banks of Newfoundland.*

side of Placentia Bay, has already contributed to the exploration phase with the construction of supply vessels and the outfitting of oil rigs anchored nearby. Presently, an oil-rig repair facility is under construction at the eastern end of Mortier Bay.

Arnold's Cove, close to Come By Chance near the head of Placentia Bay, has been suggested as a location for the fabrication of a fixed-production platform. The site of the former U.S. naval base at Argentia will likely see more activity in years to follow. The port already serves as an alternate supply base and drilling platforms usually anchor off Argentia during the spring ice invasions on the Grand Banks.

In 1980, the Atlantic Region of the Canadian Hydrographic Service (CHS Atlantic) embarked on a program to produce new charts of the Grand Banks and coastal Newfoundland. These have been newly schemed such that adjacent charts show coverage at the same scale; when the program is completed, the total number of charts that cover the area will be reduced from the present ones. Depths are portrayed using contour lines and, where soundings are shown, they are in metres and decimetres. Also, in complying with Canadian government policy, all information is printed in both English and French.

Once a chart is produced, relevant information must be constantly reviewed so that the marine community may be informed of any changes to it. Such information may include marine hazards such as wrecks, reported shoals, or Canadian Coast Guard changes to the aids to navigation (buoys, lights, fog horns, etc.). Other information may include new marine terminals, drydock facilities, or dredged channels. Charts are updated by a program known as chart maintenance and relevant changes are advertised weekly in Notices to Mariners, which are published by the federal Department of Transport.

Significant physical changes to the shoreline or sea bottom must first be surveyed and CHS Atlantic maintains a revisory survey program for this purpose. The oil-rig repair facility at Mortier Bay, a new synchrolift, and changes to depths along the waterfront in St. John's Harbour are changes typical of the work involved in the revisory survey program.

Canada's charting of the Grand Banks began in 1957. Prior to this, Admiralty charts from surveys dated to the 19th Century were widely used. The development of conventional Decca as a shipboard navigation system in the 1950s allowed for the first survey of the Grand Banks using a land-based, horizontal positioning system. The results of the survey, published by CHS in 1959, included the most accurate positions to date of the Virgin Rocks and Eastern Shoals, which are the greatest hazards to marine navigation on the Banks. Subsequent surveys from 1963 to 1966 were performed using Decca/Lambda, an unconventional but more accurate navigation system. These surveys provided sufficient information for the first Canadian chart of the Grand Banks, published in 1969. As Loran C, Hi-Fix, and MRS became superior positioning systems in the early 1970s, a more detailed survey of the Virgin Rocks and Eastern Shoals soon followed.

Under an agreement with the federal Department of Energy, Mines, and Resources in 1975, CHS and the Atlantic Geoscience Centre at BIO became jointly responsible for offshore multiparameter surveys. Such surveys gather bathymetric, gravimetric, and magnetic profiles simultaneously. The resulting data serve many users with information in the form of nautical and fisheries charts, natural resource maps, maps in the Natural Earth Science Series, and the international General Bathymetric Charts of the Oceans (GEBCO).

Multiparameter surveys involve the running of parallel survey lines at spacings of 1 to 20 nautical miles. Following detailed surveys of the waters surrounding Sable Island, multiparameter surveys were extended in 1984 at 10-mile line-spacings in the offshore from Sable Island to the Grand Banks.

The lighthouse at Cape Spear, Newfoundland, is the most easterly such guide for navigators in North America.

In 1985, more detailed bathymetric soundings on the St. Pierre Bank to the south of Newfoundland were obtained. Further work will involve gathering bathymetry to delineate the edge of the juridical shelf beyond Canada's 200 mile resource management zone, as defined in Article 76 of the Law of the Sea Treaty.

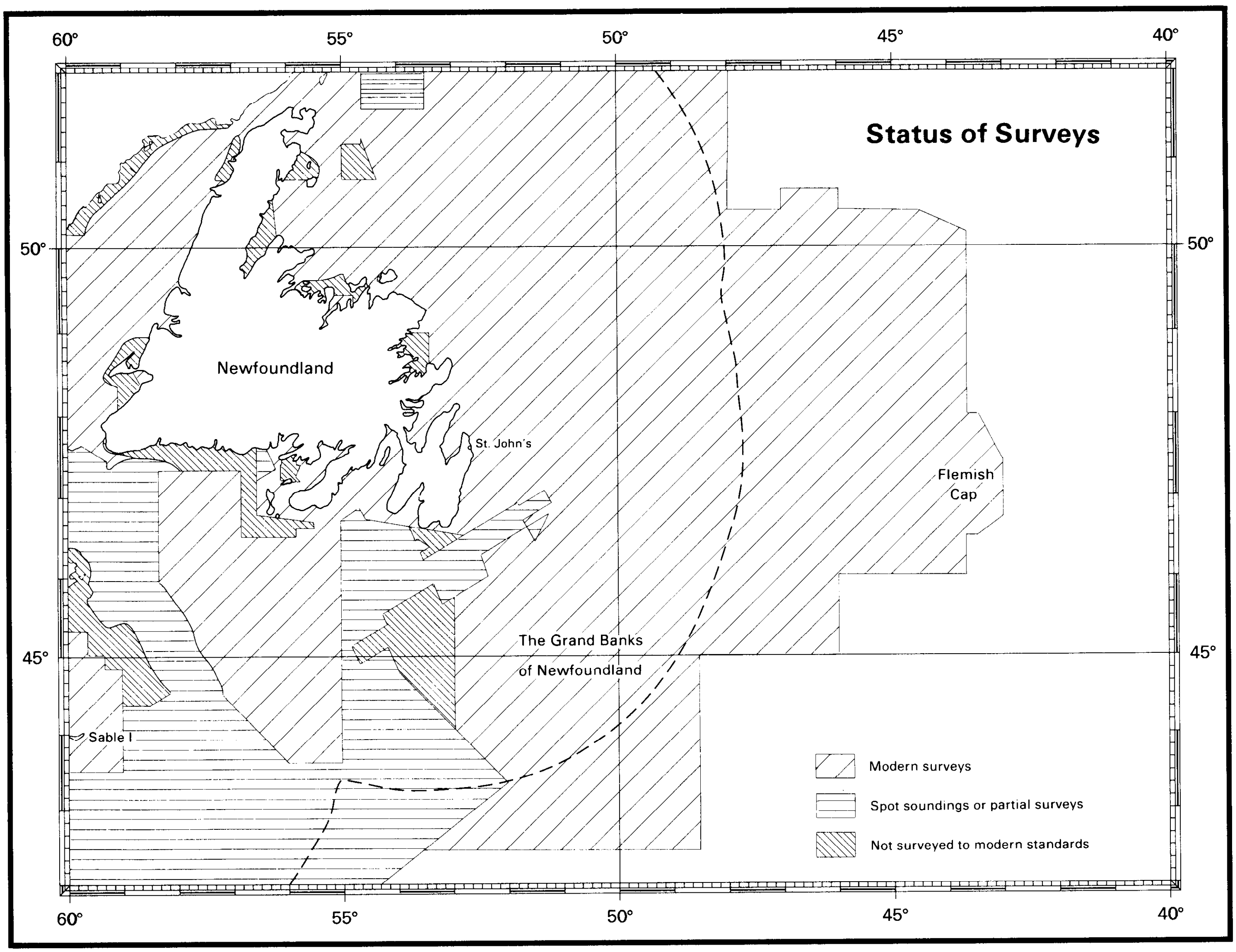
The federal Department of Transport commissioned the installation of a Loran C transmitter at Fox Harbour, Labrador, at the end of December 1983. This created the Labrador Sea chain (replacing the North Atlantic Chain) with the Master Station at Fox Harbour and Slave Station transmitters at Angissoq, Greenland, and Cape Race, Newfoundland. Loran C coverage was thus extended from eastern Newfoundland to the Grand Banks, and the Canadian East Coast Chain, for which Fox Harbour is a Slave Station, was improved along the south and west coasts of Newfoundland.

For CHS to meet its mandate, Loran C lattices must be drawn on some 20 large-scale coastal charts and about half that number of smaller scale offshore and fisheries charts. Offshore charts at scales of 350,000:l or smaller show lattices based on predicted receiver values. However, when latticing large scale charts, the land-path correction cannot be predicted with enough accuracy.

During July 1984, three weeks of calibration work was done aboard the Canadian Coast Guard Ship *Bernier* in the area of Cape Race-Cape Freels-Virgin Rocks. The NAVSTAR Global Positioning System was used to reference the correct position of the Loran C lines of position. These data, together with calibration points measured along the coastline, will produce chart lattices that have a maximum lattice error of less than 3 mm at chart scale.

The first of the new charts, Cape Pine to Cape St. Mary's, was produced in 1982. Adjoining charts from Cape Pine through to Bay Bulls have subsequently been released, and general charts extending the same coverage to the Virgin Rocks will be available by mid-1986 (third figure).

- R. Pietrzak
Atlantic Region
Canadian Hydrographic Service



3. The status of surveys by the Canadian Hydrographic Service in and around the Grand Banks area is summarized.

chapter 6

Charts and publications

Foredeck operations aboard C.S.S. Hudson *at a station off the coast of Labrador.*

CHART PRODUCTION

The Atlantic Region of the Canadian Hydrographic Service has a cartographic staff of 27 and responsibility for 424 nautical charts covering Canada's east coast from Georges Bank to Prince of Wales Strait in the Arctic.

The charts produced can be divided into three types. A New Chart is the first chart to show an area at that scale or to cover an area different from any existing chart. These charts are now constructed to the metric contour style in bilingual form using new formats. A New Edition is a new issue of an existing chart showing new navigational information and including amendments previously issued in *Notices to Mariners.* New navigational information may include new Loran C lattices from a recent extension in coverage, new shipping terminals, or a new International Boundary such as the one through Georges Bank. A Reprint is a new print of a current edition that incorporates amendments previously issued in *Notices to Mariners.*

CHS Atlantic completed another successful year of chart production in 1984. In addition to those New Charts and New Editions listed below, 93 chart amendments and 15 paste-on patches were issued through *Notices to Mariners* from the review of some 10,000 chart related items.

New Charts

4098 Sable Island (Eastern Portion)
4099 Sable Island (Western Portion)
4844 Cape Pine to Renews Harbour
4845 Renews Harbour to Motion Bay
5042 Cutthroat to Quaker Hat
5043 Quaker Hat to Cape Chidley
5047 Hopedale
5373 Approaches to George River

New Editions

4315 Sydney Harbour
4316 Halifax Harbour
4364 Beaver Harbour
4391 LaHave River
4392 Sydney Harbour (South Arm)
4447 Pomquet and Tracadie Harbours
4614 Argentia Harbour

New Editions (Loran C)

4128 Approaches to Saint John Harbour
4340 Grand Manan
4385 Osborne Head to Betty Island
4486 Chaleur Bay
4574 Approaches to St. John's

PUBLICATIONS

We present below an alphabetical listing by author of BIO publications for 1984, including some earlier publications not listed in previous editions. Articles published in scientific and hydrographic journals, books, conference proceedings, and various series of technical reports are included. For further information on any publication listed here please contact: Publication Services, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2.

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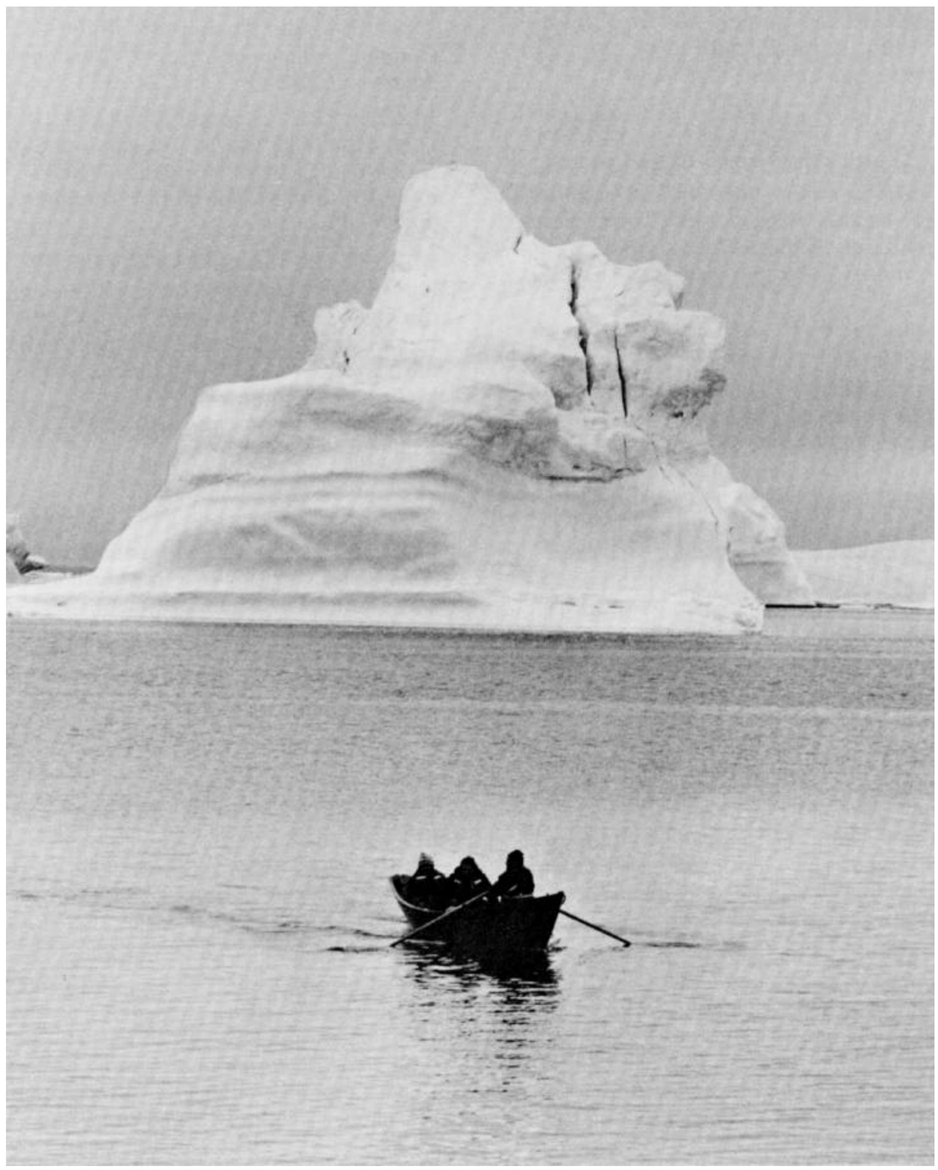

