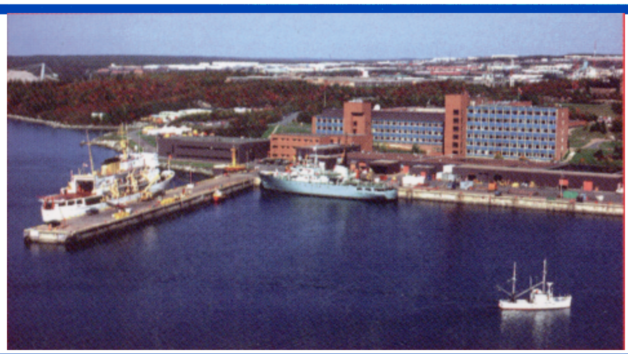
Science Review 1987



Bedford Institute of Oceanography

Halifax Fisheries Research Laboratory

St. Andrews Biological Station

Canada

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Preface

THE **Science Review** describes the federal marine science and fisheries research programs that are carried out at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia; at the Halifax Fisheries Research Laboratory, Halifax, Nova Scotia; and at the St. Andrews Biological Station, St. Andrews, New Brunswick.

The **Science Review** supercedes the **BIO Review,** which reported annually on research activities at the Bedford Institute of Oceanography (BIO) undertaken by the Department of Fisheries and Oceans (DFO), the Department of Energy, Mines and Resources (DEMR) and the Department of the Environment (DOE). The new **Science Review** reflects the 1986 integration of the science programs of the Department of Fisheries and Oceans in the Scotia-Fundy Region. The **Science Review** continues to report on the marine geoscience programs of the Atlantic Geoscience Centre of DEMR at BIO, as well as on the activities of the Seabird Research Unit of DOE.

The last issue of **BIO Review** presented information on charts and publications produced and ships' voyages undertaken during 1985; the corresponding parts of this issue of **Science Review** contain material for both 1986 and 1987.

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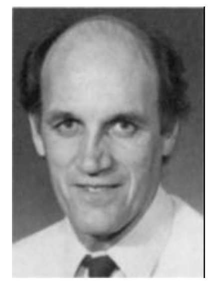
The Science Program of Scotia-Fundy Region

S.B. MacPhee, J.A. Elliott, M.M. Sinclair, and T.B. Smith

S.B. MacPhee

J.A. Elliott



M.M. Sinclair

Introduction

THE federal government is responsible for much of the Canadian scientific investigations of the oceans and their resources, and the largest marine effort is conducted by the Department of Fisheries and Oceans (DFO).The scientific research is organized to facilitate the departmental mission with respect to ocean and fresh-water fsheries, hydrography and marine sciences, and the coordination of the policies and programs of the Government of Canada respecting oceans.

The Assistant Deputy Minister, Science, is responsible for the Department's science mandate and provides science policy as well as program and administrative guidance to each of the six regions that were formed in 1986 to deliver the DFO programs (the six regions resulted from the consolidation of seven Fisheries Management Regions and four Ocean Science and Surveys Regions). The purpose of this essay is to describe the structure, goals and thrusts of the science program for Scotia-Fundy Region.

The science program of Scotia-Fundy Region is carried out from the following locations:

- Bedford Institute of Oceanography, Dartmouth, Nova Scotia. The Departments of Energy Mines and Resources and Environment also have laboratories at the Institute.
- Halifax Fisheries Research Laboratory, Halifax, N.S.
- Saint Andrews Biological Station, Saint Andrews, New Brunswick.

T.B. Smith

- Hatchery facilities at Saint John and Mactaquac in New Brunswick and in Nova Scotia, at Yarmouth, Coldbrook, Mersey and Cobequid.

Objectives of the Program

The main objectives of the program, in support of the overall departmental mission, are:

- to provide and communicate a reliable scientific basis for the management of fish and fish habitat and for aquaculture;
- to perform fundamental and applied research on the impact of deleterious substances on fish, fish habitat and aquatic ecosystems;
- to describe and understand the climate of the oceans, its coupling with the atmosphere and its influence on fish stocks and the development of non-living resources in the offshore;
- to chart the waters in an area extending from the Gulf Of Maine to the high Arctic in order to facilitate commercial navigation, fishing activities and to assist offshore development; and
- to develop and refine methodology and technology necessary to carry out the Department's scientific role and to transfer relevant technology to Canadian industry as well as to provide research vessel support to universities.

An organization chart for the Science Sector in Scotia-Fundy Region is shown in Figure 1. The science program is headed by

Regional Director Science

- Biological Sciences Branch
  - Marine Fish Division
  - Invertebrates, Marine Plants and Environmental Ecology Division
  - Biological Oceanography Division
  - Enhancement, Culture and Anadromous Fish Division
  - Fish Aquaculture and Applied Physiology Division
- Physical and Chemical Sciences Branch
  - Marine Chemistry Division
  - Coastal Oceanography Division
  - Metrology Division
  - Ocean Circulation Division
- Hydrography Branch
  - Field Surveys Division
  - Chart Production
  - Hydrographic Development
  - Navigation Group
  - Data Management and Planning
  - Tidal Section
- Marine Assessment and Liaison Division

Fig. 1. Components of the Science Sector of the Department of Fisheries and Oceans' Scotia-Fundy Region

the Regional Director, Science, and reports to the Regional Director General who is responsible for the delivery of all departmental programs in the Region. The program is organized along disciplinary lines (Branches) in the fields of Biological Sciences, Physical and Chemical Sciences and Hydrography. Brief program descriptions for the three Branches, together with achievements for 1987 and goals for 1988 are given below.

While the program is organized along disciplinary lines, efforts are made as necessary to carry out interdisciplinary research involving scientists from different Branches working together, and with scientists from the private sector, from the universities, from other regions and from other countries.

Resource Summary

A Resource Summary for the 1987-88 fiscal year (funds expressed in thousands of dollars) is shown below.

The resource figures shown include commissioned research from other government departments (DEMR, DOE, DPW, DND, and DOT) and the departmental contributions to unsolicited proposals submitted to the Department of Supply and Services and supported by DFO. The figures do not include purchase and amortization costs for major capital acquisitions such as vessels and accomodations.

	PY.	Sal.	O&M	Cap.	G&C	**Total**
Regional Director*	21.9	268.3	972.7	38.6		1,889.6
Biological Sciences	271.1	10,838.2	4726.7	440.7	304.5	16,310.l
Physical and Chemical Sciences	134.3	5538.7	2,434.6	616.1	-	8,589.4
Hydrography	71.7	2,677.4	1,411.9	234.5		4,323.8
Marine Electronic Support	21.8	938.8	185.3	33.9		1,158.0
Vessel support	164.8	7,026.0	8,661.0	435.6	-	16,122.6
TOTAL	685.6	27,887.4	18,402.2	1,799.4	304.5	48,393.5

*includes Marine Assessment and Liaison Division, Scientific Computing, and CAFSAC (Canadian Atlantic Fisheries Scientific Advisory Committee)

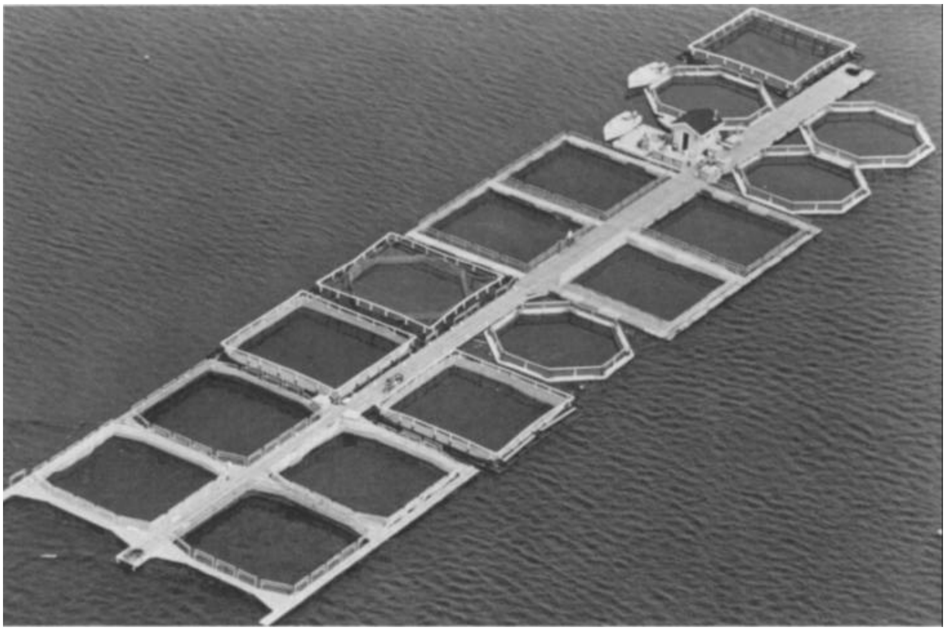
Too big for the trap! Only the smaller "canner" lobsters are selected by traps set in Morrisey's Cove, Prince Edward Island leaving the more fertile larger lobsters to sustain the population

Biological Sciences Branch

The Biological Sciences Branch through an extensive resource assessment and related research program, provides the scientific basis for the management of the fishery resource. This includes stock assessments for all major exploited species of finfsh, invertebrates marine mammals and marine plants, as well as research on assessment methodology, abundance estimates and the biology, ecology and dynamics of exploited species to conserve the resources and improve the scientific knowledge base. The Branch also carries out a program of research in aquaculture for marine finfsh and invertebrates in support of the aquaculture industry. The fresh water and anadramous fish research activities provide biological advice for the management of these species, as well as a supply of Atlantic salmon and speckled trout from the hatchery network for the enhancement program and the aquaculture industry. In addition, research is carried out in biological oceanography to study the dynamics of marine ecosystems in coastal, shelf and deep-ocean waters with special emphasis on the interdependence of biological communities, their temporal and spatial variability and their relationship with the physical and chemical conditions of the marine environment.

A sampling of the accomplishments for 1987 follows:

- Stock assessments were provided on all major exploited stocks of fish, invertebrates, marine mammals and marine plants;
- Fish health certification was provided for stocks transferred between watersheds;
- A field survey of Georges Bank was carried out to assess the recovery of the herring stock in this geographic area;
- Maximum production levels were maintained at all hatcheries and in addition to supplying 250,000 smolts for river recovery, 200,000 were supplied for the local aquaculture industry;
- Regional staff participated in solving the molluscan toxin problem in Atlantic Canada, playing a part in identifying the toxins and the source of the toxic materials;
- In cooperation with Physical and Chemical Sciences Branch, a general scientific evaluation of the likely environmental impacts of exploratory drilling on Georges Bank was completed for the Gulf of Maine Advisory Committee;
- A quantitative evaluation of the impact of acid rain on Atlantic salmon populations in Nova Scotia was carried out;
- Algorithms were developed to more effectively utilize satellite data to estimate global productivity of the oceans;



The Salmon Demonstration and Development Farm transfers technology to the growing salmon aquaculture industry in the Bay of Fundy.

- A synthesis was prepared on recent advances in biological oceanography of Arctic waters using the results of eight cruises and forty-five publications from recent research at BIO; and
- Regional staff organized the course material and participated in an innovative stock assessment course in Dakar, Senegal for francophone West Africa (an ICOD project).

Some of the goals for 1988 are:

- Improve communications between regional scientists and client groups to ensure that science programs correspond to client needs;
- Increase client input, particularly fishermens', into the stock assessment process;
- Initiate a research program, in collaboration with the fishing industry and universities, to provide a sound scientific basis for managing the increasing grey seal populations and for evaluation of alternate management strategies through *inter alia* birth control and the use of vermicides;
- Provide stock assessment for all major exploited species and fish health certification for all stocks being transferred between watersheds,
- Provide a new synthesis of the mechanisms supporting the high level of primary production on Georges Bank and its relationship with the fisheries production;
- Provide first basin-scale estimates of primary production for the North Atlantic and its impact on the global CO_2 system, in support of the Climate Research Program;
- Synthesize the accumulated results on the population biology of Browns Bank haddock, including an analysis of the oceanographic factors responsible for recruitment variability (year to year variability in the number of fish added to the stock);
- Develop an integrated five year plan for aquaculture research in Scotia-Fundy Region;
- Conjointly with other Atlantic Zone Regions of DFO, initiate an integrated research program on phytotoxins in relation to molluscan aquaculture; and
- Provide enhanced facilities for the rearing of marine fish, in particular Atlantic halibut, for aquaculture research.

Physical and Chemical Sciences Branch

In the Physical and Chemical Sciences Branch the main research efforts are devoted to:

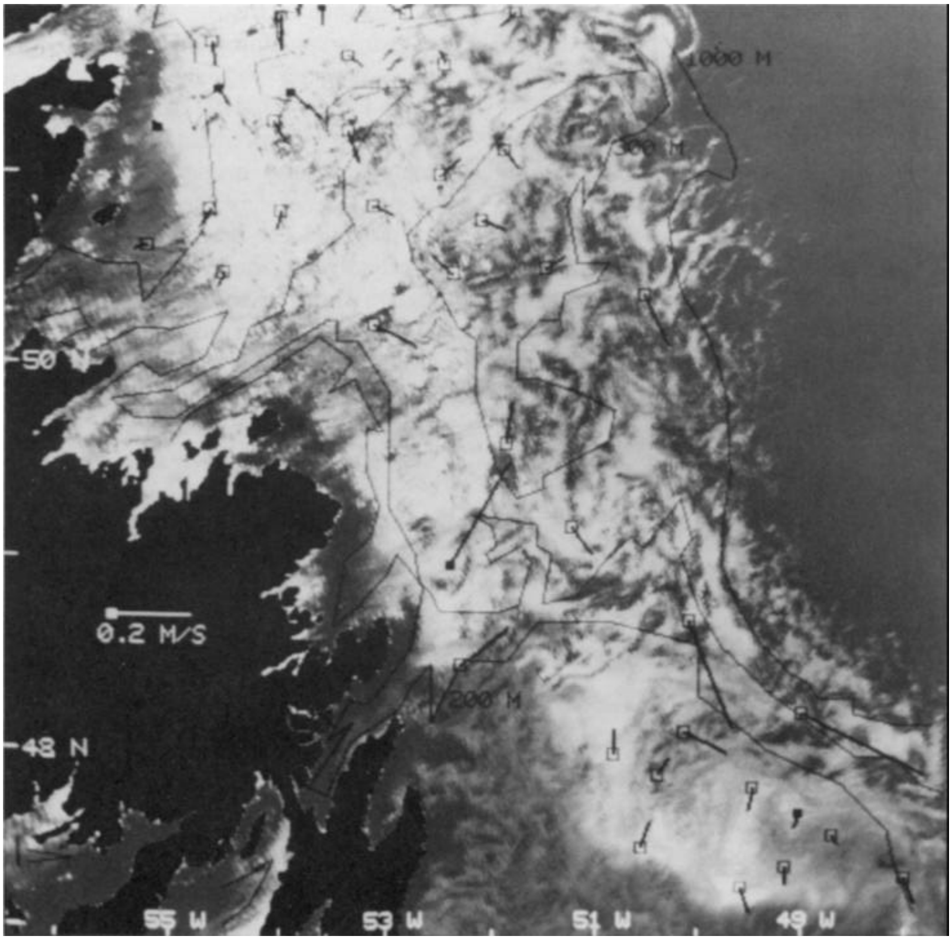
- Ocean Climate hindcasting and forecasting to provide a description of those processes that govern the annual and long term ocean and shelf circulation, verifying how the "Greenhouse" gases might affect the ocean so that climate trends can be accurately forecast and, in collaboration with the Biological Sciences Branch, determining the effects of climate variation on commercial fisheries, transportation and pollution issues;
- Marine Developments consisting of oceanographic studies that provide guidance to the safe and economic management of specific engineering developments relating to safe and efficient exploration and production of offshore energy resources, and the protection of human health;
- Living Resources consisting of oceanographic studies designed to further the understanding of the relationship between the environment and living resources and including interdisciplinary research with Biological Sciences Branch;
- Biogeochemistry consisting of studies of the processes that govern the distribution, fluxes and properties of chemical parameters including the behavior of both naturally-occurring and anthropogenic compounds in the marine environment;
- Toxicology, Contaminants and Habitat Research to identify potential marine contaminants and provide information on known marine contaminants, their pathways and effects to facilitate informed decision making and the establishment of regulations and policies, as required for the protection of marine resources and human health;
- Cooperative research programs with the private sector to further ocean industry development in Canada by making sure that the private sector has access to research and development technologies that are designed and prototyped "in house".

A sampling of the accomplishments of the Physical and Chemical Sciences Branch in 1987 follows:

- A study was carried out to establish present levels of natural and anthropogenic chemicals in the Canadian sector of Georges Bank;
- A field study was completed of the mixing and dynamics in the Newfoundland Basin where the Gulf Stream and the Labrador current systems interact

and influence the large-scale climate of this region;

- Developments of underice sampling systems for biological studies in the Arctic and use on field programs continued;
- Current meters were moored and field surveys completed to monitor the water exchange between Baffin Bay and the Northwest Atlantic as part of a regional ice modelling experiment;
- For the third year, ice beacons were placed on the Labrador ice sheet to track the southward advection as part of the sea ice climatology and modelling for the Hibernia area;
- A CODE (Centre Of Disciplinary Expertise) in marine contaminants and toxicology was established to deal with sensitive habitat issues resulting from adverse chemical changes;
- Work continued on the the development of a Climate Research Strategy for the Department to include various major international programs, departmental interests and collaboration throughout the scientific community;
- Studies were completed on the influence of mean circulation and horizontal dispersion on the survival and recruitment success of the Browns Bank gadoid stocks in collaboration with Biological Sciences Branch;
- The Branch participated in the development of a shipboard handling, refueling, and recovery system for the DOLPHIN semisubmersible, remotely operated vehicle, in collaboration with the Hydrography Branch;
- Studies were undertaken through the use of MFO induction measurements to observe the effects of petroleum hydrocarbons on flounder fish as a sample species;
- Stable carbon isotope analysis was applied to the study of growth rates in various marine organisms as part of stock management data in conjunction with Biological Sciences Branch;
- The assessment of the general oceanography of the Arctic Ocean continued based upon carbon and nutrient budgets and participation in an international cruise in the Arctic Ocean; and
- Studies continued on the effects of acid rain on salmon stocks in Nova Scotia rivers and the possible mitigating effects of adding lime to the streams were explored.



Computer monitor displav of sea ice extent and movement off Newfoundland Ice cover (white) is determined from a satellite image. Ice movement is estimated by comparing the positions of ice-field features during successive satellite overpasses (open arrows), and by monitoring positions of satellite-reporting beacons that were plced on the ice by helicopter (closed arrows).

Some of the goals for 1988 are:

- Continue research in support of the Canadian Climate Program to study the annual and interannual variability of environmental properties and fluxes on the Continental Shelf and adjacent waters in order to contribute to an improved description and understanding of the climatology of the region;
- Initiate a program to provide improved real-time information for the forecasting of waves, currents, storm surges, ice and icebergs;
- Prepare for an oceanographic program in the Greenland Sea to measure the volume of deep cold water formed annually, as part of the assessment of the effects of polar oceans on global ocean dynamics;
- Improve communications between research scientists and client groups to ensure that the science program responds to client needs,
- Increase interdisciplinary research involving the private sector, universities, and other Branches and/or Regions;
- Establish stronger links between biogeochemistry research and habitat issues that are focussed on the interface between marine chemistry and biology;
- Review strategic plans for measuring and monitoring of contaminants that affect aquatic biota, especially those for which there are departmental management responsibilities;
- Continue an active program to transfer technology to the private sector from the activities in biological sampling, acoustics, Arctic sensor development and computer software systems;

- Undertake to develop an enhanced program of interdisciplinary research with the biological science programs in the Atlantic Zone Regions;
- Develop a strategy for maintaining climate data sets such as the long-term temperature monitoring program, for incorporating these data into archives and for distributing products to client groups; and
- Maintain an active program of consultation and interaction with client groups for projects funded under the Panel on Energy Research and Development (PERD).

C.S.L. Puffin is a new hydrographic survey launch; constructed of fibreglass, the semi-displacement, round bilge hull is capable of 20 knots full speed

Hydrography Branch

The Hydrography Branch is charged with carrying out hydrographic surveys and providing navigation charts for commercial navigation and fishing and for recreational boating. The area for which the Region is responsible extends from the Canada/USA border in the Gulf of Maine to the high Arctic and from the shoreline to the 200 mile limit or farther where the natural prolongation of the landmass extends beyond 200 miles.

In addition to navigation charts and other publications such as Tide and Current Tables, Sailing Directions and Small Craft Guides and similar publications for the mariner, Territorial Sea and Fishing Zone charts are produced under the hydrographic program. Under a cooperative program with the Atlantic Geoscience Centre (DEMR) data are gathered to produce offshore maps depicting the gravitational and magnetic fields as an offshore extension of the terrestrial mapping program. The Branch also carries out an extensive research and development program aimed at accelerating the survey and chart production program.

A sampling of the accomplishments of the Hydrography Branch in 1987 follows:

- One hydrographic survey party, consisting of six hydrographers and one Sailing Directions writer, was transferred to Newfoundland Region to survey from CSS *Maxwell* - also transferred to Newfoundland Region;
- A survey of Norwegian Bay, N.W.T. was carried out, with exceptionally favorable ice conditions permitting rapid progress on the survey;
- Surveys were conducted on the Scotian Shelf to upgrade survey data for the production of New Charts to meet the demands of the fishing industry and offshore oil and gas companies;
- The survey of the boundary waters of Passamaquoddy Bay and Grand Manan Island, New Brunswick was completed, as a cooperative program with The National Ocean Survey (USA);
- Eighteen ports in Atlantic Canada were electronically swept utilizing the sweep vessel *FCG Smith;*
- A large number of inshore and coastal surveys were carried out from survey launches and other small vessels in the waters of Prince Edward Island, New Brunswick, Nova Scotia and Newfoundland;
- Through commercial contract, thirty-eight field sheets were digitized as part of the preparation of a digital data base for the Region;
- Ten New Navigation Charts, twelve New Editions, eleven chart patches and eighty-four Notices to Mariners were produced;
- The permanent Tide Gauge Network in the Region was maintained and two gauges were converted to “Dial A Tide” operation.

Some of the goals for 1988 are:

- To ensure that corrected up-to-date charts, Sailing Directions and Small Craft Guides, Tide and Current Tables and related publications are available for vessels operating in eastern Canadian waters;
- To carry out revisory surveys to investigate reported dangers to navigation and to resurvey areas in need of resurvey because of cultural changes, siltation and changes in traffic patterns;
- In cooperation with the Atlantic Geoscience Centre of DEMR, to carry out multiparameter surveys in the offshore to address resource potential, particularly in areas of importance in terms of sovereignty and maritime delimitation;
- To carry out a mission-oriented hydrographic research and development program aimed at accelerating the survey program and the production of navigation charts. Areas of research include the implementation of computer assisted data collection and chart production, the preparation of digital data bases for hydrographic data, electronic chart development and the evaluation of deep-water multi-beam survey systems; and
- To supervise hydrographic surveys of six sites along the Labrador coast and eastern Arctic in preparation for radar installations.

Summary

The foregoing paragraphs do not describe all the work of the Science Sector, but are intended to indicate the diversity of the science program of Scotia-Fundy Region. The program ranges from mission oriented fundamental or basic research, to targetted basic research, to applied research, to the application of engineering and technology principles. The science program is intended to fulfill the research mandate of the Department and it's client base within the regional areas of interest, as well as to enhance ocean science knowledge on a global scale.

The Geological Survey of Canada Frontier Geoscience Program offshore eastern Canada

D.I. Ross

D.I. Ross

Introduction

THE Frontier Geoscience Program was established in June 1984 as part of the Geological Survey of Canada's program in the oil and gas frontier regions of Canada. The program is designed to substantially expand our knowledge of the earth in the frontier areas, i.e. the Arctic and offshore regions of Canada, from the base of the crustal layer through to the sediment/water interface. The emphasis is on gaining new knowledge to stimulate petroleum exploration and assist government regulatory bodies in policing these operations. The span of activities is wide, ranging from the design of new scientific projects, through new data collection to publication of results. The activities fully complement and build on other national geoscience programs. For example; the Lithoprobe Project, a national collaborative geoscientific research program to investigate fundamental questions concerning the nature and evolution of the lithosphere in Canada; the energy research and development projects, particularly Task 6 with its objective of improving the understanding of petroleum reservoirs and geological hazards faced in hydrocarbon developments; and of course the activities of the petroleum industry itself.

The program is divided into five tasks - an Arctic logistics task and four regional tasks: East Coast; West Coast; Arctic Islands; and Western Arctic. The regional tasks are sub-divided into components reflecting the major sedimentary basins. This paper summarizes the scientific studies being carried out by staff of the Atlantic Geoscience Centre, a Division of the Geological Survey of Canada at the Bedford Institute of Oceanography, under the East Coast Task and highlights the main scientific results obtained in the four years from 1984 to the end of 1987.

Scientific Extent of the East Coast Task

The East Coast Task is divided into six regional components, viz. Scotian Shelf and Margin, Grand Banks and Margins, Labrador Sea, Baffin Bay, Gulf of St. Lawrence, and Hudson Bay (Figure 1). The planning and scheduling of specific studies in these six regions is developed on the basis of the scientific questions that must be solved if we are to understand the history and evolution of the east coast region as a whole, as well as the potential for oil and gas discoveries. Program managers, guided by a Technical Advisory Committee representing industry, university and government bodies across Canada, have been particularly aware of the need to look at the framework of the sedimentary basins - the earth processes outside the basins themselves - in attempting to decipher the history of these basins. Thus the program looks at the frontier basins in the context of the continental lithosphere on the one hand, and the bounding ocean basins on the other, so that a complete synthesis will emerge. In this way the program builds on the detailed exploration studies of the petroleum industry, providing a framework within which industry's future exploration efforts can be focussed.

In each of the six regions, projects address three major scientific issues:

1. The deep structural controls which have played an important role in the development of the sedimentary basins;
2. The internal geology and evolution of the basins, and the process of generation, accumulation and preservation of hydrocarbons; and,
3. The physical properties of the seafloor and their potential effect on development of resources.

Deep Controls on the Development of the Sedimentary Basins

Deep seismic reflection and refraction studies, supplemented with potential field studies where appropriate, are used to decipher the deep structure of the boundary between the east coast continental landmass and the adjacent ocean basin. These studies have provided the controls for developing theoretical models of the sedimentary basins formed along this east coast continental margin. In the first three years of the program the emphasis has been on the Grand Banks and margins offshore Newfoundland, including the Gulf of St. Lawrence, for the following reasons:

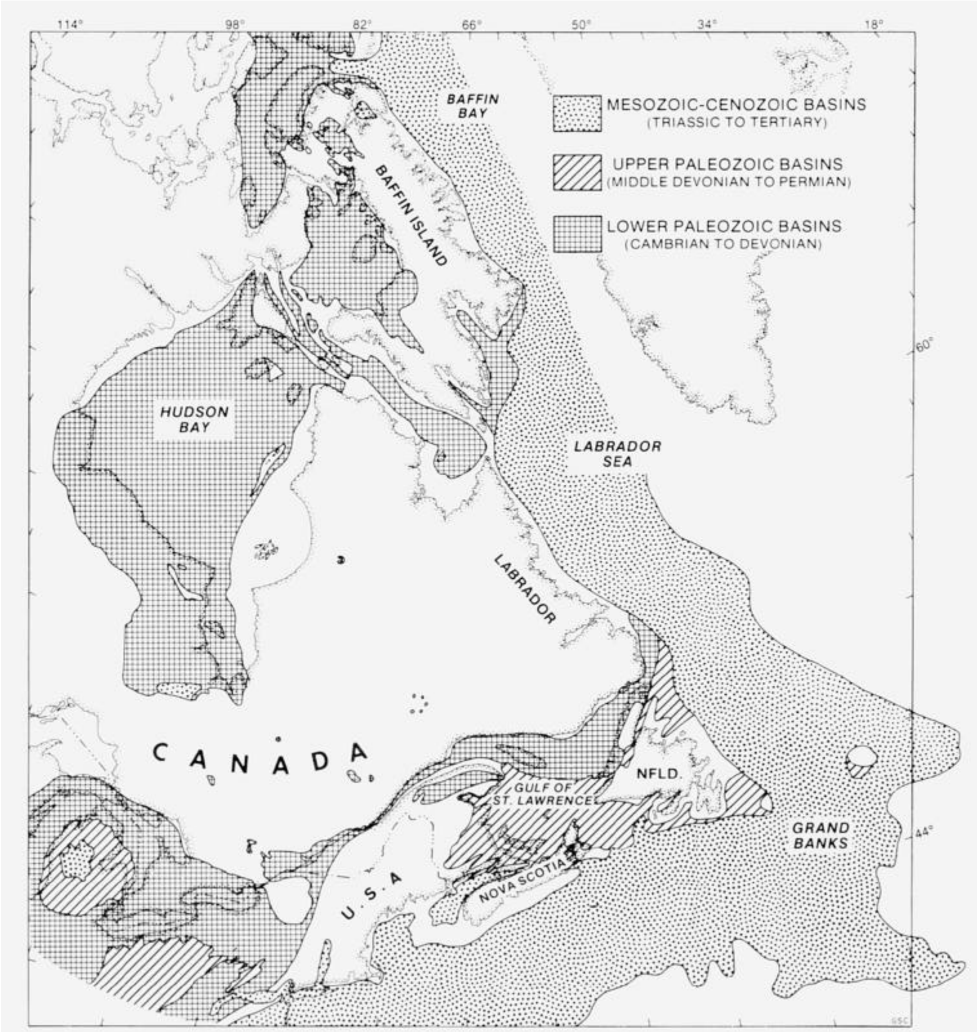


Fig. 1 Sedimentary basins of eastern Canada Separate Mesozoic - Cenozoic basins in the offshore are not identified

1. The Grand Banks of Newfoundland are bounded by a variety of types of margins formed through different geological processes - normally rifted, transform, and substantially stretched, as examples.
2. The eastern margin of the Banks has been separated from a substantial source of sediment, so that the nature of the ocean-continent transition can be studied without the hindrance of thick sediments.
3. The potential for hydrocarbons in several deep marginal sedimentary basins on the Banks is significant.
4. Newfoundland and the adjacent off-shore, is the primary location of the Lithoprobe East studies. This is an important component of the National Lithoprobe Program sponsored by the National Scientific and Engineering Research Council and the Department of Energy, Mines and Resources, with participants from industry, university and government laboratories.

In addition, the Gulf of St. Lawrence provides a water-covered window from which to study the Paleozoic basins of the Gulf of St. Lawrence and the tectonic development of the Appalachian system formed during an earlier closing of the Atlantic Ocean. These Paleozoic basins can then be compared with the Mesozoic-Cenozoic basins of the present passive margin formed during the early phases of seafloor spreading in the present Atlantic Ocean 100-200 million years ago.

A total of 4200 kms of deep seismic reflection data (20 second two-way travel time) has been obtained so far across the Appalachian terrains, the sedimentary basins of the Grand Banks, the Gulf of St. Lawrence, and the ocean margin of the eastern Grand Banks (Figure 2). While conventional exploration seismic data provides information on typically the upper 10-12 kilometres of the earth's crust, these data have imaged the crust all the way to the Moho, the boundary between the Earth's crust and mantle, 30 km and more below the surface of the earth. The results have provided important new insights into the deeper structure of the sedimentary basins which in turn has led to new models for the processes of development and the tectonic history of these basins and the potential for hydrocarbon resources that they may contain.

The Frontier Geoscience Program also provided an opportunity to develop and build ocean bottom seismometers (OBS). The OBS are deployed on the seafloor and record seismic events for refraction studies, providing information on the bulk nature of crustal layers and so complementing the reflection studies which map the depth and variations of interfaces between layers. The development, construction and maintenance of these OBS has been an excellent example of technology transfer between a government laboratory and the private sector. Originally designed by AGC staff, these units have been further developed by industry and are now maintained and operated very successfully for users in Canada and the United States, by a Halifax engineering company, Seastar Instruments Ltd.

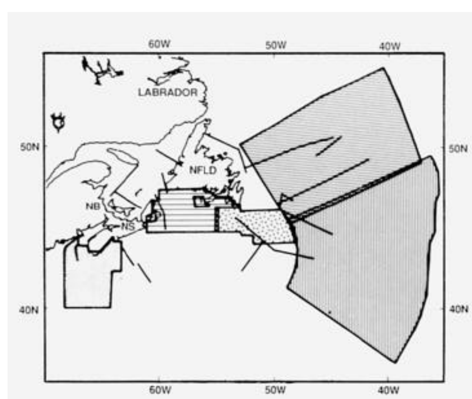


Fig. 2 Deep seismic reflection lines and aeromagnetic coverage of the Grand Banks and margins collected under the Frontier Geoscience Program.

The refraction data obtained with the OBS provide important information on acoustic velocity within the crustal layers not obtained from reflection work where the reflectors are deep.

The refraction data are used to confirm variations in structure on the deep layers of the crust and upper mantle, providing additional control for predicting appropriate geodynamic models. The successful use of the OBS off the east coast of Canada has resulted in considerable interest by the oil and gas industry in other parts of the world, providing the Atlantic Geoscience Centre with opportunities for joint projects in other sedimentary basin regions, and Seastar Instruments with an opportunity to market their services in a broader marketplace.

Potential field surveys (gravity and magnetic) provide the geophysicist with an opportunity to map changes in crustal structure over a broad area, starting from known geology onshore, well information or seismic information. Over the ocean basins, magnetic field data provide us with a chronology for the formation of the ocean crust. Airborne magnetic surveys provide coverage and a precision in data, not available with conventional shipborne surveys because of the difficulty in removing temporal variations in the earth's magnetic field which can be confused with crustal anomalies obtained from shipborne measurements. Three major aeromagnetic surveys of the Grand Banks and margins have been completed as part of the Frontier Geoscience Program. Together with earlier work in the region of St. Pierre Bank and the Laurentian Channel, these surveys complete the aeromagnetic coverage of the Grand Banks and margin (Figure 2). They are a superb data set. They provide accurate correlation of seafloor spreading anomalies and thus the timing of formaion of the ocean basins themselves, and so the basis for relating oceanic events to the development of the sedimentary basins. The data constrain the age and location of the ocean-continent boundary. They provide a correlation of geological structures between Nova Scotia and Newfoundland across the Cabot Strait. Work is continuing on the integrated interpretation of this aeromagnetic data with available seismic and gravity data across the major offshore sedimentary basins.

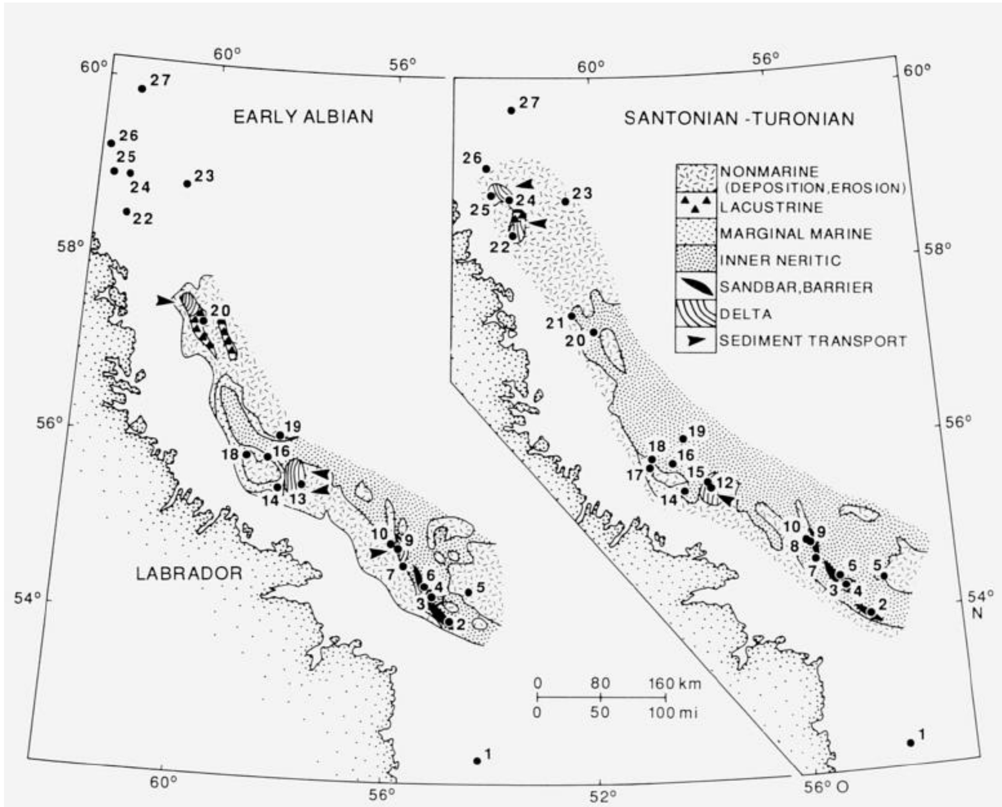


Fig. 3 An example of two of the paleo-environment maps produced for the Labrador Basin Atlas.

Internal Geology of Basins

Study of the internal geology, and generation and maturation of hydrocarbons in the sedimentary basins, is carried out primarily using industry seismic data and well information available to the Geological Survey through the offices of Canada Oil and Gas Lands Administration or the Offshore Petroleum Boards of Newfoundland and Nova Scotia. New work has concentrated on synthesizing data from the Grand Banks and Scotian Shelf. However, the first published synthesis which will appear will be of the Labrador Sea, in the form of an Atlas in early 1989. This atlas will consist of some 60 compiled maps and charts providing a composite of geophysical and geological knowledge of the Labrador shelf, margin and ocean basin (Figure 3). The Atlas will include a descriptive text for each map describing the data sources used and the basis for the interpretations included. A comprehensive bibliography will be included as a reference source to the subject content of each map and the atlas as a whole. Similar atlases for the Grand Banks and Scotian shelf and margins will be published late in 1989 with atlases for Hudson Bay and Gulf of St. Lawrence scheduled for late in 1990 and 1991 respectively.

A primary emphasis in the basin studies in all areas of the East Coast has been to complete the biostratigraphic and lithostratigraphic analyses of all key wells in the region, to tie these analyses to the seismic sections and establish a consistent stratigraphy for the region. (Stratigraphy is the study of the nature, distribution and relations of the stratified rocks of the earth's crust. *Biosfratigraphy* uses the correlation of fossils and *lithostratigraphy* uses the correlation of sedimentary sequences.) Organic geochemistry and maturation studies are being carried out on well samples and integrated with the other geological information. These studies provide key information on the nature and origin of source rocks as well as the potential total hydrocarbon generation. Combining this information with studies of the sedimentary sequences and their porosity to understand the migration of fluids in the rock sequences provides key information on accumulation and preservation of oil in the basin.

The occurence of overpressures, i.e. pressures at depth in the sediments that exceed the normal hydrostatic pressure, represent a potential hazard in exploration of an oil and gas field, sometimes resulting in an uncontrollable blowout. Understanding the cause of overpressures in a field also provides valuable information on reservoir characteristics and fluid flow at depth. Studies into the physical properties of overpressure in the area of the Venture field are being carried out as a complementary project sponsored by the Panel for Energy Research and Development. They are providing new insights into reservoir geology, fluid flow and the accumulation of hydrocarbons. This work is being extended away from the Venture Field throughout the Scotian Basin as part of the Frontier Geoscience Program and the results will be applied to studies on the Grand Banks.

Physical Properties of Seafloor Sediments

Studies of the physical properties of seafloor sediments and the potential effect they may have on the development of oil and gas resources are an important component of the program. Major site specific engineering studies must of course be undertaken by industry, and so the program stresses the importance of developing a well-founded regional framework for the understanding of processes affecting the properties of the seafloor sediments. Within this framework, the site specific studies essential for proper development of the resources can be assessed. In this respect the program echoes the recommendations of the Foundation Standards Committee, a joint committee of the Canadian Standards Association and the Canadian Petroleum Association, in emphasizing the requirement to establish both adequate site specific and regional geotechnical knowledge.

There are two main thrusts to this part of the program: a program of regional mapping of the unconsolidated sediments in the upper 100 metres below the seafloor using high resolution seismic and acoustic mapping systems and seabed sampling, and a program of core sampling using sophisticated coring and borehole drilling systems, supplemented where possible with in-situ geotechnical measurement techniques. Samples obtained from the coring program are carefully analyzed in a special physical properties research laboratory to study the properties and history of the sediments under varying geological conditions. Emphasis is placed on studies in areas of potential future production, specifically the Grand Banks and Scotian Shelf. However, we take the opportunity to collect high resolution seismic and acoustic data for surficial geological mapping whenever possible on field projects in other areas. As an example, the acquisition of additional seismic data in Hudson Bay to develop an improved understanding of the bedrock geology, provided an excellent opportunity to obtain at the same time, information on the glacial history and surficial sediments of the Bay.

Dissemination of Results from the Program

We believe that the results from the program are, and will be important. As one example, the deep crustal studies have already led to new ideas on the development of the marginal basins and the tectonic development of eastern Canada. The biostratigraphic studies completed under contract are tying the sedimentary history of much of the region together. We want to see that the customers, the potential users everywhere, get results as soon as possible - raw data immediately, and interpreted data and syntheses as soon as they have been completed.

As a result, we are publishing in a variety of ways. Raw data is being released in the GSC Open File system. Interpreted data are being released as Basin Atlases. Concepts are coming out in the scientific literature and orally in conferences and meetings.

Basin Atlases (Figure 3) are an important product of the program. These atlases will provide a synthesis of existing knowledge for each region in the form of working maps that can be updated as new information becomes available. This is a new concept of publication for the Geological Survey of Canada, and is aimed at providing a product that can be used by a wide audience of geoscience users for many purposes - from planning tools for exploration geologists to teaching tools in the universities. Maps within each Atlas will generally be at a scale of 1:2,000,000, but both larger and smaller scales will be used as appropriate to portray specific basin features or regional interpretations. Each map will be supplemented by a descriptive text summarizing the database used, the basis of interpretation and any inconsistencies or special features that require highlighting.

Conclusion

In its first four years, the Frontier Geoscience Program has already led to new understanding of the nature and timing of development of the sedimentary basins offshore eastern Canada. Compilation and syntheses of data are providing new insights into the geology and thermal history of the basins and will provide an updated regional framework for the evaluation of potential oil and gas resources. Quantitative studies of the geology and physical properties of the seafloor sediments are providing a basis for assessing appropriate production systems and will establish the regional basis for the site specific investigations required for designing environmentally safe production facilities. The Frontier Geoscience Program will continue to be the most important component of the Atlantic Geoscience Centre's scientific program for the next few years.

Georges Bank: A crossroads for seabirds

R.G.B.Brown

R.G.B. Brown

Table 1. The Seabirds of Georges Bank.

Species:	Scientific Name:	Origin:	Season:
Northern Fulmar	*Fulmarus glacialis*	Europe, Greenland	WI, SP.
Gory's Shearwater	*Calonectris diomedea*	Azores	SU.
Greater Shearwater	*Puffinus gravis*	Tristan da Cunha (Subantarctic)	SU, FA.
Sooty Shearwater	*Puffinus griseus*	Falkland Islands, Cape Horn	SU.
Manx Shearwater	*Puffinus puffinus*	Britain	SU.
Audubon's Shearwater	*Puffinus lherminieri*	Caribbean	SU.
Leach's Storm-Petrel	*Oceanodroma leucorhoa*	Atlantic Canada	SU.
Wilson's Storm-Petrel	*Oceanites oceanicus*	Antarctica, Cape Horn	SP, SU.
Northern Gannet	*Sula bassana*	Atlantic Canada	SP, FA.
Red Phalarope	*Phalaropus fulicarius*	Arctic Canada, Greenland	SP.
Great Skua	*Catharacta skua*	Europe	AY.
South Polar Skua	*Catharacta muccormicki*	Antarctica	SP, SU.
Black-legged Kittiwake	*Rissa tridactyla*	Europe, Arctic, Atlantic Canada	WI, SP
Great Black-backed Gull	*Lanus marinus*	Atlantic Canada, New England	AY.
Iceland Gull	*Larus glaucoides*	Arctic Canada, Greenland	WI, SP.
Razorbill	*Alca torda*	Atlantic Canada	WI, SP.
Common Murre	*Uria aalge*	Atlantic Canada	WI, SP.
Thick-billed Murre	*Uria lomvia*	Arctic Canada, Greenland	WI, SP.
Dovekie	*Alle alle*	Greenland	WI, SP

Note: "Season" is the period when the species is most abundant on Georges Bank: SP = Spring; SU = Summer; FA = Fall; WI = Winter; AY = All Year.

THE physical oceanography of Georges Bank is complicated. The shoal lies at the meeting place of two very different water-bodies. The cold, relatively fresh Nova Scotia Current, ultimately of Arctic origin, flows into the Gulf of Maine from the north, while the warm, salty Gulf Stream flows up from the south-west, along the outer edge of the Continental Shelf. The biological oceanography of the Bank reflects this combination of cold and warmth, through the mixture of subarctic and subtropical species in the zooplankton - small shrimp, young fish and other animals - up to fish, squid and seabirds.

This is particularly true of the seabirds. None of them breed on Georges Bank, of course - there's no land for them to nest on - but large numbers of non-breeders migrate here to feed. So many, that the Bank is an ornithological crossroads: a feeding ground for birds from the whole of the Atlantic Ocean, and the Arctic and Antarctic as well. The commonest seabirds in winter are Fulmars, miniature albatrosses from Europe and Greenland. In summer they are Greater Shearwaters, also albatross relatives, escaping from the rigours of the Subantarctic winter. Only the Great Black-backed Gulls are local birds. Table 1 lists these, and some of the other visitors to the Bank.

These seabirds are not randomly distributed. As you might expect, migrants prefer parts of the Bank with oceanographic characteristics broadly similar to those in their home seas. Audubon's Shearwaters, from the Caribbean, are commonest on the southern edge of Georges, where the warm Gulf Stream has a strong influence. Their preference is probably for the warm-water fish and zooplankton on which they feed, rather than for temperature as such. Greater Shearwaters, on the other hand, are usually commonest on the northern and eastern parts of the Bank, where the cool Nova Scotia Current is dominant. While they are up here, Greaters are also abundant in other productive, cool areas, such as the fishing banks off Newfoundland and West Greenland. When they move south again in September, they go directly, probably non-stop, across the tropics to their colony islands in the comparable cool zone in the South Atlantic Ocean. They fly from 45°N to 40°S over 9,000 km, without really changing their preferred feeding habitat.

Red Phalaropes show another kind of selectivity. They are unusual birds: swimming shorebirds, in which the females are the larger, brighter, and dominant sex. They spend their summers in the Arctic, and winter off west Africa; we see them on Georges as they migrate north in the spring. They feed by picking at individual items of prey, close to the surface - mosquito larvae in tundra pools, and zooplankton out at sea. If this technique is to work efficiently, the phalaropes have to seek out patches where the zooplankton is 10-100 times more abundant than the average density. These patches form at the boundaries between different water-bodies: specifically, where the cold Nova Scotia Current sinks beneath the warm Gulf Stream. Zooplankton is relatively buoyant and so, instead of sinking, it is trapped at the surface. The boundary between these currents, along the southern edge of Georges Bank, is marked by a long line of zooplankton - and, in spring, by enormous flocks of feeding phalaropes as well.

The other influence on the distribution of seabirds is, of course, ourselves. We weren't always benevolent. A century ago, at the peak of the handline fishery, the fishermen on Georges and other fishing banks regularly caught shearwaters as bait - and to get a taste of fresh meat. (Discriminating gourmets preferred Sooties to Greaters.) But things are very different today. Instead, we provide a gargantuan feast of trash fish, scraps and offal, spilling from the factory trawlers that work over the Bank. Some seabirds - Red Phalaropes, Razorbills - are too specialised in their feeding habits to exploit this bonanza. But the blizzard of Fulmars, Greater Shearwaters, Gannets, Kittiwakes and Great Black-backed Gulls behind every dragger is proof that the specialists are in the minority.

This exploitation has several long-term implications. It undoubtedly increases seabirds' chances of surviving through the winter, when food is scarcest; this is particularly true for juvenile birds. But do we really need more large gulls? Their population explosion in the last 40 years has already turned them into a menace to the other seabirds that breed along the coasts of New England and Atlantic Canada. And what will happen if, to feed our own expanding species, we overexploit the fishery? This is becoming more and more of a possibility, as we shift our aim from traditional food species such as cod and haddock, to an industrial fishery for smelt and other small fish that can be ground down into fish-meal to feed our cattle and chickens. The next stage may well be a fishery for the larger zooplankton. The difficulty is that these small-fry are at the base of the food-web of all the higher marine predators on Georges Bank. Zooplankton feed small fish, which feed larger fish, which feed seabirds and whales. If we take away too much of the zooplankton and small-fry at the bottom, the whole marine community may collapse - and Georges Bank, now so rich, will become a desert. We had better be very careful.

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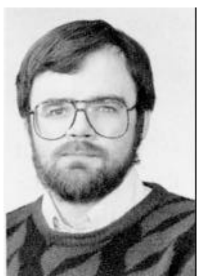
Georges Bank - Research behind the management of habitat and commercial resources

D.C. Gordon Jr., J.D. Neilson, and G. Robert

D. C. Gordon



J.D. Neilson

G. Robert

Introduction

FISH stocks and their habitat are managed with the long term goal of maintaining their health and abundance. This article briefly summarizes some of the research currently underway in the Scotia-Fundy Region in support of resource and habitat management on Georges Bank. Georges Bank is a large and shallow submarine bank located on the outer continental shelf along the southern side of the Gulf of Maine (Figure 1). Its rich fishery resources have long been exploited by Canadian and American fishermen. The October 1984 International Court of Justice (ICJ) decision granted the northeast portion to Canada. However, while Canada won exclusive rights to significant fishery resources, the transboundary nature of many of these stocks remain which gives rise to special problems concerning both research and management.

Primary production by phytoplankton on Georges Bank is very high because of near optimum conditions of light and nutrients. It is one of the most productive fishing banks in the North Atlantic (O'Reilly and Busch, 1984) and supports a diverse food web which includes both planktonic and benthic organisms and culminates in abundant finfish (cod, haddock, herring, etc.) and invertebrate (scallop, lobster, etc.) fishery resources. The landed value of Canadian fisheries from Georges Bank in 1986 was $63 million.

Apart from the special circumstances surrounding the IJC decision, the environment of Georges Bank is rather unique. Its physical features are dominated by very strong currents which are generated by large volumes of water moving into and out of the Gulf of Maine and the Bay of Fundy in response to the tidal forces. These currents promote vertical mixing of the water. During the winter, most of the water over the Bank is well-mixed from top to bottom, while during the summer solar heating produces stratification in water deeper than about 60 m. The boundary between the well-mixed and stratified areas is marked by a seasonal tidal front. The strong currents also help generate a clockwise rotation or gyre over the Bank which takes approximately 40-90 days to complete one revolution (Figure 1). However, this gyre is not a closed system and water is continually added to and lost from the Bank by radial exchange processes all times of the year. Because of strong tidal currents and storm-generated waves, sediments on the Bank tend to be coarse, primarily sand and gravel. Georges Bank has not always been a marine environment. During the last glacial period when sea level was about 100 m lower, most of it was exposed and populated by terrestrial organisms.

Management Issues

As Georges Bank includes waters under the jurisdiction of both Canada and the United States, the transboundary fish stocks located there are exploited by both nations, thus complicating their management. Finfish stocks of major significance to Canada with historical landings in excess of 1000 tonnes per year include Atlantic cod *(Gadus morhua)*, haddock *(Melanogrammus aeglefinus)*, pollock *(Pollachius virens)* and herring *(Clupea harengus)*. Recent nominal landings are shown in Figure 2. The exact causes for the fluctuations observed are not understood but both physical and biological factors are thought

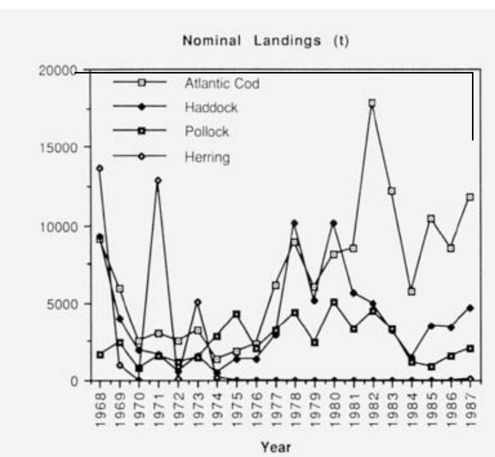


Fig. 2. Nominal Canadian landings of major finfish resources from Georges Bank between 1968 and 1987.

to be important. Other fisheries include yellowtail flounder *(Limanda ferruginea)*, cusk *(Brosme frosme)* and Atlantic halibut *(Hippoglossus hippoglossus)*.

Overfishing is the central management issue. For example, recent stock abundance

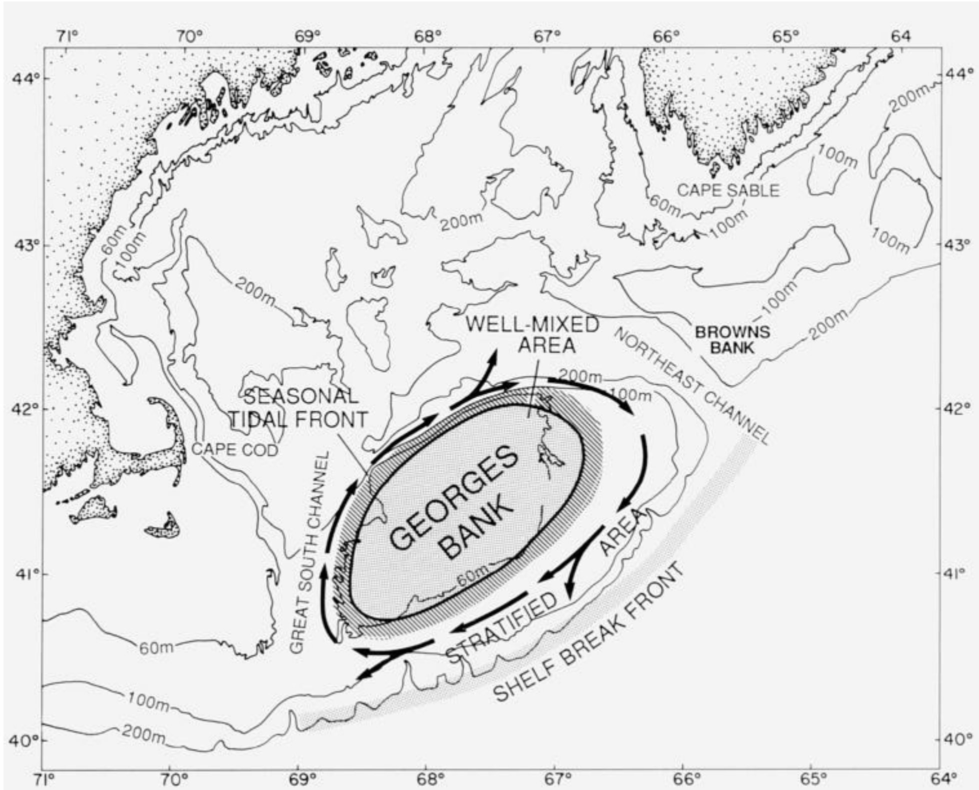


Fig. 1. Map of Georges Bank showing bathymetry, the Canadian-US international boundary and major physical oceanographic features during summer. Arrows indicate the approximate direction of average residual currents.

estimates for Georges Bank haddock are amongst the lowest observed since 1963 (Gavaris, 1987). In recent years, the haddock stock has been exploited at about twice the level recommended by scientists and recruitment has been variable, but generally poor. For Atlantic cod, abundance has shown a steady decline from 95,000 tonnes in 1978 to 34,000 tonnes in 1986. The current recommended exploitation level is less than 15,000 tonnes per year (Hunt, 1987). In the case of haddock and probably cod, limitation of fishing mortalities to acceptable levels will require joint management by both Canadian and US authorities.

A multinational fishery for herring on Georges Bank began in 1961 and yielded 2.7 million tonnes before crashing in 1977 after a classic “boom and bust” pattern brought about by overfishing. For several years, there was virtually no sign of a population that had once been estimated at 1.14 million tonnes in total biomass. The loss was felt not only in the collapse of the large fishery on adults but also in the decrease of the coastal weir fihery for juvenile herring (sardines) in Maine and New Brunswick which is assumed to have been partially dependent on emigrants from Georges Bank. Recently there have been signs of recovery of Georges Bank herring, including the occurrence of spawning and of larvae in both 1986 and 1987 (Stephenson et al., 1987). Management issues regarding this stock again focus on the need for consistent regulatory measures on both sides of the international boundary and improved understanding of the relationship between herring populations on the Bank and along the coast.

The most valuable invertebrate fishery on Georges Bank is the sea scallop *(Placopecten magellanicus)*. A management plan, developed in consultation with the fishing industry, ensures the conservation and prudent management of this resource while providing reasonable access for fishermen. In 1987, over 55,000 tonnes were caught with a landed value of approximately $60 million. As a management measure meat counts, which regulate the size of scallops harvested, have not only proven to be a useful conservation measure but they have also allowed better use of different age groups of scallops. The industry has endorsed a Total Allowable Catch (TAC) Enterprise Allocation (EA) regime to promote some stability in landing patterns. Both measures are contributing to a gradual restocking of the scallop beds. Under this regime, not only is there an upper limit to the quantities fished, but the allocation of allowable catches to the fishing enterprises involved assures them of a certain level of landings and removes the competition element (e.g. too many boats chasing too few scallops). Some fluctuations in TAC's will occur because of the great variability in the abundance of the scallop age groups available to the fishery in any one year. Biological advice on the health of the fish stocks is a key element in assisting industry in its efforts to achieve the optimal use of annual yields and available age groups. The EA program also provides the incentive to reduce the harvesting capacity through fleet streamlining by downsizing and lessening of over capitalization to improve economic stability.

Another valuable invertebrate resource exploited on Georges Bank is the lobster *(Homarus americanus)*, although at a smaller scale. Once again, the ultimate goals of resource management are conservation and increased economic benefits to the lobster industry. Since 1985, this stock has also been managed by a TAC divided into EA's. A major management issue which remains unresolved is the relationship between inshore and offshore lobster stocks.

Now that the ownership question is settled, a new management issue to arise on the Canadian sector of Georges Bank is hydrocarbon exploration and potential development. Texaco Canada Resources Ltd. proposes to drill two exploratory wells in Canadian territory near the northeast peak (ref. to Figure 1). Other wells could follow.

The management of hydrocarbon activities off Nova Scotia will be the responsibility of a joint federal-provincial board established under the new Canada-Nova Scotia Accord but DFO will continue to supply advice and information. Many studies of the environmental impacts of offshore hydrocarbon exploration and development have been conducted around the world. The results available so far suggest that in most instances the impacts are restricted to a relatively small zone around a rig. Less is known about recovery after sites are abandoned. DFO has recommended that further studies specific to Georges Bank be undertaken to help resolve present uncertainties regarding hydrocarbon activities in this important fishing area. Eight exploratory wells were recently drilled on the US sector of Georges Bank without known environmental impact. The potential environmental impacts of a production platform, however, are greater. While not objecting to hydrocarbon activities in other continental shelf regions off eastern Canada, the fishing industry has strongly opposed exploratory drilling on Georges Bank, as it also has in the US. This issue has temporarily been set aside with the announcement of a 12 year ban on drilling. Nevertheless, the need for information to help resolve this issue at a technical level remains. Some environmental impacts could be transboundary depending on the exact location of drill sites and therefore, as with fisheries, joint management programs between Canada and the US are needed.

Research Programs

A large number of applied and basic research programs in support of resource management have been conducted or are currently underway on Georges Bank by DFO. While Georges Bank is relatively well known compared to other offshore areas, there remain important information gaps.

For example, more detailed studies of water mixing and turbulence are being made across the seasonal tidal front along the northern edge of the Bank. It is not yet clear whether this front serves as a boundary or allows the net transport of water and associated plankton (including larvae) off the Bank. Whether this front is an area of convergence or divergence for water and associated organisms, which is important in predicting the fate of contaminants, is also not known.

Studies of phytoplankton productivity are designed to determine why Georges Bank is so productive. The reasons appear to be closely linked to physical processes, especially in the vicinity of tidal fronts. Feeding studies, particularly with scallops, are aimed at obtaining a greater understanding of the relationship between phytoplankton productivity and potential fish harvest. Chemical studies have established the background levels of hydrocarbons on Georges Bank. Surprisingly high concentrations of low molecular weight hydrocarbons in surficial sediments suggest that natural seepage is common.

Research on Georges Bank fishery stocks, both vertebrate and invertebrate, has included all stages of life history. Research in support of stock assessment typically deals with adults and includes annual surveys of abundance and distribution using DFO vessels. Sampling is conducted on a depth-stratified random basis to allow unbiased estimates of stock abundance. Estimates are then compared with other indices of abundance such as catch-per-unit effort statistics from the commercial fishery during the stock assessment process.

One particularly interesting aspect of fisheries ecology has been the discovery of a higher growth rate for cod and haddock on Georges Bank compared with neighbouring stocks, such as those on Browns Bank. By age 3, haddock from Georges Bank are 1.3 kg on average whereas those from Browns Bank average less than 0.9 kg. For cod, the difference is even more pronounced with respective values of 2.8 and 1.4 kg. A program under planning will examine whether such differences are caused by environmental or genetic factors. The mechanisms causing the variation in growth rate have significant implications for both the management of wild stocks and aquaculture.

Research programs are also evaluating the factors that influence the survival of the larval and juvenile stages of gadids. A multidisciplinary program currently underway will examine the implications of the seasonal tidal front on Georges Bank on the growth and distribution of fish larvae. One of the objectives is to determine the physiological condition of larvae across the front with respect to the distribution of their food supply. It has been hypothesized that high concentrations of plankton in the frontal area, upon which larvae feed, will produce healthier larvae more likely to survive than in mixed or stratified waters on either side of the front.

It has been surmised that most mortality affecting year-class strength occurs before larvae metamorphosize into juveniles. It remains unresolved whether surveys of abundance of pelagic post-metamorphosis juveniles or those conducted later in the year when juveniles have adopted a demersal life give more accurate indicators of year-class size. Research has examined the pelagic stage of life and factors which influence the position of fish in the water column. In a study of diel vertical distributions and trophic interactions of juvenile cod and haddock in mixed and stratified waters on Georges Bank, Perry and Neilson (in press) found substantial differences in the average position of haddock and cod in the water column. At a well-mixed site where food organisms were plentiful, the vertical distributions overlapped. However, at a stratified site where food organisms were relatively scarce, the distributions were more discrete (Figure 3). This suggests that the position of juvenile gadids in the water column is influenced by the interaction of several environmental factors including temperature, food supply and currents.

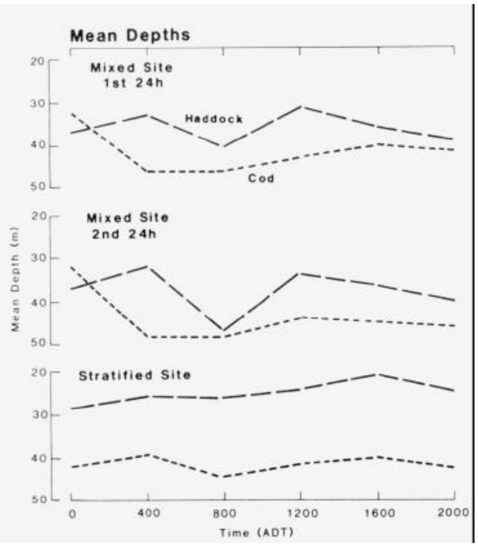


Fig. 3. Mean depth of occurrence of age-0 cod and haddock at mixed and stratified waters on Georges Bank during June 1985.

Research on Georges Bank herring has focused on the question of whether the recent resurgence is based on a remnant of the original stock or colonization by a neighbouring population. A comparison of racial attributes including morphometric, meristic, parasite, enzyme, and mt-DNA features has been completed (Stephenson and Kornfield, in press). The results indicate that the recovery is due to a resurgence of the remnant stock and not colonization by a neighbouring population.

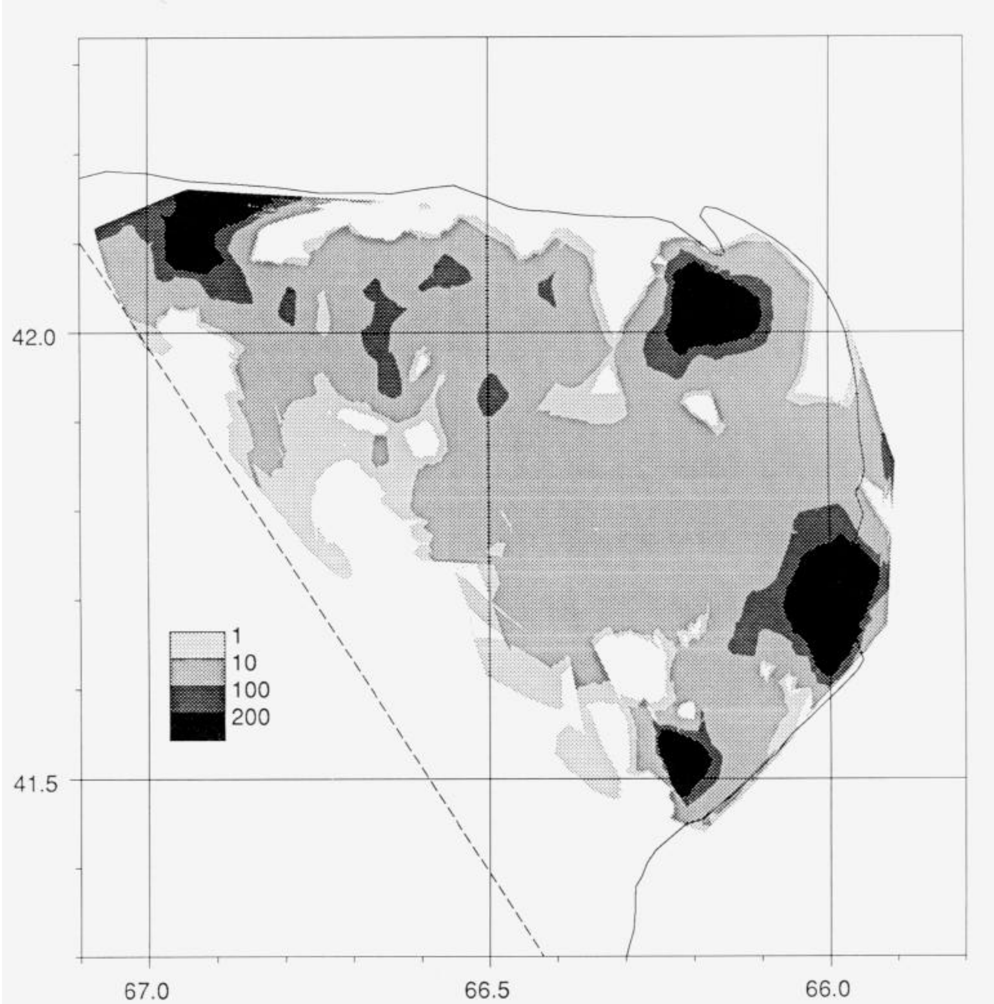


Fig. 4. Patchy distribution of a scallop year class of commercial size as identified during the 1987 Georges Bank stock survey. The increasing levels of shading correspond to the density of scallops as number of animals per standard tow. The dashed line is the ICJ boundary. The smooth line represents the 100 m isobath.

Conventional fishery research models developed for finfish management do not always apply directly to invertebrate stocks. The deep-sea scallop is non-mobile at commercial sizes and has a fast growth rate for the ages fished. Important variations occur in the annual recruitment and the stock distribution is patchy (hence the name scallop beds) (Figure 4). The fishery is targeting specific scallop beds to enhance catch rates and achieve blending of quantities of small scallop meats with fewer large meats.

To derive stock abundance estimates, improved methodologies of research survey design and analytical assessment are being investigated (Robert and Jamieson, 1986; Mohn, 1986). In addition, biological characteristics of the stock such as growth, natural mortality, and meat yield are studied to contribute to the basic understanding of the stock dynamics.

Biological investigations of larval scallop distribution on Georges Bank are in progress to establish larval geographic patterns, abundance, and variability. Preliminary results based on larval scallop length frequency data indicate that there is no substantial exchange between Georges Bank and the Scotian Shelf.

To understand the lobster population structure in the Browns Bank/Georges Bank area, extensive tagging studies are being conducted. The movement of tagged lobsters shows patterns of seasonal migrations between relatively shallow banks and the deeper water of basins and canyons (Pezzack and Duggan, 1986). Growth rate is another variable estimated from the tagging studies.

An on-going long-term project is looking at the relationship between inshore and offshore lobster stocks in Southwest Nova Scotia. The study focuses on the recruitment processes of the lobster stocks and obtaining a better understanding of the lobster larval ecology in the highly dynamic Georges Bank ecosystem.

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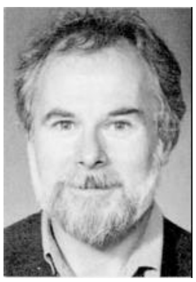
Lobster research - Back to the basics

J.D. Pringle and A. Campbell



J.D. Pringle

A. Campbell

THE American lobster *(Homarus americanus)* fishery is one of the most valuable of the many fisheries in the northwestern Atlantic (Cooper and Uzmann 1980). The 1987/88 Scotia-Fundy Region (Figure 1) yield was worth $140 million to 3,000 licensed vessels. A decade ago however, a number of the Maritime lobster stocks were deemed collapsed (annual yields were about 5% of peak yields), including those in Scotia-Fundy Region's Lobster Fishery Areas (LFA) 29-33 (Figure 1) (Robinson 1979). A detailed review of the American lobster fishery concluded that the reduced catch rates were due to growth (less than optimum yield per animal harvested) and recruitment (insufficient reproductive females) overharvesting (Dow 1980) - a conclusion reached by Robinson (1979) for a portion of the Canadian fishery. Dow (1980) noted, however, that inadequate biological knowledge existed to permit sound resource management.

Pringle (1986a) suggested that the structure of resource management agencies can influence the quality of the resource management carried out. An example is the Department of Fisheries and Oceans' science and resource management structure, pre-1980, which consisted of rather disparate groups, each with their own advice on any particular topic. The response from these groups that followed the collapse of the eastern Nova Scotia lobster fishery is illustrative of the effect of organizational structure.

Four somewhat different hypotheses by four individual Departmental scientists from four separate groups attempted to explain the collapse. Neither the fishery manager, nor the industry knew who to listen to. Dadswell (1979) suggested that the Canso Causeway interrupted larval movement to eastern Nova Scotia from the southern Gulf of St. Lawrence. Harding et al. (1983) supported this interpretation, but went on to suggest that oceanic temperatures of the Scotian Shelf were generally too cold to permit significant larval maturation except, possibly, during warm-water years. Anomalous warm-water years was suggested as the cause of the periodic peaks in lobster abundance. Robinson (1979), in contrast, felt that recruitment overharvesting (too few female lobsters, hence too few eggs) was responsible for this lobster catch decline. Earlier, Mann and Breen (1972) had suggested overfishing, but concluded that the long term reduction in lobster densities was due to habitat degradation.