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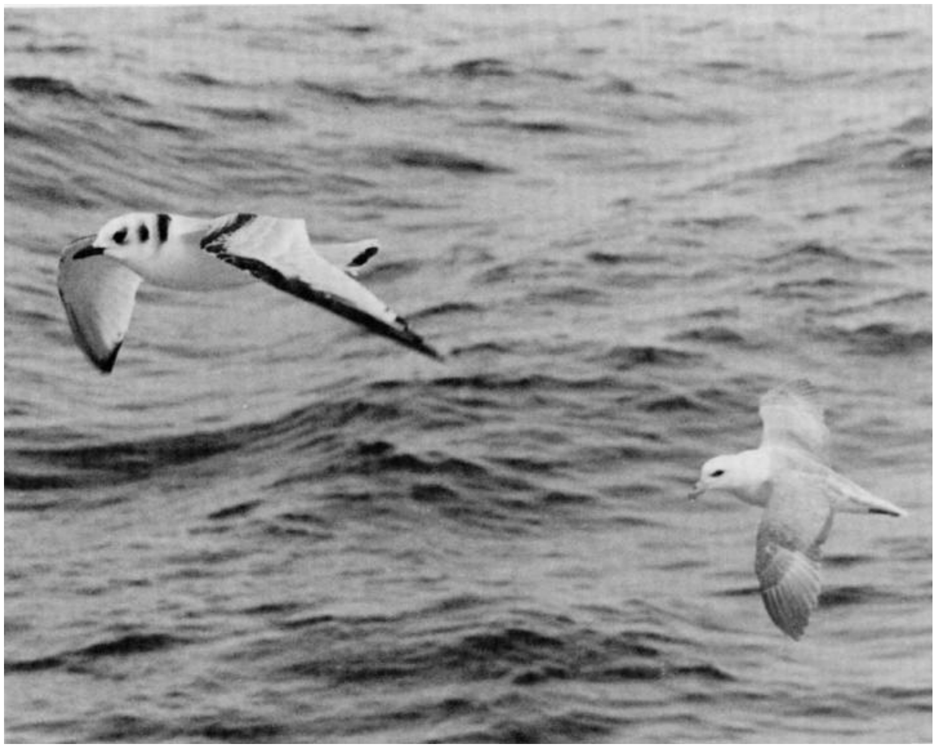

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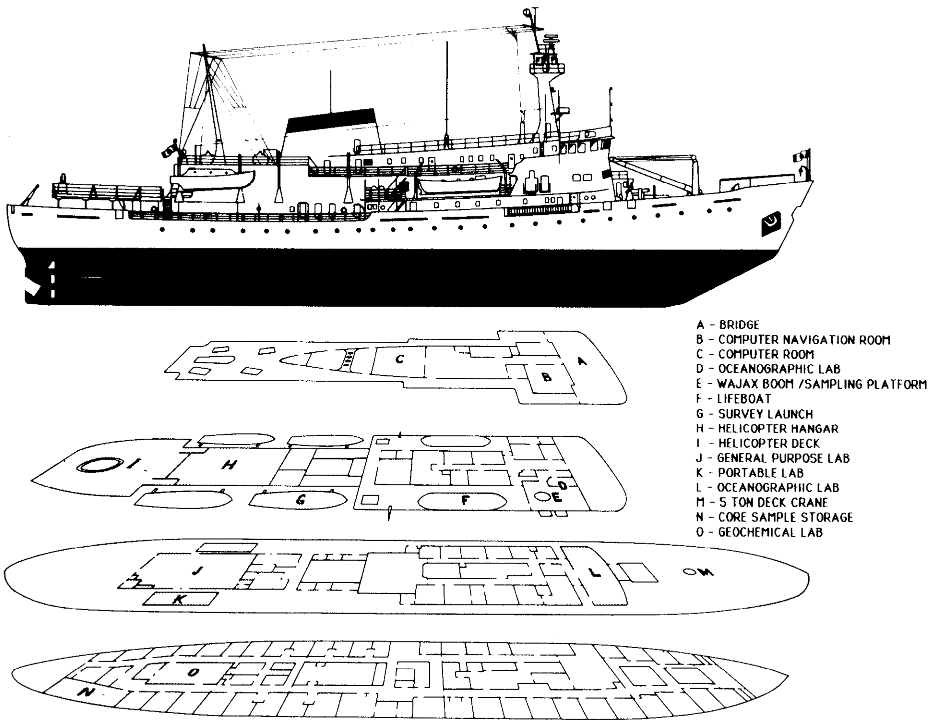
chapter 7

Voyages

C.S.S. HUDSON

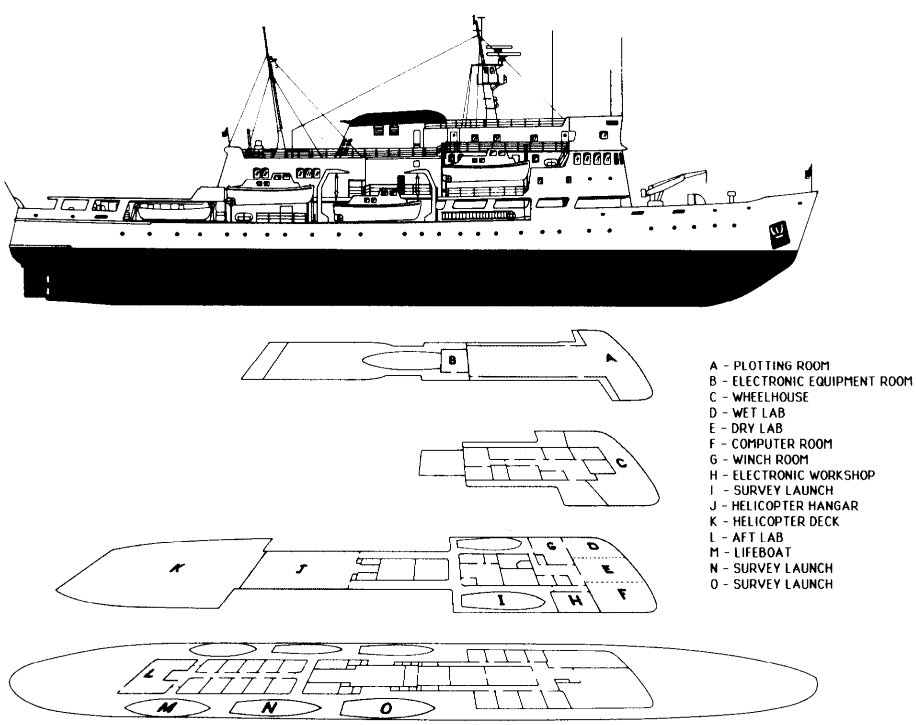


- The C.S.S. *Hudson* is a diesel-electric driven ship designed and used for multi-disciplinary oceanographic research. The ship is owned by the federal Department of Fisheries and Oceans.
- Principal Statistics - Lloyds Ice Class I hull . . . built in 1963 . . . 90.4 m overall length . . . 15.3 m overall beam . . . 6.3 m maximum draft . . . 4870 tonne displacement . . . 3721 gross registered tons . . . 17 knot full speed . . . 13 knot cruising speed in Sea State 3 . . . 80 day endurance and 23,000 n. mile range at cruising speed . . . scientific complement of 26 . . . 205 m^2 of space in four laboratories . . . two HP1000 computer systems . . . heliport and hangar . . . twin screws and bow thruster for position holding . . . four survey launches
- 225 days at sea and 30,978 n. miles steamed in 1984

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
84-001	Jan. 24 to Feb. 8	G.L. Bugden, AOL	Gulf of St. Lawrence	Reoccupy standard grid of ice forecast stations; recover satellite buoys; sampling and data collection
84-010	Apr. 9 to 19	T. Platt, MEL	Grand Banks of Newfoundland	Biological survey
84-012	Apr. 27 to May 15	R.M. Hendry, AOL	Gulf Stream south of Nova Scotia	Recover and redeploy current meter moorings; CTD survey
84-021	May 25 to Jun. 15	C.E. Keen, AGC	Continental Margin	Heat flow measurements; seismic survey
84-024	Jun. 18 to 22	C.F.M. Lewis, AGC	Avalon Channel area; Western Banks of Newfoundland	Geophysical mapping and geological sampling; test shallow refraction seismic system and deep-sea video system
84-026	Jun. 22 to Jul. 7	J.R.N. Lazier, AOL	Hamilton Bank, Southern Labrador Shelf	Replace moorings; CTD/Batfish survey; biological sampling

84-029	Jul. 18 to 25	G.B. Fader, AGC	Bedford Basin; Scotian Shelf and slope	Test Seabed II deep ocean mapping system; evaluate Hydrostar range bearing receiver; collect shallow water sidescan sonograms, seabed samples, and bottom photographs from Sable Island Bank
84-030	Jul. 27 to Aug. 26	S.P. Srivastava, AGC	Labrador Sea	Seismic reflection and refraction surveys; collect sediment cores; heat flow measurements; magnetic measurements
84-035	Aug. 28 to Sep. 11 (Phase I)	C.T. Schafer, AGC	Flemish Pass; Sackville Spur; Hamilton Spur; Labrador Slope; Eastern Edge of Makkovic Bank	Study surficial geology and morphology of slope and rise using SeaMARC I deep-tow side scan sonar system
84-035	Sep. 11 to 28 (Phase II)	B. MacLean, AGC	Labrador - southeast Baffin Shelf and Slope	Study continental shelf and slope using SeaMARC I deep-tow system
84-038	Sep. 28 to Oct. 4	J.R.N. Lazier, AOL	Hamilton Bank, Southern Labrador Shelf	Replace moorings; CTD survey; collect cores in Lake Melville
84-040	Oct. 6 to 23	D.J.W. Piper, AGC	Eastern Valley of Laurentian Fan; Scotian Slope	Study sediment deposition processes; collect data to improve acoustic stratigraphy using SeaMARC I deep-tow system
84-045	Oct. 30 to Nov. 9	P.J.C. Ryall, Dalhousie University	St. Georges, Bermuda	Test rock-core drill and towed T.V. camera; box coring
84-046	Nov. 10 to 29	D.E. Buckley, AGC	Southern Nares Abyssal Plain, Barbados	Study deep sea sediments and benthic biology
84-049	Dec. 1 to 18	T. Platt, MEL	Caribbean and U.S. continental shelf	Plankton biology; squid larval survey

C.S.S. BAFFIN



- The *C.S.S. Baffin* is a diesel driven ship designed for hydrographic surveying but also used for general oceanography. The ship is owned by the federal Department of Fisheries and Oceans.
- Principal Statistics - Lloyds Ice Class I hull . . . built in 1956 . . . 87 m overall length . . . 15 m moulded beam . . . 5.7 m maximum draft . . . 4986 tonne displacement . . . 15.5 knot full speed . . . 10 knot cruising speed in Sea State 3 . . . 76 day endurance and 18,000 n. mile range at cruising speed . . . complement of 29 hydrographic staff . . . drafting, plotting, and laboratory spaces provided . . . two HP1000 computer systems . . . heliport and hangar . . . twin screws and bow thruster for position holding . . . six survey launches
- 231 days at sea and 29,870 n. miles steamed in 1984

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
84-004	Mar. 13 to 30	D. Bowen, DFO, St. John's, Nfld.	Southeast Labrador	Collect data on harp and hooded seals
84-015	May. 1 to 31 (Phase I)	V.J. Gaudet, CHS	Sable Island	Standard navigational charting
	Jun. 4 to 15 (Phase II)	V.J. Gaudet, CHS	Scotian Shelf	Standard navigational charting
	Jun. 19 to Jul. 26 (Phase III)	V.J. Gaudet, CHS	Notre Dame Bay, Nfld.	Hydrographic survey
	Aug. 14 to Sep. 25 (Phase IV)	V.J. Gaudet, CHS; A.R. Ruffman (Geomarine Associates Ltd.)	Jones Sound	Standard navigational charting Surficial geology survey
84-031	Jul. 29 to Aug. 14	J.N. Smith, AOL	Baffin Bay; Thule Harbour	Collect water samples, sediment cores, and biota for radionuclide analysis
84-039	Sep. 25 to Oct. 12	C.K. Ross, AOL	Baffin Bay	Recover and deploy moorings; CTD survey
84-044	Oct. 19 to Nov. 30	G. Henderson, CHS	Green Bank, St. Pierre Bank, and Laurentian Channel	Multidisciplinary survey to collect bathymetry, gravity, and magnetics data

C.S.S. DAWSON

- The C.S.S. *Dawson* is a diesel driven ship designed and used for multidisciplinary oceanographic research, hydrographic surveying, and handling of moorings in deep and shallow water. The ship is owned by the federal Department of Fisheries and Oceans.

- Principal Statistics - built in 1967 . . . 64.5 m overall length . . . 12 m moulded beam . . . 4.9 m maximum draft . . . 1940 tonne displacement . . . 1311 gross registered tons . . . 14 knot full speed . . . 10 knot cruising speed in Sea state 3 . . . 45 day endurance and 11,000 n. mile range at cruising speed . . . scientific complement of 13 . . . 87.3 m^2 of space in four laboratories . . . computer suite provided . . . twin screws and bow thruster for position holding . . . one survey launch.