A similar number of hypotheses had been constructed by both government and non-government scientists to explain the relationship between inshore and offshore lobster stocks in the Gulf of Maine. Industry puzzled at the lack of coherence between scientists. Their consternation and frustration was particularly evident in 1982/83 during an attempt to implement Canadian Atlantic Fisheries Scientific Advisory Committee advice, which advocated an increase in the minimum legal size of lobsters in LFAs 34, 37, and 38 (Figure 1). Fishermen were shocked at our lack of understanding of basic lobster ecology. They refused to advocate minimum legal lobster length changes until we could answer certain basic questions, including adult movement and stock interactions.

The direction for future lobster research over the next few years was obvious (Pringle et al. 1983). No management action could take place without a better understanding of at least the natural history and population biology of lobster. Given the value of the lobster fishery, Larkin's (1980) advice should be heeded: understand well, the biology of the commercially important species.

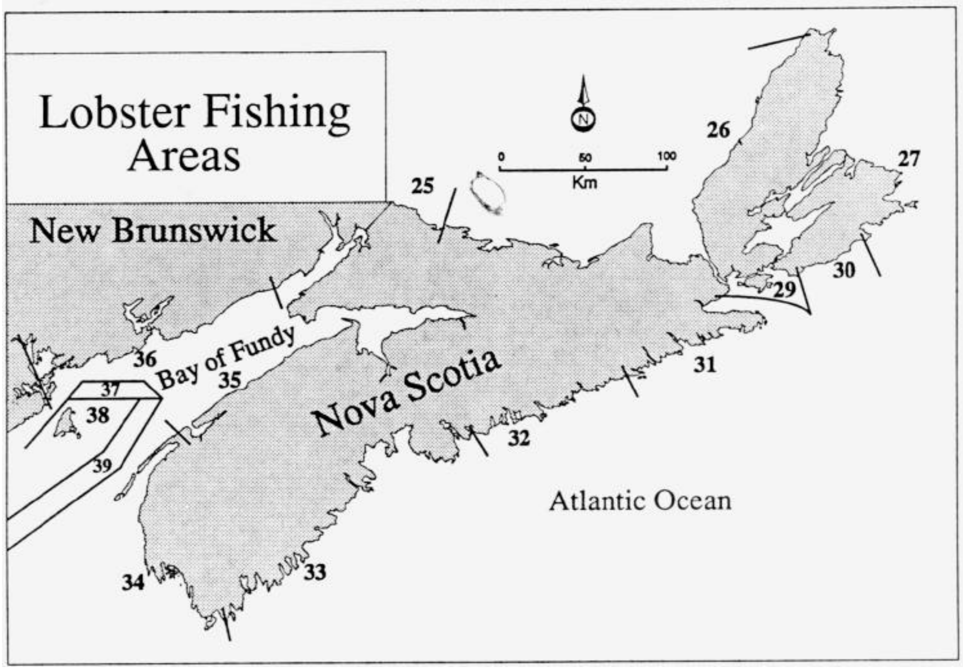


Fig. 1. Lobster fishing areas in Scotia-Fundy Region.

Lobster Larvae

Female lobster size at reproductive maturity (size at which successful mating can take place) varies with water temperature. Once a lobster attains this size it molts (sheds its shell and increases in size), mates, and develops a new shell. The eggs are retained, first inside the female (about one year) and then outside (site of incubation - about ten months). The eggs hatch and release larvae (tiny lobsters which initially do not resemble the adult lobster) in late spring/ early summer.

The larvae are planktonic (live in the water column not on the ocean bottom) and must molt three times prior to settling on the ocean bottom. They undergo marked changes in appearance between Stages I and IV (stage IV animals are identical in appearance to the adult). It was believed for a century that lobster larvae remained in the extreme surface waters (neuston upper few cm of water) and thus were strongly influenced by wind and surface currents. Hence Huntsman (1923) suggested, ". . . that the planktonic larval stage is the limiting factor (that stage which dictates future lobster numbers) for successful lobster recruitment [survival] in cooler waters . . ." Templeman (1936) supported this hypothesis when he discovered in culture that at 12°C, larvae molt after approximately 10 days to Stage II, approximately 21 days to Stage III, approximately 38 days to Stage IV, and after 56 days to Stage "V". Harding et al. (1983) hypothesized for the Scotian Shelf that the summer surface water temperatures are too cool and the zooplankton (animals that are carried by the currents) too large to allow large survivorship of larvae. They speculated that the warm bays of eastern Nova Scotia play a significant role in egg hatching and larval survival.

A lobster larval ecology study of St. Margarets Bay and its approaches was initiated in 1982, and replicated for 1983 and 1984. Sampling of the larvae, the planktonic community, and physical (eg. currents) and chemical (eg. salt concentration) oceanographic factors were carried out weekly from mid-June through September. Stage I larvae were most abundant in June (approximately 2,300 per square kilometer) and least abundant in September (approximately 100 per square kilometer). Stage IV larvae were not observed in June; they peaked in abundance in September (approximately 300 per square kilometer). Few Stages II and III larvae were captured. There appears to be somewhat more larvae inside the Bay (approximately 1,200 per square kilometer) than outside the Bay (approximately 900 per square kilometer), but Stage IVs appear more abundant outside.

Harding et al. (1983) hypothesized that the bulk of the larvae that occur in the cool waters of the Bay of Fundy and southwestern Nova Scotia, are produced on the northeastern face of Georges Bank. A mid-July (1983) cruise was carried out to: 1) assess the distribution of larvae in the Gulf of Maine by sampling a grid of stations between southwestern Nova Scotia middle grounds and Georges Bank, and 2) to assess the relationship between oceanic discontinuities (where patches of water are separated by currents of various types) and larval abundances. Few larvae were discovered on the northern half of the grid. Larvae were more abundant at the northwestern edge (heavily mixed waters) of Georges Bank and appeared to demonstrate a diurnal periodicity (they occurred in the neuston at night only) in stratified waters westward of Georges Bank.

A modified Tucker trawl (Figure 2) was designed and constructed by Biologist W.P. Vass, which permitted towing at depth. Cruises on Georges and Browns Banks in 1984, 1986, and 1987 have supported our hypothesis that the larvae are not neustonic. We have shown a stage-specific,

Fig. 2. Tucker trawl net, designed to capture lobster larvae.

daily vertical distribution (Harding et al. 1987). We now know for the first time where to capture each stage and have, for the first time, adequate techniques to capture them in large numbers.

The larval field studies are being supported with laboratory studies by Research Scientist R.W. Elner. A complex apparatus necessary to study larval behavior was designed and constructed. Studies on movement in relation to light and locomotor rhythm are underway. Graduate student B. MacKenzie (1988) assessed the influence of temperature 10°C to 22°C) on development rates and stage-specific mortalities of larvae from females raised in cold (Bay of Fundy) and warm (Northumberland Strait) summer waters. Growth rates peaked at 15°C and 18°C respectively. Temperature had little affect on stage-specific survival of larval Stages I and II, but survival of Stages III and IV was significantly reduced among lobsters reared at 10°C versus those raised at higher temperatures.

Fig. 3. Population densities of juvenile lobsters (too small for fishery) are estimated by SCUBA divers or by use of this recently developed trap.

Juvenile Lobsters

There is a need to improve our understanding of the biology and ecology of juvenile lobsters, and learn how abiotic and biotic factors influence prerecruit (animals smaller than the minimum legal size) abundance. The long-term goal is to forecast future lobster abundance (recruitment) in the lobster fishery in support of resource management. Surprisingly little information is available on juvenile lobster biology, perhaps because they are cryptic, hiding under rocks and in mud tunnels. Small juveniles do not normally enter commercial traps; and although larger juveniles (50-80 mm CL) do, many can escape between the lathe spaces designed to retain recruit-sized lobsters (greater than or equal to 81 mm CL). Recent field experiments have been directed at developing sampling methodology for juveniles. Visual searching using SCUBA diving along transects, and within corrals, was used to estimate population densities. Data on growth and movement of juveniles were accumulated using a newly developed miniaturized sphyrion tag (Bernstein and Campbell 1983). A trap was recently developed to retain juveniles (40-80 mm CL) and exclude larger lobsters (Figure 3). It should be a useful and practical tool in making standardized prerecruit lobster abundance indices a routine procedure. The diet of juvenile lobsters was shown to be reduced in the winter compared to the summer months (Elner and Campbell 1987). Juveniles were found to be active, foraging for food at night, within or close to their shelters (Lawton 1987).

Adult Migration

Recent tagging studies indicate that mature lobsters move considerably farther than immature ones, and that long-distance movement (greater than 100 km) allows some interchange of lobsters between the Bay of Fundy, Gulf of Maine, and the adjoining continental shelf (Campbell and Stasko 1985; 1986; Campbell 1986). Many mature lobsters also make seasonal migrations into shallow, warm water during summer-fall, and into deeper water during winter-spring. Many return to the location of tagging, which may involve an annual round-trip movement of 10-400 km, depending on bottom topography (Campbell and Stasko 1986; Campbell 1986; Pezzack and Duggan 1986). These apparently temperature-dependent seasonal migrations can explain some of the long- and short-distance movements of lobsters that have been recorded (Campbell and Stasko 1986). Although some lobsters may return to the same location year after year, about 10-20% of tagged mature lobsters move to other areas. Over many years, there is probably a mixing of mature lobsters throughout the continental shelf area.

For *H. americanus*, seasonal depth migrations are correlated with highest local ambient temperatures. Higher temperatures give the lobster the overall temperature requirement necessary (degree-days) for molting, growth, gonad development, egg extrusion (Cooper and Uzmann 1980), and egg development (Campbell 1986). Berried females hatching eggs in relatively warm, shallow coastal or bank waters may confer a survival advantage on the larvae by decreasing development time to attain the benthic stage (bottom dwelling stage) (Huntsman 1923; Caddy 1979).

Seasonal migrations by mature lobsters have several implications for lobster fishery management in this area. The movements complicate both our ability to discern the location of brood stock and estimate its size. The movement of mature lobsters to shallow water during summer, when the fishing season is closed, protects these lobsters from exploitation. However, as mature females tend to move to deeper water earlier in the fall than do mature males, the males are more vulnerable to the early fall fishery in the Bay of Fundy (Campbell and Stasko 1986).

Lobster Habitat

Little is known about marine community and ecosystem ecology. With regard to lobsters, we do not know its total physical habitat requirements, nor the flora and fauna necessary for healthy stocks. K.H. Mann (then Senior Scientist, Marine Ecology Laboratory) undertook in the mid 1960’s, a most necessary study of the food chain leading to the lobster. The work was begun in St. Margarets Bay, Halifax County, in the mid-1960’s. Seaweed biomass was high, and an early prognostication suggested ample food for lobster (Miller and Mann 1973). Nevertheless, Mann and Breen (1972) felt that there was sufficient evidence to hypothesize lobsters as the major predator of sea urchins. Dr. Mann warned fishery managers that ecosystems can take only so much abuse. He inferred that the transformation of eastern Nova Scotia's near shore waters, from a lush seaweed association to "barren grounds" (in essence, bare rock and sea urchins), was due to a decline in lobster densities. He noted that this was a non-cyclic phenomenon (Mann 1977); urchin densities would remain sufficiently high to prevent seaweed recolonization. He then speculated that lobsters require seaweeds. The overall conclusion was that we were dealing with a non-cyclic phenomenon. Seaweed would not increase in abundance until urchin densities (no. per unit area of bottom) declined dramatically, the latter would not happen unless lobster numbers increased; given the fishing pressure, it was unlikely that lobster densities would increase.

R.J. Miller designed an experimental field study which would assess the value of seaweed to commercially important, near-shore species such as lobster (Miller 1985). He recorded in the course of this study, the death, by disease, of large numbers of urchins along the Halifax County coastline in 1981 (Miller and Colodey 1983). The disease could infect and kill the host in 10 days. By 1983, urchins along most of Nova Scotia's eastern and southern shores had succumbed to the disease. Approximately 300,000 t of sea urchins died. Seaweed recolonized the barren grounds (Miller 1985). Urchins, however, are making a comeback. It should be noted that lobster densities have increased, but this phenomenon is not completely coincidental with the increase in seaweed abundance and the demise of the sea urchins. Modelling techniques have been employed to describe the system (Mohn and Miller 1987). We have concluded that this disease is sufficient to control sea urchin densities and that a large environmental factor, such as Gulf of St. Lawrence discharge, may be responsible for the instability of the lobster/kelp community along eastern Nova Scotia (Pringle 1986b).

R.J. Miller has surveyed the entire coastline using transects and "spot dive" techniques (Moore et al. 1986). The seaweed recovery and the attendant faunal assemblages are being monitored.

It is obvious that further study of the lobster and its habitat is required before we will understand the major causes of interannual fluctuations in lobster densities. As in the past few years, the research team will require not only lobster biologists, but those skilled in biological and physical oceanographic techniques. Good science, however, does not always translate into good resource management (Pringle 1985). It is imperative, in Canada's resource management system, that the Department of Fisheries and Oceans strive for credibility with the primary and secondary sectors of the industry. Only then can good science become good resource management.

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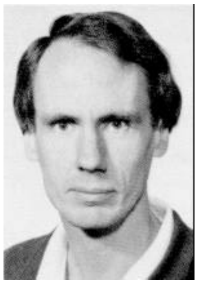
A history of chemical oceanographic research in the Gulf of St. Lawrence

P.M. Strain



P.M. Strain

THIS article will outline a few aspects of the history of chemical oceanography in the Gulf of St. Lawrence, the St. Lawrence Estuary, and the Saguenay Fjord (Figure l), showing how advances in several different areas of science have led to an improved understanding of the behaviour of chemicals in the Gulf of St. Lawrence system. These advances have included the improvement of analytical chemical methods, developments in oceanographic sampling techniques, and the improved design of field programs that concentrated sampling effort on the locations most important to the behaviour of each chemical. At the same time, physical oceanographers have provided estimates of water flows into and out of the Gulf of St. Lawrence that have been used to calculate the amounts of chemicals moving through the Gulf.

Organic Matter Geochemistry

Organic matter, which is composed mostly of carbon, is the material that makes up the soft tissues of plants and animals. It is an important chemical component in both fresh and salt water. As organic matter decomposes, dissolved oxygen is consumed and acid is produced - these chemical reactions cause important changes in the chemical conditions experienced by other chemicals. In addition, chemicals such as some toxic metals are adsorbed by organic matter and will be deposited in bottom sediments at the same locations. Organic matter exists as particles suspended in the water, dissolved in the water, and incorporated in bottom sediments.

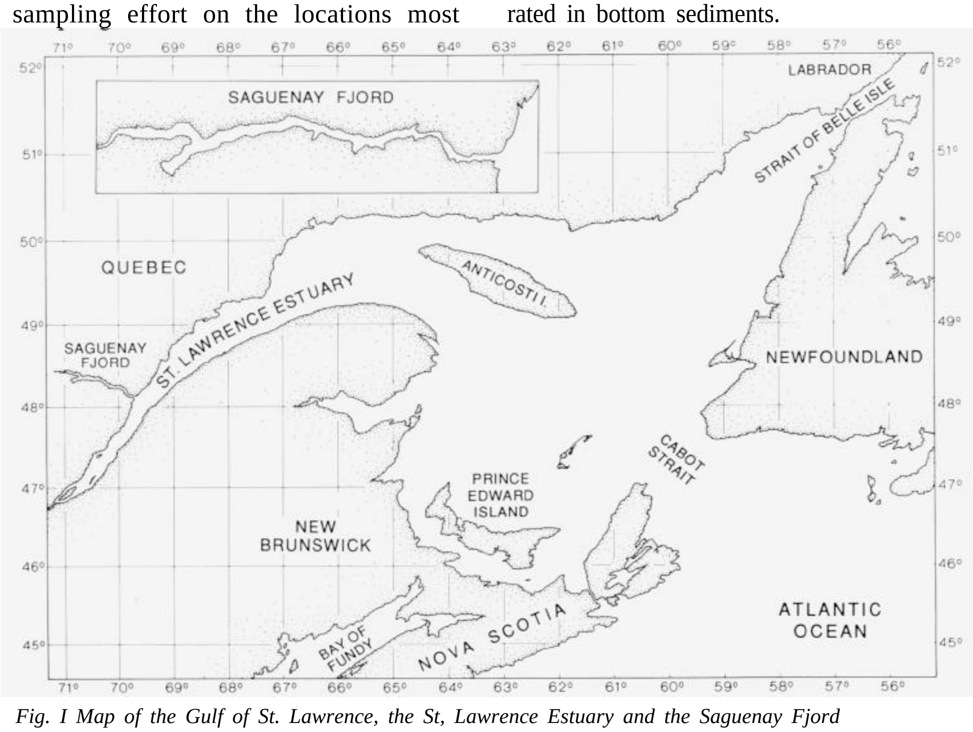


Fig. I Map of the Gulf of St. Lawrence, the St, Lawrence Estuary and the Saguenay Fjord

The carbon isotope study of organic matter provides a good example of how advances in oceanography require advances in chemical methods. Carbon, like most elements, has more than one naturally occurring non-radioactive isotope - carbon-12 and carbon-13. There are very small, but measurable differences in the $^{13}C/^{12}C$ ratio in carbon from different sources - e.g. the amount of ^{13}C in land plants is less than that in phytoplankton growing in the St. Lawrence Estuary. A technique for the measurement of carbon isotope ratios in the organic matter in sediments was developed for use at BIO. A study of carbon isotopes in surface sediments of the St. Lawrence Estuary and the Gulf has shown that the organic matter that comes into the Gulf in the St. Lawrence River discharge at Quebec City is found in sediments only in the St. Lawrence Estuary. The results of this study, while interesting, were limited. They made it obvious that an improved understanding of organic matter behaviour in the Gulf would be possible only if isotope measurements were available on additional types of organic matter. Accordingly, the analytical methods were improved so that the much smaller samples available for suspended particulate matter and the organic matter sampled by plankton tows could also be analyzed. These developments made it possible to conduct an integrated field program to examine the behaviour of organic matter in much more detail. At the same time, other evidence was increasingly showing that many important chemical changes occur in estuaries, where the most active mixing of fresh and salt water occurs. Therefore, field work was focussed on the St. Lawrence Estuary.

The study of organic matter also illustrates how an increasing understanding of both these estuarine processes and of the physical dynamics of the system led to further advances in the geochemistry. The isotope study of sedimentary carbon had concluded that essentially all of the organic matter in upper St. Lawrence Estuary sediments was from terrestrial sources. Another study, which measured the concentrations of organic matter and the ratios of carbon to nitrogen in the organic matter, challenged this conclusion on the basis of the sedimentary carbon/nitrogen ratios. These researchers calculated that terrestrial material accounted only for 3-50% of the organic material.

The resolution of this controversy became one of the goals of a project designed to monitor the organic carbon in the St. Lawrence River discharge. Twice monthly samples were collected from the River for more than four years. The results of this combined study, which measured both carbon isotope and carbon/nitrogen ratios, showed that there are pronounced seasonal variations in both sources and quantity of the organic matter in the River. Through most of the year, terrestrial matter dominates the river input, but there are important contributions from organic matter produced in the river at some times of year. The organic matter in upper Estuary sediments is mostly terrestrial material. These results made an important contribution to an understanding of the fluxes of organic carbon into the Gulf. The design of this program reflected an increasing awareness that careful measurements of the chemical inputs to estuaries is essential to the understanding of geochemical cycles in nearshore waters.

Trace Metal Geochemistry

The study of trace metals in estuaries has undergone radical changes in the last 20 years. These changes include advances in analytical methods for measuring trace metals in both dissolved and particulate phases and the development of sample collection, storage and preservation techniques necessary to avoid the contamination of samples. Because the concentrations of many trace metals are very low in seawater, it is difficult to collect a sample whose metal concentrations have not been significantly changed by airborne metal particles from the research ship, by exposure to metal components of the sampling equipment or even by exposure to plastics whose manufacture requires the use of metal compounds.

Trace metal geochemists at BIO were among the first to recognize the importance of estuarine processes in controlling fluxes of trace metals across the continental shelves to the deep ocean. As in the organic carbon studies, this recognition led to a concentration of effort on the St. Lawrence Estuary and the Saguenay Fjord and to the detailed description of river inputs and their seasonal cycles. Furthermore, these workers realized that the Gulf system, with its restricted connections with the Atlantic and the large distances between its principal inlets and outlets, could serve as an excellent setting in which to measure the transports of materials through the coastal zone into the open ocean. At about the same time, calculations of water fluxes through Cabot Strait became available. Chemical oceanographers combined this physical oceanographic information with their chemical expertise to construct a global model predicting the residence times of trace metals in the world’s oceans. Similar approaches have also been used in the construction of budgets for organic matter, nutrients, and suspended matter for the Gulf of St. Lawrence. Geochemical budgets compare the inputs of a chemical to an area like the Gulf of St. Lawrence with its outputs. If the inputs to an area exceed the outputs, there must be processes active within the region that cause the loss; conversely, if outputs exceed inputs, processes with the region must be producing the chemical.

Mercury Pollution in the Saguenay Fjord

The history of studies on mercury pollution in the Saguenay Fjord provides both an example of how basic research is important in the resolution of environmental problems and an illustration of how advances in a number of fields may be required to reach correct answers. As part of a study on the trace metals in the sediments of the Gulf system, abnormally high levels of mercury in the sediments of the Saguenay Fjord were discovered. An examination of the distribution of mercury in the region suggested that a chlor-alkali plant on the Saguenay River was the source of most of this pollution.

An increasing awareness that a number of Canadian water bodies were contaminated with mercury led to government regulations on discharges from chlor-alkali plants in 1971. Post-regulation concerns included questions of whether industry was complying with the discharge regulations and how quickly and to what extent affected water systems might recover. A budget was developed for mercury inputs which predicted that the water in the Saguenay system would recover from the mercury pollution in as short a period as two years, whereas Saguenay sediments would require much longer periods to be free of contamination. The balancing of this budget required a surprisingly large flux of mercury through the Saguenay in 1973, two years after the regulations were imposed. This result suggested either that industry had not complied with the discharge limits or that mercury was being re-released from sediments contaminated prior to 1971.

Concurrent with this work, another group at BIO was actively investigating the history of sediment deposition in the Saguenay Fjord. Once again analytical method development was an important part of this program. Lead-210 is a naturally occurring radioactive isotope of lead that is produced in the atmosphere, from which it is scavenged and transported into freshwater and coastal sediments. It was first realized in the early 1970’s that lead-210 could be used to date sediment cores from some coastal environments. It was further realized that the sediments at the head of the Saguenay Fjord were ideal for this technique. Simultaneous determination of the age of sediments and the mercury concentration in sediment cores showed that the mercury contamination began at the same time as the start-up of the chlor-alkali plant, and that mercury inputs to the sediments decreased dramatically at the depth in the cores deposited in 1971. These results were consistent with industry complying with government regulations. This and later work showed that the high mercury fluxes in the budget for 1973 were due to remobilization of mercury from sediments in the Saguenay River that had been accumulated prior to 1971.

Petroleum Hydrocarbon Geochemistry

A number of major oil spills which occurred in the late 1960’s and early 1970’s, including the grounding of the

Arrow in Chedabucto Bay, N.S., showed the necessity of having information available on the background concentrations of oil in the environment to properly assess the impact of such accidents. Unlike almost every other measurement carried out by the Chemical Oceanography Division at BIO, the methods for determining the concentration of the dissolved/dispersed fraction of petroleum in seawater have remained the same since the first Gulf survey was carried out in 1970. Therefore, the oil measurements made in the Gulf over the period 1970-1979 represent the only direct measurements on the history of pollution inputs to the Gulf.

Analysis of this data (Levy 1985) has shown that the most important source of petroleum for the Gulf of St. Lawrence is the open Atlantic (large amounts of water flow through Cabot Strait into the Gulf from the Atlantic Ocean). Background concentrations in the Gulf declined through the 1970's, presumably due to regulations restricting discharges of oil from ships on the high seas. These conclusions, however, are reached at the limit of the precision of the data. Further advances in understanding might have to wait for new developments in analytical methods.

Where to from Here?

Does this analysis of the relationships between sampling and analytical methods, geochemical expertise, and physical oceanography say anything about the way future efforts should be directed in chemical oceanography in the Gulf of St. Lawrence? A consideration of recent developments in these fields might indicate where advances in chemical oceanography in the Gulf of St. Lawrence might come next, although the problems most ripe for solution may not be the ones of highest priority.

A number of analytical methods have either been significantly improved or made available for the first time since the BIO field work in the Gulf was conducted. Advances in gas chromatography, for example, have led to much greater reliability and lower detection limits in the determination of chlorinated environmental pollutants such as DDT and the PCB's. New studies on these compounds would have a better chance at understanding their fate in the marine environment than earlier studies which could only detect these materials at a few contaminated sites. Other chlorinated organic compounds (e.g. camphenes and dioxins) have become of environmental concern in recent years. Analytical methods for their determination may be sufficiently well developed to allow examination of selected samples in potentially contaminated locales.

Just as the growth of agricultural crops is limited by the availability of nutrients such as nitrogen and phosphorus in soil, plankton growth in the sea is limited by the availability of nutrients. In the Gulf, the availability of nitrogen (most often found in the form of the nitrogen compound, nitrate) is thought to be the limiting factor. It is now apparent that a full understanding of the marine cycling of nitrogen must include consideration of ammonia as well as simple nitrogen-containing organic compounds such as urea. Methods for ammonia, albeit painstaking ones, have been available for some time, but have yet to be applied to the Gulf in a large scale program. Reliable analytical methods for organic nitrogen compounds require further work.

Recent evidence suggests that colloids may be important in the geochemistry of both trace organic and trace inorganic constituents. Colloids are very small particles that cannot be trapped by normal filters and which do not settle to the bottom. Some studies of metal-organic interactions in colloids are available, but both better methods and more field-based research is required to understand the importance of this phase in areas like the St. Lawrence Estuary. Sampling colloids is technically very difficult, but the recent application of high volume filtration techniques developed in medical research to the separation of the colloidal phase in seawater shows promise.

It is also now recognized that further advances in understanding the geochemistry of both natural and man-made organic materials requires the study of individual classes or individual organic compounds. Selecting the important compound types from the bewildering suite of organic chemicals that make up marine organic matter will not be simple, but may be the only way to gain additional insights into important geochemical processes.

Understanding the nature of the variability of chemical concentrations in coastal environments would be an important advance in the chemical oceanography of regions like the Gulf of St. Lawrence. Current chemical models of the Gulf consider seasonal variability in a very simple way - data may not even be available for all seasons. Almost no information is available on other scales of variability in the Gulf. Are there important multi-year cycles or long term trends? Are there very rapid changes associated with daily or tidal cycles that could significantly alter our view of the important processes controlling chemical distributions? The answers to such questions would have important practical applications. For example, it would be necessary to know the natural variability of a trace metal distribution in order to determine whether concentrations were being altered by an industrial discharge - i.e. is an increase in concentration due to natural variability or indicative of increasing pollution?

Another direction that new work should take results from recent physical oceanographic studies of the Gulf. They suggest that the dynamics of the Gulf are potentially quite different from the descriptions that have been used as bases for chemical models in the past. Water flows into the Gulf through the Strait of Belle Isle may be much larger than previously believed. Such flows could transport chemicals into the Gulf. They also may make it necessary to re-determine the water flows through Cabot Strait, which were calculated assuming that no water exchange occurs through the Strait of Belle Isle. Previous chemical oceanographic models on the Gulf should be reexamined in view of these recent developments in physical oceanography. Existing data may not be adequate to evaluate the importance of the area near the Strait of Belle Isle to the chemical oceanography of the entire Gulf system. Due to previous ideas on its importance, its relative isolation and its long period of ice cover, it has received comparatively little attention on chemical oceanographic cruises. Additional sampling in the Strait of Belle Isle, and along the north shore of the Gulf where inflow would be most intense, may be required. Cooperative work with physical oceanographers may be required to develop improved chemical models for the Gulf of St. Lawrence.

The Canadian Atlantic Storms Program (CASP)

C. Anderson

*C. **Anderson***

The origin of winter storms.

THE winter weather most Canadians experience living halfway between the equator and the North Pole is due largely to the interaction between two air masses - the cold polar air mass, and the warmer subtropical air mass. The irregular boundary between these two air masses, called the polar front, circles the earth between 30 and 60 degrees north latitude (Figure 1). Our stormy weather is caused by atmospheric disturbances that develop and move from west to east along the front. These storms are characterized by low atmospheric pressure, a counter-clockwise wind pattern, and precipitation.

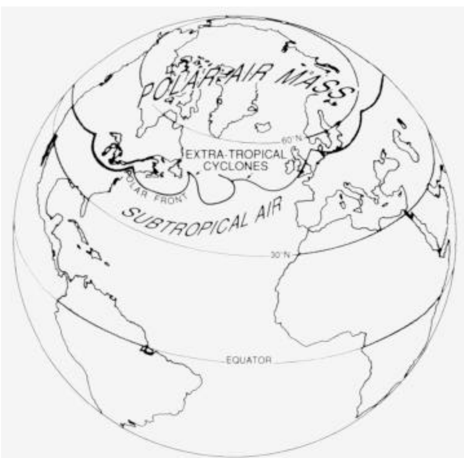


Fig. 1 The irregular boundary between the cold north polar air mass and the warmer subtropical air mass, called the polar front, circles the earth between 30 and 60 degrees north latitude. Atmospheric disturbances develop on the front and move from west to east.

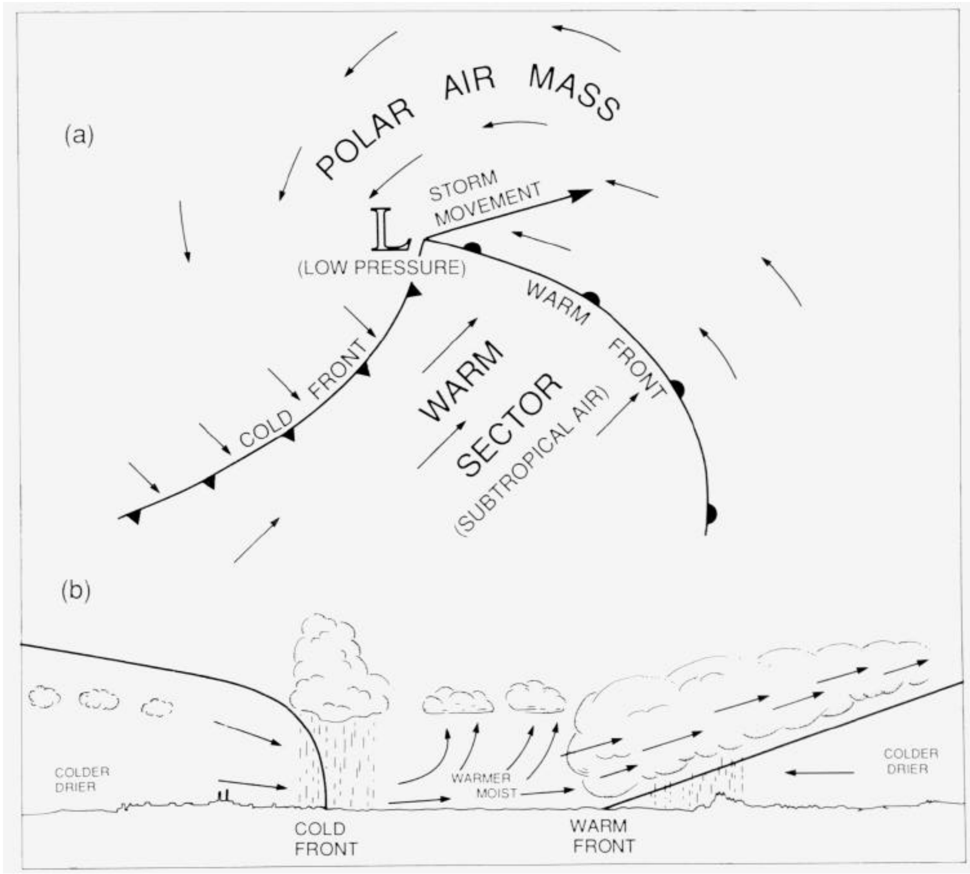


Fig. 2 (a) As a subtropical cyclone develops, a wedge of warm subtropical air (the warm sector) gradual& penetrates poleward into the colder polar air mass. As the storm develops, low air pressure develops at its centre, and the wind increases in intensity. The wind circulates around the developing low pressure zone in a roughly circular pattern (b) Precipitation occurs along the warm and cold fronts bounding the warm sector, as warm moist air is forced upward over colder, drier air. Behind the warm front, warm air rises gradual&, producing steady, light to moderate precipitation At the cold front, moist air is forced rapidly aloft, resulting in heavier precipitation of shorter duration.

The first complete description of the formation and growth of storms outside the tropical latitudes was given in the early 1920's by Norwegian meteorologists. Using surface observations of atmospheric pressure, air temperature, clouds, and precipitation, they described the growth of small atmospheric disturbances in which a wedge of warm subtropical air gradually penetrates poleward into the colder polar air mass (Figure 2). As the storm develops, the air pressure at its centre drops, and the winds increase in intensity. The wind circulates around the developing low pressure zone in a roughly circular pattern, giving these storms their name - "extra-tropical cyclonic storms."

The water vapor carried by the warm air is the source of the rain or snow that accompanies storms. Precipitation occurs along the warm and cold fronts bounding the warm sector, as warm moist air is forced upward over colder, drier air. Behind the warm front, warm air rises gradually, producing steady, light to moderate precipitation. At the cold front, moist air is forced rapidly aloft, resulting in heavier precipitation of shorter duration. The precipitation begins high above the ground as ice crystals, but it reaches the earth as rain, freezing rain, hail, or snow depending on the temperature of the air through which it falls.

The Norwegian model of extra-tropical cyclonic storms, formulated more than half a century ago, is still used by meteorologists to describe the large-scale features of storms. The weather maps carried by North American newspapers and television show them as low pressure systems, typically 1000 km in size, with their warm fronts, cold fronts, and precipitation zones, much as originally described by the Norwegian meteorologists.

More recent research has shown that small-scale features also exist within storms. These features were not described by earlier investigators who relied on widely-spaced weather observers on the ground. Modern research tools, such as weather radar and sensitive instruments carried into the atmosphere by balloons and aircraft, have revealed that within storms there are cells and bands of intense precipitation only 10-50 km wide. The wind patterns, when viewed in detail, are much more complex than implied by the large-scale Norwegian model. Narrow zones of high winds are found along the warm and cold fronts. These small-scale storm features may have devastating effects in terms of property damage and loss of life, but cannot be predicted using present-day weather observing and forecasting methods.

The effects of storms on the ocean.
The ocean responds readily to atmospheric conditions at its surface (Figure 3). Wind blowing over the sea generates waves on its surface, from ripples less than a centimeter high, to storm-driven waves that can reach more than 15 m in height. The force of the wind also causes motion in the water below the sea surface. The large-scale general circulation of the oceans is maintained by the long-term average pattern of wind over the whole globe. Storm winds, however, generate locally-intense currents which may be several times stronger than the average wind-driven current.

Fluctuations in sea level are also caused by the surface wind, and by atmospheric pressure over the ocean. Near coasts, storm-driven currents may transport water either toward or away from the land, causing extraordinary sea level changes during and after storms. The low atmospheric pressure at the centre of storms allows water to be forced in from the surrounding region of higher air pressure, producing a rise in sea level. The sea surface movement associated with storms, known as “storm surge,” each year causes thousands of deaths around the world as surges flood low-lying coastal areas.