- 244 days at sea and 25,809 n. miles steamed in 1984

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
84-002	Feb. 16 to 22	G. Fowler, AOL	Bedford Basin	Test Dalhousie Deep TV System and Nordco Drill
84-003	Feb. 17 to Mar. 6	D. Bidgood, NSRF	St. Pierre Bank	Piston coring and high-resolution seismic reflection profiling; sidescan system testing
84-005	Mar. 8 to 16	C. Amos, AGC	Sable Island Bank; Banquereau Bank	High resolution shallow seismic and sidescan sonar survey
84-006	Mar. 19 to 24	B. Johnson, Dalhousie University	Sable Island Bank; Banquereau Bank	Seismic site surveying for oil/gas development; equipment evaluation; zooplankton sampling

84-007	Mar. 27 to Apr. 4	N.S. Oakey, AOL	Laurentian Fan	Study mixing processes, and turbulence in the mixed layer; test and evaluate EPSONDE II
84-008	May 22 to 29	P.C. Smith, AOL	Browns Bank	Recover and redeploy moorings; hydrographic survey; biological sampling in the surface layer; track and recover surface drifters
84-009	Apr. 6 to 19	A.W. Herman, AOL	Laurentian Channel, Scotian Shelf	Zooplankton and phytoplankton surveying; equipment trials; tests of optical plankton counter and servo-controller
84-011	Apr. 24 to Mar. 1	D. Scott, Dalhousie	Northern Scotian Shelf	Seismic surveying and piston coring
84-016	May 2 to 8	K.T. Frank, MEL	Brown's Bank, southwest Nova Scotia	Measure production processes related to fishery by intensive biological and physical sampling using mini-BIONESS and Ametek Doppler current profiler
84-017	May 10 to 16	D.L. McKeown, AOL	Scotian Shelf/Slope	Evaluate acoustic positioning equipment; conduct mooring engineering experiments; test an in-situ particle sampler
84-020	Jun. 21 to Jul. 7	H. Miller, Memorial University	Newfoundland's south coast; Placentia Bay and Bay St. George	Underwater gravity survey; heat flow measurements and deployment of current meters
84-023	Jun. 5 to 20	S.D. Smith, AOL	Newfoundland Shelf	Obtain data for iceberg drift computer model; recover tide gauge mooring and weather buoy
84-025	Jun. 10 to 16	J.N. Smith, AOL	Pt. Lepreau area, Bay of Fundy	Environmental monitoring
84-027	Jul. 16 to 22	K.T. Frank, MEL	Browns Bank, southwest Nova Scotia	Mini-BIONESS sampling; Ametek profiling; plankton tows; test high frequency acoustic equipment
84-028	Sep. 29 to Oct. 12	T. Platt, MEL	Southern Grand Banks	Study distribution and growth dynamics of microplankton
84-033	Jul. 24 to 31 (Phase I)	T. Chriss and D. Huntley, Dalhousie University	Emerald Basin region	Test and gather bottom turbulence data using tripod-based instrumentation system; obtain stereo bottom photographs; CTD and rosette casts
	Jul. 31 to Aug. 2 (Phase II)	R. Boyd, Dalhousie University	Eastern Shore, N.S.	Sidescan and seismic subbottom profiling
84-034	Aug. 15 to Sep. 1	J.A. Elliott, AOL	Scotian Shelf Edge	Study the current surges resulting from high amplitude internal waves
84-036	Sep. 5 to 19	R.M. Hendry, AOL	Gulf Stream at 39°30'N, 59°W	Study Gulf Stream variability; CTD/XBT survey; recover engineering mooring; water sampling -
84-037	Oct. 15 to 29	D.D. Sameoto, MEL	Eastern Scotian Shelf and western Grand Banks	Study the distribution of chlorophyll and zooplankton
84-041	Nov. 1 to 7	J.K. McRuer, MEL	Southwest Nova Scotia	Measure production processes related to fisheries
84-042	Sep. 20 to 27	T. Chriss, Dalhousie University	Emerald Basin and Sable Island Bank	Collect bottom turbulence data and data on seabed conditions
84-043	Nov. 14 to 27	P.C. Smith, AOL	Southwest Nova Scotia	Recover and deploy short-term and long-term surface moorings; drift experiments; CTD survey
84-048	Nov. 29 to Dec. 7	G.L. Bugden, AOL	Scotian Shelf, Gulf of St. Lawrence	Recover tide gauges; CTD survey; moor satellite buoys
84-050	Dec. 7 to 15	G. Gartner and A. Hay, Memorial University	Baie d'Espoir, Fortune Bay, and Hermitage Bay, Newfoundland	Biological sampling; CTD and photographic surveys; seismic surveys

C.S.S. MAXWELL

- The C.S.S. *Maxwell* is a diesel-driven ship designed and used for inshore hydrographic surveying. The ship is owned by the federal Department of Fisheries and Oceans.
- Principal Statistics - built in 1962 . . . 35 m overall length . . . 7.6 m moulded beam . . . 2.1 m maximum draft . . . 270 tonne displacement . . . 262 gross registered tons . . . 12.2 knot full speed . . . 10 knot cruising speed in Sea State 2 . . . 10 day endurance and 2400 n. mile range at cruising speed . . . scientific complement of 7 . . . drafting and plotting facilities . . . two survey launches
- 167 days at sea and 5,683 n. miles steamed in 1984

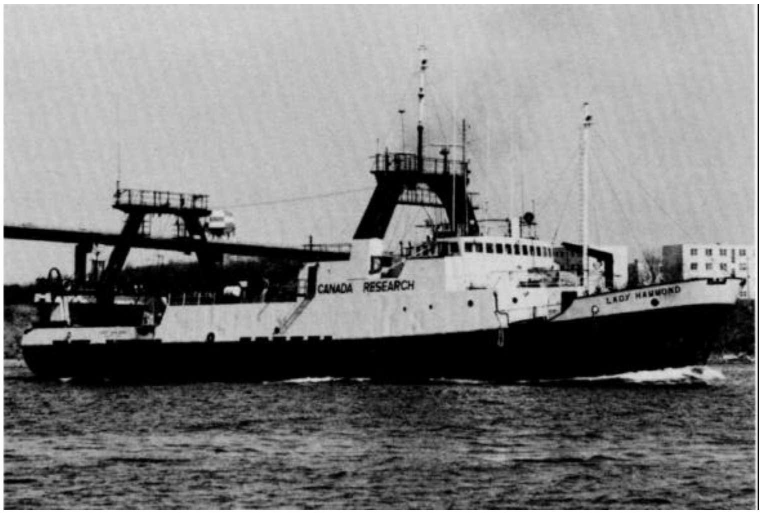
VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
84-013	Jun. 12 to 26	M. Eaton, CHS	Halifax/Sydney	Loran-C calibration; NAVSTAR testing
84-018	May 1 to Jun. 8 (Phase I)	D. Blaney, CHS	Bay of Fundy	Standard navigational charting
	Jun. 26 to Aug. 2 (Phase II)	D. Blaney, CHS	Bay of Fundy	Standard navigational charting
	Aug. 7 to Nov. 2 (Phase III)	D. Blaney, CHS	Strait of Belle Isle; Argentia, Nfld.	Standard navigational charting

C.S.S. NAVICULA

- The C.S.S. *Navicula* is a wooden-hulled fishing vessel owned and operated by the federal Department of Fisheries and Oceans and used for research in biological oceanography.
- Principal Statistics - built in 1968 . . . 19.8 m overall length . . . 5.5 m moulded beam . . . 110 ton displacement . . . 78 gross registered tons
- 142 days at sea and 3,580 n. miles steamed in 1984

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
84-014	May 7 to 29 (Phase I)	G. Rockwell, CHS	Northumberland Strait	Navigational chart revisions
84-014	Sep. 8 to Oct. 26 (Phase II)	G. Rockwell, CHS	Northumberland Strait	Navigational chart revisions
84-022	Jun. 1 to Jul. 31	T. Lambert, MEL	St. Georges Bay	Ichthyoplankton sampling

LADY HAMMOND



- The *Lady Hammond*, a converted fishing trawler, is chartered by the Department of Fisheries and Oceans from Northlake Shipping Ltd. and used specifically for fisheries research. The ship is operated by DFO's Atlantic Fisheries Service (Scotia-Fundy Region): its main user is the Marine Fish Division, which has components at BIO and in St. Andrews, N.B. Except as otherwise noted below and in the remainder of this chapter, "officers in charge" are affiliated with the Atlantic Fisheries Service's Scotia-Fundy Region. Staff of other regions (Quebec, Gulf, or Newfoundland) are identified separately.
- Principal Statistics - built in 1972 . . . 54 m overall length . . . 11 m overall beam . . . 5.5 m maximum draft . . . 306 gross registered tons . . . 13.5 knot maximum speed . . . 12 knot cruising speed.

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
H1l1	Jan. I5 to 17	T. Rowe11	NAFO 4X, SA5 to Florida	Squid survey, Gulf Stream
H112	Feb. 7 to 24	P. Hurley	NAFO 4X, 5Ze	Ichthyoplankton survey
H113	Mar. 2 to 6	G. McClelland	NAFO 4X	Collections of parasite study
H114	Mar. 22 to 30	P. Hurley	NAFO 4X, 5Ze	Ichthyoplankton survey
H1l5	Apr. 2 to 13	K. Zwanenburg	NAFO 4VWX, 5Ze	Redfish survey
H116	Apr. 17 to 26	P. Hurley	NAFO 4X, 5Ze	Ichthyoplankton survey
H117	May 2 to 11	W. Hickey	NAFO 4VWX	Square/diamond mesh comparisons
H118	May 14 to 24	P. Hurley	NAFO 4X, 5Ze	Ichthyoplankton survey
H119	May 28 to Jun. 8	A. Gascon, AFS QUEBEC	NAFO 4s	Cod tagging
H120	Jun. 12 to 22	P. Hurley	NAFO 4X, 5Ze	Ichthyoplankton survey
H121	Jun. 25 to Jul. 18	P. Rubec, AFS GULF	NAFO 4T	Redfish survey
H122	Jul. 20 to Aug., 10	S. Akenhead, AFS NFLD.	NAFO 2J, 3KLMNOP	Oceanographic survey
H123	Aug. 15 to 31	G. Sharp	NAFO 4X	Lobster larval survey and gear trials
H124	Sep. 4 to 16	L. Savard, AFS QUEBEC	NAFO 4RST	Shrimp survey
H125	Sep. 18 to 27	A. Frechette, AFS QUEBEC	NAFO 4RST	Stomach collection, ichthyoplankton
H126	Oct. 6 to 22	D. Waldron	NAFO 4X, 5Z, Y	Silver hake trawl survey
H127	Oct. 10 to Nov. 5	R. Halliday	NAFO 4VWX	Deep sea trawling
H128	Nov. 8 to 19	P. Hurley	NAFO 4X	Gear trials
H129	Nov. 22 to Dec. 10	J. McGlade	NAFO 4WX, 5Z, Y	Pollock trawl survey

E.E. PRINCE

- The *E.E. Prince* is a steel stern trawler used for fisheries research, and experimental and exploratory fishing. The ship is owned by the federal Department of Fisheries and Oceans, and it is operated by DFO's Atlantic Fisheries Service (Scotia-Fundy Region).
- Principal Statistics - built in 1966 . . . 39.9 m overall length . . . 8.2 m overall beam . . . 3.6 m maximum draft . . . 421 ton displacement . . . 406 gross registered tons.

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
P300	Jan. 21 to Feb. 21	U. Buerkle	NAFO 4VW	Herring acoustic survey, Chedabucto Bay
P301	Feb. 27 to Mar. 16	J. Sochasky	NAFO 4X	Larval herring survey
P302	Mar. 21 to 29	L. Dickie, MEL	NAFO 4X	Acoustic experiment with MEL ecology
P303	Apr. 2 to 9	W. Hickey	NAFO 4W	Square/diamond mesh comparative study
P304	Apr. 16 to 27	J. Worms, AFS GULF	NAFO 4T	Crab survey
P305	Apr. 4 to May 12	R. Mohn	NAFO 4VM	Shrimp survey
P306	May 15 to 26	W. Lundy	NAFO 4VWX	Scallop survey
P307	May 30 to Jun. 8	W. Hickey	NAFO 4VM	Square/diamond mesh comparative study
P308	Jun. 15 to 29	J. Dawe, AFS NFLD.	NAFO 3PsLNO	Squid survey
P309	Jul. 3 to 20	C. Taylor, AFS NFLD.	NAFO 3KL	Snow crab survey
P310	Jul. 23 to 27	R. Mohn	NAFO 4VM	Shrimp survey
P311	Jul. 31 to Aug. 22	J. Robert	NAFO 5Ze, 4X	Scallop survey
P312	Sep. 5 to Oct. 4	D. Clay, AFS GC LF	NAFO 4T (inshore)	White hake survey
P313	Oct. 9 to 16	J. Tremblay	NAFO 4X	Scallop larvae survey
P314	Oct. 19 to 27	M. Etter	NAFO 4VM	Shrimp survey
P315	Nov. 1 to 15	M. Power	NAFO 4X	Larval herring survey
P316	Nov. 19 to 28	D. Wildish	NAFO 4X	Benthic survey

M. V. ALFRED NEEDLER

- The *M. V. Alfred W.H. NEEDLER* is a diesel-driven ship owned by the federal Department of Fisheries and Oceans, and used for fisheries research. It is operated by the DFO's Atlantic Fisheries Service (Scotia-Fundy Region).
- Principal Statistics - built in 1982 . . . 50.3 m overall length . . . 10.9 m beam . . . 925.03 gross registered tons . . . complement of 10 scientific staff . . . equipped with up-to-date communication systems, electronics, navigational aids, research equipment, and fishing gear.

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
N021	Jan. 16 to 22	L. Dickie, MEL	NAFO 4WX	Acoustic experiment with ECOLOG
N022	Jan. 27 to Feb. 5	M. Ahrens, AFS GULF	NAFO 4VN	Herring Survey
N023	Feb. 13 to 28	W. Smith	NAFO 4X, 5Ze	Cod and haddock tagging
N024-25	Mar. 2 to 27	J. Neilson / J. Scott	NAFO 4VW	Groundfish trawl survey
N026	Apr. 9 to 18	J.W. Baird, AFS NFLD.	NAFO 3Ps	Groundfish survey
N027	Apr. 26 to May 10	C.A. Rose, AFS NFLD.	NAFO 3NO	Groundfish survey
N028	May 17 to 21	G.H. Kean, AFS NFLD.	NAFO 3L	Groundfish survey
N029	Jun. 4 to 14	J. Neilson	NAFO 5X, 5Ze	Juvenile haddock survey
N030	Jun. 18 to Jul. 7	J.J. Maguire, AFS GULF	NAFO 4T	Mackerel larvae survey
N031-32	Jul. 10 to Aug. 2	S. Smith / J. Hunt	NAFO 4WX, 5Ze	Groundfish trawl survey
N033	Aug. 7 to 18	M. Ahrens, ASF GULF	NAFO 4T	Juvenile herring survey
N034	Sep. 6 to 13	L.M. Dickie, MEL	NAFO 4X	Acoustic experimental survey (MEL)
N035	Sep. 17 to Oct. 10	J. Young	NAFO 4VWX, 5Ze	Squid abundance trawling survey, tagging and gear trials.
N036	Oct. 9 to 18	S. Smith	NAFO 4VM	Groundfish trawl survey
N037	Oct. 22 to Nov. 2	M. Strong	NAFO 4WX	Groundfish trawl survey
N038	Nov. 5 to 30	M. Ahrens, AFS GULF	NAFO 4T	Herring acoustics survey

*GADUS ATLANTICA**

*The *Gadus Atlantica* is a vessel chartered by the Newfoundland Region of DFO's Atlantic Fisheries Service.