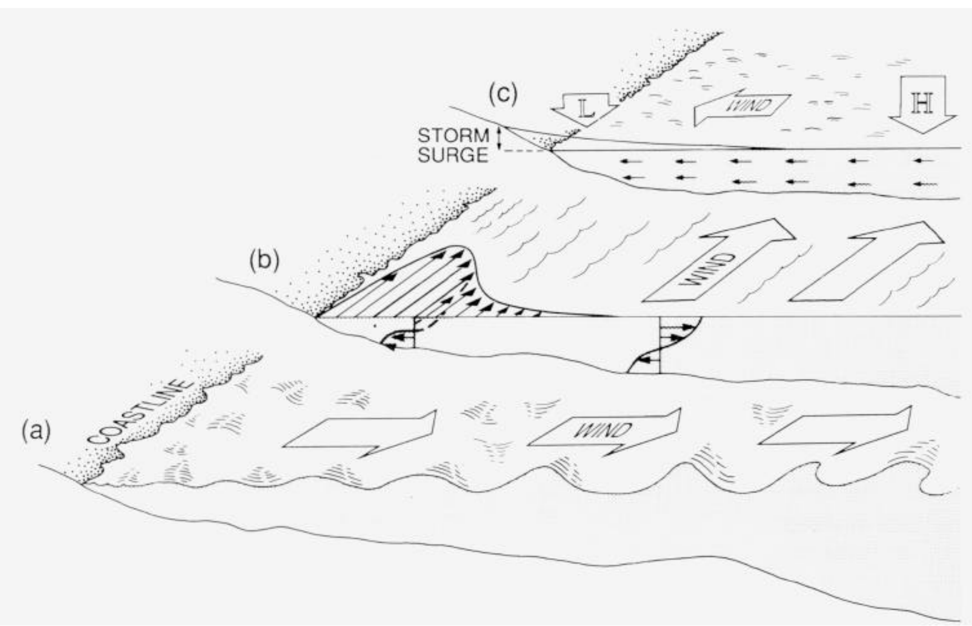


Fig. 3 The ocean responds readily to atmospheric conditions at its surface. (a) Wind blowing over the sea generates surface waves, which grow in proportion to the wind speed and the time and distance over which it blows. (b) The force of the wind also causes complex motions in the water below the sea surface. (c) Near coasts, storm-driven currents can transport water toward the land causing sea level to rise during and after the storm (storm surge). The low atmospheric pressure (L) at the centre of storms allows water to be forced in from the surrounding region of high air pressure (H), contributing to storm surge.

The importance of storm forecasting.
A thorough understanding of storms and their effects on the ocean is of value for several reasons. Accurate weather forecasting obviously benefits everyone whose activities are affected or controlled by the weather. In addition to the general public, this includes, for example, those involved with public safety, agriculture, transportation and construction. On Canada’s coasts, reliable forecasts of the weather and sea conditions are important to the safety of thousands of fishermen and workers on offshore drilling rigs.

Extremes in the weather and the associated sea conditions also determine the design of marine structures such as wharves, breakwaters, ships, and drill rigs. Civil engineers and naval architects therefore need to know the levels of extreme weather that are likely to occur, and the surface waves, currents, and sea levels that would result from those extremes. Studies of the what would have occured under a given set of circumstances are known as “hindcasts.”

Computer models of the atmosphere and ocean are used to make forecasts and hindcasts. A computer model is a set of mathematical statements of the physical laws that govern the motion and heating of the atmosphere and ocean, and, in the case of the atmosphere, the formation of clouds and precipitation. The computer applies the laws to a known starting state (defined by observations) and predicts the state for a short time later. This process is repeated for a large collection of points in the atmosphere or ocean, and for a large number of time steps totalling up to several days. The accuracy of such computer models is limited because the governing laws are not fully understood, and by the speed and size of available computers. Advances in understanding the laws of physics and in computer technology are being made continually, but much remains to be accomplished.

The Canadian Atlantic Storms Program. In 1984, Canadian meteorologists and oceanographers began a co-operative research program to learn more about winter storms over the Maritime provinces, and their effects on the adjacent ocean. The program, known as the Canadian Atlantic Storms Program (CASP), called for making intensive measurements in the atmosphere and ocean during a four-month period in the winter of 1985-86. The measurements would then be analysed and used to improve theoretical and computer models of storms and the storm response of the ocean.

Meteorologists from the Atmospheric Environment Service (AES) of Environment Canada, and oceanographers from the Bedford Institute of Oceanography (BIO) in the Department of Fisheries and Oceans have combined their efforts to obtain a detailed description of east coast Canadian winter storms and their effects on the ocean. One of the goals of the meteorologists is to improve the accuracy of their winter storm forecasts, particularly of the small-scale extremes of precipitation and wind within the storms.

The BIO oceanographers are also interested in forecasting. They are developing computer models that use wind forecasts produced by AES to predict the ocean waves, currents, and sea levels that result from storms. Present-day computer models of the ocean surface predict the height and length of surface waves (the “sea state”) over large areas of the ocean up to several days in advance. However, as in short-term weather forecasting, much can be done to improve the accuracy of these forecasts. In the future, similar forecasts of ocean currents and storm surges are expected to be possible for important regions of Canada’s coastal oceans.

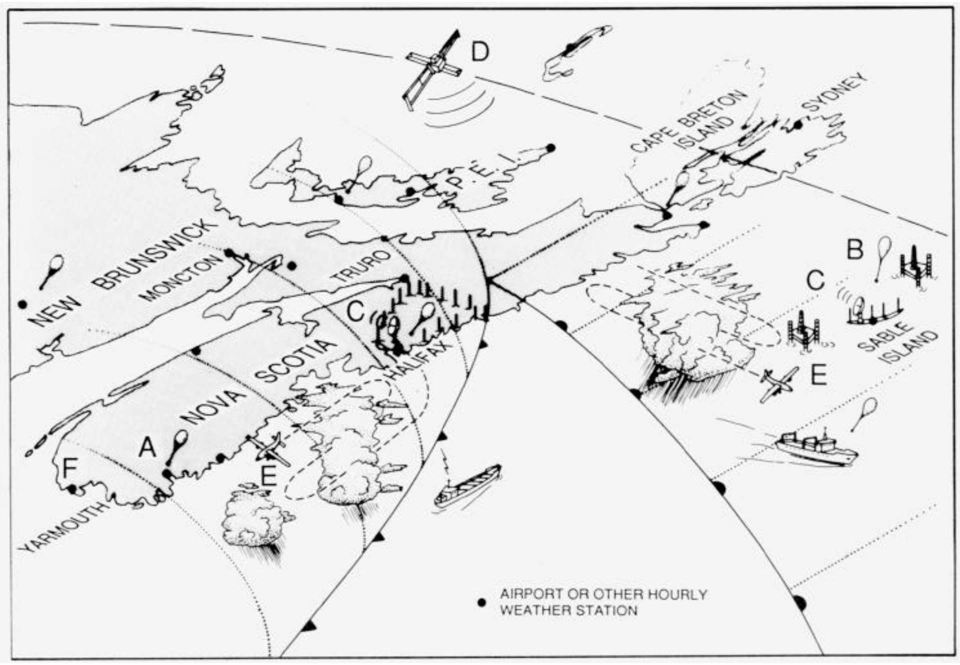


Fig. 4 CASP meteorologists used a variety of methods to observe storms. Balloons were sent aloft at frequent intervals from land and ship stations (A and B) to record how temperature, humidity, pressure, and wind varied with height above the surface. Weather radars (C) and satellites (D) were used to observe precipitation and cloud patterns. Research aircraft (E) were flown through the storms to make closely-spaced measurements of wind, temperature, humidity, pressure, and precipitation at different altitudes. Hourly weather observations are made routinely at airports in the region (F).

The CASP field program

To observe the details of storms, the CASP meteorologists used a network of observers and automatic instruments on land and at sea in the Maritimes and Newfoundland to record surface pressure, temperature, wind, and precipitation. Balloons were sent aloft at frequent intervals from land and ship stations to record how temperature, humidity, pressure, and wind varied with with height above the surface. (See Figure 4.) Weather radars and satellites were used to observe precipitation and cloud patterns. Research aircraft were flown through the storms as they moved through the Maritimes to make closely-spaced measurements of wind, temperature, humidity, pressure, and precipitation at different altitudes.

The BIO oceanographers directed their attention to the Scotian Shelf, the shallow (up to 200 m deep) continental shelf region lying between the Nova Scotia mainland and the deep Atlantic Ocean. Working in a 100 by 120 km area to the east of Halifax (Figure 5), they made measurements of ocean currents, waves, and water properties (salinity and temperature) every half hour for four months. Currents and water properties were measured by current meters suspended at various depths below the surface, and the observations stored on magnetic tape inside the instruments for later analysis. Surface waves were measured by instrumented buoys which rode the waves and continuously reported wave measurements to shore via radio. Sea level gauges were installed at strategic points along Nova Scotia’s 700 km coastline to record fluctuations in sea level. At the beginning and end of the field program, surveys were made by ship of the temperature and salinity of the water overlying the shelf.

Conducting a major storm study in winter presented the CASP scientists with many challenges. Based on a study of historical weather records, nine winter storms were expected to pass through the southern Maritimes between January 15 and March 15 with gale force winds (winds exceeding 60 km per hour). In 1986, 16 such storms were observed during that 60 day period, each with the power to damage or destroy the scientific instruments intended to monitor them. Hundreds of instruments were employed, and they had to withstand storm winds, snow, rain, and freezing rain, ocean waves, and freezing spray.

Flying research aircraft through the storms, and going to sea to maintain the network of CASP buoys also posed risks to

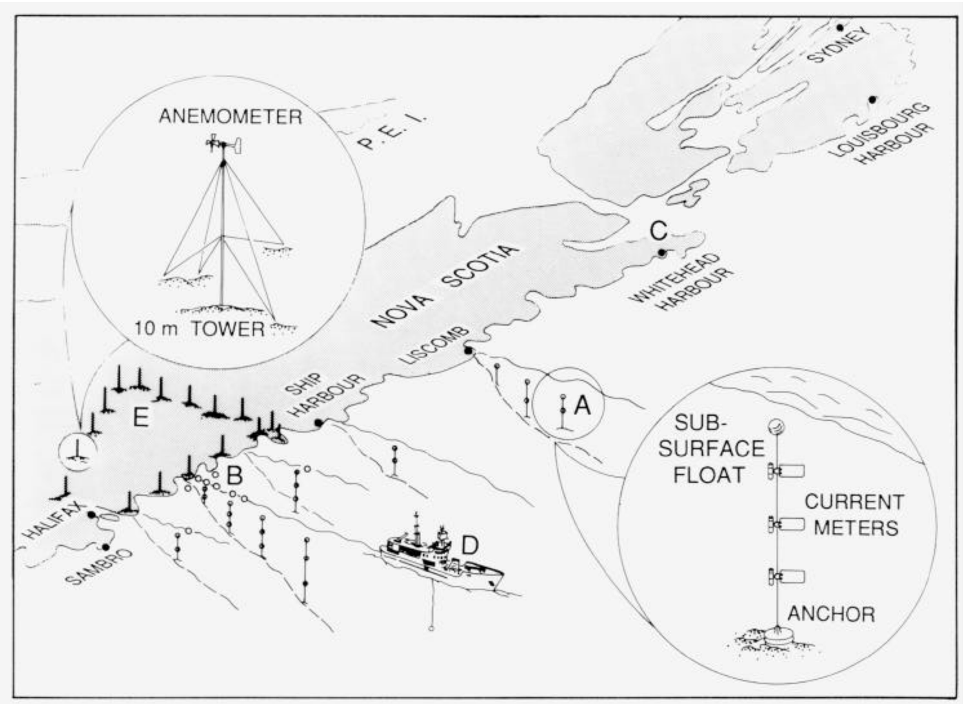


Fig. 5 The CASP oceanographers used current meters (A) to record currents and water properties every half hour for four months. Surface waves were measured by instrumented buoys (B). Sea level gauges (C) were installed along the Nova Scotia coast to record sea level fluctuations. Research vessels (D) made surveys of the temperature and salinity of the water overlying the shelf: Anemometer towers (E) recorded wind speed and direction every ten minutes.

equipment, and to the researchers themselves. Nevertheless, as a result of careful planning, and a run of good luck, the CASP winter field program was very successful. Despite the expected loss of some data, the CASP atmospheric and oceanographic observations contain a wealth of information about winter storms that will take several years to analyse.

Results of the program.

The oceanic and atmospheric observations collected during the CASP field program can be used to test our understanding of many aspects of the ocean's response to storms. Most oceanographic studies of wind-driven currents and waves do not have the benefit of simultaneous measurements from large meteorological networks, making it more difficult to correctly interpret their results. By working with AES, the BIO oceanographers obtained an especially detailed description of the storm winds that affected the Scotian Shelf during the CASP field program. For example, detailed wind measurements made on the Nova Scotia mainland during CASP gave BIO oceanographers good estimates of the movements of warm and cold fronts, an important element in explaining the generation of the observed wind-driven currents.

Ocean currents

Under the influence of the earth's rotation, large-scale patterns of storm-driven currents and sea level fluctuations, known as "shelf waves," are established on continental shelves and migrate slowly along the coast over periods of several days. The currents and sea level fluctuations associated with these waves are generally strongest adjacent to the coast, but unlike ocean surface waves, shelf wave motions are not visible to the eye. Studies of the CASP sea level data have shown a direct relationship between shelf waves detected on the Scotian Shelf and the wind over the shelf. They also showed that shelf waves generated by winds over the Grand Banks of Newfoundland travel to the Scotian Shelf, arriving one or two days after the passage of a storm. The significance of these findings is that in order to predict storm-driven currents and sea levels in a given coastal area, it is necessary to take into account not only the local wind, but the effects of storms in remote areas as well.

The most immediate oceanic response to storms is the generation of horizontal currents known as "inertial currents." The CASP current and wind measurements clearly showed the generation of inertial currents by the rapid increase in wind speed at the onset of storms, and by the abrupt changes in wind direction that accompany the passage of storm fronts. Inertial currents are stronger than the currents associated with shelf waves, and reached speeds of up to 1 km/hr during the largest storms in CASP They are weak near the coast, however, where the effects of shelf waves tend to be strongest. Therefore, ocean forecasting models will have to accurately predict both the shelf wave and inertial motions. The models will also require information about the passage of storm fronts in order to correctly forecast the inertial currents.

Surface waves

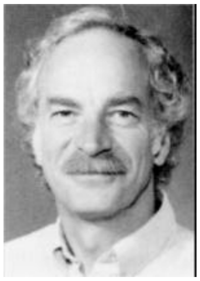
The CASP surface wave measurements are one of the largest and most complete sets of wave data ever gathered. The wave buoys were anchored in water of varying depth near the coast, and therefore are useful in describing the alteration of wind-driven surface waves as they approach the coast and enter shallow water. Such information is required to test future wave forecasting systems that attempt to predict wave heights near coasts. The data also provide information about the rate of growth of waves due to the wind in the early stages of their development, for example shortly after the onset of a storm.

Conclusions.

The Canadian Atlantic Storms Program is contributing to a more complete understanding of winter storms on Canada's east coast and of the response of the ocean to storms. Cooperation between oceanographers and meteorologists has produced an especially useful set of storm data for the eastern Canadian coastal region. Oceanographic measurements made in CASP are guiding the development of ocean forecasting models, and can be used to test the skill of the resulting models.

Long term changes in the Labrador Current

J.R.N. Lazier



J.R.N. Lazier

Summary

FISH catches in the waters east of Newfoundland vary from year to year but so do the temperature, salinity and speed of the water. We are trying to find connections between the abundance of fish and the changing environment.

Introduction

The Labrador Current flowing down the east coast of Canada is famous for ice and cold water, the biggest cod fishery in the world, the birds, whales and seals that feed in it and the natural gas and oil that lie beneath it (Figure 1). Humans have exploited the living resources for eighty centuries, but not always wisely. Many bird species for instance are gone to supply the needs of bygone fashions and overfishing in the 1960's severely depleted some fish stocks.

To protect these resources Canada declared, in 1977, a 200 mile limit. This meant the country would manage all the resources in and under the ocean up to 200 nautical miles (370 km) from the land. The new boundary includes most of the Labrador Current.

Good management needs accurate information. Back at the time of the 200 mile declaration we knew as much about the Labrador Current as any other part of the ocean around Canada. This knowledge came from observations collected in the late 1920's and early 1930's following the loss of the Titanic to a Labrador Current iceberg. Since 1977 however, Canada has become the world's largest exporter of fish and fish products and the sixty year old oceanographic knowledge is not adequate for managing these precious resources which are coming under even more pressure as the demand for Canada's fish increases.

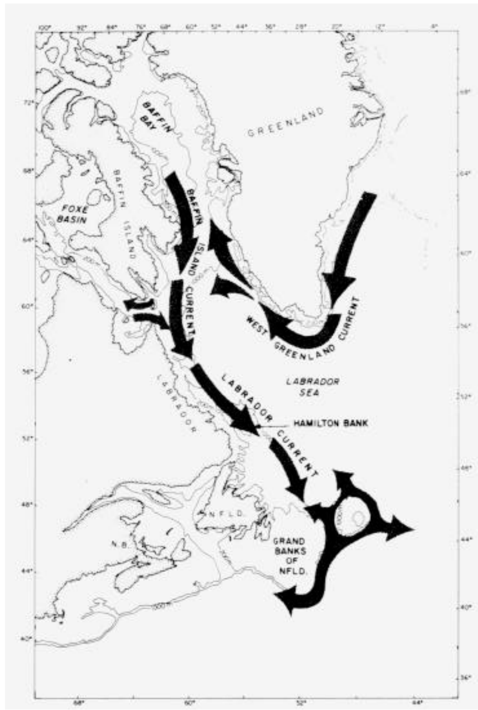


Figure 1 Ocean currents east of Canada: the Labrador Current arises from the Baffin Island and Greenland currents, plus the outflow from Hudson Bay.

One thing we eventually must understand about the fish is why there is so much variation from one year to the next in the number that grow up to be adults. Is it because one year is colder than another or because the wind blew from the wrong direction at the wrong time or because too many fish were caught? There are many possible reasons but before answers can be found we must have a thorough understanding of why the environment varies from year to year. These long term changes are well known to be large in and near the Labrador Current. The whalers, over one hundred years ago, knew how the weather off west Greenland could be bitterly cold one year and relatively mild the next. The amount of ice off Newfoundland varies greatly from winter to winter and has been, for years, an indicator of the severity of the winter. The iceberg that sank the Titanic in 1912 at 42°N was much further south than icebergs normally get because that was an unusually severe year for ice.

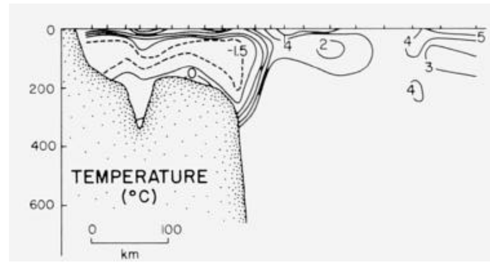


Figure 2 Temperature measured in July 1985 in a section across the continental shelf and slope at Hamilton Bank. Note the cold layer over the shelf compared to the warmer water in the deep ocean. The main part of the Labrador Current lies over the upper part of the slope, where the temperature changes rapidly from -1.5°C to 3.0° C at 100m depth.

Measuring the Current

The only way we are going to get the data we require is to go and start measuring the temperature, salinity and speed of the current in some key locations (Figure 2). The temperature and salinity data are important because the fish avoid water that is too cold or too salty. The data are also used to calculate the current's speed in regions where we can't afford to put the instruments that measure the speed directly and to find the relationships between the changing weather in the atmosphere and the changing environment in the sea. Continuous records of the speed of the current are compared with wind over the ocean and runoff from the land to determine the main forces that determine the strength of the current and the variations over seasons and longer.

We began this measuring program in 1978 by placing four continuously recording current meters at important locations in the current near Hamilton Bank on the

Labrador shelf. When these instruments are replaced, once or twice a year, maps of the temperature and salinity near each instrument are made using data obtained from sensors lowered through the water from the ship. The original idea was to obtain records of temperature, salinity and current flow at as many sites as we could afford for at least ten years. These data would provide a start in understanding the current's variations through the seasons and between the years. But the Labrador Current is like no other current on earth. Most of the winter it is covered with ice and in the spring it is infested with icebergs that can be big enough to scrape the bottom 300 metres below the surface. If the iceberg hits the measuring equipment suspended between the surface and the bottom, we usually don't see the equipment again. A different and unexpected problem was the high rate at which our stainless steel mooring wires corroded in the cold current. Before we overcame this problem with plastic lines, four or five instruments were lost. Two of these were later recovered after floating across the ocean. One to the Azores and one to Ireland, both with perfect records. Both had broken free just two weeks before we arrived to pick them up.

In spite of all the problems, some excellent multiyear records have been collected. A summary of the variations or fluctuations in the current speed at one location is shown in Figure 3. This is a spectrum. The mean or average current is removed and energy of the variations is plotted against the frequency of the variations. If this presentation is new to you, think of music. The axis along the bottom gives the frequency or pitch of the music. High notes to the right, low notes to the left. The axis up the side gives the energy or loudness for each frequency. In our plot the twice daily oscillation due to the tide is a high note. It is normally a prominant feature at the high frequency (short period) end of current spectra.

Figure 3 also shows us that most of the energy in the current's oscillations is found at periods between five and fifty days with a peak at ten days. These are the variations which are driven by the varying winds and pressures associated with the parade of storms across the Labrador Sea, especially in winter. The curve also shows that

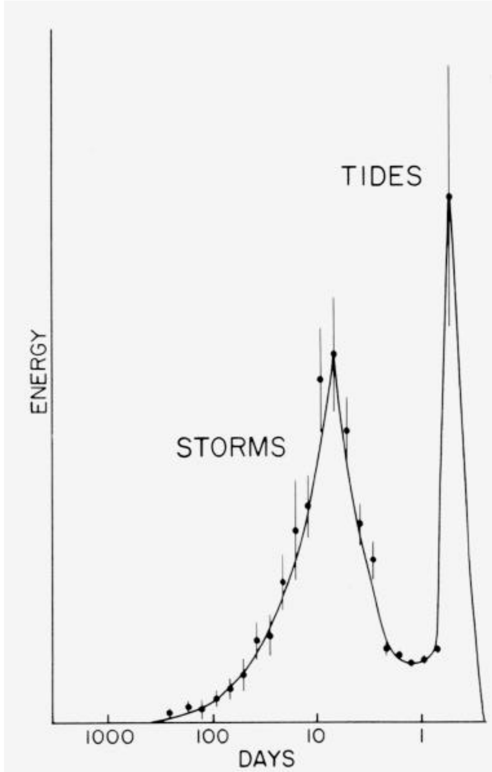


Figure 3 Energy of the variations in the Labrador Current versus the period of the variations.

changes with periods of years and longer, that is, the changes that are of primary interest in our study, have very little energy compared with the energetic short period variations. Returning to the music analogy; the tides are a single and loud high frequency note. The storms generate a lot of loud notes with the loudest at a period of ten days but the notes made by the annual and inter annual changes are, in comparison with the others, very quiet even though they may be the most important in our study of long term changes.

To study the long term changes, we want to get rid of the fluctuations due to the tides and the storms. They are so big they hide the weak low frequency oscillations. We want to turn down the treble and turn up the base. This is easily done on the computer and when all the higher frequency oscillations have been removed the longer and smaller oscillations become visible as shown in Figure 4. This tangled picture includes all the smoothed velocity records we have obtained at 400 metres depth close to the strongest part of the Current. Each line represents the speed of the current, without tide or storm fluctuations, over a period of eighteen months. Although the pattern varies a lot from one year to the next the speed of the current clearly changes through the year. The minimum is in February, March or April with a value between 0.0 and 0.1 metres per second (m s^{-1}), while the maximum occurs in the autumn or winter between September and February with a value of ~= 0.2m s^{-1}.

The Annual Cycle in Current Speed

The first question we want to answer is why the speed of the Labrador Current changes through the year as it clearly appears to in Figure 4. The obvious explanation is that the current stays the

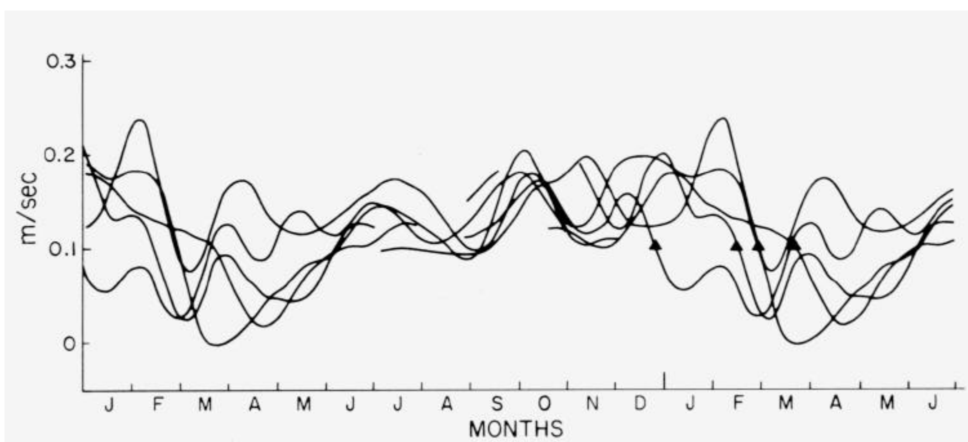


Figure 4 Smoothed records of downstream velocity measured between 1980 and 1987 at 400m depth in 1000m of water near the centre of the Labrador Current. The 18-month overlapping blocks of data accentuate the annual variation. A mark on each curve indicates where the flow drops below 0.1 m s^{-1} in winter.

same all year but moves close to then away from our instrument bringing faster then slower regions of the current to the instrument. We know this is probably not the reason because of an interesting fact.

Sea level changes from one side of an ocean current to the other. This fact is similar to the phenomenon reported daily in the weather forecasts which tell us how the atmospheric pressure is changing as the currents of air pass over our heads. The sea level change associated with the pressure change across a current of water is small but measurable. Across the strongest currents in the ocean such as the Gulf Stream the sea level changes by about one metre. Across the Labrador Current the change is only about 15 centimetres, but that is enough to be calculated using sea level observations at the shore and temperature and salinity measurements from the other side of the current in the middle of the Labrador Sea. Temperature affects sea level in the middle of the ocean because, like most other substances, it expands with heating. The salinity of the water also affects the height of sea level. Higher salinity like cooling makes the water denser which reduces the sea level.

By doing these calculations we find that the sea level goes up and down with the seasons at the shore and in the middle of the Labrador Sea but that it goes up and down more at the shore than in the middle of the sea. From this we conclude that the sea level, or pressure, drop across the Current varies throughout the year. This indicates that the speed of the current must be changing with the seasons just as the current meter observations in Figure 4 indicated. We therefore conclude that the strength of the current really does change through the year but what makes it change?

One reason is found in our observation that the sea level goes up and down more near the shore than in the open ocean. Our measurements of temperature and salinity from these areas show that the sea level goes up in summer partly because the water is warmer but this effect is about the same on both sides of the current. Sea level also goes up in summer because of the increased amount of fresh water being mixed into the seawater. The fresh water is from the spring melting on land and sea and is carried to the Labrador Current by the rivers emptying along the the Labrador coast and into Hudson Bay, Foxe Basin, Baffin Bay. Much of the fresh water comes from the Arctic Ocean via the currents around Greenland but this flow probably takes more than a year. Unlike the temperature effect the sea level rise due to the fresh water is much greater over the continental shelf than over the open ocean because it tends to be confined there by the current. This uneven rise and fall between the waters over the shelf and open ocean gives rise to the annual variation in sea level across the current. We tentatively conclude, therefore, that the annual variation in the speed of the current is mainly due to the annual cycle in fresh water flow. The fact that the maximum flow occurs late in the year is because the fresh water has to come a long way and only moves at about 20 cm s^{-1}.

Another thing we would like to know about the annual cycle is how constant it is from year to year. Does the current, for example, always have the same maximum and is it always reached on the same date? The curves in Figure 4 show the speed of the current in summer to vary somewhat but to be more or less the same from year to year. In winter the current is seldom the same. In February for instance the curves show the smoothed current as low as 5 centimetres per second (cm s^{-1}) and as high as 25 cm s^{-1}, but in July the range is only about 5 cm s^{-1}. This difference from summer to winter in the year to year variation on a particular date has more to do with the phase or timing of the cycle than with its amplitude. The amplitude, or difference between the minimum and the maximum current over the year, is about the same from year to year. The timing of the winter decrease, however, changes dramatically from year to year.

Every year, for example, the speed goes from its highest values to its lowest values in winter, but in one year the drop occurs around Christmas and in another it occurs three months later at the end of March. This seems like a large change from one year to the next but so far we don't know what causes it or what the consequences are. Maybe the drop in the current speed in the winter has something to do with freeze-up in the north and the shift from one year to the next occurs because freeze-up comes at different times. This, of course, is just speculation but continued study in the years ahead will help us to understand how these changes are connected with climatic changes in other parts of the world and with the changes in the local fishery.

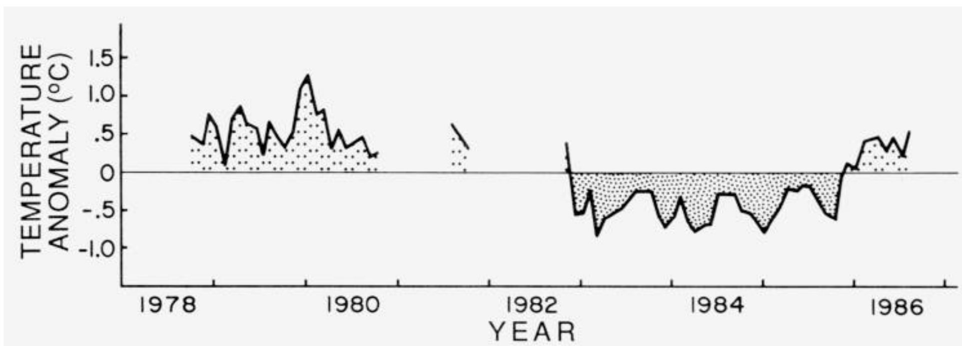


Figure 5 Monthly temperature at 200m depth west of Hamilton Bank, showing that from late 1982 through 1985 temperature was about 1°C colder than during the rest of the record

Temperature Changes

Over the years we have also been lucky to observe a large shift in the temperature of the water over the Labrador shelf. This was measured close to the bottom in 200 metres of water on the western side of Hamilton Bank. These data are shown in Figure 5 as a series of monthly anomalies. The point for January 1980 is the monthly mean for that month subtracted from the mean of all the Januarys in the record. This presentation emphasizes long term departures from the average. The temperature clearly was much higher, relative to the average, during the first two years than in the period between the autumns of 1982 and 1985. Then in 1986 the water warmed back up to the previous values.

We are still not sure why the temperature changed so radically over the years. Preliminary studies suggest that the cold conditions are abnormal and occur when the weather patterns shift and cause larger than normal amounts of cold arctic air to blow over northern Labrador Sea. The cold air takes the heat out of the water but the amount of the change seems much larger than is ever observed in the ocean close to Halifax and Dartmouth. Such large changes seem to be more common in the arctic.

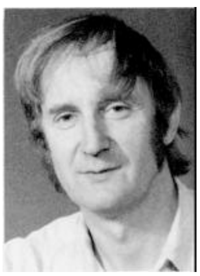
Even though our understanding of the causes of the abnormally cold water is a little shaky, we are certain that the cold water had a big influence on the movement of the cod fish off Newfoundland. Cod fish avoid water that is below 0°C and when the water was colder than normal the fish tended to stay offshore in the warm deep water rather than cross the cold water into the inshore areas where they normally go in the summer. The fishermen who work the inshore waters off southern Labrador reported lower catches in the cold years and an abundance of "slub" in their nets, which is a slimy substance that thrives in the extra-cold water.

Conclusions

When this investigation began ten years ago we knew it would be a long struggle to gain the information and the understanding we require to manage the resources and here we are ten years later only beginning. We have learned a lot about how to make the observations in one of the world's most hostile environments and we have greatly improved the technology. We have also obtained some extremely valuable data but a full understanding of what drives the annual cycles and the inter-annual differences in those cycles is still beyond us but a good foundation is in place. Understanding the connections between the local year to year changes and other changes in the earth's climate is also a fascinating and valuable pursuit but it is still a few years in the future.

Global change and the coastline of Canada

J. Shaw



J. Shaw

Introduction

A significant number of scientists now believe that a global rise in sea level is now under way. One set of scenarios for the year 2075 suggests a maximum rise of 213 cm, a minimum rise of 38 cm and a most likely rise in the range 91 to 137 cm (Hoffman et al, 1983). The cause of the anticipated rise is well known. Human activities have now reached such an intensity that they are affecting global climate, supplementing the natural changes which were already under way. With rising levels of trace gases in the atmosphere (carbon dioxide, methane, and nitrous oxide), a global warming trend is anticipated. Glaciers will melt faster than at present, adding water to the world oceans. The oceans will also expand in volume as they warm.

Canadians should be concerned about this anticipated rise, given that we possess the longest coastline in the world under a single jurisdiction (250,000 km). The Canadian coastline extends across several climatic zones, includes a wide variety of coastal types, and encompasses areas which have a range of human activities. There is now an awareness that this extensive and varied coastline may be sensitive to global-scale environmental changes.

The effects of sea-level rise.

How will the anticipated rise affect the coastline? There is no simple answer, as different parts of the coastline will be affected in different ways. This is because of the existing regional variations in relative sea-level change - a legacy of the melting of the vast ice sheets which covered most of Canada 18,000 years ago. (We use the term "relative sea-level" because a change in sea-level as measured in any particular area does not mean that the "global" sea-level has changed. An apparent sea-level change could be caused by a local rise or fall in land.)

Two examples illustrate how different regions of Canada have experienced different patterns of sea-level change. In northwestern Newfoundland, sea level has apparently fallen by about 20 m over the past 7,000 years. Formerly the land was depressed by the weight of glacier ice, and has been rebounding (Grant, 1980). By contrast, along the south coast of Nova Scotia, 1000 km from our first example, sea level has risen about 30 m in the same period of time (Piper et al, 1986). Here, a bulge in the earth's crust formed on the periphery of the former ice sheet and has since been collapsing. At Halifax, Nova Scotia, the rise continues, at a rate of about 40 cm per century (Grant, 1970).

The Atlantic coast of Nova Scotia is a good example which we can use to illustrate some of the effects of global sea-level rise. Geologists have evolved models of how the coastal zone in this region responds to the rise in sea level that followed the melting of the ice sheets (Piper et al, 1986; Boyd et al, 1987). The rising sea reworked the glacial sediments which covered the landscape. The liner material, silt and clay, was carried offshore into deep basins or moved into estuaries by tidal action. Sands and gravels were incorporated into beaches and as the sea level rose, beaches retreated landwards, often over-riding the muddy sediments deposited in estuaries and lagoons. Evidence of the sea-level rise can also be found offshore. Scientists working a short distance off the coast in late 1987 used geophysical methods to pinpoint the location of bodies of former estuarine deposits. Specific targets were identified for coring operations to obtain samples for studies of sea-level change and other aspects of seabed geology. One of the cores recovered on this cruise contained fresh-water peat, 8800 years old, at a depth of 20 m below present sea-level. Estuarine sediment at a depth of 45 m was dated at just under 11,000 years before present, and contained pollen which showed a shrub-tundra environment.