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
GA92	Feb. 16 to 28	W.D. Smith	NAFO 4X and 5Z	Tag, measure, and release spawning cod

CO-OPERATIVE VOYAGES

During 1984, the Marine Fish Division participated in co-operative voyages aboard the USSR's research vessel *Let Kievu* (abbreviated as LK below)

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
LK03/04	Sep. 17 to Oct. 26	B. Wood, P. Perley	NAFO 4VWX	Determine the abundance of O-group silver hake on the Scotian Shelf

chapter 8

Organization and staff

BIO is a research institute of the Government of Canada operated by the Department of Fisheries and Oceans (DFO), both on its own behalf and for the other federal departments that maintain laboratories and groups at the Institute. Research, facilities, and services are co-ordinated by a series of special and general committees.

BIO also houses the office of the Northwest Atlantic Fisheries Organization (Executive Secretary - Captain J.C.E. Cardoso); the analytical laboratories of the Department of the Environment's (DOE) Environmental Protection Service (Dr. H.S. Samant); and the Atlantic regional office of the Canada Oil and Gas Lands Administration of the Department of Energy, Mines and Resources (DEMR). In leased accommodation at BIO are the following marine-science related private companies: Huntec Ltd., Wycove Systems Ltd., and Franklin Computers Ltd.

We present below the major groups at BIO together with their managers and a list of Institute staff as at July 1985. Telephone numbers are included in the first list: note that Nova Scotia's area code is 902 and the BIO exchange is 426. In the staff list, the group or division for which an individual works is given in abbreviated form following his/her name: the abbreviations used are defined in the list of major groups immediately below.

DEPARTMENT OF FISHERIES AND OCEANS

A.R. Longhurst
DG - Director-General 3492

OID - Ocean Information Division
H.B. Nicholls, Head 3246
Public Relations
C.E. Murray, Manager 3251

MS - Management Services
G.C. Bowdridge, Manager 6166
Administrative Services
J. Broussard, A/Chief 7037
Financial Services
E. Pottie, Chief 7060
Materiel Management Services
R.J. Stacey, Chief 3487

P - Personnel Services
J.G. Feetham, Manager 2366

AOL - Atlantic Oceanographic Laboratory
J.A. Elliott, Director 7456
AOL - 1. Chemical Oceanography
J.M. Bewers, Head 2371
AOL - 2. Coastal Oceanography
C.S. Mason, Head 3857
AOL - 3. Metrology
D.L. McKeown, Head 3489
AOL - 4. Ocean Circulation
R.A. Clarke, Head 2502

CHS - Canadian Hydrographic Service (Atlantic Region)
A.J. Kerr, Director 3497
T.B. Smith, Assistant Director 2432
CHS - 1. Field Surveys
R.C. Lewis, A/Head 2411
CHS - 2. Chart Production
T.B. Smith, A/Head 2432
CHS - 3. Hydrographic Development
R.G. Burke, Head 3657
CHS - 4. Navigation
R.M. Eaton, Head 2572
CHS - 5. Planning and Records
R.C. Lewis, Head 2411
CHS - 6. Tidal
S.T. Grant, Head 3846

MEL - Marine Ecology Laboratory
K.H. Mann, Director 3696
MEL - 1. Biological Oceanography
T.C. Platt, Head 3793
MEL - 2. Environmental Quality
B.T. Hargrave, Head . . . . , 3188
MEL - 3. Fisheries Oceanography
D.C. Gordon, Head 3278

IF - Institute Facilities
R.L.G. Gilbert, Manager 3681
IF - 1. Ships
J. Parsons, Head 7292
IF - 2. Engineering Services
D.F. Dinn, Head 3700
IF - 3. Computing Services
D.M. Porteous, Head 2452
IF - 4. Library Services
J.E. Sutherland, Head 3675
IF - 5. Publication Services
M.P. Latremouille, Head 5947

MFD - Marine Fish Division
W.D. Bowen, Chief 8390
CAFSAC - Canadian Atlantic Fisheries ScientiJtc Advisory Committee - Secretariat D. Geddes 8486

DEPARTMENT OF ENVIRONMENT

SRU - Seabird Research Unit (Canadian Wildlife Service)
D.N. Nettleship, Head 3274

DEPARTMENT OF ENERGY, MINES AND RESOURCES

AGC - Atlantic Geoscience Centre (Geological Survey of Canada)
M.J. Keen, Director 2367
D.I. Ross, Assistant Director 3448
AGC - 1. Administration
C. Racine, Head 2111
AGC - 2. Eastern Petroleum Geology
J.S. Bell, Head 2730
AGC - 3. Environmental Marine Geology
D.J.W. Piper, Head 7730
AGC - 4. Program Support
K.S. Manchester, Head 3411
AGC - 5. Regional Reconnaissance
C.E. Keen, Head 3413

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BURKE, Walter *CHS-1*

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COLLINS, Gary *IF-3*
COLLINS, Mike *CHS-1*
COMEAU, Ernest *CHS-1*
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Mchel Goguen.

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CONOVER, Bob *MEL-1*
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CONRAD, David *AOL-1*
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COTTLE, Wayne *IF-1*
COURNOYER, Jean *IF-2*
COX, Brian *Hudson*
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CRANSTON, Ray *AGC-3*
CRAWFORD, Keith *CHS-2*
CREWE, Norman *AOL-1*
CRILLEY, Bernard *AGC-2*
CRUX, Elizabeth *CHS-2*
CUNNINGHAM, Carl *AOL-1*
CUNNINGHAM, John *CHS-2*
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CUTHBERT, Jim *IF-3*

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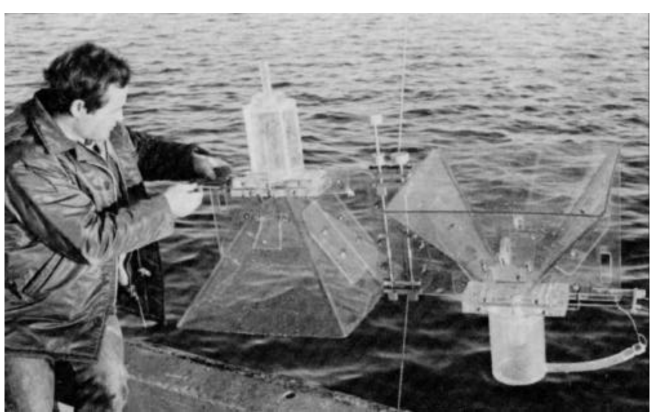
DALE, Jackie *MEL*
DALEY, Bob *Baffin*
DALZIEL, John *AOL-1*
DANIELS, Marilyn *IF-4*



Peter Vass.

DANEAU, Joan *IF-1*
DEARNLEY-DAVISON, Jack *IF-2*
DEASE, Ann *MS*
DEASE, Gerry *IF-2*
DeLONG, Bob *IF-2*
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FITZGERALD, Bob *AGC-3*
FLEMING, Dave *CHS-2*
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FORBES, Donald *AGC-3*
FORBES, Steve *CHS-3*
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GRANT, Al AGC-2
GRANT, Gary AGC-2
GRANT, Steve *CHS-6*
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GREGORY, Don *AOL-4*
GREGORY, Doug *AOL-2*
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HACKETT, Dave *AGC-4*
HACKETT, Jennifer *AOL-4*
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HARDING, Gareth *MEL-2*
HARDY, Iris *AGC-4*
HARGRAVE, Barry *MEL-2*
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HAYES, Terry *AGC-1*
HEAD, Erica *MEL-1*
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HENDERSON, Gary *CHS-1*
HENDERSON, Terry *AGC-1*
HENDRY, Ross *AOL-4*
HENDSBEE, Dave *AOL-4*
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HEPWORTH, Deborah *CHS-2*
HERMAN, Alex *AOL-3*
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HILLIER, Blair *AGC-4*
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HOLT, Donna *AGC-4*
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HORNE, Jack *IF-2*
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HUGHES, Mike *AGC-4*
HURLEY, Peter *MFD*

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JAMIESON, Steve *P*
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JOLLIMORE, Shirley *IF-4*
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JONES, Roger *CHS-2*
JORDAN, Francis *AOL-2*
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Don Chandler.

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KAY, William *AGC-5*
KEDDY, Lil *MS*
KEEN, Charlotte *AGC-5*
KEEN, Mike *AGC*
KEENAN, Pat *AOL-2*
KEIZER, Paul *MEL-2*
KELLY, Bruce *IF-2*
KEPKAY, Paul *MEL-2*
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KING, Rollie *IF-1*
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KNOX, Don *AOL-3*
KRANCK, Kate *AOL-2*

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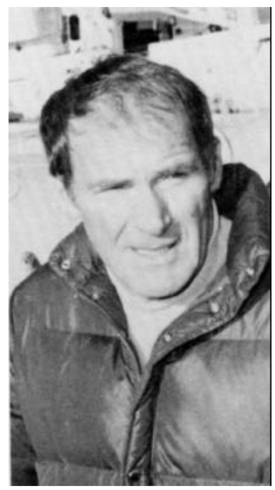
LEVY, Eric *AOL-I*



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LISCHENSKI, Ed *CHS-2*
LITTLE, Betty *P*
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LORING, Douglas *AOL-1*
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MOEN, Jon *AOL-2*
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PORTEOUS, Dave *IF-3*
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PRITCHARD, John *AOL-2*
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PROUSE, Nick *MEL-2*
PURDY, Phil *MS*

QUON, Charlie *AOL-4*

RACINE, Carol *AGC-1*
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REID, Ian *AGC-5*
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REINHARD, Harry *MS*
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RIPPEY, Jim *Hudson*
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ROCKWELL, Gary *CHS-1*
RODGER, Glen *CHS-1*
ROOP. David *CHS-1*
ROSE, Charlie *IF-2*
ROSS, Charles *AOL-4*
ROSS, David *AGC-1*
ROSS, Jim *CHS-2*
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RUMLEY, Betty *AOL-2*
RUSHTON, Laurie *MEL-1*
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RUXTON, Michael *CHS-1*
RYAN, Anne *CHS-1*

SABOWITZ, Norman *IF-4*
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SANDSTROM, Hal *AOL-4*
SAUNDERS, Jo-Anne *IF-4*
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SCHIPILOW, Cathy *CHS-2*
SCHWARTZ, Bernie *IF-2*
SCHWINGHAMER, Peter *MEL-2*
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SCOTT, Ray *IF-1*
SEIBERT, Gerald *OID*
SELIG, Byron *Hudson*
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SHAY, Juanita *IF-2*
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SHERIN, Andy *AGC-4*
SHIH, Keh-Gong *AGC-5*
SHOTTON, Ross *MEL-3*
SILVERT, Bill *MEL-3*
SIMMONS, Carol *MEL-2*
SIMMS, Judy *AOL-1*
SIMON, Jim *MFD*
SIMPSON, Pat *MFD*
SINCLAIR, Alan *MFD*
SLADE, Harvey *IF-5*
SMITH, Alan *CHS-2*
SMITH, Burt *CHS-l*
SMITH, Bill *MFD*
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SMITH, Fred *IF-1*
SMITH, John *AOL-1*
SMITH, John *MEL-1*
SMITH, Marion *AOL-2*
SMITH, Michelle *SRU*
SMITH, Peter *AOL-2*
SMITH, Steve *MFD*
SMITH, Stu *AOL-4*
SMITH, Sylvia *MEL*

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SPARKES, Roy *AGC-3*
SPENCER, Florence *AGC-4*
SPENCER, Sid *IF-2*
SRIVASTAVA, Shiri *AGC-5*
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Gerry Connolly.

STEELE, Trudi *AOL-4*
STEEVES, George *IF-2*
STEPANCZAK, Mike *AOL-3*
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STIRLING, Charles *CHS-1*
STOBO, Nancy *MFD*
STOBO, Wayne *MFD*
STOCKMAL, Glen *AGC-5*
STODDART, Stan *Hudson*
STOLL, Hartmut *IF-2*
STRAIN, Peter *AOL-1*
STRUM, Loran *Hudson*
STUART, Al *IF-2*
STUIFBERGEN, Nick *CHS-4*
SUTHERLAND, Betty *IF-4*
SWIM, Minard *CHS-1*
SYMES, Jane *P*
SY MONDS, Graham *AOL-4*
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TAN, Francis *AOL-1*
TANG, Charles *AOL-2*
TAYLOR, Bob *AGC-3*
TAYLOR, George *MEL-3*
TEE, Kim-Tai *AOL-4*
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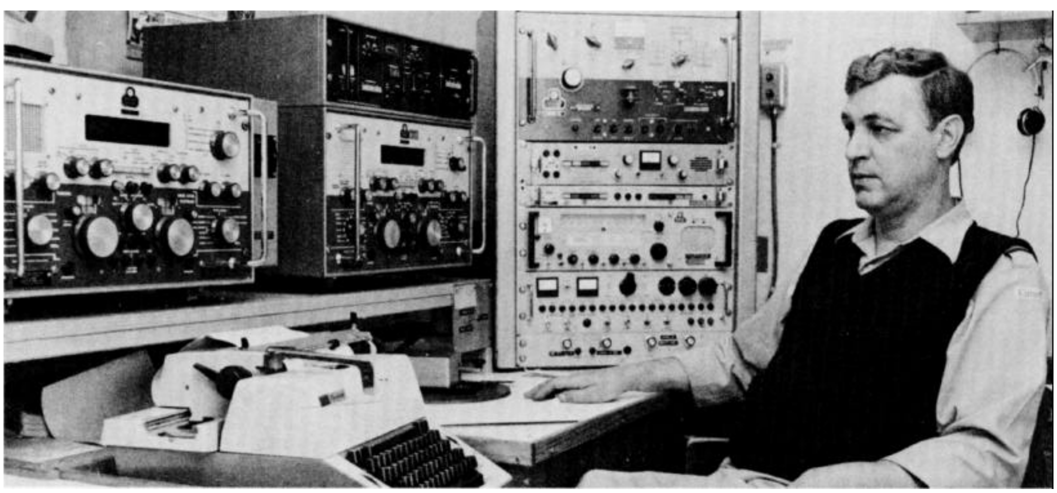
THOMAS, Frank *AGC-2*
TILLMAN, Betty *P*
TINSLEY, Beth *AGC-1*
TOLLIVER, Deloros *AGC-1*
TOMS, Elaine *IF-4*
TOPLISS, Brenda *AOL-2*
TOTTEN, Gary *IF-1*
TOULANY, Bechara *AOL-2*
TRITES, Ron *MEL-3*