It is expected that the additional global sea-level rise will accelerate rates of change at the coastline in this region. Coastal bluffs which now have average retreat rates of 1 m per year (Taylor et al, 1985) may erode faster. To keep pace with the anticipated rise, many beaches may experience rapid landward migration or may even be destroyed. Figure 1 shows the dramatic changes at Story Head, one of a number of beaches monitored by coastal geologists based at the Bedford Institute of Oceanography. It is possible that the rise may exceed the rate of vertical accretion of the salt marshes which fringe the numerous estuaries in the region, eliminating this important habitat.

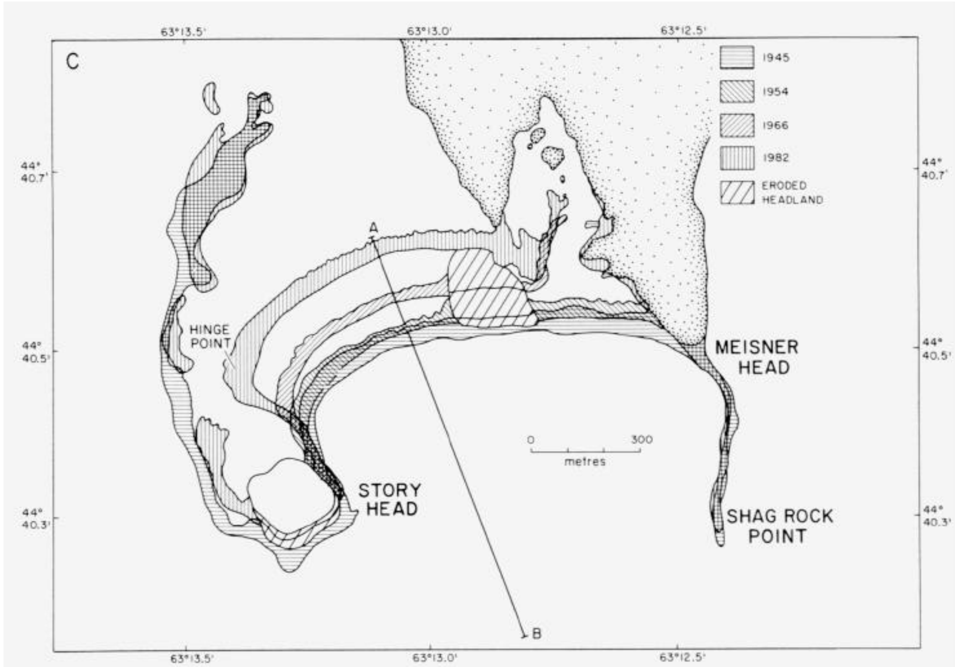


Fig. 1 This beach at Storey Head, on Nova Scotia's Atlantic coast, is being monitored by coastal geologists based at the Atlantic Geoscience Centre. It has been moving landwards at an average rate of about 8 metres per year. Here the rise of sea level due to global change would add to the existing regional subsidence of 30 cm per century. Beaches such as this may be destroyed From Forbes et al (in review).

Direct human impact

What about the direct impact on human populations? Along the predominantly rural Nova Scotia coastline, property loss will continue and buildings will be threatened, but these have long been accepted hazards (Figure 2). Throughout the Maritimes there are examples of settlements which may be placed under increased risk. For example, in southern Newfoundland the town of Placentia (Figure 3), built on a gravel beach-ridge plain (Shaw and Forbes, 1987), is already susceptible to flooding associated with extreme tides, storm surges and high rainfall. A future sea-level rise would increase the likelihood of flooding (coastal protection structures are now under consideration for the town).

The impact on human structures will be greatest in large coastal urban areas. Some studies have already been completed on the possible effects in such locations. For example, it has been concluded that a one metre sea-level rise at Saint John, New Brunswick, would cause an increase in the

Fig, 2 The settlement of Neil's Harbour on Cape Breton Island after a storm surge in October 1983. Total damage in the region was estimated to cost $2.7 million The projected sea-level rise would increase the incidence of such events. Photo courtesy of R. B. Taylor.

Fig. 3 The town of Placentia in Newfoundland is built on a low gravel beach-ridgeplain and is already susceptible to flooding. The plans for coastal protection structures may have to take into account the effects of the projected sea-level rise.

height of coastal storm surges and more frequent flooding of the lower river (Martec Ltd., 1987). There would be flooding of residential areas and industrial facilities, disruption of road and rail transportation systems, inundation of sewage and industrial waste treatment lagoons, power plant and wharves. Also, along the Saint John River, increased flooding would threaten rich farmland and disrupt the TransCanada Highway.

Change in the Arctic

Beyond Atlantic Canada different sets of problems will be encountered in regions of different climate and with different existing backgrounds of sea-level change. The Arctic is a special case, highly sensitive to change and with a great length of varied coastline. More than one third of Canada's coastline is on the Arctic islands alone. Higher sea-levels may flood low-lying coasts such as the Mackenzie Delta and parts of the Tuktoyaktuk Peninsula in the Beaufort Sea, the Arctic Coastal Plain and in the eastern Arctic, fiord-head deltas on the Baffin Island coast.

We can anticipate increased coastal bluff erosion on the Beaufort Sea coast, where retreat rates of up to 13 m per year were reported by Forbes and Frobel (1985). Unlike on more southern coasts, the sands and muds in these bluffs are often ice-bonded, and high retreat rates can be linked to thawing and slumping and erosion by sea ice, in addition to wave action. Here, and in other parts of the Arctic, the effects of warming climate will be felt directly at the coastline. Warmer sea temperatures may cause permafrost to degrade, allowing the ground to sink. This, combined with the sea-level rise, will increase erosion at the coast.

Arctic beaches are ice-locked for most of the year. Reduced amounts of sea ice could result in longer annual duration of open water conditions at many beaches. The consequent increases in fetch (the length of open water over which winds may blow and generate waves) would result in increased wave activity (Figure 4) and increased erosion. Such changes not only poses problems for settlement sites such as Tuktoyaktuk, but will have implications for future development, such as projected pipelines.

The Pacific Coast

The west coast of Canada will have its own problems. Here, relative sea-level patterns have varied regionally during the past 10,000 years and continue to show variation. Victoria is probably being uplifted at present while the Vancouver and Prince Rupert areas are subsiding at rates of 1 to 2 mm per year (Clague and Bornhold, 1980). Cliff and other shore erosion

Fig. 4 A summer storm rages on a beach in the high Arctic. Most Arctic beaches are subject to open water conditions for short periods each year. Increased warming may lead to less ice, increased wave action and more erosion. Photo courtesy of R. B. Taylor.

problems in the Vancouver area may be exacerbated in the future, but more important will be the possible flooding of the Fraser Delta. Costly modifications to the existing dyke system may be required to protect the very large real estate investment on the low-lying delta plain, primarily in the communities of Delta and Richmond.

The British Columbia coast is in a tectonically active area (the Cascadia subduction zone lies west of Vancouver island). Atwater (1987) reported on evidence from adjacent Washington that six major catastrophic subsidence events and their associated tsunamis (tidal waves) have occurred during the last 7000 years, caused by major earthquakes. The hazards associated with such events may outweigh the slower effects of the postulated sea-level rise.

Coastal research and global change

The International Geosphere Biosphere Program is a broad initiative aimed at "a fuller understanding of the earth as an interconnected whole". Canadian researchers are well equipped to participate in this international effort. We recognize that the history of the past 20,000 years is a record of change: the retreat and final dissipation of great ice sheets, the subsequent northward migration of boreal and temperate forest zones, and of course, the rises and falls in relative sea-level as the crust and ocean respond to the new conditions. Now that we are aware of the strong possibility of a rapid sea-level rise, we will continue to gather information about past sea-levels, since even in Atlantic Canada there are large areas where the nature of past changes remains uncertain. Without this knowledge the local impact of global trends cannot be predicted adequately.

We will also continue with routine coastal surveys to detect changes in coastal configuration. New monitoring sites may be established in Arctic areas which, as has been suggested, may be especially susceptible to change.

Finally of course, we shall continue to watch for signs of the predicted rise. If and when it happens, we should be prepared.

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Ocean Mapping at the Atlantic Geoscience Centre

R. Macnab and D.J.W. Piper

R. Macnab

D.J. W Piper

Introduction

A significant portion of Canada's resource heritage lies off our three coasts. Fishing and mineral rights are now the nation's exclusive property out to 200 nautical miles in the Atlantic, Arctic, and Pacific oceans. In the Atlantic and Arctic Oceans, there is an additional potential for controlling non-living resources over vast areas of the sea bed beyond 200 miles: the terms of this extended jurisdiction are defined in the 1982 United Nations Convention on the Law of the Sea, and will be recognized when sixty nations have ratified the Convention (about half that number have ratified so far).

Ultimately, Canada's total marine resource area (Figure 1) could be half the size of the nation's primary landmass; fully a third of that - equalling the combined areas of Manitoba, Saskatchewan, and Alberta - would lie beyond the 200 mile limit.

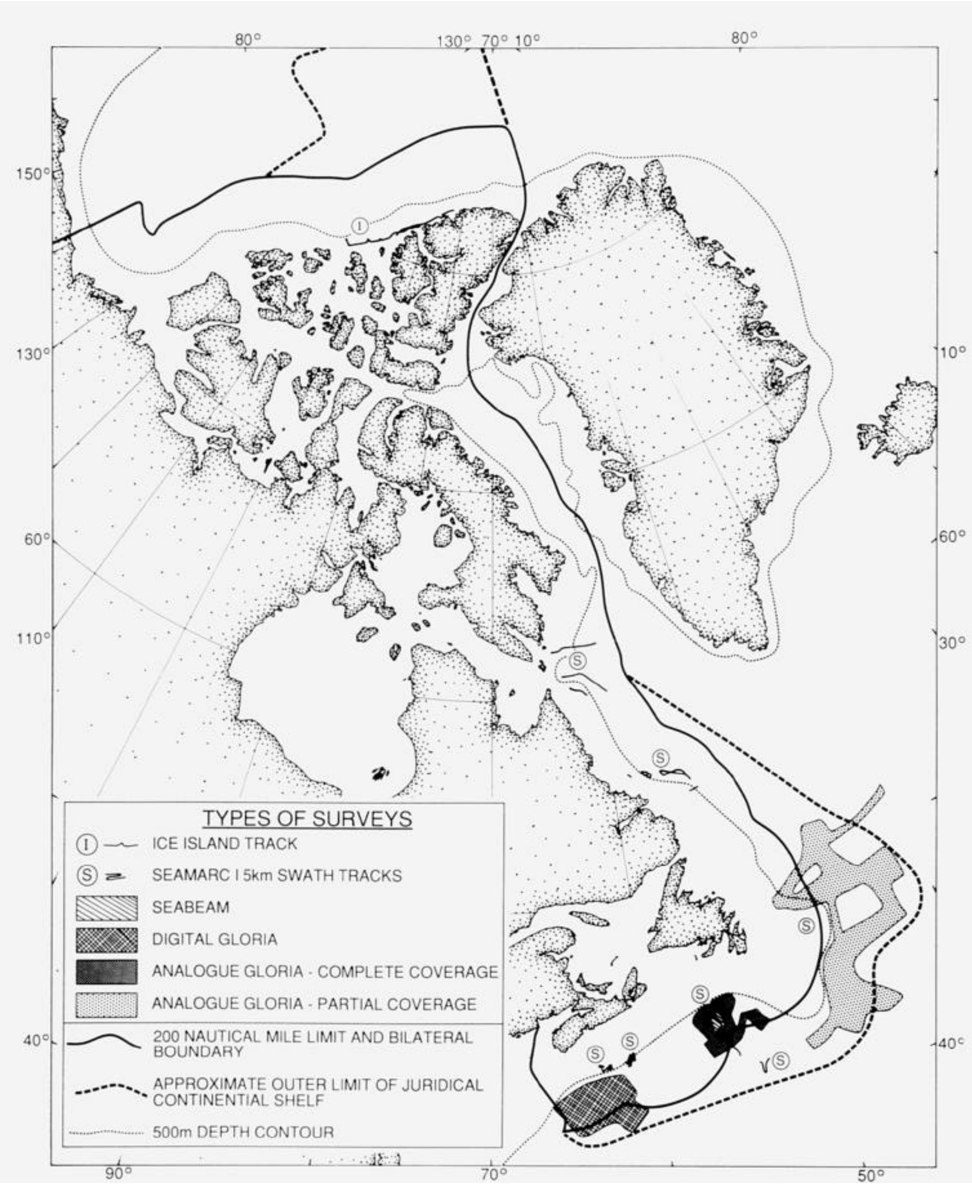


Fig. 1. This map shows Canada's 200 nautical mile limit and the possible outer limit of the juridical continental shelf as defined in the 1982 United Nations Convention on the Law of the Sea. It also shows those areas of Canadian jurisdiction on the continental margin that have been surveyed with modem swath mapping systems: SEA BEAM, SeaMARC I, and GLORIA. Included is the track of the Ice Island in the Arctic Ocean other than this track, sounding data on our far Arctic margin is restricted to spot soundings through the ice.

This underwater frontier presents the same sorts of scientific and resource challenges as did the land frontier over the last two centuries. Two of the most fundamental challenges are to gather basic information about the shape and composition of the sea floor and its underlying structures, and to present that information in the form of detailed maps. Akin to topographic and geologic maps on dry land, these maps are essential prerequisites for many activities in the offshore: navigation, fishing, scientific research, exploration, drilling and mining, cable and pipeline routing, waste disposal, and the construction and emplacement of offshore structures.

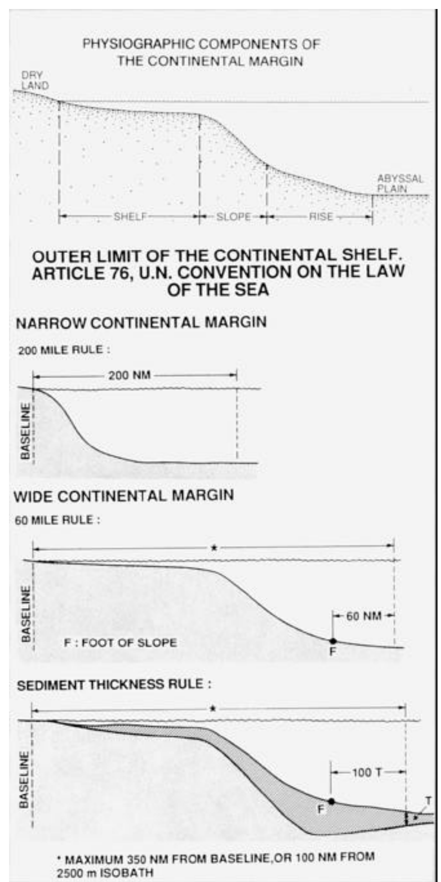
Few areas of the continental shelf and beyond have been systematically surveyed to the modern standards required for increased management and utilization during the next fifty years. The topography of some parts of the shallow continental shelf has been mapped in detail. However, over large portions of the continental shelf and over most of the deeper regions of the

Component Parts of the Continental Margin

There's more to a continent than the part that sticks out of the ocean: there is also a fringe that extends below sea level, creating a transition zone between dry land and the deep sea bottom. This zone is known as the continental margin, and generally consists of three parts: the shelf, the slope, and the rise.

The width of the margin varies substantially in different parts of the world. For instance, it extends more than 500 kilometres across some parts of the Grand Banks of Newfoundland, while off Vancouver Island, it measures only about 30 kilometres.

The continental shelf is a shallow, gently sloping zone that extends from



the shore to a point where the bottom abruptly begins to steepen. Worldwide, here is considerable variability, but the greatest average depth of the shelf is usually of the order of 200 metres, with a gradient of 1 in 1000.

The continental slope begins where he shelf ends, with a strong increase in bottom gradient - usually more than 1 in 40. It is bounded at its outer limit by an abrupt decrease in gradient, in depths that may range from 1500 to 3500 metres.

The continental rise is the sea floor beyond the base of the continental slope, generally with a gradient between 1 in 40 and 1 in 1000, and leading down to the flat abyssal plain.

With the 1982 signing of the UN Convention on the Law of the Sea, a new definition of 'continental shelf entered the lexicon: within the Treaty's context, the term applies to the 'natural prolongation' of a coastal state's land territory. This includes the continental slope and rise, in addition to the physiographic shelf described above.

Where the outer edge of this legal or juridical continental shelf is located depends on the width of the continental margin. If the margin is narrow (as it is off western Canada), the juridical shelf has a width of 200 nautical miles (about 365 km); it matches the Exclusive Economic Zone, where the coastal state exercises jurisdiction over living and non living resources. If the margin is wide (as it is off eastern and northern Canada), the juridical shelf depends on the topography of the sea floor and the subbottom, and may be up to 350 nautical miles (about 640 km) wide. In this latter case, the coastal state exercises jurisdiction over non living resources of the continental shelf beyond 200 nautical miles.

With its potential for creating confusion, this new nomenclature seems to be an unfortunate amendment to the language. Nevertheless, the new meaning of 'continental shelf is firmly embedded in the vocabulary of international law. In any given context, therefore, it is important to be explicit about the definition that applies.

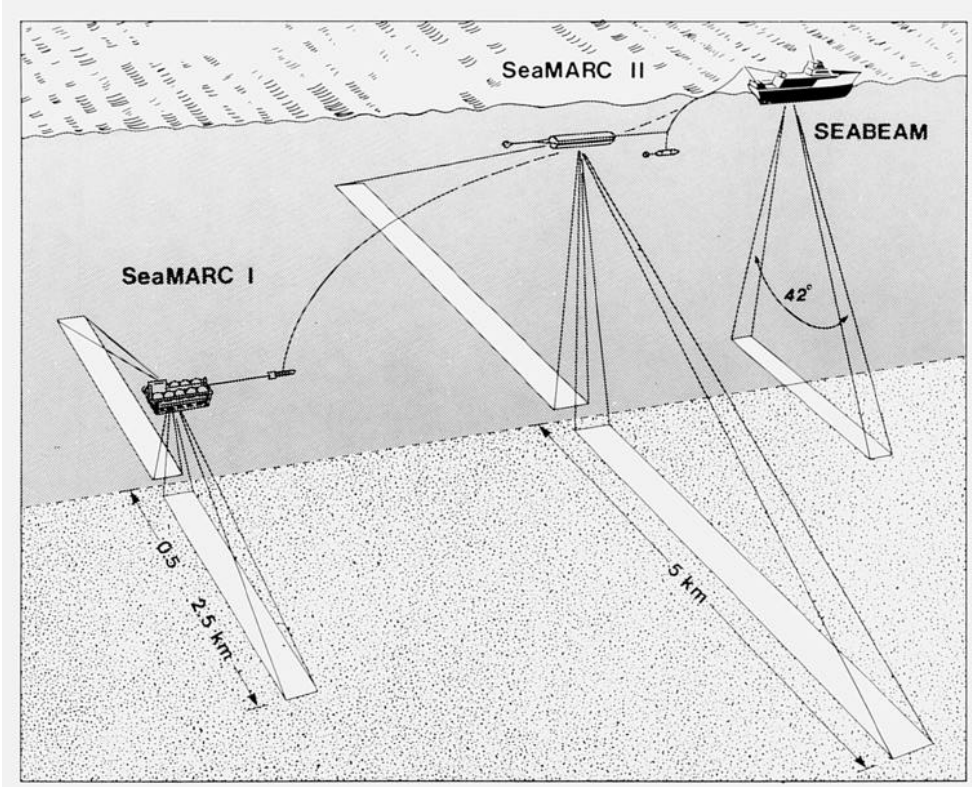


Fig. 2. Three different types of swath mapping systems are illustrated in this figure. SeaMARC I is a sidescan sonar that measures the acoustic reflectivity of the sea floor, giving marine geologists some idea of the physical composition of the seabed material; the system is towed near the bottom to achieve maximum detail over a relatively narrow swath, and does not measure depths. SEA BEAM is a hullmounted sounding system that measures sixteen water depths accurately and simultaneously by using a fan-shaped beam Se&ARC II is a combined sidescan sonar and sounding system that simultaneously measures water depth and acoustic reflectivity. SeaMARC II depth measurements are not as accurate as those made with SEA BEAM, nor are the acoustic reflectivity observations as detailed as those made with SeaMARC I; however the system has the advantages of rapid and simultaneous coverage, and is more economical for mapping large areas. (Figure courtesy Earl E. Davis, Pacific Geoscience Centre, Sidney, B.C.)

continental slope and rise, we have so far only managed to resolve the major topographic features of the sea floor. As for structures beneath the sea floor, our knowledge in most areas is even more rudimentary, because it is based on cross sections of sediment and rock that are derived from widely-spaced seismic profiles.

Mapping techniques

We live in an era of high-resolution mapping from outer space, using an array of satellite-borne optical and microwave techniques to render crisp, detailed representations of the earth's outer surface. It is ironic and frustrating that these methodologies cannot be applied to the task of sea floor mapping, and that we must continue to rely on a technological approach that was developed in the first years of this century: the echo sounder.

The only effective and economical way of exploring the earth beneath the sea still entails the transmission of an acoustic pulse from a sound source at a known location, and the measurement of the arrival time of that pulse as it is reflected back to a receiving array. Granted, recent years have brought many refinements to the methodology, resulting in substantial increases in accuracy and resolution, higher data rates, and improvements to the handling, display, and interpretation of the data.

Detailed topographic surveys require advanced tools that are efficient at collecting and handling large quantities of data. Such a tool is the hull-mounted SEA BEAM system, which measures the depth of water along a narrow swath of sea floor

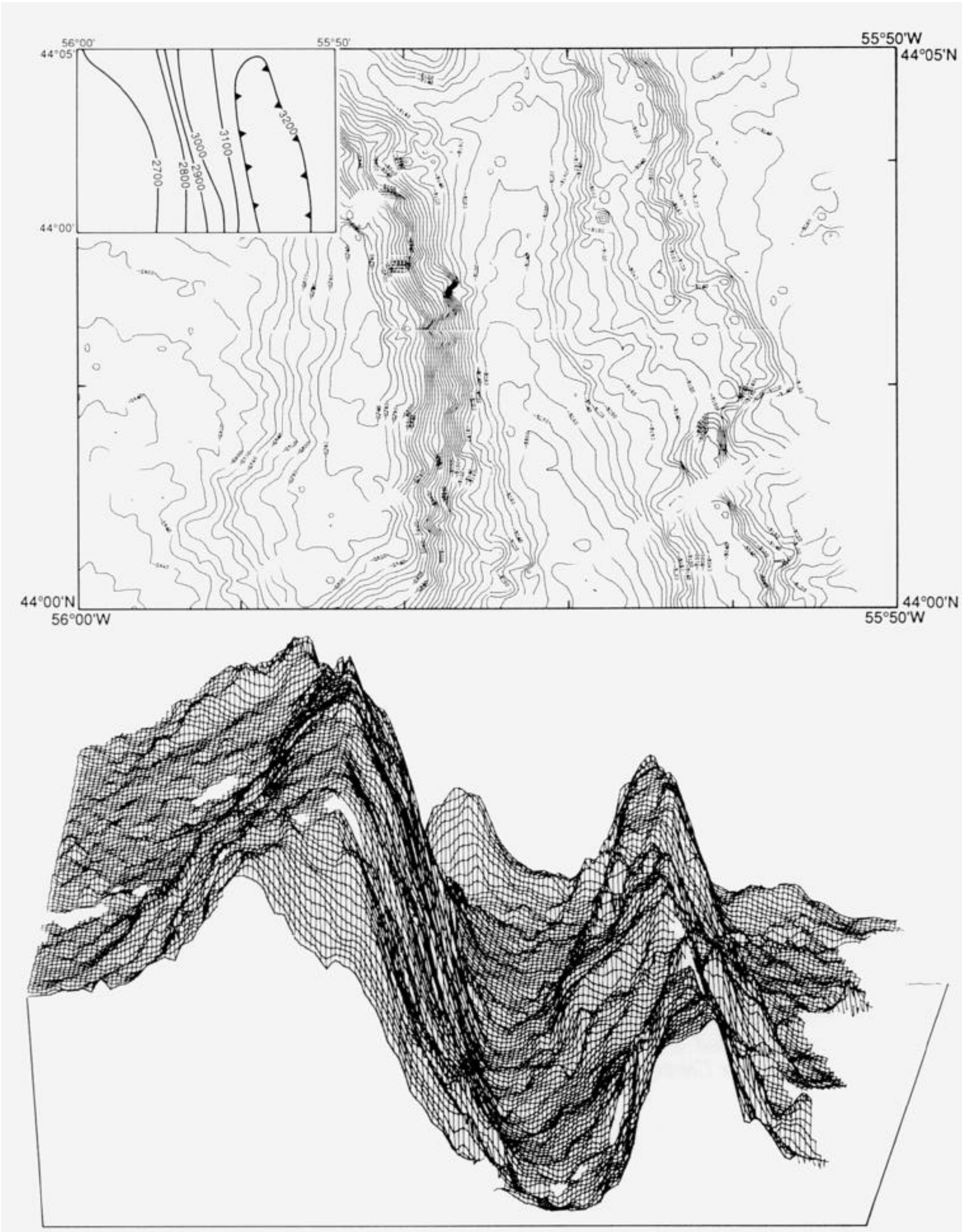


Fig. 3. In one pass, a vessel equipped with SEA BEAM can map a swath of sea floor that is nearly as wide as the ocean is deep. Recorded in digital form, the observations are sufficiently dense and accurate to lend themselves to a variety of computer-based graphical display techniques, e.g. as detailed contour maps of the ocean bottom (top part of figure, with inset showing the same area as previously mapped with conventional equipment), or as perspective views that portray very effectively the texture and undulations of the sea bed (lower part of figure). (Figure prepared by John Hughes Clarke from data collected by the NECOR SEA BEAM system on ATLANTIS II Cruise 116, Senior Scientist A.N. Shor)

by performing sixteen oblique soundings simultaneously and in a direction perpendicular to the axis of the ship (Figure 2). It provides detailed hydrographic information in areas where only generalized features were known from previous conventional sounding (Figure 3).

Mapping of sediments at the sea floor, important for example in the selection of cable routes, requires similar swath mapping of acoustic backscatter in order to derive an idea of the physical composition of the ocean bottom i.e. is it hard or soft? does it consist of line-grained sediment or coarse material? This work can be carried out by towed sidescan sonar systems similar to SeaMARC (Sea Mapping And Remote Characterization), which displays variations in returning acoustic pulses that are caused by changes in bottom relief and reflectivity (Figure 4).

Mapping of the deeper geological structure requires a variety of complementary techniques: seismic reflection profiling, similar in principle to echo sounding, but with a much stronger acoustic pulse that penetrates the sea floor and bounces off buried layers of rock (Figure 5); measurement of the earth's gravity and magnetic fields, to detect changes in the density and magnetization of buried material; and drillholes to bring back actual rock samples from deep layers.

In the Arctic Ocean and in the channels of the Arctic Archipelago, persistent ice cover presents a formidable barrier to conventional shipboard mapping operations. By the early 1990's, the availability of Canada's new Class 8 icebreaker should make it possible to contemplate certain types of underway measurements, such as swath mapping. However it will still be important to develop new mapping techniques in order to improve our rates of data collection, and to lift our knowledge of these areas beyond that of an occasional measurement every hundred square kilometers; in all likelihood, these techniques will entail the use of alternative survey platforms such as manned and unmanned submersibles to deploy instruments beneath the ice, and aircraft to carry out appropriate observations (such as measurements of the earth's magnetic and gravity fields) as they overfly the polar pack.

Recent developments sponsored by the Canadian Hydrographic Service may increase our survey capabilities in ice covered waters: ARCS (Autonomous Remotely Controlled Submersible) consists of a robot vehicle that measures depth while executing a survey pattern beneath the pack ice; TIBS (Through Ice Bathymetry System) is based on the principle that sea water is a conductor whose thickness can be measured by an airborne electromagnetic sensor. Both technologies have been tested, with results that show promise under certain operating conditions.

All of the above observations need to be complemented by an effective navigation system that yields accurately the position of the survey platform. In waters off the East and West coasts, this is most often accomplished by land-based radionavigation systems like Loran C, complemented in certain applications by the US Navy Navigation Satellite System. Arctic operations usually require the establishment of special navigation systems; these are costly, and pose severe logistical challenges. The Global Positioning System (GPS) offers considerable promise for ocean mappers: by 1992, its network of 24 satellites should be in place, delivering continuous and accurate fixes worldwide to operators with relatively simple and inexpensive receivers.

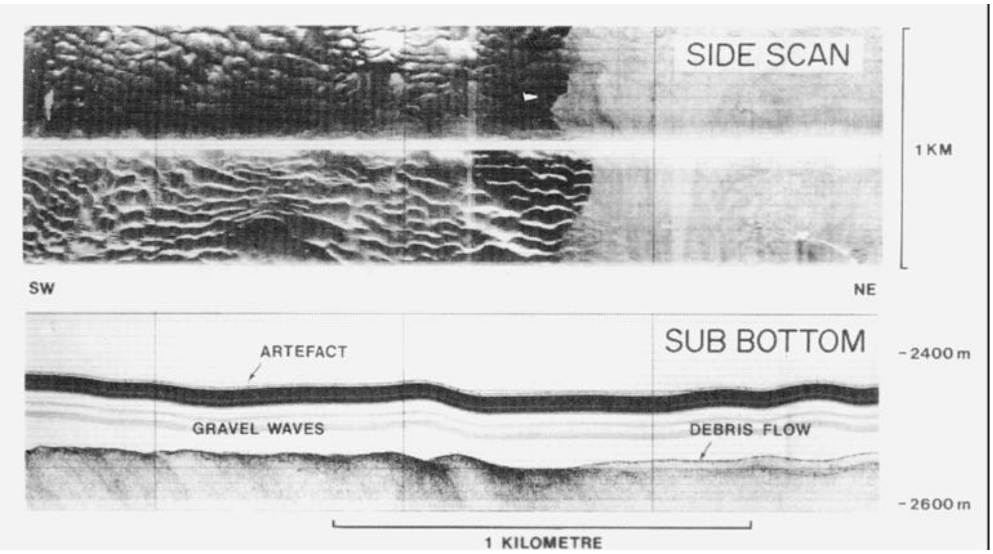


Fig. 4. The upper part of this figure B a sidescan record from the Laurentian Fan at a depth of 2500 m. It was obtained with SeaMARC I, which is towed near the seafloor to obtain high resolution images over narrow swaths. The lower part of the figure is a seismic reflection record obtained simultaneously to show what the shallow sediment structures look like (the artefact is produced by SeaMARC to indicate how high above bottom the towed body is 'flying'. The record show giant gravel waves on the seabed (left) overlain by a thin muddy debris flow (right). The gravel reflects acoustic energy well, and thus appears much darker than the mud, which is a poor reflector. Images such as these are an aid to selection of deer, sea cable routes. (From Piper et al, Geology, v. 13, p 538-541)

Recent experience

Over the last five years, staff of the Atlantic Geoscience Centre, in collaboration with their colleagues in the Canadian Hydrographic Service (CHS), have been experimenting with a variety of techniques that may provide us with the means to map the ocean in the next decades.

A series of cruises between 1982 and 1984 with Lamont-Doherty Geological Observatory used the SeaMARC I 5-km swath deep water sonar system to map in detail several selected small areas of the continental slope off Labrador, Newfoundland and Nova Scotia (Figure 1). These operations were directed mostly at the identification of submarine landslides. In conjunction with this work, scientists from the Oceanography Department of Dalhousie University developed the CHIRP sonar, which transmits a multi-frequency acoustic pulse to obtain improved imagery of sub-bottom features.

GLORIA (Geological Long Range Inclined Asdic) is a towed sidescan sonar system that measures and records acoustic backscatter from sea floor swaths that are up to 60 km wide. In the 1970's, the British Institute of Ocean Sciences imaged some selected strips of seafloor on the Scotian and Newfoundland Margins with GLORIA (Figure 1). The observations were not digital, so they were not amenable to enhancement with modern techniques for signal and image processing. In 1987, there was an opportunity to map about 60,000 square kilometres of the continental margin off western Nova Scotia using a digital GLORIA system. This survey was carried out in collaboration with the US Geological Survey; for the first time, it revealed details on the topography and sediments of the continental rise in this area.

In 1986, again in cooperation with U.S. agencies, SEA BEAM was used to acquire the first detailed deep-water bathymetric map on the eastern Canadian continental margin: about 4000 square kilometres were mapped on the Laurentian Fan, which is the major deposition area for continental material that is eroded from the region drained by the St. Lawrence River.

To complement exploration work undertaken by the petroleum industry, the Frontier Geoscience Program of the Geological Survey of Canada has supported the use of other techniques for mapping deep offshore geology. Seismic reflection and refraction have imaged structures down to 60 km in the crust and upper mantle: both techniques use high pressure air to emit large impulses of acoustic energy from surface-towed airguns; the reflection method uses a hydrophone streamer, which is a listening device towed behind the vessel, to measure the time taken by an acoustic impulse to travel down to and back from reflective interfaces between buried sediment layers; in the refraction method, the listening device is temporarily implanted on the ocean bottom, and measures the time taken by an impulse to travel horizontally through the sediment layers (Figure 5).

Detailed aeromagnetic surveys have been mobilized in a number of areas in order to extrapolate known land geology into the offshore, to corroborate seismically-derived estimates of the depth and extent of sedimentary basins on the continental shelf (which are potential sites for concentrations of gas and oil), and to identify sea floor spreading anomalies for plate tectonic studies.