VANDERMEULEN, John *MEL-2*
VARBEFF, Boris *IF-2*
VARMA, Herman *CHS-1*
VASS, Peter *MEL-2*
VAUGHAN, Betty *IF-2*
VAUTOUR, Jean-Claude *CHS-1*
VERGE, Ed *AOL-2*
VETESE, Barb *AGC-1*
VEZINA, Guy *IF-2*
VILKS, Gus *AGC-3*
VINE, Dick *IF-2*
VIOLETTE-HARVEY, Claire *IF-2*

WADE, John *AGC-2*
WALDRON, Don *MFD*
WALKER, Bob *AOL-2*
WALSH, Carl *IF-1*
WARD, Brian *IF-2*
WARDROPE, Dick *IF-2*
WARNELL, Margaret *IF-3*
WATSON, Nelson *MEL-1*
WEBBER, Shirley *MS*
WELLS, Richard *CAFSAC*
WENTZELL, Cathy *MS*
WESTHAVER, Don *IF-2*
WESTON, Sandra *CHS-2*
WHITE, George *MFD*
WHITE, Joe, *MS*
WHITE, Keith *CHS-3*
WHITEWAY, Bill *AOL-3*
WHITMAN, John *AOL-3*
WIECHULA, Marek *IF-3*
WIELE, Heinz *IF-5*
WILE, Bruce *AOL-4*
WILLIAMS, Doug *MS*
WILLIAMS, Graham *AGC-2*
WILLIAMS, Pat *AOL*
WILLIS, Doug *MEL-2*
WILSON, George *Hudson*
WILSON, Jim *IF-2*
WINTER, Danny *IF-2*
WINTERS, Gary *AGC-3*
WOOD, Rick *Baffin*
WOODSIDE, John *AGC-5*
WRIGHT, Dan *AOL-4*
WRIGHT, Morley *IF-2*

YEATS, Phil *AOL-1*
YOULE, Gordon *AOL-3*
YOUNG, Gerry *MFD*
YOUNG, Scott *AOL-3*

ZEMLYAK, Frank *AOL-1*
ZINCK, Maurice *MEL-2*
ZWANENBURG, Kees *MFD*



Phil Rafuse.

chapter 9

Project listing

We present below a current listing of the projects (A,B,C, etc.) and individual investigations (1,2,3, etc.) being undertaken by the four major components of the Bedford Institute of Oceanography: the Atlantic Oceanographic Laboratory, Marine Ecology Laboratory, Atlantic Geoscience Centre, and Atlantic Region of the Canadian Hydrographic Service. For more information on these projects and those of other BIO components, feel free to write to Publication Services, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2.

ATLANTIC OCEANOGRAPHIC LABORATORY

A. SURFACE AND MIXED-LAYER OCEANOGRAPHY

1. Humidity exchange over the sea (HEXOS) programme *(S.D. Smith, R.J. Anderson)*
2. Studies of the growth of wind waves in the open sea *(F. W. Dobson)*
3. Wave climate studies *(W. Perrie, B. Toulany)*
4. Oil trajectory analysis *(D. J. Lawrence, J.A. Elliott)*
5. Iceberg drift track modelling *(S.D. Smith)*
6. Microstructure studies in the ocean *(N.S. Oakey)*
7. Near-surface velocity measurements *(N. S. Oakey)*
8. Investigations of air-sea fluxes of heat and momentum on large space and time scales using newly calibrated bulk formulae *(F. W. Dobson, S.D. Smith)*
9. Labrador coast ice *(G. Symonds)*
10. Gulf of St. Lawrence ice studies *(G. L. Bugden)*
11. Marginal ice zone experiment (MIZEX): Wind stress and heat flux in the ice margin *(S.D. Smith, R.J. Anderson)*
12. Small-scale structure in a Gulf Stream warm core ring *(C.L. Tang, A.S. Bennett, D.J. Lawrence)*
13. Sea ice dynamics - MIZEX *(G. Symonds)*
14. Wind sea dynamics *(W. Perrie, B. Toulany)*

The Gadus Atlantica *under steam.*
(Courtesy of the Norrhwest Atlantic Fisheries Centre)

15. Current measurements near the ocean surface *(P.C. Smith, D.J. Lawrence, J.A. Elliott, D.L. McKeown)*

B. LARGE-SCALE DEEP-SEA OCEANOGRAPHY

1. Labrador sea water formation *(R.A. Clarke, N.S. Oakey, J. -C. Gascard (France))*
2. Modelling the Labrador Sea *(C. Quon)*
3. Labrador current variability *(R . A. Clarke)*
4. Age determinations in Baffin Bay bottom water *(E.P. Jones)*
5. Moored measurements of Gulf Stream variability: A statistical and mapping experiment *(R.M. Hendry)*
6. Newfoundland basin experiment *(R.A. Clarke, R.M. Hendry)*
7. Problems in geophysical fluid dynamics *(C. Quon)*
8. Northwest Atlantic atlases *(R.F. Reiniger, D. Gregory, R.A. Clarke, R.M. Hendry)*
9. Norwegian/Greenland sea experiment *(R.A. Clarke, J.A. Swift (Scripps Institution of Oceanography), J. Reid, (Scripps Institution of Oceanography), N.S Oakey, E.P. Jones, R. Weiss (Scripps Institution of Oceanography))*
10. Baseline hydrography: North Atlantic at *48°N (R.M. Hendry)*
11. Studies of the North Atlantic current and the seaward flow of Labrador current waters *(J.R.N. Lazier, D. Wright)*
12. Geochemical tracer studies *(G. T. Needler, D. Wright)*
13. Ship of opportunity expendable bathythermography programme for the study of heat storage in the North Atlantic Ocean *(F. W. Dobson)*
14. Gulf Stream extension experiment *(R . M. Hendry)*

C. CONTINENTAL SHELF AND PASSAGE DYNAMICS

1. Circulation off southwest Nova Scotia: The Cape Sable Experiment *(P.C. Smith. D. Lefaivre (OSS Quebec), K.T. Tee, R. W. Trites)*
2. The Shelf Break Experiment: A study of low-frequency dynamics and mixing at the edge of the Scotian Shelf *(P.C. Smith, B.D. Petrie)*
3. Flow through the Strait of Belle Isle *(B.D. Petrie, C. J. R. Garrett (Dalhousie University), B. Toulany, D. Greenberg)*
4. Shelf dynamics - Avalon Channel experiment *(B.D. Petrie, C. Anderson)*
5. Current surges and mixing on the continental shelf induced by large amplitude internal waves *(H. Sandstrom, J.A. Elliott)*
6. Batfish internal waves *(A.S. Bennett)*
7. Theoretical investigations into circulation and mixing on Georges Bank: Dynamics of tidal rectification over submarine topography *(J. W. Loder, D. Wright)*
8. Numerical models of residual circulation and mixing in the Gulf of Maine *(D.A. Greenberg, J. W. Loder, P.C. Smith, D. Wright)*
9. Theoretical investigations into circulation and mixing on Georges Bank: Mixing and circulation on Georges Bank *(J. W. Loder, D. Wright)*
10. Circulation and dispersion on Browns Bank: The physical oceanographic component of the Fisheries Ecology Program *(P.C. Smith)*

D. CONTINENTAL SHELF AND PASSAGE WATER-MASS AND TRANSPORT STUDIES

1. Analyses of the physical oceanographic data from the Labrador Current *(J.R.N. Lazier)*
2. Flemish Cap Experiment *(C.K. Ross)*
3. Long-term monitoring of the Labrador Current at Hamilton Bank *(J.R.N. Lazier)*
4. Long-term temperature monitoring *(D. Dobson, B.D. Petrie)*

Collecting water samples from C.S.S. Hudson's sampling platform on a winter's night.

5. Data management and archival *(D. N. Gregory)*
6. Development of a remote sensing facility in the Atlantic Oceanographic Laboratory *(C.S. Mason, B. Topliss, L. Payzant)*
7. Oceanography of the Newfoundland continental shelf *(B.D. Petrie, J. Moen)*
8. Eastern Arctic physical oceanography *(C.K. Ross)*
9. Water transport through and in the Northwest Passage *(S.J. Prinsenberg, B. Bennett)*
10. Heat and salt budget studies for the Grand Banks Program *(J. W.Loder, K.F. Drinkwater, B.D. Petrie)*

E. OCEANOGRAPHY OF ESTUARIES AND EMBAYMENTS

1. Saguenay Fjord study *(G.H. Seibert)*
2. Gulf of St. Lawrence frontal study *(C. Tang, A.S. Bennett)*
3. Seasonal and interannual variability in the Gulf of St. Lawrence *(G. L. Bugden)*
4. Laurentian Channel current measurements *(G.L. Bugden)*
5. The Gulf of St. Lawrence - Numerical modelling studies *(K. T. Tee)*
6. Tidal and residual currents 3-D modelling studies *(K.T. Tee, D. Lefaivre)*
7. Bay of Fundy tidal power - Studies in physical oceanography *(D. A. Greenberg)*
8. Physical dynamics of particulate matter *(K. Kranck)*
9. Bottom and surface drifters *(D. Gregory, F. Jordan, L. Petrie)*
10. Suspended sediment modelling *(D. A. Greenberg, C. L. Amos)*
11. Winter processes in the Gulf of St. Lawrence *(G.L. Bugden)*
12. Modelling historical tides *(D. A. Greenberg, D. Scott (Dalhousie University), D. Grant (GSC Ottawa))*
13. Storm surges *(D.A. Greenberg, T.S. Murty (OSS Pacific))*
14. Circulation and air/sea fluxes of Hudson Bay and James Bay *(S. J. Prinsenberg)*
15. Foxe Basin mooring observation program to study tidal current, mean circulation, and water mass formation and transport *(S.J. Prinsenberg)*
16. Tidally induced residual current - Studies of mean current-tidal current interaction *(Y. Tang, K.T. Tee)*

F. SENSOR DEVELOPMENT

1. Anemometers for drifting buoys *(J.-G. Dessureault, D. Harvey)*
2. CTDs and associated sensors *(A. S. Bennett)*
3. Thermistor chains on drifting buoys *(G.A. Fowler, J.A. Elliott)*
4. Towed biological sensors *(A. W. Herman, M.R. Mitchell, S. W. Young, E.F. Phillips, D. Knox)*
5. The dynamics of primary and secondary production on the Scotian Shelf *(A. W. Herman, D.D. Sameoto, T. Platt)*
6. Vertical profiling biological sensors *(A. W. Herman, M.R. Mitchell, S. W. Young, E.F. Phillips)*
7. Zooplankton grazing and phytoplankton production dynamics *(A. W. Herman, A.R. Longhurst, D.D. Sameoto, T. Platt)*
8. Real-time data acquisition *(A.S. Bennett)*
9. CTD sensor time constant measurements *(A.S. Bennett)*
10. Moored biological sensors *(A. W. Herman, M. R. Mitchell, S. W. Young, E.F. Phillips)*
11. Satellite estimations of primary productivity *(B.J. Topliss, T.C. Platt)*
12. Optical properties of Canadian waters *(B.J. Topliss)*

G. SURVEY AND POSITIONING SYSTEM DEVELOPMENT

1. Bottom-referenced acoustic positioning systems *(D. L. McKeown)*
2. Ship-referenced acoustic positioning systems *(D. L. McKeown)*
3. Multifrequency acoustic scanning of the water column *(N.A. Cochrane)*
4. Doppler current profiler *(N.A. Cochrane)*

H. OCEANOGRAPHIC INSTRUMENT DEVELOPMENT

1. Mooring system development *(G.A. Fowler, A.J. Hartling, R.F. Reiniger, J. Hamilton)*
2. Handling and operational techniques for instrument/cable systems *(J. -G. Dessureault, R.F. Reiniger, D.R. Harvey)*
3. In-situ sampling of suspended particulate matter *(D. L. McKeown, B. Beanlands, P.A. Yeats)*

1. NEARSHORE AND ESTUARINE GEOCHEMISTRY

1. Estuarine and coastal trace metal geochemistry (P.A. Yeats, *D.H. Loring)*
2. Atmospheric input into the ocean *(P.A. Yeats, J.A. Dalziel)*
3. Sediment geochronology and geochemistry in the Saguenay Fjord *(J.N. Smith, K. Ellis, R. Nelson, D. Nelson)*
4. Organic carbon transport in major world rivers: The St. Lawrence River, Canada *(R. Pocklington, F.C. Tan)*
5. Physical-chemical controls of particulate heavy metals in a turbid tidal estuary *(D.H. Loring)*
6. Organic carbon sinks in shelf and slope sediments *(R. Pocklington, E. Premuzic)*
7. Arctic and west coast fjords *(J.N. Smith, K. Ellis, C. T. Schafer, J.P.M. Syvitski)*
8. Chemical pathways of environmental degradation of oil *(P.M. Strain, E.M. Levy)*
9. Climate variability recorded in marine sediments *(J.N. Smith, K. Ellis, C.T. Schafer)*
10. Isotope geochemistry of major world estuaries *(J.M. Edmond (Massachusetts Institute of Technology), F.C. Tan)*
11. Review of chemical oceanography in the Gulf of St. Lawrence *(J.M. Bewers, C. Cosper, E.M. Levy, D.H. Loring, R. Pocklington, J.N. Smith, F.C. Tan, P.A. Yeats)*
12. Radioecological investigations of plutonium in an arctic marine environment *(J.N. Smith, K.M. Ellis, A. Aarkrog)*

J. DEEP OCEAN MARINE CHEMISTRY

1. Nutrient regeneration processes in Baffin Bay *(E.P. Jones)*
2. The carbonate system and nutrients in Arctic regions *(E.P. Jones)*
3. Distribution of sea-ice meltwater in the Arctic *(F.C. Tan, P.M. Strain)*
4. Trace metal geochemistry in the North Atlantic *(P.A. Yeats, J.A. Dalziel)*
5. Natural marine organic constituents *(R. Pocklington, J.D. Leonard)*
6. Paleoclimatological studies of Lake Melville sediment cores *(F.C. Tan, G. Vilks)*
7. Comparison of vertical distribution of trace metals in the North Atlantic and North Pacific oceans *(P.A. Yeats)*
8. Radionuclide measurements in the Arctic *(J.N. Smith, K. Ellis, E.P. Jones)*
9. Carbon isotope studies on particulate and dissolved organic carbon in deep sea and coastal environments *(F.C. Tan, P.M. Strain)*

A conference in progress in BIO's main auditorium.