Bathymetric mapping in the Arctic has been a staple of the CHS mandate for many years, relying on icebreakers or strengthened ships to carry out isolated track soundings or systematic surveys in many parts of the inter-island channels. On the polar ice, numerous spot measurements of water depth have been recorded, using through-ice sounding equipment transported by helicopter (an expensive and slow way of collecting data!). This work can be complemented to some extent by operations on the Ice Island (Figure l), which provides an offshore base for helicopter missions, as well as a platform for deploying sounding and seismic equipment. In inter-island areas inaccessible to

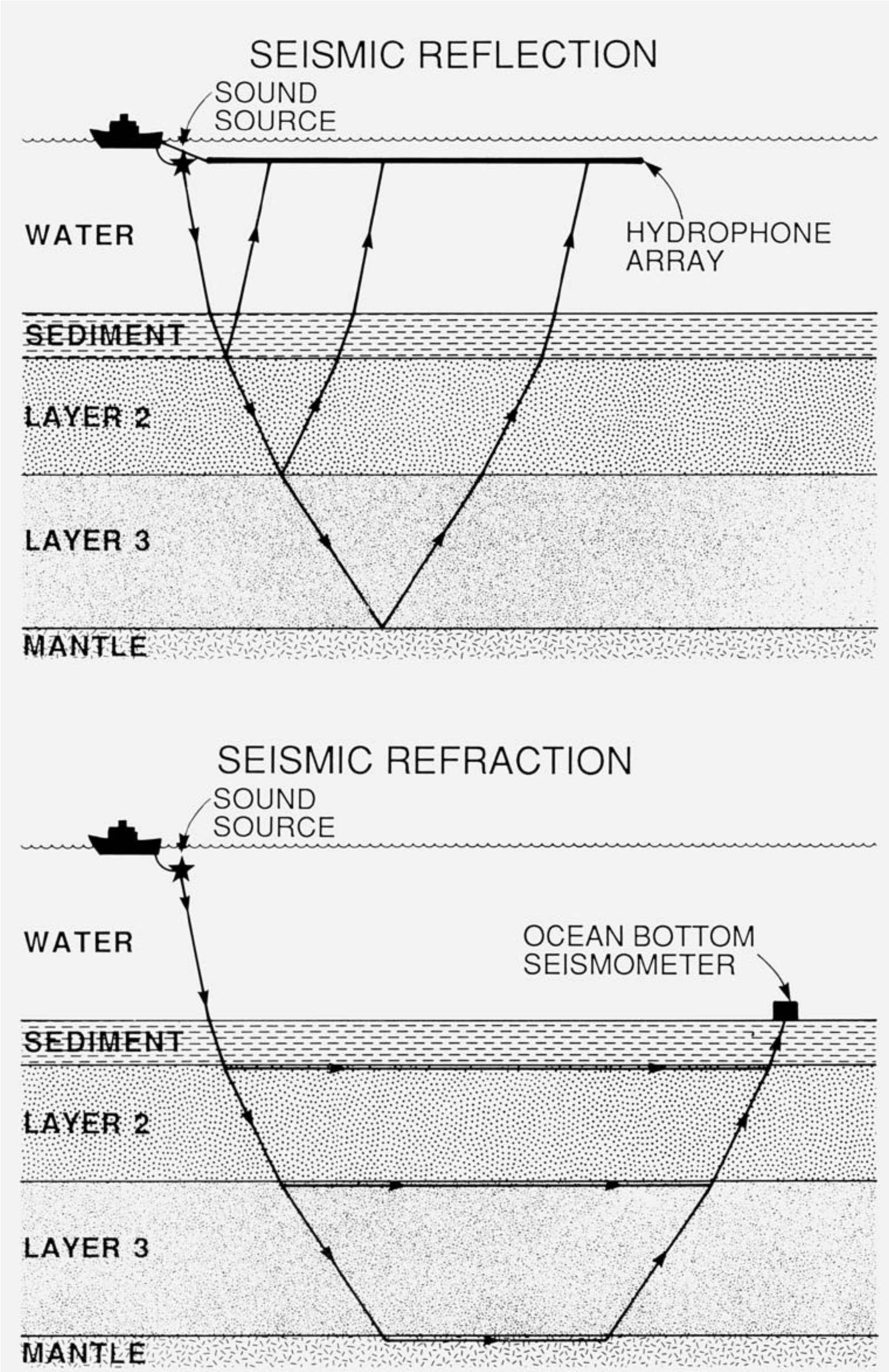


Fig. 5. Seismic reflection and refraction: complementary techniques. Both utilize a sound source to create acoustic waves that penetrate the seafloor. The reflection technique uses an array of listening devices towed near the surface, and measures the times taken by the acoustic waves to travel down to, and back from, the interfaces that separate buried sediment layers. The refraction technique uses a listening device on the sea floor, which picks up the sounds that have travelled along the sediment layers. These readings permit a seismologist to calculate sound velocities through the various sedimentary layers. The velocities can then be combined with the reflection observations to calculate the thickness of the layers.

large vessels, and where temporary open water leads permitted such work, AGC geologists have in recent years deployed small helicopter-portable craft on local expeditions to undertake mapping and sediment sampling.

The future

Mapping of Canada's ocean floor over the next few decades will require the close cooperation of industry, government agencies and universities. Development of new techniques for ocean mapping has historically begun in the academic community, and Canadian universities continue to be a source of innovation in ocean mapping. Government agencies have the experience of managing multi-purpose mapping programs, and of collaborating with universities in developing scientific and technical spin-offs from such programs.

There are opportunities for Canadian industry, with its existing reputation for petroleum-related surveys, to move into the new fields of resource and cable route mapping in overseas markets; these markets can be expected to grow as more coastal nations begin to appreciate the value of the new offshore resources bestowed upon them by the UN Convention on the Law of the Sea.

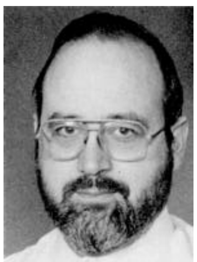
We anticipate that over the next two decades, all of the deep water areas adjacent to Canada's east and west coasts will be mapped with swath mapping systems providing both bathymetry (such as obtained with SEA BEAM) and acoustic backscatter (such as obtained with SeaMARC). By then, polar mapping systems should have progressed to the point where we can routinely deploy a mix of surface and under-ice platforms for detailed measurements of water depth in permanently ice-covered waters.

Within a similar time frame, the more detailed geophysical mapping of the offshore should also be in hand. Aeromagnetic surveys will complement the extensive sets of shipboard data collected to date; given the promise of present techniques, airborne gravity mapping may also become a reality over permanently ice-covered waters. There will be a dense grid of seismic reflection profiles, and good coverage of both deep seismic profiles and reconnaisance wells.

Complementing these field activities will be the development of facilities to handle and display the vast quantities of digital data arising from such a mapping program. With these laboratory tools installed on new generations of powerful computers, scientists will be able to manipulate large, complex data sets and to interpret them with unprecedented ease. Only then will our understanding of the geological resources of the deep sea begin to approach the knowledge levels that we achieved on land several decades ago.

Vertical acoustic sweep systems - A new capability for the Canadian Hydrographic Service

R. G. Burke



R. G. Burke

Iutroduction

THE legislated mandate of the Canadian Hydrographic Service (CHS) is to chart Canada's navigable waters to ensure the safety and efficiency of marine transportation. The Canada Shipping Act, under the Charts and Publications Regulations, requires that every vessel over 100 tonnes operating in Canadian waters should have on board and use the latest editions and largest scale Canadian Hydrographic Service charts that apply to the area being navigated.

The past few decades have seen the shipping industry undergo a dramatic evolution. Tankers, bulk carriers and general cargo vessels have steadily increased in draft and tonnage. Many new and unique vessels have been designed and built for diverse applications such as transporting oil rigs and deep ocean mining. State-of-the art navigation systems now allow the ship's navigator to continually and accurately obtain the position and speed of his vessel at all times.

In most instances basic economics dictate that ships be larger in order to make commercial operations profitable. Operations, in turn, must be geared to maximize cargoes and minimize time in port. These same economic pressures also come to bear directly on shipowners and masters to compromise the traditional underkeel safety margins. As these safety margins shrink, the mariner is forced to rely more and more on hydrodynamic engineers in their predictions of vessel motion under a wide variety of operating conditions and the competence of hydrographers and the accuracy of their measurements that are used in producing a chart.

The Canadian Hydrographic Service (CHS) has always been actively aware of the ever-changing demands as a result of the developments in the marine community. In addition, the CHS has always utilized the most up-to-date and accurate survey systems available. From an international perspective, the CHS has gained a reputation as being one of the most competent and technologically advanced hydrographic organizations in the world. In order to keep abreast of requirements, the CHS has endeavoured to develop and implement new survey techniques that employ state-of-the-art technology.

One of these technologies, the vertical acoustic sweep system, was first acquired by the Canadian Hydrographic Service in 1983. The sweep system provides our Hydrographers with the capability to routinely carry out detailed 100 percent bottom coverage surveys of critical navigation areas such as dock sites, dredged channels and harbour approaches.

An echo sounder consists of a transmitter, receiver, transducer, graphical recorder and timing device. An electrical pulse from the transmitter is converted to an acoustic pulse by the transducer. The pulse travels through the water at about 1500 m/s, is reflected by the sea bottom, received by the transducer, and converted back to an electrical signal before passing to the receiver. The timing circuit measures the time interval from the moment of transmission until the echo is received. This time is divided by two to determine the time for travelling one way. The transmit pulse, delay and echo are transferred to a graph calibrated directly in water depth.

The vertical acoustic sweep system is a specialized sounding system that may consist of 4 to 96 transducers arranged in a linear array to give 100 percent bottom coverage in water depths from a few metres to 100 m. Most of the systems in use give 5 to 30 m. of coverage. Depending upon the level of sophistication, the system may have a very complex computer-based logging and navigation system as is currently used in CHS's newest sweep vessel, the *FCG Smith* or be very simple with a graphical output on a conventional echogram.

Historical Background

One of the first investigations into the use of sweep systems with the CHS com-

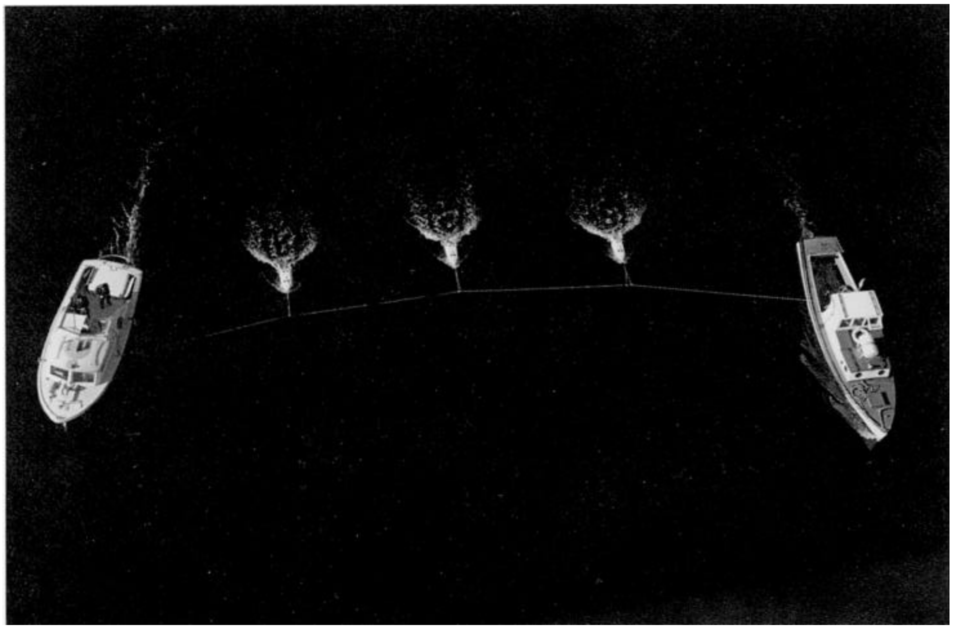


Fig. I Experimental Sweep System utilizing standard ED0 9040 echo sounders.

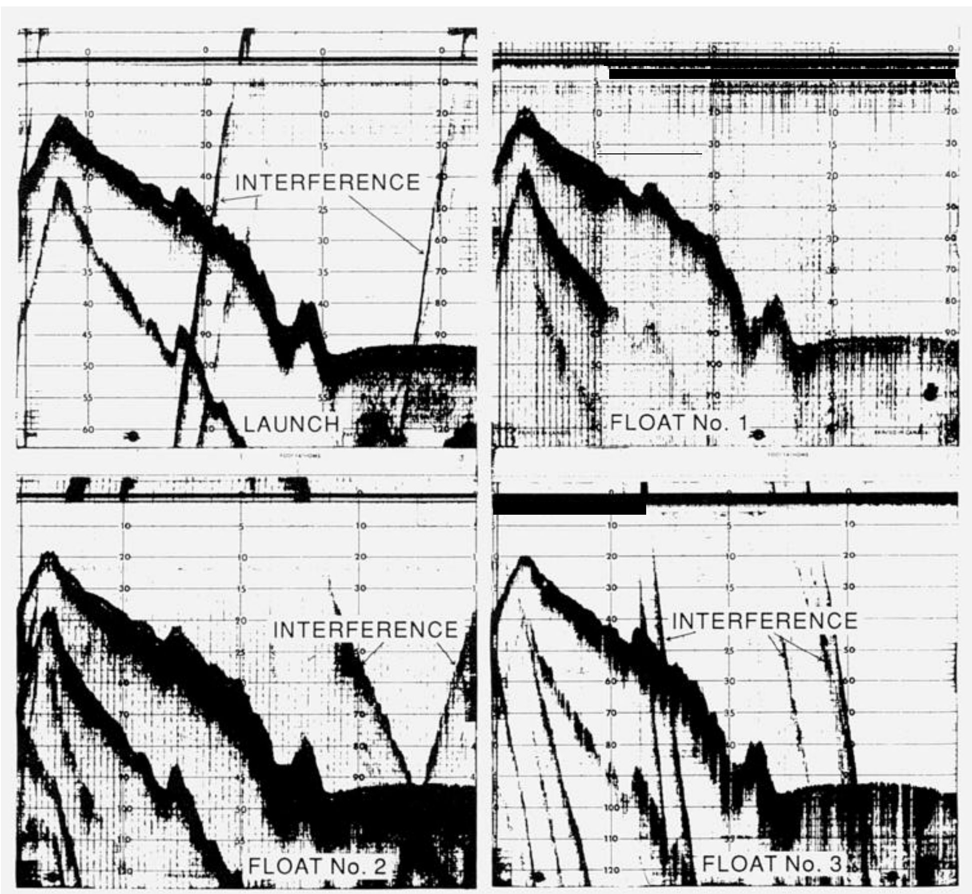


Fig. 2 Echograms from the experimental sweep system.

menced during the mid sixties. A prototype system was configured utilizing two survey launches and four conventional echosounders. One transducer was installed in the master launch with three transducer-equipped floats being towed at evenly spaced intervals on a line kept tight by the slave launch (Figure 1). A hydrographer on the master launch operated the four echosounders. Extensive testing was carried out with the system; however, its operation was very demanding and it proved difficult to manoeuver the launches in restricted areas. Furthermore, the system was prone to a high degree of crosstalk between transducers which, in turn, made the accurate interpretation of the echograms very difficult (Figure 2). Crosstalk is a situation where acoustic pulses from one transducer are picked up by another. The resulting echo grams on the echo sounders receiving two or more signals can indicate false bottoms. (Figure 2).

During the early seventies a Raytheon 719 Channel Sweep System was acquired. In order to overcome the difficulties in deploying an array of transducers, a floating boom that could be used from a small vessel was developed (Figure 3). While this system was far more compact and much easier to deploy than its predecessor, it had a number of limitations that made it difficult to extract the pertinent depth information. Consequently the system was never operationally deployed.

The First System

No further investigation into vertical acoustic sweep systems occurred until 1981. In the interim, manufacturers in both Europe and the United States had made significant improvements in sweep technology. During the fall of 1981 funds from the Ministry of Transport Research and Development Transportation Program were made available to acquire a sweep system for use in the Arctic. The acoustic sweep system was introduced in response to the TERMPOL Code that was prepared by the Departments of Transport and Environment. It was implemented to govern the conditions under which oil tanker berthing facilities could be operated, especially in the Arctic. It is a stringent set of regulations which, in part, dictate that all approaches, dock sites and turning basins be swept to ensure that no hazards are present.

In the fall of 1982 a contract was let to the Danish firm of Navitronic AS to supply the Canadian Hydrographic Service's first vertical acoustic sweep system. After an extensive study of existing mechanisms for the deployment of transducers, it was decided to design and fabricate the boom structure at the Bedford Institute of Oceanography. Navitronics supplied the remainder of the system including the sounding, data logging and post processing equipment and software. The operational requirements of the arctic system dictated that it be deployable from a conventional vessel and that it be modular to the point where the largest single component could be transported in a small aircraft such as the Twin Otter.

A boom was fabricated using standard three-metre sections of radio-mast and two Laser sailboat hulls (Figure 4). The structure was pulled by an A-Frame attached to the front of a survey vessel. Standard automative trailer hitches were used to attach the floats to the boom and boom to the A-frame. Guy wires were used to keep the structure perpendicular to the vessel. The 18 transducers were fitted with fairings to reduce water drag and attached to two-metre long struts. An elastic cord and pivot block were used to attach each strut to the boom. This mechanism allowed for variable spacing of the transducers and "kick back" in the event the transducer or strut encountered a solid object.

A transducer has a given measurement angle (i.e. beam width) that defines its foot print on bottom at a given depth. That footprint is directly proportional to water depth. To ensure 100% bottom coverage it is important that the transducer spacing be no greater than the width of the footprint in the shallowest depth to be encountered. Consequently, the operator could set the transducer spacing to ensure 100% bottom coverage in the survey area.

The system was normally trucked to the survey site. Two men required 8 to 10 hours to assemble or dismantle the boom mechanism. Once operational, the system surveyed a 30-m swath on each pass. The survey speed never exceeded four or five knots with the shallowest sounding from each of the 18 transducers being logged on magnetic tape every 5 m. In addition to the depths, time, boom orientation and position sensor data were also recorded.

Fig. 3 Raytheon 719 Channel Sweep System using a boom system developed by the Canadian Hydrographic Service.

Fig. 4 The CSL Tudlik with a 30 metre boom

A portable HP9836 based processing system was normally carried to the site for "quick look" processing to ensure 100 percent bottom coverage had been obtained and validate the collected data. Final and more detailed processing was always carried out at the Bedford Institute of Oceanography using the larger and more powerful HP1000 computer system.

The first operational deployment of the vertical acoustic sweep system came in September 1983. It was used to carry out a detailed survey of the 48 kilometre long channel of New Brunswick's Miramichi

River. On this survey it is estimated that over 100 million depth measurements were made, of which 1.5 million were logged for subsequent data processing!

Before the first project was completed, the system's capabilities were clearly demonstrated. Several large boulders in the dredged channel that had been missed by conventional survey techniques were detected by the sweep system. It has been successfully deployed on many projects in Nova Scotia and New Brunswick. In a demonstration of its arctic capabilities, the system was used to carry out a survey on the southern coast of Ellesmere Island near the community of Grise Fiord during the summer of 1984. In addition, the system was loaned to Public Works Canada along with training and support from the CHS for a number of their projects. They, in turn, have recently acquired a system for their own use.

The FCG Smith

The success of the "transportable" system provided a catalyst for a second and larger dedicated sweep vessel. The goal was to acquire the most modem, efficient and capable sweep system in the world. A contract for the construction of the *FCG Smith* was awarded to Georgetown Shipyards in Prince Edward Island during January 1984. A catamaran hull was selected to provide a high degree of stability and manoeuverability. The principle particulars of the vessel are:

Overall length	34.8 metres
Beam	14 metres
Draft	2.1 metres
Gross Tonnage	429.7 tonnes
Speed	10.5 knots
Shaft Horsepower	2x400HP
Swath Coverage	42 metres
Crew	11

The *FCG Smith* is the largest catamaran ever built in Canada.

The vessel (Figure 5) is named after Frank Clifford Goulding Smith who served as the Dominion Hydrographer of the Canadian Hydrographic Service from 1952 to 1957. A 33-channel Navitronic sweep system has been installed on the vessel. The sweep system's computer is also interfaced to the auto-pilot and may be used to steer the vessel along predetermined survey lines. While a number of positioning systems have been used with the vessel, the Krupp Atlas Polarfix is utilized on most projects because of its high inherent accuracy.

Polarfix is a range bearing laser positioning system. A specially designed prism is fixed to the vessel's mast and a shore-based laser tracking unit measures the range and bearing to the prism. A telemetry link transmits the range and bearing data to the ship and the sweep system's computer computes the position of the vessel and provides this information for steering along predetermined survey lines. Polarfix has an operational range of 5.0 km and an accuracy of ± 1.0 m.

A self-contained computer center on the *FCG Smith* houses a MicroVax II computer and associated peripherals for on-site processing of data. The data processing software has been written by Hydrographic staff at BIO. Some 300,000 to 500,000 depth measurements are logged during a normal survey day. A comprehensive suite of programs allows the data processor to create survey track and swath coverage plots, select the critical shallow depths for the field sheet and interactively edit any erroneous data. The final field sheet, which is eventually used in the production of a nautical chart, is normally plotted at a scale from l/1,000 to l/5,000, and will only portray 0.5 to 2 percent of all the depth data that were initially gathered.

Since the *FCG Smith* was commissioned in 1986 the vessel has undertaken numerous survey projects throughout the Atlantic Provinces. During the past two survey seasons it is estimated that the *FCG Smith* has logged and processed over 50 million depth soundings from areas such as Yarmouth, Liverpool, Halifax, Sydney, Port-aux-Basques, Charlottetown and the Miramichi.

With the introduction of the *FCG Smith*, the "transportable" system was transferred to the Central Region of the CHS, Burlington, Ontario, where it is used on a routine basis for sweeping harbour approaches, canals, basins and dock sites. Together, the two systems have greatly enhanced the capability of the CHS to fulfil its mandate of providing accuracy and up-to-date charts of Canada's navigable waters.

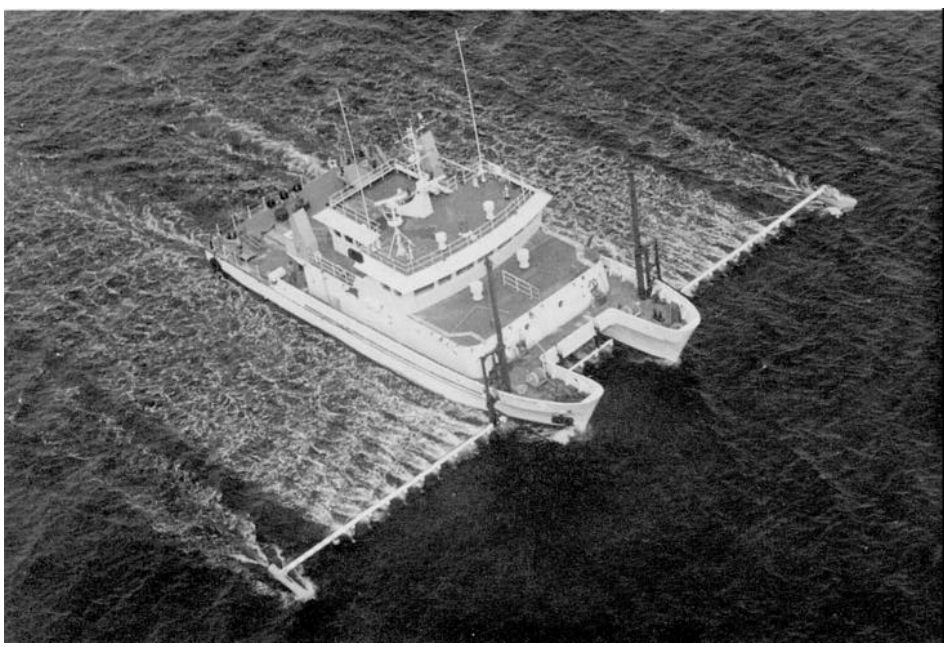


Fig. 5 The CSS FCG Smith.

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Electronic Chart Developments

S. T. Grant

S.T. Grant

Introduction

A nautical chart is a map that shows the positions of islands, shallow water areas, deep channels and the coastline and contains a wealth of other information. It is used by mariners to safely and efficiently navigate their vessels. The Electronic Chart (EC) uses the advances in computer and video display technology of the past decade (eg. video games) to present the information normally found on the paper nautical chart along with other useful information such as ship's course and speed and radar on a high resolution video display located on the ship's bridge. It offers many advantages over the conventional paper chart but to achieve the full potential a number of major technical and administrative problems will have to be solved.

The EC is the culmination of many years of efforts to centralise and clearly display in real time, all the information the mariner needs to know. In the early days, as devices such as logs (for measuring ship's speed), gyro compasses, radars and electronic positioning systems (devices that use special radio waves to determine a ship's position at sea) became available they were clustered on the bridge where they could be seen at a glance. However, the chart always remained as a separate item and there was always a delay between obtaining a position, plotting it on the chart and then extracting the necessary information (eg. water depth) for comparison with the appropriate device (eg. echo sounder). This took so long that while the mariner always knew where he had been, he never knew exactly where he was at that instant.

During the seventies rapid advances in computer and video display technology resulted in displays that showed the vessel's position relative to a simplified coastline. The high resolution colour displays of the eighties resulted in better prototype ECs that were starting to approach the quality of the nautical chart. Mariners who used these few rudimentary systems were generally impressed with the fact that for the first time they could continuously and in real time have a bird's-eye-view of their ship in relation to nearby charted features (eg. coastlines). They also were able to see their past ship's track plotted in far more detail than they could ever do manually.

Electronic Charts are only as good as the navigation systems used to determine the ship's position. Using this information the EC can accurately locate the ship's symbol on the display relative to charted features. If the position is in error the symbol is in the wrong place and the mariner may think his vessel is safe when in fact it may be in danger of running aground. This problem will be solved to a large extent when the new U.S. Satellite positioning system - Navstar Global Positioning System (GPS) - becomes generally available in the early nineties. It will provide world-wide continuous positioning accurate to between 10 and 100 metres. The mariner has never had this capability in the past and an EC will be necessary to exploit its full potential.

However, even with GPS, there will be times when the mariner will want to check the accuracy of his ship's position. ECs are therefore being designed that combine the chart display with the radar image. If the radar image matches the charted shore line the mariner will have immediate conlirmation of the accuracy of his ship's position.

The fully developed EC will have a profound impact on marine navigation in Canada and throughout the world. It will give seafarers the full benefit of the revolutionary positioning capabilities of GPS. Indeed, the capabilities of GPS cannot be fully exploited without a continuously updated automatic display. The EC will be particularly important in congested harbors, in low visibility such as fog and snow or when ice has removed the buoys and markers. It will help large tankers to berth safely, will enable ferries to remain on schedule and will greatly simplify navigation for the growing number of pleasure boaters.

The EC will have a special role in the Arctic. By superimposing the ship's radar image of the ice edge on a chart background, it will enable the mariner to see readily where the ice is blocking a navigation channel and to distinguish ice-edge echoes from coastline echoes. In addition, the EC provides a cost-effective means of supplying chart data to the limited number of Arctic users without having to actually print the paper chart.

The EC will enable shipping to move under conditions where at present it would remain tied up and to navigate more safely and to tighter schedules at all times. This will reduce shipping costs, and, once proved, will also reduce insurance premiums. It will minimize the risk of grounding leading to loss of life, property damage and pollution with its high clean-up costs.

The heart of the EC is the digital data or EC Data Base (ECDB) it uses to draw the various chart features on the display. To date EC manufacturers and mariners have been digitizing nautical charts themselves for their systems. In the (near?) future, when GPS becomes available and the technology improves the demand for digital chart data will increase dramatically. Since Hydrographic Offices are responsible for producing the nautical charts the responsibility will naturally fall on them to supply this data. Most of the Hydrographic Offices around the world presently have very little of their nautical chart information in digital form. Experience with existing data bases tells us that long before the full ECDB is available the problem of keeping it up-to-date will far outweigh the task of getting old data into it. The problem is exacerbated by the fact that, unlike land based data bases where the users can have easy access via the phone lines, etc. the users of the ECDB will be at sea most of the time. Special internationally agreed upon data exchange techniques and data formats therefore may be needed for both the original data and updates.

A number of activities that are presently taking place within Canada and internationally are described in the following pages.

Precise Integrated Navigation System (PINS)

With one notable exception most EC activity in Canada has been in the Canadian Hydrographic Service (CHS), Department of Fisheries and Oceans. The exception is the Precise Integrated Navigation System, an EC developed by Offshore Systems Ltd., North Vancouver, B.C. They first developed their EC to help ships navigate in the ice-covered Beaufort Sea during oil exploration. They began marketing it in 1986 and presently have systems operating on both coasts of North America as well as on Coast Guard icebreakers in the St. Lawrence River. They are now working on a new EC system, the Shipboard Integrated Navigation and Display System (SINADS), which will integrate radar with all the existing features of PINS.

The CHS Electronic Chart Testbed

The CHS EC program was started in the late seventies and was coordinated by Mike Eaton, Head, B.I.O. Navigation Group until just recently when he retired. The CHS EC program can be broken down into the following interrelated projects:

- the Electronic Chart Testbed and EC Specifications
- Electronic Chart Data Base (ECDB) Studies
- Display Design and Advanced Features
- Data Exchange Techniques and Formats

The EC Testbed development was started in 1984:

"1. To develop specifications for the ECDB to be produced by the CHS and

2. To investigate the effect of the EC on safe navigation."

(Eaton, 1987)

One main design requirement was that the Testbed should be flexible. Flexibility, that is, the ability to change the display, demonstrate different optional approaches to EC problems, etc. were, and still are, more important for the Testbed than speed, user friendliness and other characteristics of operational systems. In order to achieve the necessary flexibility it was also decided to use the Universal Systems Ltd. (Fredericton, N.B.) Computer Aided Resource Information System (CARIS) as the basis for the Testbed because it had the geographic information management infrastructure necessary to manage the very complex EC features and also because CARIS was already widely used throughout the CHS. Digital charts had already been created using CARIS.

At present the EC Testbed consists of a modified CARIS system and Radar and Positioning subsystems. The CARIS system consists of a Digital Equipment Corp. microvax II computer with 5 megabytes of

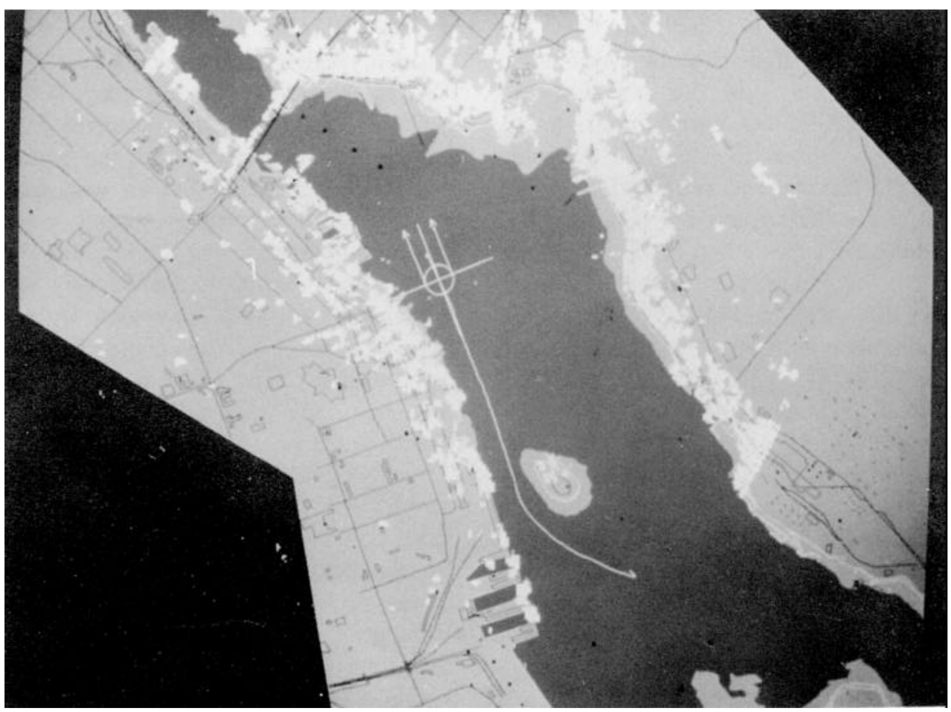

Fig. 1. Electronic Chart Testbed display of Halifax Harbour with radar. Ships symbol carries parallel index bars used to plot clear passage ahead The radar is offset 30 m east from chart because ship is positioned by GPS NAVSTAR on new satellite datum whereas chart data was on old North American datum at that time.

memory, two 70 megabyte disks for system software and chart data, Tektronix 4225 and Digital Equipment Corp. GPX Graphics terminals and an alphanumeric terminal. The Radar subsystem consists of a custom digitizer developed by McGill Radar Laboratory, McGill University, Montreal, using a Digital Equipment Corp. PDP 11/73 computer and a Racal/Decca model 970 3-cm radar. The positioning subsystem changes with the circumstances but has used Loran-C, GPS and Mini-Ranger.

The EC Testbed has been tested and demonstrated in Halifax Harbour each year since the start of the project (See Figure 1.) and has yielded much useful information. It has taught us a lot about how different EC features can and cannot be displayed and how the data must be organized to deal with the variety of ways the mariner will have to use it. Feedback from the many mariners, cartographers, hydrographers, managers and others who have seen the demonstrations, both in real life and via the several video recordings that have been made, have also been very useful. Indeed, Mike Eaton, who managed the EC Testbed project, was also on the International Hydrographic Organization (IHO) Working Group responsible for producing the IHO EC Specifications (IHO, 1987) and results from the EC Testbed tests and demonstrations therefore contributed significantly to the definition of those specifications. In recognition of the leading role of the CHS in EC generally and with the EC Testbed in particular, Canada was invited to participate in a major international test of electronic charts in the North Sea in October 1988.

ECDB Studies

The need for a CHS hydrographic digital data base and data base management system has been recognized for some time. A number of studies have been carried out and a pilot project is now underway to create a prototype data base management system for the CHS. It is generally believed that a separate paper chart data base will be derived from the verified hydrographic source data base. Indeed, digital chart files created interactively using CARIS already exist for over 100 CHS charts. The question that the EC program raises is: Will the ECDB be derived from the paper chart data base, will it exist in parallel and obtain its data directly from the hydrographic source data base or will the paper chart data base be derived from the ECDB? Another view is that the hydrographic source data base and its management system will be sophisticated enough to serve simultaneously as source data base, ECDB and paper chart data base. It is also unclear at this stage what structure the ECDB will have, how it will be integrated with the information in the Tide Tables and Sailing Directions and whether it will be created and kept up-to-data by the CHS or by a private company under licence.

When the EC dam is transferred to a shipboard EC it will have to be reorganized to fit the manufacturers software system. The onboard data base is called the Electronic Navigation Chart (ENC). Many mariners and hydrographers feel that electronic charts should always display a Minimum Data Set for Safe Navigation which can never be removed from the EC display. It would contain features such as:

- ship's symbol
- ship's danger contour (ie. contour of depth equal to or slightly deeper than the ship's draft)
- coastline and low water line
- buoys, lights, beacons, ranges, etc.
- bridges, overhead cables, etc.
- prohibited anchorage areas
- some topography (eg. land contours)

However, there are others who feel that this is far too much information for critical situations.

Display Design and Advanced Features

A small but interesting study was carried out under contract to study the effects of colour and display clutter on the user's ability to extract important information. The study concluded that different colours were needed for the EC compared to the paper chart (eg. light blue for deep water rather than white) and that an exact reproduction of the paper chart was far too cluttered for a video display. Text had to be about twice as large as on the paper chart (symbols were about 1.3 times larger) and it was more suitable to have the text suppressed and selectively displayed on demand (eg. buoy characteristics). Many symbols presently used on the paper chart were found to be unsuitable for the EC. Also, a number of exotic suggestions were found to be completely unacceptable. For example, buoys that flashed the same colour and rate as the real buoy were found to be too distracting.

Work is also being done in other areas such as generalization and tide adjusted depths. Generalization is the process of smoothing the wiggles along a coastline as the scale is decreased. The eye does this automatically as you step back from a chart. The problem of doing this automatically by computer processing is not trivial. A number of algorithms have been devised that will work reasonably well on idealized data sets but not so well in the real world. The problem is further complicated by the fact that text generally does not change scale and therefore may overlap other features as the scale is decreased. Also, some text is not wanted at very small scales. Similar problems arise with symbols such as buoys, current arrows, etc.

In most sea ports the depth of water at any particular spot changes as the tide rises and falls. Nautical charts portray the depth of water at low tide. Studies are underway to determine how the depth being shown on the EC can be corrected to account for the height of tide.

Other advanced topics such as Artificial Intelligence and Expert Systems are also being discussed in connection with the EC.

Data Exchange Techniques and Formats

These topics have been studied for some time by the CHS and other agencies desiring to transmit geographic information efficiently, accurately and quickly. In the recent past the main medium for exchanging data was magnetic tape and the data being transferred was relatively simple. However, with the advent of Geographic Information Systems, distributed data bases and the like, it has become necessary to transmit not just the data but the structure or topology of the data base as well as a plethora of other information. It is important for these systems to know the relationships among the various elements such as the fact that water is to the left of a line and land is to the right, etc.

The media of dam exchange are also changing. Far more data is transmitted electronically via the telephone system and satellite links today than in the past and new high density devices such as compact disks are becomming more popular. These new media are also able to handle much larger volumes of data at much faster rates and with fewer errors.