K. MARINE POLLUTION CHEMISTRY

1. Petroleum hydrocarbon components *(E.M. Levy)*
2. Point Lepreau environmental monitoring program *(J.N. Smith, K. Ellis, R. Nelson, J. Abriel)*
3. Canadian marine analytical chemistry standards program *(J.M. Bewers, P.A. Yeats, J.A. Dalziel)*
4. International activities *(J.M. Bewers, E.M. Levy, D.H. Loring, J. N.Smith)*
5. Joint Canada/FRG Caisson experiments *(D.H. Loring, R. Rantala, F. Prosi)*
6. Marine emergencies *(E.M. Levy)*
7. Heavy metal contamination in a Greenland fjord *(D.H. Loring)*
8. Intercalibration of petroleum residues in the water column and sea-surface microlayer *(E.M. Levy)*
9. ICES intercalibration for trace metals in sediments *(D.H. Loring)*
10. Petroleum residues in the eastern Canadian Arctic *(E.M. Levy)*

Brian Petrie and Linda Payzant discuss a satellite image in BIO's image analysis centre.

MARINE ECOLOGY LABORATORY

A. PRIMARY PRODUCTION PROCESSES

1. Biotropical properties of the pelagic ocean *(T. Platt)*
2. Physiology and biochemistry of photosynthesis, respiration, and growth in marine phytoplankton *(J.C. Smith, T. Platt)*
3. Respiration, nutrient uptake, and regeneration in natural plankton populations *(W.G. Harrison, J.C. Smith, T. Platt)*
4. Physical oceanography of selected features in connection with marine ecological studies *(E.P. W. Horne)*
5. Physiology of marine micro-organisms *(W.K. W. Li)*
6. Picoplankton in the marine ecosystem *(D. V. Subba Rao)*
7. Biological oceanography of the Grand Banks *(E.P. W. Horne and others)*

B. SECONDARY PRODUCTION PROCESSES

1. Carbon and nitrogen utilization by zooplankton and factors controlling secondary production *(R.J. Conover)*
2. Ecology of microzooplankton in the Bedford Basin, Nova Scotia *(M.A. Paranjape)*
3. Development of profiling equipment (BIONESS) and LHPR for plankton and microplankton *(D.D. Sameoto)*
4. Secondary production and the dynamic distribution of micronekton and zooplankton on the Scotian Shelf *(D.D. Sameoto, A.W. Herman, N. Cochrane)*
5. Nature and significance of vertical variability in zooplankton profiles *(A.R. Longhurst)*
6. Nutrition and biochemistry in marine zooplankton *(E.J.H. Head)*
7. BIOSTAT program: Zooplankton and micronekton *(D.D. Sameoto)*
8. Feeding studies on zooplankton grown in an algal chemostat *(E.J.H. Head, R.J. Conover)*

C. ATLANTIC CONSHELF ECOLOGY

1. Scotian Shelf resources and the Shelf ichthyoplankton program: Data acquisition over large spatial and long temporal scales *(R.J. Conover)*
2. Seasonal cycles of abundance and distribution of microzooplankton on the Scotian Shelf *(M.A. Paranjape)*
3. Comparison of methods used for calculation of secondary production from zooplankton population data *(R.J. Conover)*
4. Comparative studies of functional structure of pelagic ecosystems *(A.R. Longhurst)*

D. EASTERN ARCTIC ECOLOGICAL STUDIES

1. Shore-based studies of under-ice distribution of zooplankton, their reproduction and growth, and the relative importance of epontic and pelagic primary production in their preparation *(R.J. Conover)*
2. Summertime shipboard studies in the eastern Canadian Arctic *(E.J.H. Head)*
3. Feeding dynamics of zooplankton and micronekton of the eastern Arctic *(D.D. Sameoto)*
4. Distribution and abundance of microzooplankton in the Arctic *(M.A. Paranjape)*
5. Ecophysiological aspects of marine microbial processes *(W.K.W. Li)*
6. Field and laboratory studies of diapause in copepods *(N. H. F. Watson)*

E. ECOLOGY OF FISHERIES PRODUCTION

1. Acoustic analysis of fish populations and development of survey methods *(L.M. Dickie and others)*
2. Genetics of production parameters. I. Information from breeding experiments and electrophoretic analyses *(L.M. Dickie, A. Mallet)*
3. Genetics of production patterns. II. Variations in genotypes among marine environments and year-classes *(L.M. Dickie, A. Mallet)*
4. Metabolism and growth of fishes *(S.R. Kerr, K. Waiwood)*
5. Mathematical analysis of fish production systems *(W. Silvert)*
6. Size-structure spectrum of fish production *(S.R. Kerr and others)*
7. Plankton growth rates in relation to size and temperature *(R.W. Sheldon)*
8. Bioenergetics: Marine mammals *(P.F. Brodie)*
9. Feeding strategies and ecological impact of bivalve larvae *(C. Abou Debs)*
10. Mathematical analysis of fish population interactions *(S.R. Kerr, L.M. Dickie)*
11. Marine mammal - Fisheries interaction *(P.F. Brodie)*
12. Grand Banks ecosystem models *(W. Silvert and others)*

F. ENVIRONMENTAL VARIABILITY EFFECTS

1. Residual current patterns on the Canadian Atlantic Continental Shelf as revealed by drift bottles and seabed drifters *(R.W. Trites)*
2. Water-type analyses for NAFO areas *(R.W. Trites, K.F. Drinkwater)*
3. Effects of Hudson Bay outflow on the Labrador Shelf *(K.F. Drinkwater)*
4. Larval transport and diffusion studies *(R.W. Trites, T. Rowell, E. Dawe)*
5. Oil distribution in relation to winds and currents following the break-up of the KURDISTAN *(D.J. Lawrence, R.W. Trites, J.H. Vandermeulen)*
6. Environmental variability-Correlations and response scales *(R.W. Trites)*
7. Climatic variability in the NAFO areas *(R.W. Trites, K.F. Drinkwater)*
8. Baffin Island fjords *(R. W. Trites)*

Troubleshooting electronic instruments - Alex Herman and Scott Young.

G. FISHERIES RECRUITMENT VARIABILITY

1. Steady state model and transient features of the circulation of St. Georges Bay *(K.F. Drinkwater)*
2. The decline of lobster stocks off the Atlantic coast of Nova Scotia *(G.C.H. Harding and others)*
3. Nutrition and growth of micro-, macro-, and ichthyoplankton *(R.W. Sheldon)*
4. Vertical movement of plankton, suspended matter, and dissolved nutrients in the water column of coastal embayments *(G.C.H. Harding and others)*
5. Characterization of water masses by particle spectra as a means of predicting larval fish survival *(R.W. Sheldon)*
6. Langmuir circulation and small-scale distribution of the plankton *(T. Lambert and others)*
7. Primary production dynamics *(K.F. Drinkwater)*
8. Coupling of pelagic and benthic production systems *(P. Schwinghamer, R.W. Sheldon, S. R. Kerr)*
9. Instrument development for surveys of particle size distributions *(R.W. Trites)*
10. Trophic relations in nearshore kelp communities *(K.H. Mann)*
11. Mixing and the temperature-salinity characteristics of the water in the southeastern Magdalen Shallows *(K.F. Drinkwater)*
12. Fish reproductive strategies *(T. Lambert)*
13. Recruitment of larval lobsters along southwest Nova Scotia, Bay of Fundy, and Gulf of Maine *(G.C.H. Harding and others)*
14. Fine-scale measurements of larval survival *(K.T. Frank)*
15. Dispersal strategies of marine fish larvae *(K.T. Frank)*
16. Broad-scale spatial coherence of reproductive success among discrete stocks of capelin *(K.T. Frank, W. Leggett, J. Carscadden)*
17. Southwest Nova Scotia fisheries ecology-benthic production processes *(P. Schwinghamer, D.L. Peer, J. Grant)*

H. SUBLETHAL CONTAMINATION AND EFFECTS

1. MFO induction by PCBs and PCB replacements *(R.F. Addison)*
2. Organochlorines in seals *(R.F. Addison)*
3. Fate, metabolism, and the effects of petroleum hydrocarbons in the marine environment *(J.H. Vandermeulen)*
4. Organochlorine dynamics in the marine pelagic ecosystem *(G.C.H. Harding, R.F. Addison)*
5. Transfer of metalloids through the marine food chain *(J.H. Vandermeulen)*
6. Hazard assessment of “new” environment contaminants *(R.F. Addison)*
7. “Calibration” of MFO system in winter flounder as an effects monitoring tool *(R.F. Addison)*

I. BAY OF FUNDY ECOLOGICAL STUDIES

1. Ice dynamics in the upper reaches of the Bay of Fundy *(D.C. Gordon)*
2. Primary production in the Bay of Fundy *(D.C. Gordon, P.D. Keizer, N. Prouse)*
3. Concentration, distribution, seasonal variation, and flux of inorganic nutrients and organic matter in shallow waters and intertidal sediments in the upper reaches of the Bay of Fundy *(D.C. Gordon and others)*
4. Intertidal primary production and respiration and the availability of sediment organic matter *(B. T. Hargrave, P. Schwinghamer, C. Hawkins)*
5. Microbial ecology of the Bay of Fundy *(L. Cammen, P. Schwinghamer)*
6. Subtidal benthic ecology of the Bay of Fundy *(P. Schwinghamer, D. L. Peer)*
7. Intertidal benthic ecology of the upper reaches of the Bay of Fundy *(P. Schwinghamer and others)*
8. Zooplankton studies in Cumberland Basin *(N. Prouse)*
9. Production, export, and ecological importance of Bay of Fundy saltmarshes *(D.C. Gordon and others)*

10. Modelling of Bay of Fundy ecosystems *(D.C. Gordon and others)*

J. DEEP OCEAN ECOLOGY
1. Deep ocean benthic community studies *(P. Schwinghamer)*
2. Mobility of radionuclides and trace metals in sediments *(P.E. Kepkay)*
3. Activity of scavenging amphipods in transfer of material in the deep ocean *(B.T. Hargrave)*
4. Vertical fluxes under the Arctic ice cap *(B.T. Hargrave, D.C. Gordon, G. C. H. Harding)*
5. Microbial metabolism at interfaces *(P.E. Kepkay)*

ATLANTIC GEOSCIENCE CENTRE

A. COASTAL PROGRAM
1. Consulting advice on physical environmental problems in the coastal zone *(R.B. Taylor)*
2. Morphology, sedimentology, and dynamics of Newfoundland coast *(D.L. Forbes)*
3. Coastal environments and processes in the Canadian Arctic Archipelago *(R.B. Taylor)*
4. Sediment dynamics and depositional processes in the coastal zone *(D.L. Forbes)*
5. Beaufort Sea coast *(P.R. Hill)*
6. Permafrost processes in Arctic beaches *(R.B. Taylor)*

B. COASTAL INLETS
1. The physical behaviour of suspended particulate matter in natural aqueous environments *(J.P.M. Syvitski)*
2. Sedimentology of fjords *(J.P.M. Syvitski)*
3. Sediment dynamics - Head of the Bay of Fundy *(C.L. Amos)*
4. The Recent paleoclimatic and paleoecologic records in fjord sediments *(C.T. Schafer)*
5. Satellite calibration for suspended sediment concentration in marine coastal environments *(C.L. Amos)*

C. SOUTHEASTERN CANADIAN MARGIN
1. Bedrock and surficial geology, Grand Banks and Scotian Shelf *(G.B. Fader)*
2. Ice scouring of continental shelves *(C.F.M. Lewis)*
3. Stability and transport of sediments on continental shelves *(C.L. Amos)*
4. Quaternary geologic processes on continental slopes *(D.J.W. Piper)*
5. Facies models of modern turbidites *(D.J.W. Piper)*
6. Engineering geology of the Atlantic shelf (C.F.M. *Lewis)*
7. Marine geotechnical study of the Canadian eastern and Arctic continental shelves and slopes *(K. Moran)*

D. EASTERN ARCTIC AND SUBARCTIC
1. Eastern Baffin Island shelf bedrock and surficial geology mapping program *(B.C. MacLean)*
2. Surficial geology, geomorphology, and glaciology of the Labrador Sea *(H.W. Josenhans)*
3. Quaternary methods in marine paleontology *(G. Vilks)*
4. Near-surface geology of the Arctic island channels *(B.C. MacLean)*
5. Quantitative Quaternary paleoecology, eastern Canada *(P.J. Mudie)*
6. Temporal and spatial variation of deep ocean currents in the western Labrador Sea *(C.T. Schafer)*
7. Ice-island sampling and investigation of sediments (ISIS) *(P.J. Mudie)*

E. WESTERN ARCTIC
1. Surficial geology and geomorphology, Beaufort Sea *(S.M. Blasco)*
2. Beaufort Sea boundary dispute studies *(P.R. Hill)*

F. GEOCHEMISTRY
1. Environmental geology of the deep ocean *(D.E. Buckley)*

G. REGIONAL GEOPHYSICAL SURVEYS
1. East coast offshore surveys *(R.F. Macnab)*
2. Evaluation of Kss-30 gravimeter *(B.D. Loncarevic)*
3. An earth science atlas of the continental margins of eastern Canada *(S.P. Srivastava)*
4. Arctic Ocean seismic refraction and related geophysical measurements *(H.R. Jackson)*
5. Potential fields data base operation *(J.M. Woodside)*
6. Seismic refraction along the Canadian Polar margin *(H.R. Jackson)*
7. Satellite altimetry applications for marine gravity *(J.M. Woodside)*
8. Regional geophysics of the Mesozoic-Cenozoic of Baffin Bay and Labrador Margin

H. DEEP STRUCTURAL INVESTIGATIONS
1. Comparative studies of the continental margins of the Labrador Sea and the North Atlantic *(S.P. Srivastava)*
2. Seismic studies of continental margins and ocean basins of the North Atlantic (LASE) *(I. Reid)*
3 Surficial geology and crustal structure of the Alpha Ridge, Arctic Ocean *(H.R. Jackson)*
4. Seismicity studies of the eastern Canadian margins *(I. Reid)*
5. Ocean Drilling Program site survey, Labrador Sea *(S.P. Srivastava)*

I. THEORETICAL MODELLING
1. Rift processes and the development of passive continental margins *(C.E. Keen)*

J. BASIN ANALYSIS AND PETROLEUM GEOLOGY
1. Regional subsurface geology of the Mesozoic and Cenozoic rocks of the Atlantic continental margin *(J.A. Wade)*
2. Geological interpretation of geophysical data as an aid to basin synthesis and hydrocarbon inventory *(A.C. Grant)*
3. Compilation of geoscientific data in The Upper Paleozoic basins of south-eastern Canada *(R.D. Howie)*
4. Stratigraphy and sedimentology of the Mesozoic and Tertiary rocks of the Atlantic continental margin *(L. F. Jansa)*
5. Reconnaissance field study of the Mesozoic sequences outcropping on the Iberian Peninsula *(L.F. Jansa)*
6. Evolution of east coast Paleozoic Basins *(J.S. Bell)*
7. Sedimentary basin evolution of the continental margin of Newfoundland, Labrador, and Baffin Bay *(D. McAlpine)*
8. Geology of the eastern margin of Canada and other parts of the Canadian offshore *(G.L. Williams)*

K. RESOURCE APPRAISAL
1. Hydrocarbon inventory of the sedimentary basins of eastern Canada *(J.S. Bell)*
2 Rank and petrographic studies of coal and organic matter dispersed in sediments *(P.A. Hacquebard)*
3 Maturation studies *(J.S. Bell)*
4 Interpretation of geophysical data from the Scotian margin and adjacent areas as an aid to basin synthesis and to estimation of hydrocarbon potential *(B.C. MacLean)*
5 Sedimentological and geochemical studies of hydrocarbon reservoirs, offshore eastern Canada

L. BIOSTRATIGRAPHY
1. Identification and biostratigraphic interpretation of referred fossils *(S.M. Barss)*
2. Palynological zonation of the Carboniferous and Permian rocks of the Atlantic provinces, Gulf of St. Lawrence, and northern Canada *(S.M. Barss)*
3. Biostratigraphy of the Atlantic and relevant areas *(R.A. Fensome)*
4. Taxonomy, phylogeny, and ecology of palynomorphs *(R.A. Fensome)* ,
5. DSDP dinoflagellates *(G.L. Williams)*

6. Biostratigraphic zonation (Foraminifera, Ostracoda) of the Mesozoic and Cenozoic rocks of the Atlantic shelf (P. *Ascoli)*
7. Biostratigraphic data-processing development *(S.M. Barss)*
8. Quaternary biostratigraphic methods for marine sediments *(G. Vilks)*
9 Quantitative stratigraphy in paleo-oceanography and petroleum basin analysis *(F.M. Gradstein)*

M DATA BASES
1 Geological Survey of Canada representative on steering committee for the Kremp palynologic computer research project *(M.S. Barss)*
2. Information base-offshore east coast wells *(G.L. Williams)*
3. Data inventory *(I. Hardy)*
4. Coastal information system development *(D. Forbes)*

N. TECHNOLOGY DEVELOPMENT
1. Sediment dynamics monitor - RALPH *(D.E Heffler)*
2. Development of Vibracorer/drill for geotechnical, geological, and engineering studies *(K.S. Manchester)*
3. Development and implementation of cable handling and maintenance procedures *(K.S. Manchester)*
4. Seabed *II (G.B. Fader)*
5. Digital single channel seismic data *(B. Nichols)*
6. CIGAL - Computer Integrated Geophysical Acquisition and Logging *(B.D. Loncarevic)*

0. SPECIAL PROJECTS
1. Ocean Drilling Program planning *(D.I. Ross)*
2. Boundary disputes: St. Pierre and Miquelon; Beaufort Sea *(D.I. Ross)*

Gordon Fader and Bob Miller aboard C.S.S. Hudson.

ATLANTIC REGION, CANADIAN HYDROGRAPHIC SERVICE

A. FIELD SURVEYS
1. Coastal and Harbour Surveys:
St. Mary's Bay, N.S. *(D.A. Blaney)*
Saint John Harbour, N.B. *(D.A. Blaney)*
Strait of Belle Isle, Nfld. *(D.A. Blaney)*
Argentia, Nfld. *(D.A. Blaney)*
St. John's Harbour, Nfld. *(D.A. Blaney)*
Halifax Harbour, N.S. *(C. Stirling)*
Goose Bay, Labrador *(K. Malone)*
Yarmouth Harbour, N.S. *(S. Dunbrack, D.A. Blaney, J. Ferguson)*
Notre Dame Bay, Nfld. *(V. Gaudet)*
Jones Sound, N.W.T. *(V. Gaudet)*
New Brunswick - North Shore Harbours *(E.J. Comeau)*
2. Offshore Scotian Shelf *(V. Gaudet)*
3. St. Pierre Bank *(G.W. Henderson)*
4. Revisory Survey of Pictou, N.S., to Chaleur Bay, N.B. *(G. Rockwell)*
5. Miramichi River *(G. Rockwell)*
6. Nachvak Fiord, Labrador *(E.J. Comeau)*
7. Longstaff Bluff, Foxe Basin *(E.J. Comeau)*
8 Navy Board Inlet, N.W.T. *(C. Stirling)*
9 Contract survey of Notre Dame Bay, Nfld. *(K. Malone)*
10 Contract survey of Roche Bay and Approaches, N.W.T. *(G.W. Henderson)*

B. TIDES, CURRENTS, AND WATER LEVELS
1. Ongoing support to CHS Field Surveys and Chart Production *(S.T. Grant, C. O'Reilly, L. MacDonald, C. P. McGinn, G.B. Lutwick, F. Carmichael)*
2. Operation of the Permanent Tides and Water Levels Gauging Network *(S.T. Grant, C. P. McGinn, G. B. Lutwick, F. Carmichael, L. MacDonald)*
3. Review and update of 1986 Tide Tables and Sailing Directions *(S.T. Grant, C. O'Reilly)*
4. Tidal and Current Surveys and Numerical Modelling Projects *(S.T. Grant)*
   - Numerical tidal model of Hudson Strait/Ungava Bay *(under contract to Martec Ltd.)*
   - Tidal and current survey of Hudson Strait/Ungava Bay *(under contract to Terra Surveys Ltd.)*
   - Co-tidal study of Miramichi River/Estuary *(under contract to Discovery Consultants Ltd.)*
   - Tidal Survey of Miramichi River/Estuary *(under contract to Marinav Ltd.)*
5. Co-tidal Chart Study of Yarmouth Harbour *(C. O'Reilly)*
6. P.I.L.P program to transfer tidal survey technology to MacAuley Surveys, Moncton, N.B. *(S.T. Grant, C.P. McGinn)*

C. NAVIGATION
1. Loran-C calibrations in Atlantic Canada for large-scale charts *(R.M. Eaton)*
2. Loran-C error accuracy-enhancement for Atlantic Canada (N. *Stuifbergen)*
3. Navstar evaluations *(R.M. Eaton)*
4. Upgrading BIONAV *(H. Boudreau)*
5. Development of electronic charting *(R.M. Eaton)*

D. CHART PRODUCTION
1. Production of 8 New Charts, 7 Standard New Editions, and 5 New Editions for Loran-C *(T.B. Smith, S. Weston)*

E. SAILING DIRECTIONS
1. Publication of the Small Craft Guide, Saint John River, Third Edition *(R. Pietrzak)*
2. Revisions to Sailing Directions, Nova Scotia (SE Coast), and Bay of Fundy *(R. Pietrzak)*

F. HYDROGRAPHIC DEVELOPMENT
1. Implementation of a portable Navitronic vertical acoustic sweep system *(R.G. Burke, S.R. Forbes)*
2. Design specifications for a dedicated sweep *vessel (R.G.Burke, S.R. Forbes)*
3. DOLPHIN Trials - Sable Island Bank *(R.G. Burke, K. Malone)*
4. Enhancing automated field surveys *(H. Varma, K.T. White)*
5. Enhancing computer-assisted chart production *(S.R. Forbes)*

G. RESEARCH AND DEVELOPMENT
1. ARCS - Development of an Autonomous Remotely Controlled Submersible for use in the Arctic under ice cover *(under contract to International Submarine Engineering Ltd.)*

chapter 10

Excerpts from the BIO log

- 1984 at BIO began with triple honours for the Marine Ecology Laboratory (MEL): papers published in the sixties by Bob Conover, Lloyd Dickie, and Ken Mann were selected as Citation Classics, the most cited papers in their particular disciplines over decades.

- Early in the year, Felix Gradstein of the Atlantic Geoscience Centre (AGC) taught a course on new concepts and methods in stratigraphy at the University of Kharagpur in India: Trevor Platt of MEL, together with American and Chilean colleagues, taught a course on pelagic ecology at the Catholic University of Chile. At the invitation of the People's Republic of China, Francis Tan and Charles Quon of the Atlantic Oceanographic Laboratory (AOL) conducted separate lecture tours at various Chinese institutions and universities.

- Based on work done by BIO staff, the Canadian Hydrographic Service (CHS) published the 3rd edition of the Small Craft Guide for the Saint John River in New Brunswick: this supplement to the Small Craft Chart included, for the first time, oblique aerial photographs and historical notes on the River.

- CSS *Hudson* began her 1984 voyages [voyage 84-001, January 24 through February 8] with a 2-week multidisciplinary survey of the Gulf of St. Lawrence. Under AOL senior scientist Gary Bugden, 6 scientific parties made a variety of measurements, many the first of their kind taken in the Gulf during winter, that permitted scientists to compare seasonal variations in the biological, physical, and chemical processes at work in the Gulf.

- Using the icebreaker CCGS *Labrador*, the Atlantic Region of CHS completed field sheets for a new route connecting Davis Inlet to Nain, Labrador, which cuts 6 hours from the steaming time between these two northern communities and provides a sheltered navigation corridor expected to be ice-free earlier in the shipping season than was the previously used route.

- A team of 5 biologists from the Marine Fish Division (MFD) spent February on Sable Island counting and tagging the year's crop of grey seal pups: 5824 pups were produced of which 5188 were tagged. Of the total produced, 700 died from natural causes before they could begin their lives at sea.

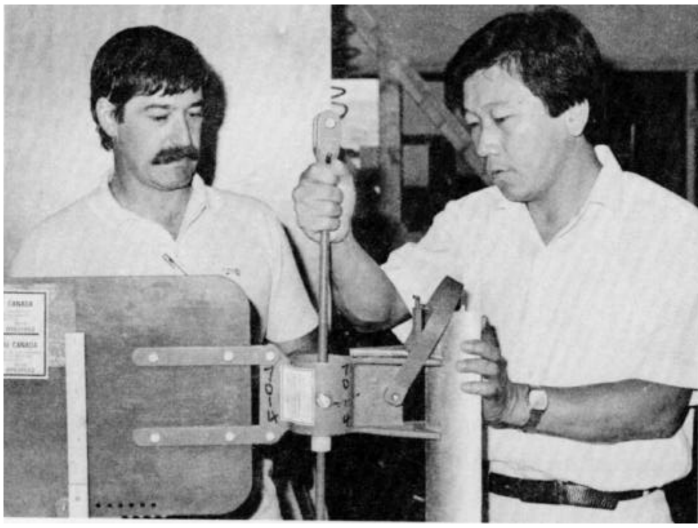
- During March, CSS *Baffin* worked the front in the ice fields off southern Labrador. Two parties conducted independent studies from the ship: scientists from MEL, DFO's Northwest Atlantic Fisheries Centre, and the Smithsonian Institution (USA) collected data on harp and hooded seals while other MEL oceanographers investigated the physiology of phytoplankton below the late-winter ice cover just as solar radiation increased and growth of plant life was imminent.

- From March 17-22, a major international meeting was held at Lava1 University: organized by Ken Mann and Trevor Platt of MEL at the request of the Scientific Committee on Oceanic Research, it brought together leading theoreticians from many disciplines. Some of the potential applications of thermodynamics, information theory, flow analysis, and statistical mechanics to biological oceanography were outlined for the audience of mainly biological specialists.


KELLY BENTHAM

Ken Mann, Lloyd Dickie, and Bob Conover.

C.S.S. Hudson, *the largest vessel in our fleet.*



AOL's Bruce Pinsent advises Korean engineer Ho Kyung Jun. AOL is helping Korean Ocean Research and Development Institute develop its ocean study capabilities under a UN. Development Program.

KELLY BENTHAM

Michael Latremouille, editor of the BIO Review.

- Each year, CHS at BIO conducts courses on navigation using Loran C and Satnav and on surveying of tides and currents for both BIO staff and external users. This year, 43 persons from as far east as St. John's and as far west as Quebec City attended February's navigation courses and 27 mostly external participants enrolled in March's tidal/current surveying course.

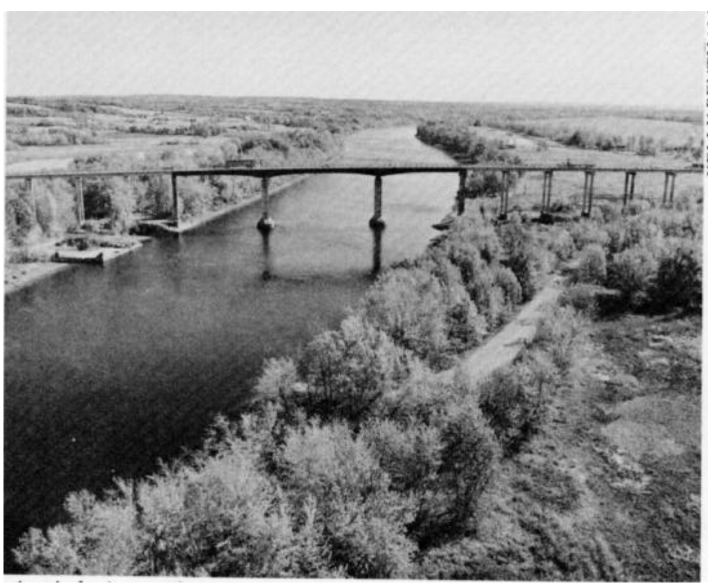
- In April, AGC geologists collected some 500 m of continuous rotary-core samples for various geological studies from the Hibernia I-46 oil well. All hydrocarbon maturation data from the East Newfoundland Basin's 9 wells are being analysed to allow a hydrocarbon generation model for the area to be constructed.

- In late May, it was learned that BIO *Review '82* and its editor, Michael Latremouille, had won the 1983 Distinguished Technical Communication Award from the Society for Technical Communication's Eastern Ontario Chapter.

- A major new edition of Chart 4910 (Miramichi River, New Brunswick) was released in May depicting the new navigational channel and associated navigational aids. This publication capped a 3-year, multimillion dollar program by the departments of Public Works, Transport, and Fisheries and Oceans to provide a safer and deeper navigational channel for marine interests in the area.

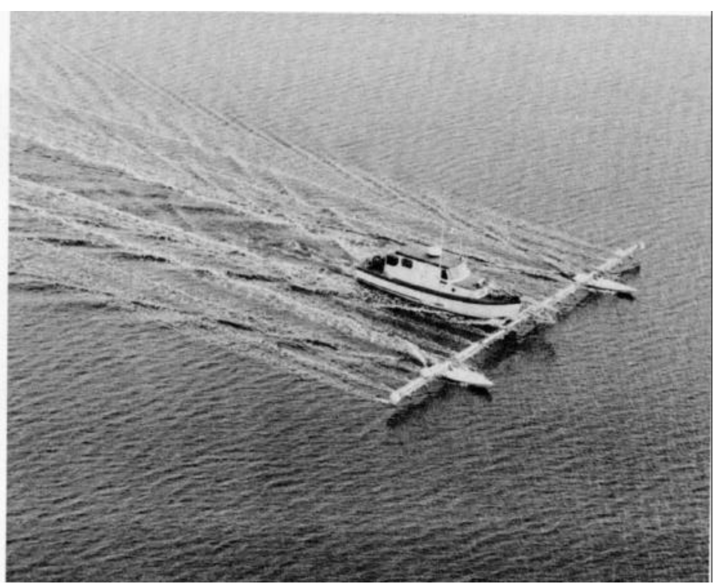
- A comprehensive review was completed by AGC staff of all geological data pertinent to the Labrador Continental Shelf: these data will form the basis for a 1:2,000,000 Quaternary sediment-map to be published in a new edition of the *Geology of Canada,* a multivolume work now being prepared as a periodic review of Canada's geology and as a Canadian contribution to the Geological Survey of America's centennial project known as "The Decade of North American Geology".

- Ray Sheldon of MEL, in recognition of his outstanding research on the linear biomass spectrum of the ocean, was



Aerial view of the Saint John River, New Brunswick.

KELLY BENTHAM



The transportable "'sweep" system provides total bathymetric survey coverage for charting of harbours.

awarded the degree of Doctor of Science by the University of Manchester.

- BIO's quadrennial Open House Days were held May 30th through June 3rd. Over 30,000 visitors came to view the many exhibits, tour research vessels, witness equipment demonstrations, and attend a popular series of lectures by scientists on topics of interest to the public such as offshore oil and gas potential and Bay of Fundy tidal power and its environmental implications.

- The 2nd joint annual congress of the Canadian Meteorological and Oceanographic Society and the Canadian Geophysical Union was attended by over 400 people from May 29th through June 1st at Dalhousie University in Halifax. BIO staff contributed to and benefitted from the congress's success in many ways: over 45 papers were presented or co-authored by BIO staff, over 60 BIO scientists participated including 9 who served on organizing committees, and delegates were given a special preview tour of BIO's open house days.

- In a very successful test voyage aboard CSS *Hudson* in June, the prototype Seabed II deep ocean mapping system first described in *BIO Review '83* was put through its paces. It returned high-quality data and yielded new scientific findings on the Verrill Canyon. Seabed II, the first totally Canadian deep-ocean technology, was developed in a special government-industry project by Huntec '70 Ltd.

- Since the late 70s, AOL has been working to develop current meter moorings that can be deployed and safely recovered after one year or longer. Safe mooring-exposure times were less than 3 months but, in June, five 470-m long moorings of 4 current meters each were recovered after an exposure of 1 year in the Gulf Stream off eastern Canada.

- In July, visiting scholar Rong Wang of the Institute of Oceanology, Chinese Academy of Sciences, completed a 1-year project with MEL's Bob Conover that resulted in discovery of an improved method for determining zooplankton grazing rates in the oceans.

- Using Office of Energy Research and Development funds, AOL engineers completed development of technology to increase the operating depth of the Batfish towed vehicle from 200 to 425 m at a towing speed of 8 knots. This enhancement permits much deeper and more detailed surveys of the ocean's surface layers to be made.

- During the summer of 1984, AOL installed an in-house image-analysis system as a research tool for oceanographic applications. The cover illustration for this edition of *BIO Review* was prepared on this system, which comprises a VAX-750 computer and Adage colour image terminal together with software developed by Perceptron Computing Ltd. of Toronto. BIO scientists have now been trained on the system and University of Miami software containing oceanography-specific image analysis routines is being brought in.

- A BIO "total coverage" bathymetric survey system developed through Arctic Transportation R&D funds was given its first operational Arctic trials in August. The transportable sweep system functioned well under Arctic conditions and valuable experience was gained on deploying it from a ship's launch.

- In August, AGC staff completed aerial video coverage of almost the entire coast from Tuktoyaktuk Peninsula to the Alaska border and collected other data that will provide information on the long-term rates of coastal erosion for the Beaufort Sea.

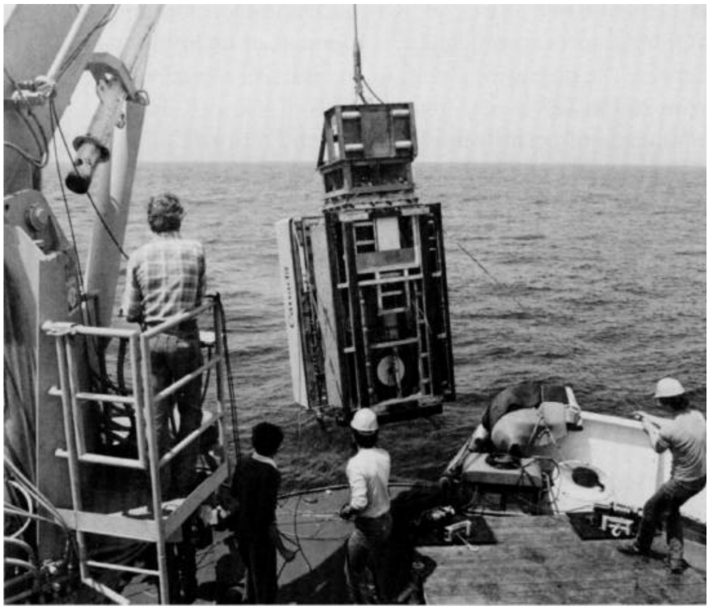
- The Marine Fish Division reviews the annual fish stock assessments it has conducted through the Canadian Atlantic Fisheries Scientific Advisory Committee each year to identify and resolve problems. At a workshop in late August, they completed the most comprehensive and generalized review of their methods and programs to date. As a result, significant improvements were made to the 1985 assessments.

- Scientists from AOL participated in the international marginal Ice Zone Experiment (MIZEX) aboard the German icebreaker *Polarstern* in Fram Strait between Spitzbergen and

ROGER BELANGER

Grey seals on Sable Island during breeding season.

The German (F. D.R.) research vessel Polarstern *was used during the international Marginal Ice Zone Experiment.*



The Seabed II deep ocean mapping system during its sea trials.

Space walker Kathy Sullivan visited BIO in 1984.

Greenland through June and July. The experiment was designed to study the meteorology and oceanography of areas near the edges of large ice-fields.

- In early September, a special session on the biology and ecology of squids in the Northwest Atlantic was held at BIO. Organized by the Northwest Atlantic Fisheries Organization, it brought together 45 specialists from Canada, Cuba, Denmark, the Federal Republic of Germany, France, Japan, Norway, Poland, Portugal, the United Kingdom, and the United States to review the many advances of recent years in cephalopod biology and to discuss directions for future research.

- In early October, BIO hosted the annual meeting of the Madrid-based International Commission for the Conservation of Atlantic Tunas. This was followed by a special scientific session on the status of the bluefin tuna of the Northwest Atlantic, a topic of great interest to us here in the Maritimes.

- The 686-page report "Update on the marine environmental consequences of tidal power development in the upper reaches of the Bay of Fundy" was published in October [see Chapter 6, Gordon and Dadswell, 1984]. The report, expected to be referred to for years to come, summarizes all the Fundy research projects conducted since 1976 that were co-ordinated by the Atlantic Provinces Council on the Sciences and in which many MEL staff participated.

- The fourth Offshore Technology Exposition (CORE) was held in Halifax in mid-October. Both AGC and DFO at BIO exhibited. One AGC display was a diode-lit oil and gas map of offshore eastern Canada depicting the locations of all exploratory wells drilled and their status. DFO at BIO displays included the prototype ARCS vehicles for under-ice surveys and a model of the storm that sank the *Ocean Ranger*.

- Trevor Platt of MEL and Farooq Azam of the Scripps Institution of Oceanography were joint winners of the 1984 Rosenstiel Award in Oceanographic Science presented by the University of Miami and the American Association for the Advancement of Sciences. They were cited for having "spearheaded" the most significant advances in biological oceanography over the past ten years".

- By late November, CSS *Baffin* had completed a 33-day combined hydrographic-geophysical survey south of Newfoundland in which over 6600 nautical miles of track data were collected at 10-mile line spacings. The project was jointly undertaken by the Gravity, Geothermics, and Geodynamics Division of DEMR's Earth Physics Branch, AGC, and the Atlantic Region of CHS.

- This year, for the first time, BIO scientists had direct access to a Cray 'super-computer' through the DOE/AES facility in Dorval, Quebec. BIO use of the facility was much heavier than forecast for studies such as modelling of large-scale ocean circulation and baroclinic wave structure and numerical solving of a finite difference equation related to lithospheric deformation.

Dr. Wally Broecker, a geochemist at the Lamont-Doherty Geological Observatory, was the ninth recipient of the A. G. Huntsman silver medal for excellence in the marine sciences. He received the medal for his wide ranging research into the chemical processes operating in the oceans, particularly his use of radioisotopes in dating minerals, ocean sediments, and sea water. His work eventually led to investigations tracing the slow deep flow within the oceans and estimating the rates at which the ocean exchanges its waters over the entire globe.

- During the year, AOL continued its assistance, begun in 1981, in the development of Korean ocean study capabilities. Under a United Nations Development Program, 5 AOL technologists will spend about 34 weeks over the next 3 years at KORDI, the Korean Ocean Research and Development Institute, and 4 KORDI engineers will spend a total 50 weeks over that period at AOL and at the DFO Marine Environmental Data Services Branch in Ottawa.

- AOL was a major participant in the Pilot Experiment of the Humidity Exchange Over the Sea (HEXOS) program that was carried out in November at an offshore research platform in the North Sea, 10 km off the coast of the Netherlands.

- Among the visitors to BIO during 1984 were:

Dr. Terence Armstrong of the Scott Polar Research Institute; President Eanes of Portugal and senior members of his staff; the Canada-United States Military Co-operation Committee, which comprised some 20 senior officers from both countries; Mr. Christopher Trump, Vice President of SPAR Aerospace; participants in the fourth summer training camp in ocean management conducted this year in Halifax by the International Ocean Institute of Malta in co-operation with the Centre for Foreign Policy Studies at Dalhousie University; Professor Wolfgang Krauss of the Institut fur Meereskunde, FRG; Captain A. Civetta, Chief Hydrographer of the Italian Navy with his staff and the Italian military attache; Dr. Warren Godson, Senior Science Advisor with the Atmospheric Environment Service (DOE) in Downsview, Ontario; Dr. Andrew Y. Carey, Jr., Professor of Oceanography at the College of Oceanography, Oregon State University; Professor Yoshiaki Toba of the Geophysical Institute of Tohoku University in Japan; and Dr. Kathryn Sullivan, a mission specialist on NASA's 1984 shuttle flight 41G and a graduate of Dalhousie University.

BIOMAIL

BIO's Marine Advisory and Industrial Liaison office, or BIOMAIL for short, is there to:

- assist in obtaining oceanographic information for you
- help you solve your problems with any aspect of oceanography
- smooth the transfer of our know-how to your company
- facilitate joint projects with BIO and industry
- bring the right people together for an expansion of oceanographic industry.

BIOMAIL's scope is not limited to local or Canadian aspects; we have access to global ocean information and expertise. The office is here to serve the interests of Canadian industry for the benefit of Canadian citizens.

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THE BEDFORD INSTITUTE OF OCEANOGRAPHY (BIO) is the principal oceanographic institution in Canada; it is operated within the framework of several federal government departments; its staff, therefore. are public servants.

BIO facilities (buildings, ships, computers, library, workshops, etc.) are operated by the Department of Fisheries and Oceans. The principal laboratories and departments are:

Department of Fisheries and Oceans (DFO)

- Canadian Hydrographic Service (Atlantic Region)
- Atlantic Oceanographic Laboratory
- Marine Ecology Laboratory
- Marine Fish Division

Department of Energy. Mines and Resources (DEMR)

- Atlantic Geoscience Centre

Department of the Environment (DOE)

- Seabird Research Unit

BIO operates a fleet of three research vessels, together with several smaller crafts. The two larger scientific ships, *Hudson* and *Baffin,* have global capability, extremely long endurance. and are Lloyds Ice Class I vessels able to work throughout the Canadian Arctic.

BIO has four objectives:

(1) To perform fundamental long-term research in all fields of the marine sciences (and to act as the principal Canadian repository of expertise).

(2) To perform shorter-term applied research in response to present national needs, and to advise on the management of our marine environment including its fisheries and offshore hydrocarbon resources.

(3) To perform necessary surveys and cartographic work to ensure a supply of suitable navigational charts for the region from George's Bank to the Northwest Passage in the Canadian Arctic.

(4) To respond with all relevant expertise and assistance to any major marine emergency within the same region.

W.D. Bowen - Chief, *Marine Fish Division, DFO*

M.J Keen - Director. *Atlantic Geoscience Centre. DEMR*

A.J. *Kerr - Director, Atlantic Region. Canadian Hydrographic Service, DFO*

K.H. Mann - Director, *Marine Ecology Laboratory, DFO*

J.A. Elliott - Director, *.Atlantic Oceanographic Laboratory. DFO*

D.N. Nettlehip - Seabird *Research Unit. Canadian Wildlife Service, DOE*

Fisheries
and Oceans

Pêches
et Océans

Energy, Mines and
Resources

Énergie, Mines et
Ressources

Environment

Environnement