International Electronic Chart Activities
The International Hydrographic Organization (IHO), Monaco, recognized the importance of Electronic Charts to the future of hydrography in 1986 when it established its Committee on Electronic Chart Display and Information Systems (COE). They felt that a COE was necessary because:

1. Increasing emphasis by industry, and an increasing diversity of Electronic Chart Display and Information System (ECDIS) equipments are being made available to the mariner;
2. Of recognition by the International Maritime Organization (IMO) of the potential for increased safety in navigation of an ECDIS conforming to appropriate standards, and in particular the establishment by the IMO Sub-Committee on Safety of Navigation of a small Study Group to consider certain ECDIS matters;
3. The development by the IHO Committee on the Exchange of Digital Data of a format suitable to "parent" an exchange format for ECDIS data; and
4. The publication of a comprehensive study on ECDIS by the North Sea Hydrographic Commission which specifically recommended that an IHO Working Group on ECDIS be established.

Two ad hoc Working Groups were formed for special projects.

IHO-COE and Other ECDIS Specifications
The first Working Group, under the Chairmanship of RAdm. van Opstal, R. Neth. N., who had been Chairman of the North Sea Hydrographic Commission's study on ECDIS was asked to prepare a working paper on the content and characteristics of the ECDB. Canada was represented by M. Eaton on that group. He and the other 9 members have produced one of the most comprehensive descriptions of an ECDIS available - the IHO "Second Draft Specifications for Electronic Chart Display and Information Systems". They represent the Hydrographic Oflice view and are based on the assumption that the ECDIS should be the equivalent of the paper chart. A second smaller study with representatives from Canada, U.S.A., United Kingdom and the Federal Republic of Germany is now looking into the problems of updating the ENC.

The U.S. Radio Technical Commission for Maritime Services (RTCM) has also produced a set of ECDIS specifications. While they are very similar to the IHO-COE specifications they tend to reflect the views of users and manufacturers and include one major addition. They define three different categories of ECDIS equipment ranging from large ocean-going vessels to smaller commercial vessels (eg. ferries and fishing vessels) to small pleasure craft (RTCM,1988).

The North Sea Project 1987-88
The second Working Group was established to carry out a project designed to:
- determine the type and level of cooperation necessary between HOs to produce an ECDB
- test how different ECDIS equipment works on an ECDB according to IHO-COE specifications
- test different methods of ENC updating
- demonstrate the potential of the EC to shipping authorities, HOs and other marine interests
- give IHO-COE information about costs/resources needed to establish regional ECDBs

The group is jointly lead by Norway and Denmark. This project, called the North Sea Project 1987-88, was started with a meeting in Copenhagen in June 1987. The participants included Norway, Sweden, Denmark, Federal Republic of Germany, United Kingdom, Netherlands, France and Canada. Finland, Belgium and the U.S.A. were observers. Each of the participants were to digitize one of their harbors and send the data to the Norwegian Hydrographic Service where it would be entered into a specially designed ECDB. The data would later be sent to the 10 manufacturers who have been selected to take part in the month long sea test onboard the Norwegian Survey Ship *Lance* in October, 1988.

International Activities in Data Exchange Techniques and Formats
In the early eighties the IHO recognized the need for a common international data exchange format for the exchange of digital chart data when it created the Committee on the Exchange of Digital Data. They developed a preliminary standard based on magnetic tape being the transfer medium that was endorsed by the IHO member States at the International Hydrographic Conference, 1987. Unfortunately no attempts to use it were made until the North Sea Project got underway. After considerable effort on the part of the organizers it was determined that the IHO approved format was not yet fully enough developed to handle the amounts and types of EC data that were being produced. Since there was insufficient time to upgrade the IHO approved format for the North Sea Project it was decided to use the internal Norwegian Hydrographic Service format instead.

Meanwhile, a number of other data transfer formats were being developed around the world that took advantage of and were consistent with the latest advances in digital telecommunications technology. The Canadian Map And Chart Data Interchange Format (MACDIF), being developed by IDON Corp., Ottawa, and being supported in part by the CHS, is one of the most advanced formats presently available anywhere.

Conclusion
The Electronic Chart is still in its infancy but it is growing up fast. Mariners who have used the rudimentary systems that presently exist are recognizing the improvements the EC brings to both the safety and economic aspects of ship operations and the word is spreading fast. As technology advances and the demand for these systems increases the demand for digital hydrographic chart data will also increase. Hydrographic Offices around the world have a very small percentage of their data in digital form and a tremendous effort is required, not just to digitize the charts, but also to design the data bases, develop the administrative and technical infrastructure (both nationally and internationally) to transfer the data to the Electronic Chart user and, perhaps even more important, to keep it up-to-date. Hydrographic Offices and the various international agencies involved with charting and shipping operations have started to look at these problems but they still have a long way to go. The problem is more difficult because changing technology makes the task somewhat like shooting at a moving target.

Fortunately, most workers in the field recognize the need to be flexible and to keep an open mind at this stage.

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Biological instrumentation for underice studies in the Arctic

A.W. Herman

A. W Herman

DURING the spring months of March-June, landfast ice in Lancaster Sound supports high levels of algal growth on the underice surface. The algae become a food source for zooplankton and provide the seed population for summer phytoplankton growth in the Sound following breakup. This underice growth starts rapidly in April during the onset of 24 hour daylight and is accompanied by large concentrations of grazing zooplankton. Persistent low temperatures maintain a steady ice growth of about 2-3 cm simultaneous with algal growth and, as a result, a profile of the ice layer shows algae distributed throughout the bottom few centimeters of the ice sheet. The most concentrated layer occurs at about 2 cm above the underice surface, corresponding to the late April bloom. Although growth continues into June, increases in air and ice temperatures result in 'sloughing' or falling off of ice algal layers, thereby seeding the waters below.

Measurements of the underice Arctic biology required unique instrumentation to withstand the harsh Arctic environment. A program of instrument development and sampling of underice algae and zooplankton populations in Lancaster Sound, NWT, commenced in 1985 (see Figure 1) as a result of collaboration between the Metrology Division (Physical and Chemical Sciences Branch), Biological Oceanography (Biological Sciences Branch) and the University of Waterloo. Instrument development is the result of team effort; playing key roles were: Don Knox, head of the Instrument Machine Shop and also John Conrad were heavily involved in the design, construction and testing of all our underice instruments; Ted Phillips (our electronics development technician) developed the necessary probe and deck elec-

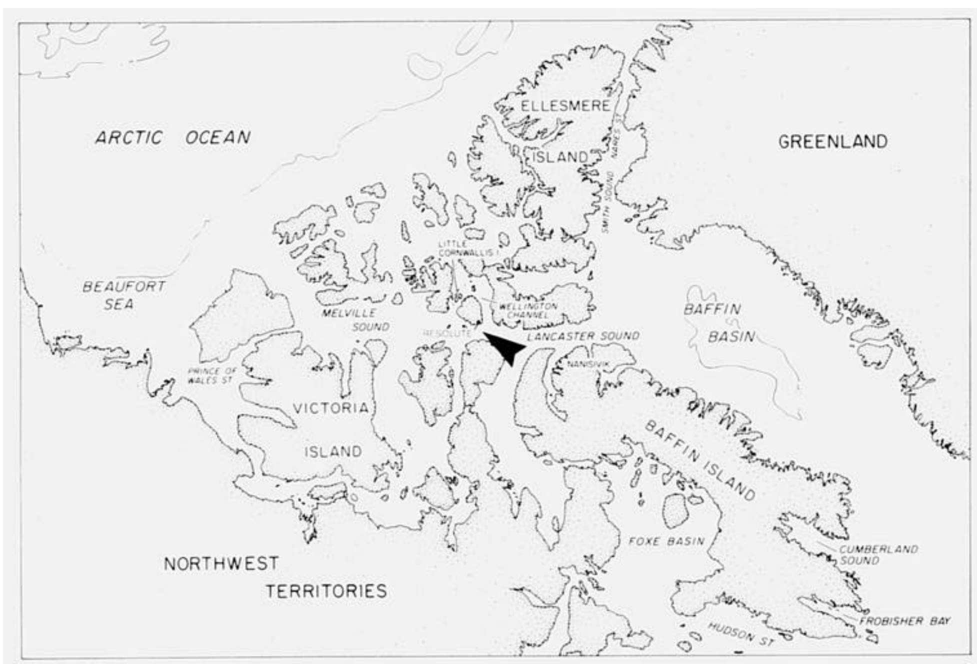

Fig. 1 Eastern Canadian Arctic with arrow indicating area of operations in Barrow Strait and Lancaster Sound

tronics and data links; Michel Mitchell (our physical scientist) developed the data acquisition and computer interfacing while both he and Jeff Spry (our biologist) supervised the field logistics and experiments.

Sampling of ice algae and zooplankton have been traditionally approached by using divers who sample the underice waters by removing ice samples, implanting chambers in the underice surface for the measurement of algal growth or deploying suction devices for capturing zooplankton. The major problem with diver sampling is the contamination of the underice surface by air bubbles and subsequent penetration of air into the porous ice thereby nullifying these measurements. Our approach to developing samplers has been to deploy instruments remotely from the ice surface through ice holes which could be augered in a relatively short time (~2 min). These holes would be relatively small in diameter, about 22-25 cm. The device would be deployed through the ice hole and then made to 'reach out' horizontally at some distance from the hole (~1 m) in order to sample an undisturbed region of the ice.

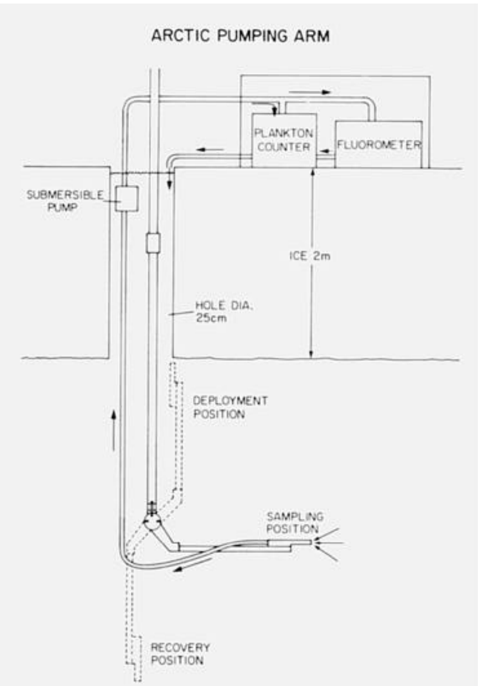

Fig. 2 The underice pumping arm used for sampling zooplankton The operational zooplankton and chlorophyll were accomplished with a plankton counter and fluorometer on the ice surface.

The first device developed to accomplish this type of sampling was the underice pumping arm shown in Figure 2. The sampler arm mounted on a mast is deployed through the ice hole in a folded position. Once clear of the hole, the arm is released by a trip wire pulled from the surface. A tension spring located at the elbow provides the force necessary to rotate the arm which is then locked in the 90° sampling position (shown in Figure 2). The arm can then be moved to the underice surface. When sampling is completed, the trip wire is again pulled, releasing the arm to the 180° position and allowing recovery through the ice hole. The underice arm now provides a vehicle for deploying and carrying various sensors and collecting samples.

The first sampling problem approached was that of measuring zooplankton concentrations within a meter of the underice surface. The underice arm shown in Figure 2 can be easily used as a profiler within a few meters of depth from the ice surface. Water, pumped to surface from a nozzle attached to end of the arm, was filtered in a cod end bucket for later analysis.

The pumped outflow can also be transferred to an electronic zooplankton counter (Herman, 1988) measuring zooplankton concentrations and sizing all animals. A fraction of the outflow was also transferred to a Turner fluorometer measuring chlorophyll concentrations (the indicator of algal biomass) in the near surface water. Both instruments were housed in an insulated box and powered by a portable generator. The entire system was portable and could be transported by snowmobile and sled.

Initial data and results from the pumping arm revealed two startling facts. First, the Arctic copepod Pseudocalanus was highly aggregated in the first 10 cm under landfast ice (Conover, *et al*, 1986) during spring, reaching concentrations as high as 10^6 per cubic meter. Second, the lack of any significant algal concentrations in the immediate upper water layer suggested that these copepods were utilizing the ice algae directly.

The second sampling problem was that of measuring the distribution of algae within the bottom ice layers. Fluorometric techniques usually employed in the oceans were ineffective since algal concentrations were too high and would 'quench' the light signals within the first millimeter of ice layer. Optical penetration of the algal layers with an intense light beam was necessary so that the degree of reflection of light by these algal layers could be used as the measure of these concentrations. The instrument design is shown in Figure 3. An intensive infrared (IR) beam is focused into a thin slice with dimensions 2 mm thick and 2 cm deep (looking into the page, Figure 3) and directed into the ice at an angle of 45°. An algal layer (e.g. at 2 cm depth, Figure 3) will reflect light back into

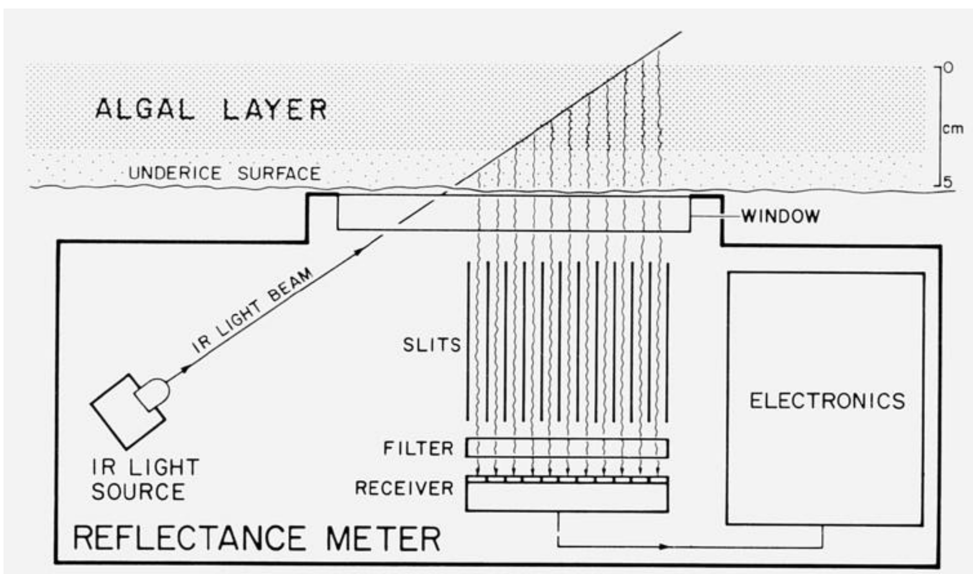

Fig. 3 The reflectance meter used to detect algal layers in the underice surface.

a linear array photodiode receiver which is 'looking at' various depth segments of the ice through a series of aperture slits. The reflection meter measures algal layers remotely and instantaneously while mounted on the underice arm. The device is light, portable and easily transported while providing rapid and wide areal coverage of frozen sea ice.

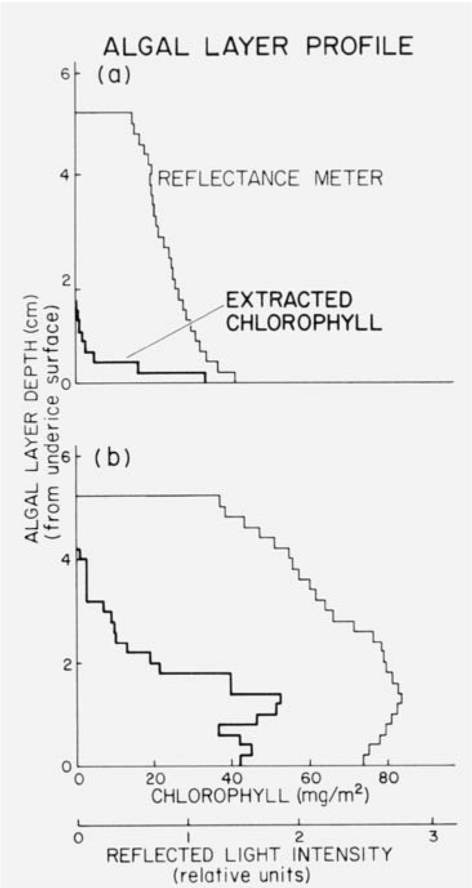

Fig. 4 Algal layer profiles determined by direct chlorophyll assay and by reflectance measurement showing (a) a narrow layer at the surface and(b) a broad layer between 1-2 cm.

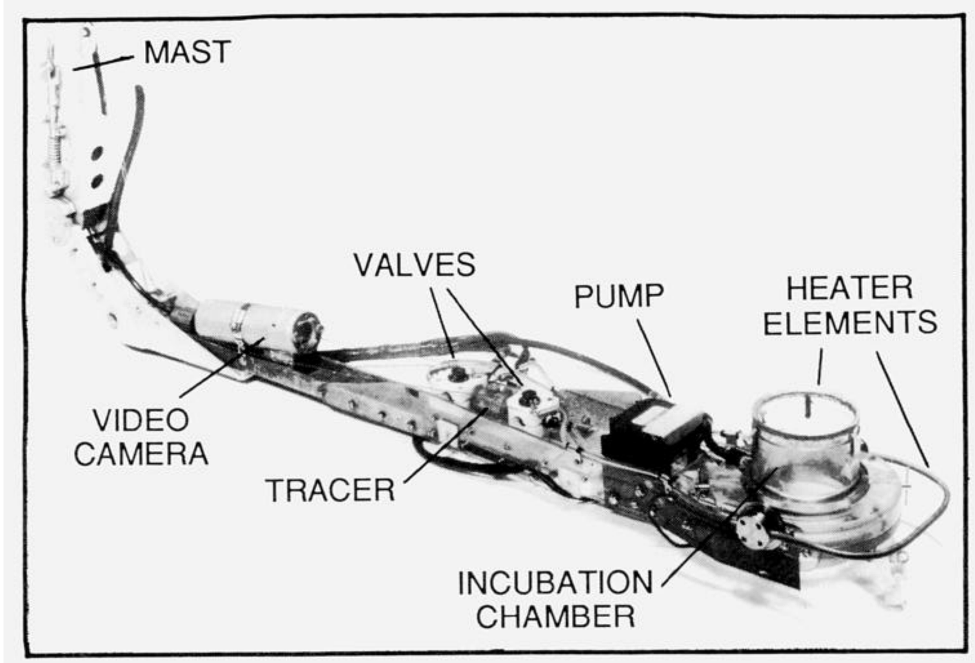

Fig. 5 The underice incubator used for measunng in situ growth rates of the underice algal layers.

Examples of algal layer measurements are shown in Figure 4 which illustrates cases of high and low algal concentrations and an intercomparison between the reflectance measurement and the corresponding algal layer concentrations determined from chlorophyll extraction. Figure 4(b) shows a detected algal layer situated between 1-2 cm. The reflected signal contains both an algal component and scattered light background. The reflected signal can be calibrated against algal concentrations and the reflectance meter can be used in the field to display profiles in biomass units.

The next sampling problem was that of measuring in situ growth rates of algae in the ice. Previous sampling (Schrader, *et al,* 1981) used divers to implant chambers by hammering them into the ice. The divers would then inject a C-14 tracer into the chamber which would be taken up by the algae (over a 1-2 hr. period) at a rate corresponding to their growth production rate. The soft 2 cm layer was then removed by a scraper deployed by the divers and the algae sample returned to surface for analyses. However problems of air bubble contamination still persisted. The measurement depth was too shallow and there was no information on the algal production profile throughout the ice; only the integrated total production was measured.

The underice incubator shown in Figure 5 was developed to overcome these problems. The chamber is deployed on the standard arm; however, it can be implanted into the ice to a depth of 5 cm. This is accomplished by using a heating coil mounted in the upper rim which allows penetration by melting. A small pump injects the C-14 tracer and mixes it uniformly in the chamber. Following an incubation period of about 2 hr, a U-shaped heater element 'carves' out a dome-shaped ice section (shown in Figure 6) containing the incubated core. The entire sample is removed from the ice hole using the standard arm recovery. Rather than analyze the entire integrated sample, thin sections are sliced off the face of the core and analyzed individually thereby resulting in a profile of algal layer production.

An example of production profiles sampled with the incubator during April and May 1987 in Resolute Bay, N.W.T. is presented in Figure 7. Most of the total carbon production is seen to occur in the first 2 cm from the underice surface. The profiles shown in Figure 7 are part of a three month time series of production measurements sampled during 1987 in Lancaster Sound using the incubator arm. Such rapid and synoptic measurements of production under frozen sea ice will allow us to map the history of underice algal growth during the spring months, measure total production and abundance and allow us to determine the role underice algae in the ecological food chain.

One of the most active feeders of ice algae are the indigenous amphipods of 1-3 cm length which appear under the ice

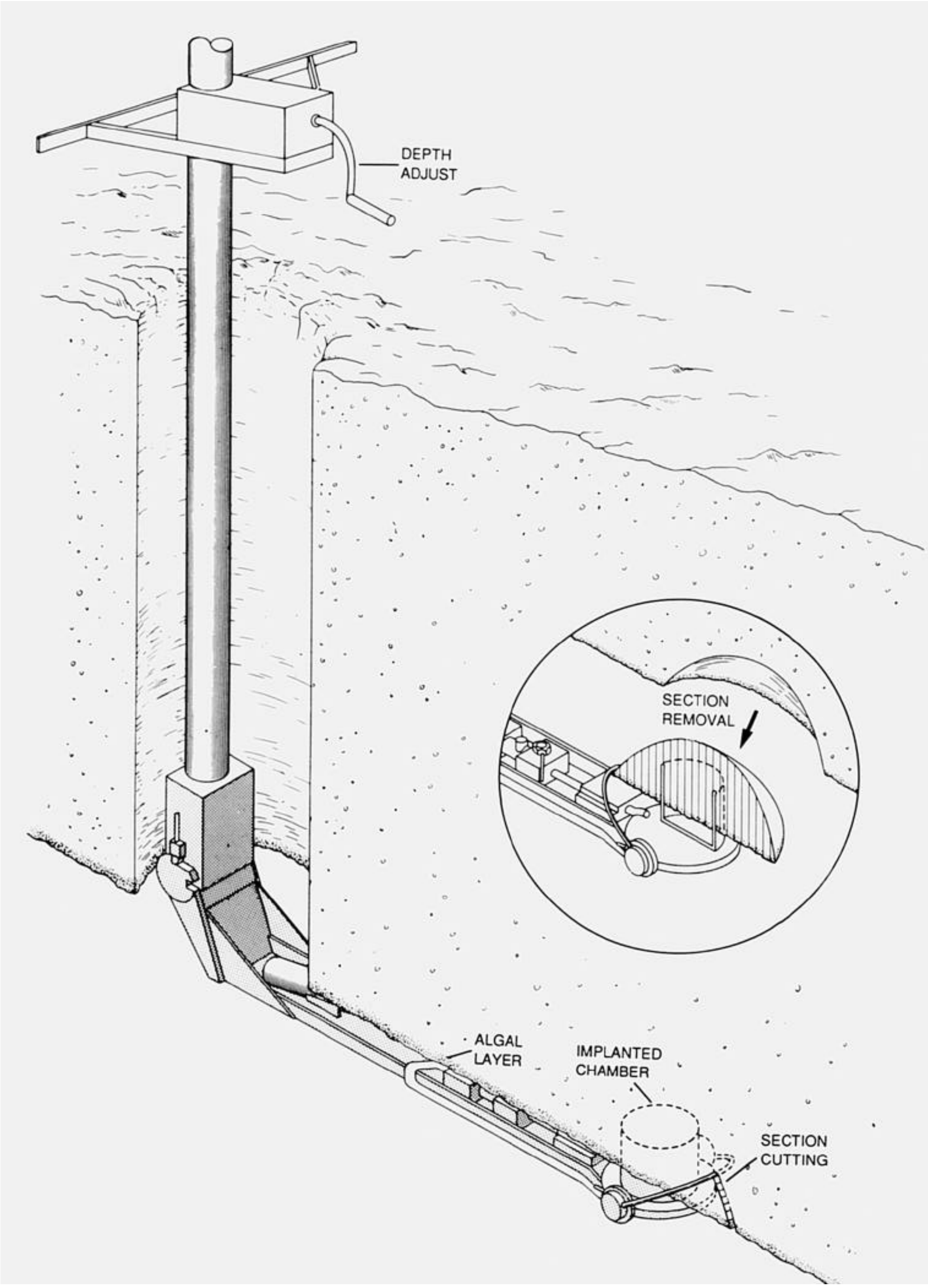

Fig. 6 An example of the operation of *the underice incubator.*

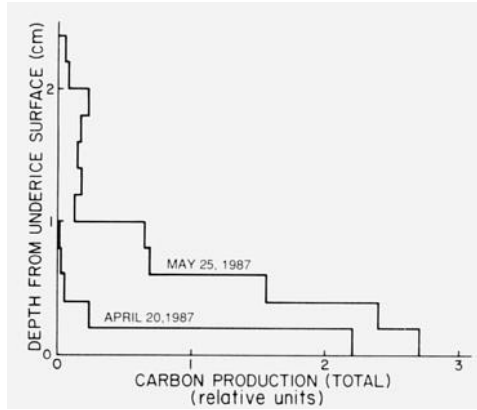

Fig. 7 Production profiles measured (one month apart) with the underice incubator.

surface during the spring months. Lab experiments with these animals are difficult since they are physically disturbed when removed from their habitat, partly due to the method of their removal. Figure 8 shows the amphipod collector which was designed to entrap amphipods and to accomplish recovery in the most delicate manner possible. The collector net mounted on the arm is directed into the tidal current flow which results in animals trapped in a transparent cod end bucket. As the arm is released in the recovery position, the neck of the collector net becomes pinched as the bucket falls to the vertical position thereby entrapping all the collected animals. The arm is then recovered through the ice hole with the animals still swimming in about one-half liter of seawater in the bucket.

Knowledge of current direction is required for the proper orientation of the amphipod collector net. A current meter deployable through an ice hole was designed for this purpose and is shown in Figure 9. The current vane aligns itself horizontally in the flow direction while folding in a vertical position for deployment and recovery. During operation, the rotational position of the vane is transferred to surface and displayed by a mechanical pointer or measured electronically with a potentiometer. Flow magnitude is also measured by mounting an electromagnetic flow sensor.

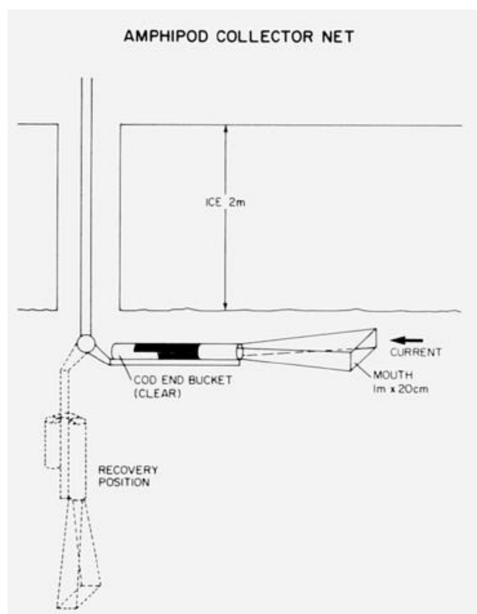

Fig. 8 An amphipod collector net used to capture amphipods at the undersurface.

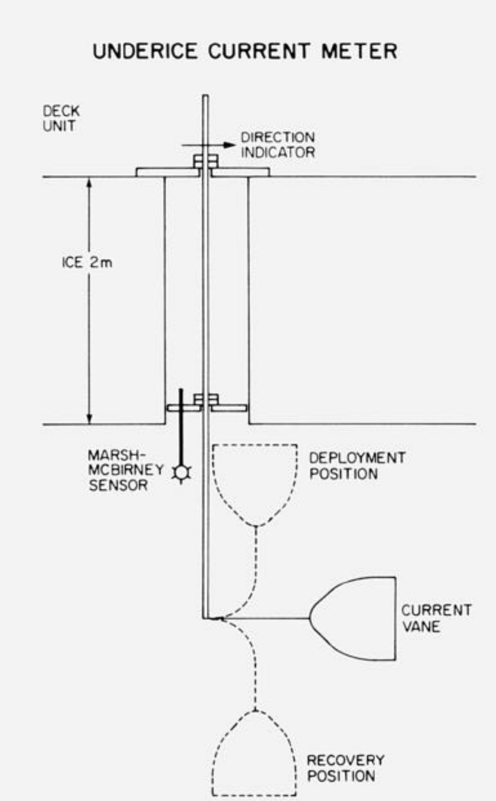

Fig. 9 An underice current meter capable of being deployed through a 24 cm diameter ice hole.

All the instruments described here and others were designed to survive the harsh Arctic environment and to be portable, allowing scientists to survey large areas of frozen waterways. Generally each of these instruments has a single unique function and measures a single parameter relating to under-ice plankton and their environment.

The data provided by these instruments is allowing us to probe the nature of our Arctic underice food chain and to respond quickly to future survey requirements of our ecologically sensitive Arctic waterways.

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Charts and Publications

CHART PRODUCTION

The Scotia-Fundy Region of the Canadian Hydrographic Service has a cartographic staff of 25 and responsibility for 420 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. A Reprint is a new print of a current edition that incorporates amendments previously issued in Notices to Mariners.

In addition to the New Charts and New Editions listed below, about eighty chart amendments and ten paste-on patches were issued through Notices to Mariners each year.

1986

New Charts

4236 Taylors Head to Shut-in Island
4243 Tusket Islands to Cape St. Marys
4817 Bay Bulls to St. Mary's Bay
4831 Fortune Bay-Northern Portion
5338 Rivière Koksoak

New Charts (by Contract)

4045 Sable Island Bank to St. Pierre Bank
4047 St. Pierre Bank to Whale Bank
4049 Grand Bank, Northern Portion to Flemish Pass
7310 Jones Sound
7570 Barrow Strait and Viscount Melville Sound
7571 Viscount Melville Sound
7572 Viscount Melville Sound and M'Clure Strait
7980 Byam Martin Channel to Maclean Strait

New Editions

4245 Yarmouth Harbour and Approaches
4313 Letang Harbour
4319 Saint John Harbour and Approaches
4376 Louisbourg Harbour
4379 Liverpool Harbour
4460 Charlottetown Harbour
4544 Deer and St. Jones Harbours
4587 Mortier Bay
4722 Terrington Basin
5403 Pritzler Harbour to Maniitur Cape
8010 Grand Bank, Southern Portion

New Editions (Loran C) (by Contract)

4012 Yarmouth to Halifax
4013 Halifax to Sydney
4015 Sydney to Sainte-Pierre
4017 Cape Race to Cape Freels
4017 (Decca)
4021 Pointe Amour to Cape Whittle and Cape St. George
4022 Cabot Strait and Approaches, Scatarie Island to Anticosti Island
4023 Northumberland Strait
4320 Egg Island to West Ironbound Island

1987

New Charts

M305 Hague Line
4118 St. Mary's Bay
4234 Country Island to/a Barren Island
4832 Fortune Bay-Southern Portion/Partie sud
4848 Holyrood and/et Long Pond
5048 Cape Harrigan to/aux Kidlit Islands
7487 Fury and Hecla Strait

New Editions

4396 Annapolis Basin
4498 Pugwash Harbour and Approaches
4547 Bull Arm
4885 Port Harmon and Approaches/et les Approches
5138 Sandwich Bay

New Edition Compilation

4426 Restigouche River

New Edition Drafting (Contract)

4011 Approaches to/Approches à Bay of Fundy
4016 Saint Pierre to St. John's
4426 Restigouche River
4459 Summerside Harbour and Approaches/et les Approches
8014 Grand Banc/Grand Bank, Partie nord-est/ Northeast Portion
8015 Funk Island and Approaches/et les Approches

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We present below alphabetical listings by author of publications produced in 1986 and 1987 by DFO, DOE and DEMR staffs at BIO and by DFO Science Staff at the Halifax Fisheries Research Laboratory and at the St. Andrews Biological Station. 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: Marine Assessment and Liaison Division, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2 (Telephone 902-426-3559).

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Voyages

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, and it is operated by DFO's Scotia-Fundy Region.
- Principal statistics - Lloyds Ice Class I hull . . . built in 1956 . . . length 86.9m . . . breadth 15.lm draft 5.7m . . . freeboard to working deck 3.3m . . . 4987 tonnes displacement . . . 3511 gross registered tons . . . 15.5 knot full speed . . . 10 knot service speed . . . 76 day endurance . . . 18,000 n. mile range at service speed . . . complement of 29 hydrographic staff drafting, plotting, and laboratory spaces provided MICRO VAX II computer . . . heliport and hangar twin screws and bow thruster for position holding . . . six survey launches.
- 214 (187) days at sea and 16,498 (20,730) n. miles steamed in 1986 (1987)

VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
86-007	Apr. 28-Jul. 17	V. Gaudet, CHS M.G. Swim, CHS	Grand Manan Island	Standard navigational charting
86-023	Jul. 31-Oct. 1	V. Gaudet, CHS	Strait of Belle Isle, Labrador Coast Bylot Island, Singer Inlet (Ungava Bay)	Standard navigational charting and sampling
86-033	Oct. 7-Nov. 3	M.G. Swim, CHS	Grand Manan Island, N.B., Passamaquoddy Bay	Standard navigational charting and DOLPHIN trials
87-001	Feb. 24-Mar. 13	A. Clarke, PCS	Newfoundland Basin	Batfish/CTD survey of Sub-Arctic front and convection study in the Newfoundland Basin Gyre
87-002	Mar. 15-29	C. Tang, PCS	Northern Grand Banks	Temperature and salinity and collection of ice data for remote sensing validation
87-010	Apr. 9-May 15	V. Gaudet, CHS	Scotian Shelf	Standard navigational charting
87-016	May 20-29	R. Haedrick, Memorial	White and Notre Dame Bays, Newfoundland	Biological and physical oceanography
87-020	Jun. 1-Aug. 12	V. Gaudet, CHS	N.W. Coast of Newfoundland, Passamaquoddy Bay	Standard navigational charting
87-027	Aug. 17-Oct. 14	M.G. Swim, CHS	Norwegian Bay Viscount Melville Sound, Baffin Island	Standard navigational charting (CHS) and AGC study on the seabed sediments in Norwegian Bay
87-039	Oct. 30-Nov. 20	M.G. Swim, CHS	Scotian Shelf	Standard navigational charting

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, and it is operated by DFO's Scotia-Fundy Region.

- Principal statistics - built in 1967 . . . length 64.5m . . . breadth 12.2m . . . draft 4.6m . . . freeboard to working deck 1.5m . . . 2007 tonnes displacement . . . 1311 gross registered tons . . . 14 knot full speed . . . 10 knot service speed . . . 45 day endurance . . . 11,000 n. mile range at service speed . . . scientific complement of 13 . . . 87.3 m^2 of space in four laboratories . . . computer suite . . . twin screws and bow thruster for position holding . . . one survey launch.

- 203 (202) days at sea and 25,985 (28,481) n. miles steamed in 1986 (1987).

VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
86-001	Apr. 1-11	C. Anderson, PCS	Scotian Shelf	CM Moorings/Surface Buoys
86-005	Apr. 15-28	C. Tang, PCS	Southern & Eastern Grand Banks and Flemish Cap	CM Moorings/Surface Buoys
86-008	May 1-6	P. Wangersky, Dalhousie	Scotian Shelf	CM Moorings/Surface Buoys
86-011	May 9-19	K. Frank, BSB	Brown's Bank Bay of Fundy	Ichthyoplankton dynamics
86-012	May 22-31	D. McKeown, PCS	Scotian Shelf	Engineering Trials
86-015	Jun. 3-14	B. Loncarevic, AGC	Gulf of St. Lawrence off Sept Isles Bay	Survey a large positive gravity anomaly
86-016	Jun. 16-Jul. 6	J. Syvitski, AGC	Central and Lower St. Lawrence Estuary, Saguenay Fiord, Gaspe Coast and Baie des Chaleurs	Study of the paleoenvironment to determine the stability of seafloor sediments and document the Quaternary history of basin infilling processes; study organic compounds in sediments
86-022	Aug. 2-7	P. Wangersky, Dalhousie	Scotian Shelf	Seasonal distribution and composition of seasonal macroaggregates
86-025	Aug. 11-14	N. Cochrane, PCS	Outer Scotian Shelf	Acoustic Backscattering
86-026	Aug. 19-Sep. 10	H. Miller/R. Haedrich, Memorial	Northeast Coast of Newfoundland	Underwater gravity, seismic and CTD surveys, collection of cores and biological samples
86-028	Sep. 12-20	K. Frank, BSB	Grand Banks	Capelin recruitment processes
86-030	Sep. 24-Oct. 7	A. Herman, PCS	Emerald Basin, Banquereau Bank	Zooplankton/Chlorophyll Surveys
86-031	Oct. 8-21	C. Ross, PCS	Grand Banks	CM Recovery/Batfish Tow/CTD cast

86-035	Oct. 23-Nov. 1	Howell, NSRF Boyd, Dalhousie	Sable Island, Scotian Slope	Quaternary seismic stratigraphy and sediment characteristics
86-036	Nov. 4-9	P. Wangersky, Dalhousie	Scotian Shelf	Seasonal distribution and composition of macroaggregates
86-037	Nov. 13-Nov. 23	G. Bugden, PCS	Gulf of St. Lawrence	Ice forecast
86-039	Jul. 8-15	B. Long, INRS	Laurentian Channel, Natashguan, Magdalen Islands, Aspy Bay	Geophysical survey
86-041	Nov. 24-30	C. Amos, AGC	Venture Cohasset and Olympia well sites, Sable Island Bank, Scotian Shelf	Seismic survey of Cohasset borehole site and development of tracers at the Venture and Olympia sites
87-005	Apr. 8-14	E. Levy, PCS	Scotian Shelf	Baseline measurements on hydrocarbons and effects of oil on benthic organisms
87-007	Apr. 21-26	B. Johnson, Dalhousie	Emerald Basin	Study of nepheloid layer and inversions using CTD, camera and pumps
87-012	Apr. 29-May 15	C. Ross, PCS	Grand Banks	Study of current structure and seasonal variation in stratification
87-015	May 19-24	J.N. Smith, PCS	Bay of Fundy	DFO environmental monitoring of Pt. Lepreau, New Brunswick, nuclear power plant
87-018	May 27-Jun. 5	J. McRuer, BSB	Brown's Bank	Physical and biological influences on growth and distribution of haddock and cod larvae
87-021	Jun. 10-17	B. Long, INRS,	Gulf of St. Lawrence	Study of the paleoenvironment of the Deltaic Fan of the Natashquaa River
87-023	Jun. 18-27	J. Syvitski, AGC	Chaleur Bay	Study of Holocene sediment infill processes, development of Holocene stratigraphic and placer models
87-024	Jun. 30-Jul. 11	D. McKeown, PCS	Scotian Shelf	Gear testing
87-026	Jul. 20-Aug. 7	J. Lazier, PCS	Labrador Sea	Long-term monitoring of Labrador current
87-030	Aug. 10-19	A. Hay, Memorial	East Newfoundland	Biological and physical oceanographic studies
87-032	Aug. 21-29	A.E. Aksu, Memorial	West and South Newfoundland	Seismic survey
87-035	Sep. 1-11	N. Oakey, PCS	Scotian Shelf	To map solitons and test equipment
87-036	Sep. 15-28	K. Frank, BSB	Grand Banks	Measure production of larval capelin and determine effects of crude oil on capelin larvae
87-038	Oct. 2-9	K. Frank, PCS	Bay of Fundy	Suspended particulate matter distribution and transport, and gear tests
87-041	Oct. 14-29	C. Ross, PCS	Grand Banks	Current structure, mixed layer properties and seasonal variation in stratification
87-042	Nov. 2-9	D. Forbes, AGC	N.S. Eastern Shore	Ground truthing of acoustic data for surficial geology mapping
87-043	Nov. 11-12	B.D. Johnson, Dalhousie	Emerald Basin	Distribution of trace substances

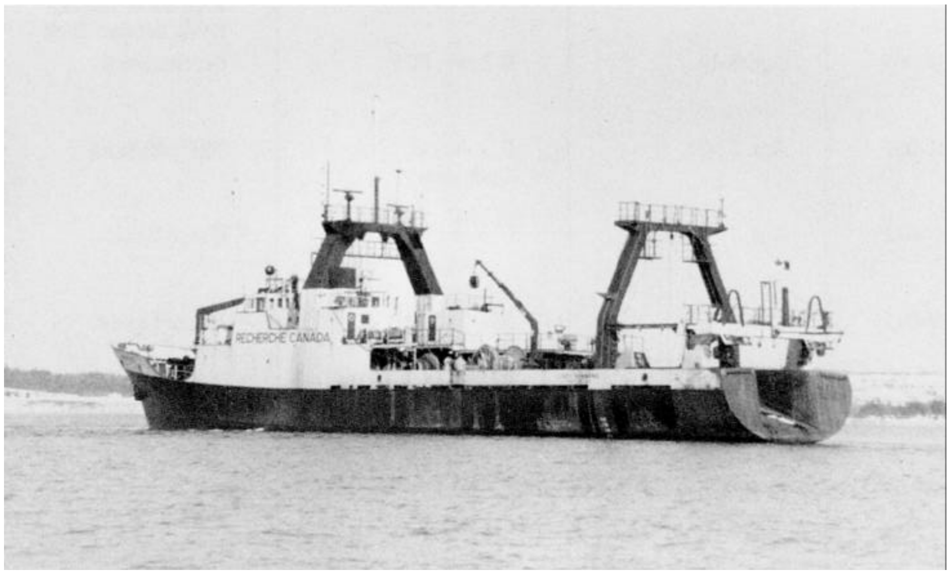
87-044	Nov. 17-27	K. Howells, NSRF	Chedabucto and St. Georges Bays	Geological bedrock structure, surficial sediment and glacial deposition
87-045	Nov. 28-Dec. 8	G. Bugden, PCS	Gulf of St. Lawrence	Ice forecast and climatological studies
87-050	Dec. 13-20	B. Sullivan, W. King, Fisheries Officers	Scotian Shelf	Fisheries Patrol

LADY HAMMOND

- The ***Lady Hammond,*** a converted fishing trawler, is owned by Northlakes Shipping Limited and is chartered by the Department of Fisheries and Oceans specifically for fisheries research. The vessel is operated by DFO's Scotia-Fundy region: her main user is the Biological Sciences Branch, which has components at BIO, in Halifax, and in St. Andrews, N.B.

- Principal statistics - built in 1972 . . . length 57.9m . . . breadth 11.0m . . . draft 4.8m . . . freeboard to working deck 2.5m . . . 897 gross registered tons . . . 15 knot full speed . . . 12.5 knot service speed . . . 30 day endurance . . . 8,000 n. mile range at service speed.

- 221 (173) days at sea and 30,718 (24,580) n. miles steamed in 1986 (1987).



VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
	1986			
H148	Jan. 6-10	J. McGlade, BSB	NAFO 5Ze, 4VWX	Pollock survey
H149	Jan. 14-25	F. Cahill	NAFO 3Ps	Scallop survival-deck exposure
H150	Jan. 27-31	P.. Vass, BSB	NAFO 4X	Plankton gear trials
H151	Feb. 3-9	J. McGlade	NAFO 4X	Pollock eggs/larvae
H152	Apr. 14-18	P. Vass, BSB	Bedford Basin	Plankton gear trials
H153	Apr. 21-May 2	D. Duggan, BSB	Browns/Georges Banks	Lobster survey
H154	May 5-Jun. 9	P. Ouellet, BSB	NAFO 4R and 4S	Larval invertebrates
H155	Jun. 16-27	I. Perry, BSB	Georges Bank	Juvenile gadids
H156	Jun. 30-Jul. 18	G. Harding, BSB	SW. Nova Scotia	Lobster larvae
H157	Jul. 21-30	K. Waiwood, BSB	Browns/Baccaro Banks	Live fish collections
H158	Aug. 4-27	P. Rubec	Gulf of St. Lawrence	Redfish survey
H159	Sep. 2-25	D. Clay, Gulf	NAFO 4T	Groundfish abundance survey
H160	Sep. 29-Oct. 14	M. Tremblay, BSB	Georges Bank	Scallop larvae
H161	Oct. 15-17	P. Hurley, BSB	Bedford Basin	CTD data acquisition trials
H164	Oct. 20-30	J. Martell	NAFO 4W/Sable & Western Bank	Fish samples - sealworm abundance
H165	Nov. 13-27	B. Hickey, BSB	NAFO 4X	Sea trials - "Mermaid" RCV systems
H166	Dec. 4-9	D. Clay, Gulf	NAFO 4T	Biology of white hake
	1987			

H167	Feb. 27-Mar. 4	K. Naidu, Newfoundland	NAFO Div., 3Ps	Scallop survey
H168	Mar. 6-18	T. Collier, Newfoundland	NAFO Div., 30/3N Tail Grand B.	Groundfish survey
H169	Mar. 23-Apr. 3	J. Neilson, BSB	Georges/Browns Banks	Larval gadid survey
H170	Apr. 13-22	D.J. Martell, BSB	NAFO Div., 4VS-W, Scotian Shelf	Parasite collections (sealworm)
H172	May 18-26	D. Clay, Gulf	Southern Gulf of St. Lawrence	4T Groundfish survey
H173	May 27-Jun. 13	G. Chouinard, Gulf	Southern Gulf of St. Lawrence	Juvenile gadid abundance
H174	Jun. 17-23	D. Clay, Gulf	Southern Gulf	4T Groundfish survey
H175	Jun. 25Jul. 9	K. Waiwood, BSB	Sable Island Gully	Juvenile/mature halibut survival experiments
H176	Jul. 13-31	G. Harding, BSB	Gulf of Maine	Lobster larvae
H177	Aug. 4-Aug. 26	E. Laberge, Quebec	Gulf of St. Lawrence	Redfish abundance survey
H178/179	Aug. 31-Sep. 24	D. Clay, Gulf	Southern Gulf of St. Lawrence	Groundfish abundance survey
H180	Sep. 28-Oct. 20	M. Tremblay, BSB	Georges/Browns Banks	Larval scallop survey
H181	Oct. 23-Nov. 12	Stephenson/ Power, BSB	SW Nova Scotia/ Georges Bank	Herring larvae
H182	Nov. 18-Dec. 6	J. Carscadden, Newfoundland	NAFO Div., 3LNO, Grand Banks	Larval capelin survey

C.S.S. J.L. HART

- The C.S.S. J.L. Hart is a steel stern trawler used for fisheries research, including light trawling operations (bottom and mid-water), ichthyoplankton surveys, oceanographic sampling and scientific gear testing. The ship is owned by the federal Department of Fisheries and Oceans, and is operated by DFO’s Scotia-Fundy Region. It is stationed at the St. Andrews Biological Station, St. Andrews, N.B., and conducts most of its work locally in Passamaquoddy Bay and in the Bay of Fundy.

- Principal statistics - built in 1974 . . . length 19.8m . . . breadth 6.lm . . . draft 3.65m . . . 109 tonnes displacement . . . 89.5 gross registered tons . . . 10 knot full speed . . . 8.5 knot service speed . . . 7.5 day endurance . . . 2,000 n. mile range at service speed scientific complement of 3.

- 152 (125) days at sea and 9,368 (7,793) n. miles steamed in 1986 (1987).

VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
	1986			
	Jan. 17,21, 28,31, Feb. 4-5, 10, Mar. 3-6.	M.J. Dadswell, BSB	Bay of Fundy	Scallop sampling

	Apr. 1-2			
	Jan. 22, 29-30, Feb. 11, Mar. 11	D. Aiken, BSB	Bay of Fundy	Collection of fish and lobster food for experimental animals
	Feb. 12-14, Mar. 12-14	J. Hunt, BSB	Bay of Fundy	Fish tagging
	Feb. 18-21	S. Campana, BSB	Bay of Fundy	Juvenile cod survey
J001	Apr. 8-9, 28-30, May 1-9	M.J. Dadswell, BSB	Bay of Fundy	Scallop sampling
J002	Jun. 4-13	D. Wildish, BSB	Bay of Fundy	Benthic survey
J003	Jun. 16-19	M.J. Dadswell, BSB	Bay of Fundy	Scallop sampling
J004	Jun. 20-24, 26	D. Wildish, BSB	Bay of Fundy	Benthic survey
J005	Jun. 25, 27, Oct. 16-17	D. Aiken, BSB	Bay of Fundy	Fish and lobster food
J006	Jul. 7-11	D. Wildish, BSB	Bay of Fundy	Benthic survey
J007	Jul. 14-15	M.J. Dadswell, BSB	Bay of Fundy	Scallop sampling
J008	Jul. 16-18	R. Stephenson, BSB	Bay of Fundy	Juvenile herring survey
J009	Jul. 22, 25	A. White, BSB	Bay of Fundy	Red tide sampling
J010	Jul. 23-24	R. Stephenson, BSB	Bay of Fundy	Juvenile herring survey
J011	Jul. 28-31	D. Wildish, BSB	Bay of Fundy	Benthic survey
J012	Aug. 1-8	M.J. Dadswell, BSB	Bay of Fundy	Scallop sampling
J013	Aug. 18-29	J. Campana, BSB	Bay of Fundy	Juvenile cod survey
J014	Sep. 2-12	R. Stephenson, BSB	Bay of Fundy	Juvenile herring survey
J015	Sep. 15-19	D. Wildish, BSB	Bay of Fundy	Benthic survey
J016	Sep. 22-30 Oct. 1-2	R. Stephenson, BSB	Bay of Fundy	Larval herring survey
J017	Oct. 3-15	M.J. Dadswell, BSB	Bay of Fundy	Scallop survey
J018	Oct. 20-31	R. Stephenson, BSB	Bay of Fundy	Larval herring survey
J019	Nov. 3-7	M.J. Dadswell, BSB	Bay of Fundy	Scallop sampling
J020	Nov. 20-21	M.J. Dadswell, BSB	Bay of Fundy	Scallop sampling
J021	Nov. 26	M.J. Dadswell, BSB	Bay of Fundy	Scallop sampling
	1987			
J022 J023 J024 J025	Jan. 1-5, 14, 16, Feb. 9, 13, 18-19, Mar. 17 May 6	M.J. Dadswell, BSB	Bay of Fundy	Scallop survey
J026	May 11-12	D. Wildish, BSB	Bay of Fundy	Benthic survey
J030	Jun. 15-17	K.G. Waiwood, BSB	Bay of Fundy	Fish food collection
J031	Jun. 22-30 Jul. 1-3	M.J. Dadswell BSB	Bay of Fundy	Scallop survey
J032	Jul. 6-10	D. Wildish, BSB	Bay of Fundy	Benthic Survey
J033	Jul. 13-18	T. Amaratunga, BSB	Bay of Fundy	Clam survey
J034	Jul. 27-31 Jul. 1-3	R. Stephenson, BSB	Bay of Fundy	Herring survey
J035	Aug. 17-19	D. Wildish/ D. Graham, BSB	Bay of Fundy	Benthic/scallop survey

J036	Aug. 20	R. Stephenson, BSB	Bay of Fundy	Herring survey
J037	Aug. 26-28	M.J. Dadswell, BSB	Bay of Fundy	Scallop sampling
J038	Aug. 31-Sep. 4	R. Stephenson, BSB	Bay of Fundy	Herring survey
J039	Sep. 8-9	D. Wildish, BSB	Bay of Fundy	Herring survey
J040	Sep. 10	R. Chandler, BSB	Bay of Fundy	Scallop survey
J041	Sep. 14-Oct. 1	R. Stephenson, BSB	Bay of Fundy	Herring survey
J042	Oct. 5-6	D. Wildish, BSB	Bay of Fundy	Benthic survey
J043	Oct. 7, 13-2	R. Chandler, BSB	Bay of Fundy	Scallop survey
J044	Oct. 22-30	R. Stephenson, BSB	Bay of Fundy	Herring survey
J045	Nov. 23-26	R. Chandler, BSB	Bay of Fundy	Scallop survey
J046	Nov. 27, Dec. 1-3	K. Waiwood, BSB	Bay of Fundy	Fish food
J047 J048	Dec. 10-11, 23	R. Chandler/ T.D. Iles, BSB	Bay of Fundy	Scallop and herring collection

C.S.S. HUDSON

- The C.S.S. *Hudson* is a diesel-electric driven ship designed and used for multidisciplinary marine science research. The ship is owned by the federal Department of Fisheries and Oceans, and is operated by DFO's Scotia-Fundy Region. The Atlantic Geoscience Centre of the Department of Energy, Mines and Resources is a major user of this vessel.
- Principal statistics - Lloyds Ice Class I hull . . . built in 1962 length 90.4m breadth 15.2m . . . draft 6.3m . . . freeboard to working deck 3.2m . . . 4847 tonnes displacement . . . 3721 gross registered tons . . . 17 knot full speed . . . 13 knot service speed . . . 80 day endurance . . . 23,000 n. mile range at service speed scientific complement of 31 . . . 205m^2 of space in four laboratories computer system heli-port and hangar twin screws and bow thruster for position holding . . . four survey launches.
- 190 (196) days at sea and 27,489 (30,613) n. miles steamed in 1986 (1987).

VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
86-006	Apr. 17-May 20	A. Clarke, PCS	Nfld. Basin, East of Grand Banks	Current Meter/CTD Array/Survey
86-013	May 27-Jun. 15	I. Reid. AGC	Laurentian Fan, Orphan Basin and Margin	Investigation of deep crustal structure by seismic refraction
86-017	Jun. 18-28	G. Fader, AGC	Whale Deep, Avalon Channel and Halibut	Surficial and shallow bedrock geology for surficial mapping of proposed pipeline corridors

			Channel, Haddock Channel, Green Bank, Grand Banks of Newfoundland	
86-018	Jul 2-14	R. Parrott, AGC	Grand Banks Flemish Pass	Determination of geological control on seabed engineering properties and stability features
86-021	Jul. 24-Aug. 6	J. Lazier, PCS	SW Labrador Sea/ Shelf	Labrador Current studies
86-021	Aug. 7-26	C. Ross, PCS	Nain Bank, Eastern Labrador Sea, Baffin Bay	Moorings/CTD/Batfish
86-027	Aug. 26-Sep. 25	B. MacLean, AGC	Wellington Channel Byam Martin Channel, Viscount Melville, Prince Regent, Barrow Strait areas, Arctic Islands	Collection of physical, geophysical, geotechnical, biological, physical oceanography and hydrographic data
86-029		K. Drinkwater BSB	Ungava Bay Hudson Strait	Physical oceanography
86-034	Nov. 4-16	D. Piper, AGC	Emerald Basin, Scotian Slope St. Pierre Slope and Laurentian Fan	Seismic survey and test of long coring facility in the Grand Banks, Scotian Shelf and Emerald Bank areas to evaluate sediment stability
86-040	Oct. 5-20	H. Josenhans, AGC	Hudson Bay	Correlation of glacial stratigraphy and geomorphology, and deglaciation of the Laurentide Ice Sheet
86-040	Oct. 21-31	H. Josenhans, AGC	Hamilton Bank, Labrador Shelf	Study of the Western Boundary Undercurrent along the Labrador Slope by its effects on sediment and foraminiferal distributions through time
87-003	Apr. 3-14	K. Manchester/ L. Mayer, AGC	Emerald Basin, Laurentian Fan	Conduct seismic surveys and test new modified
87-008	Apr. 21-May 6	D. Piper, AGC	Flemish Pass	Study of global flux of organic carbon to near surface abyssal sediments; long cores and seismic profiles of Grand Banks margin; study of relationships between organic matter and geotechnical properties
87-014	May 7-14	G. Fader, AGC	Grand Banks	Bedrock study of the eastern Grand Banks
87-019	May 16-Jun. 8	C. Keen, AGC	Grand Banks	Measurement of seismic reflection and refraction, gravity and magnetics along deep reflection lines
87-022	Jun. 11-Jul. 7	T. Platt, BSB	North Atlantic	Investigation of open ocean distribution of phytoplankton biomass in support of climate research
87-025	Jul. 16-Aug. 2	K. Louden, Dalhousie	Labrador Sea	Study effects of changing spreading rate on crustal structure, age at which spreading stopped, and nature of recent sediment deposition
87-028	Aug. 3-21	H. Josenhans, AGC	Hudson Bay	Vertical and lateral distribution of surficial and subsurface geological units, seafloor and paleosediment dynamics

87-031	Aug. 23-Sep. 17	C. Ross, PCS	Hudson Strait, Baffin Bay	Seismic survey, current meter deployment and recovery, CTD surveys
87-033	Sep. 18-Oct. 6	G. Vilks, AGC	Davis Strait, Baffin Bay	Sedimentary history on Baffin Island shelf and quaternary stratigraphy in other areas
87-037	Oct. 9-Nov. 2	R.A. Clarke, PCS	Newfoundland Basin	Mooring recovery, CTD sections and Batfish mapping along edge of N. Atlantic Current

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, and was operated by DFO's Scotia-Fundy until 1987, when it was transferred to DFO's Newfoundland Region to be used for the same purposes.

- Principal statistics - built in 1962 . . . length 35.0m . . . breadth 7.6m . . . draft 2.4m . . . 278 tonnes displacement . . . 262 gross registered tons . . . 12.2 knot full speed . . . 10 knot service speed . . . 10 day endurance . . . 2,400 n. mile range at service speed scientific complement of 7 . . . drafting and plotting facilities . . . two survey launches.

- 180 days at sea and 2,020 n. miles steamed in 1986.

VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
86-004	Apr. 14-May 2	R.M. Eaton, CHS	Bedford Basin	Electronic chart testing
86-010	May 6-Oct. 30	J. Ferguson, CHS	Passamaquoddy Bay, Cobscook Bay, Maine, U.S.A.	Standard navigational charting
86-043	Nov. 5-21	R.M. Eaton, CHS	Bedford Basin	Electronic chart testing

C.S.S. NAVICULA

- The *C.S.S. Navicula* is a wooden-hulled fishing vessel owned by the federal Department of Fisheries and Oceans. It is operated by DFO's Scotia-Fundy Region and used for research in biological oceanography.

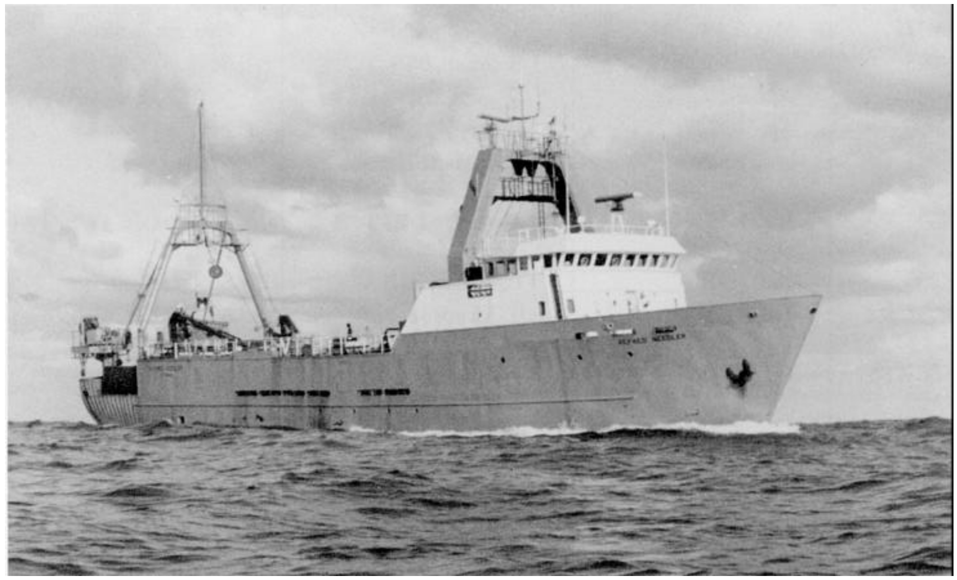
- Principal statistics - built in 1968 . . . length 19.8m . . . breadth 5.85m . . . draft 3.25m . . . 104 tonnes displacement . . . 78 gross registered tons . . . 10 knot full speed . . . 9 knot service speed . . . 8 to 10 hours/day endurance . . . 1,000 n. miles range at service speed.

- 101 (116) days at sea and 5,259 (5,715) n. miles steamed in 1986.

VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
86-003	Apr. 7-May 30	J. McRuer/ K. Frank, BSB	Southwest Nova Scotia	Determine nursery areas for juvenile fish
86-014	Jun. 3-Aug. 30	T. Lambert, BSB	Southern Gulf of St. Lawrence	Mackerel spawning and white hake juvenile/adult survey
86-014	Sep. l-Oct. 6	T. Lambert, BSB	Southern Gulf of St. Lawrence	Herring spawning bed survey
86-044	Oct. 9-16	J. Horne, Dalhousie	Southwest Nova Scotia	Juvenile fish distribution
87-006	Aug. 24-27 Nov. 5-9	A. Fraser, PCS	Sydney Harbour	Baseline measurements of hydrocarbons and effects of oil on benthic organisms
87-009	Apr. 22-May 20	J. McRuer	St. Mary's Bay to Cape Sable Island	Juvenile cod and haddock survey
87-017	Jun. 1-11,	D. Clay, Gulf	Gulf of St. Lawrence	Hake, flounder and American plaice surveys
87-029	Aug. 31-Sep. 18	T. Lambert, BSB	Northumberland Strait	Herring spawning beds
87-047	Jun. 14-23	R. Miller, AGC	East Coast of Cape Breton Island	Near shore survey for sand, gravel and other non-fuel mineral resources
87-049	Nov. 16-17	S. Poynton, BSB	Chebucto Head	Live fish collection

M. V. ALFRED NEEDLER

- The *M.V. Alfred Needler* is a diesel-driven steam trawler owned by the federal Department of Fisheries and Oceans. It is operated by DFO's Scotia-Fundy Region and used for resource surveys and other fisheries research including acoustics, juvenile fish ecology and recruitment studies.
- Principal statistics - built in 1982 . . . length 50.3m . . . breadth 11.0m . . . draft 4.9m . . . freeboard to working deck 2.5m . . . 877 tonnes displacement . . . 925 gross registered tons . . . 13.5 knot full speed . . . 12.0 knot service speed . . . 30 day endurance . . . 3,000 n. mile range at service speed . . . scientific complement of 10 . . . contemporary communications systems, electronics, navigational aids, research equipment and fishing gear.
- 203 (214) days at sea and 29,671 (28,827) n. miles steamed in 1986 (1987).

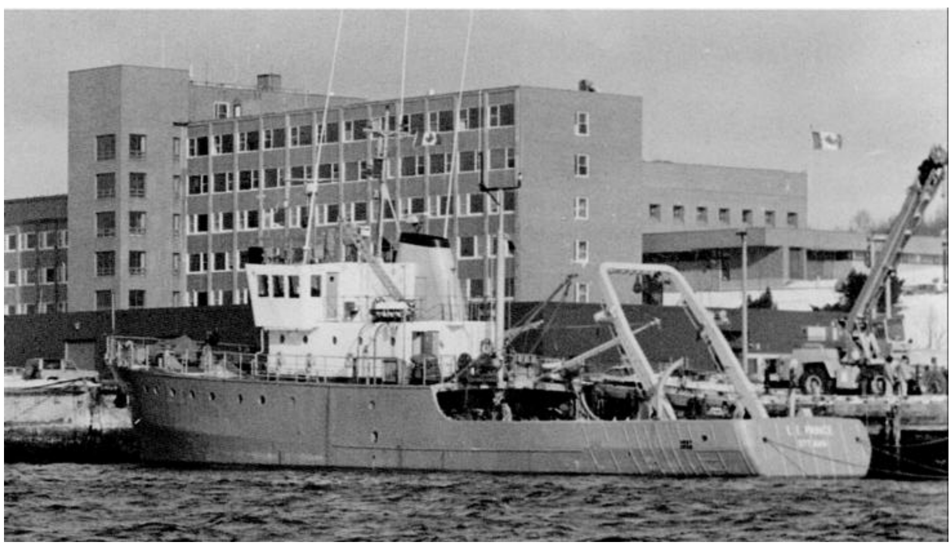


VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
	1986			
N056	Jan. 8-28	T. Rowell, BSB	Miami - Halifax	Determine spawning areas of squid
N057	Feb. 10-20	C. Dale, BSB	Emerald Basin	Larval/juvenile squid and deep sea fish species
N058	Feb. 24-28	D. Waldron, BSB	NAFO 4X	IOP training
N059	Mar. 3-13	J.S. Scott, BSB	Georges Bank	Groundfish survey
N060	Mar. 17-26	J. Hunt, BSB	Scotian Shelf	Groundfish survey
N061	Apr. 30-May 5	P. Ouellet, BSB	NAFO 4R and 4s	Shrimp larvae
N062	May 19-30	D. Beanlands, BSB		Groundfish survey
N063	Jun. 2-20	L. Dickie, BSB	Gulf of St. Lawrence	Cod/capelin acoustics
N064	Jun. 24-28	L. Fourtier, Gulf	Gulf of St. Lawrence	Herring larvae
N065	Jul. 7-17	P. Koeller, BSB	Scotian Shelf	Standard groundfish survey
N066	Jul. 21-30	S. Smith, BSB	Scotian Shelf	Standard groundfish survey
N067	Aug. 25-Sep. 5	R. Halliday, BSB	Georges Bank	Scotian Slope fishes
N068	Sep. 16-23	D. Duggan, BSB	Browns Bank	Lobster bycatch
N069	Sep. 29-Oct. 10	W. Smith, BSB	Continental shelf	Redftsh survey
N070	Oct. 14-23	J. Hunt, BSB	Scotian Shelf	Groundfish survey
N071	Oct. 28-Nov. 5	M. Buzeta, BSB	Georges Bank	Groundfish survey
N072	Nov. 13-Dec. 1	W. Legge, Newfoundland	NAFO 3L	Groundfish survey
	1987			
N073	Jan. 5- 11	D. Clay, Gulf	Southern Gulf of St. Lawrence	4T Groundfish abundance survey
N074	Feb. 2-6	M. Showell, BSB	Scotian Shelf	International observer training
N075	Feb. 7-10	D. Clay, Gulf	Southern Gulf of St. Lawrence	4T Groundfish abundance survey

N076	Feb. 18-Mar. 4	E. Dawe, Newfoundland	Scotian Slope	Juvenile squid abundance and distribution in Gulf Stream water
N077	Mar. 9-19	J.S. Scott, BSB	Georges Bank	Groundfish survey
N078	Mar. 23-Apr. 1	S. Smith, BSB	Scotian shelf	Groundfish survey
N079	Apr. 6-15	W. Smith, BSB	NAFO Div. 4VsW	Haddock tagging
N080	Apr. 27-May 21	P. Ouellet, BSB	NAFO Div. 4RS	Distribution of shrimp larvae
N081	May 25-29	D.J. Martell, BSB	Scotian Shelf	Plaice survey (sealworm abundance)
N082	Jun. 1-12	C. Annand, BSB	NAFO Div. 4Wk/4Wl	Live fish collections for parasite studies
N083	Jun. 15-19	L. Dickie, BSB	Scotian Shelf	Ecolog acoustic tests
N084	Jun. 22-25	C. Morrison, BSB	NAFO Div. 4Wk/4Wl	Live fish collections for parasite studies
N085/86	Jun. 29-Jul. 22	P. Koeller/ S. Smith, BSB	Scotian Shelf	Groundfish inventory
N087	Jul. 27-Aug. 6	R. Losier, BSB	Georges/Browns Banks	Peglagic juvenile gadid abundance and distribution
Nil	Aug. 10-11	P. Fanning, BSB	Chebucto Head	Collection of live fish
N088	Sep. 3-12	T. Rowell, BSB	Sable/Banquereau	Clam recovery
N089	Sep. 22-Oct. 1	R.G. Halliday, BSB	Slope/Coastal Water	Mesopelagic fishes
N090				
N091	Oct. 13-15	S. Poynton, BSB	NAFO Div. 4Wk	Collection of live fish for parasite studies
N092	Oct. 19-29	W. Smith, BSB	Banquereau Bank	Redfish
N093	Nov. 1-27	M. Chadwick, Gulf	Southern Gulf of Lawrence	Herring acoustics

E.E. PRINCE

- The *E.E. Prince* is a steel stern trawler used for fisheries research, including experimental and exploratory fishing and resource surveys. The ship is owned by the federal Department of Fisheries and Oceans and is operated by DFO's Scotia-Fundy Region.
- Principal statistics - built in 1966 . . . length 39.6m . . . breadth 8.2m . . . draft 3.65m . . . freeboard to working deck 0.7m . . . 580 tonnes displacement . . . 406 gross registered tons . . . 10.5 knot full speed . . . 10.0 knot service speed . . . 14 day endurance . . . 3,000 n. mile range at service speed.
- 208 (180) days at sea and 22,290 (20,749) n. miles steamed in 1986 (1987).



VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
	1986			
P330	Jan. 18-Feb. 2	C.A. Dickson, BSB	Chedabucto Bay	Herring acoustics, abundance estimation
P331	Feb. 17-21	D. Sameoto, BSB	Scotian Shelf	Plankton collection
P332	Mar. 17-24	L. Dickie, BSB	Browns/LaHave Banks	Gear testing, Ecolog
P333	Apr. 17-28	R. Dufour, Quebec	NAFO 4T	Crab tagging
P334	May 5-15	M. Ette, BSB	Scotian Shelf	Shrimp survey

P335	May 20-29	M. Lundy, BSB	Browns/Georges Banks	Scallop survey
P336	Jun. 2-12	I. Suthers	Southwest Nova Scotia	Larval/juvenile cod distribution
P337	Jun. 16-27	B. Mercille, Quebec	NAFO 4T-4Vn	Mackerel eggs/larvae
P338	Jun. 30-Jul. 8	B. Mercille, Quebec	NAFO 4T	Mackerel eggs/larvae
P339	Jul. 9-17	E. Laberge, Quebec	NAFO 4T	Mackerel larvae
P340	Jul. 21-Aug. 1	R. Dufour, Quebec	Gulf of St. Lawrence	Crab prerecuit survey
P341	Aug. 11-27	G. Robert, BSB	Georges Bank	Scallop survey
P342	Sep. 2-Oct. 6	Y. Lavergne, Quebec	NAFO 4RST	Shrimp survey
P343	Oct. 15-24	M. Etter, BSB	Scotian Shelf	Shrimp distribution
P344	Oct. 27-Nov. 13	M. Power, BSB	Bay of Fundy	Larval herring abundance
P345	Nov. 17-Dec. 11	R. Shotton, BSB	Gulf of St. Lawrence	Herring acoustics
	1987			
P346	Jan. 9-29	C.A. Dickson, BSB	Chedabucto Bay	Herring acoustics
P347	Mar. 24-30	L. Dickie, BSB	Scotian shelf	Groundfish acoustics
P348	Apr. 7-9	C. Morrison, BSB	Chedabucto Head	Parasite collections
P349	Apr. 15-23	P. Perley, BSB	Georges/Browns Banks	Larval gadid survey
P350	May 4-11	M. Etter, BSB	Scotian Shelf	Shrimp distribution and abundance survey
P351	May 19-29	M. Lundy, BSB	Georges/Browns Banks	Scallop survey
P352	Jun. 3-12	R. Dufour, Quebec	NAFO Div. 4S, Gulf of St. Lawrence	Crabs
P353	Jun. 17-Jul. 2	B. Mercille, Quebec	NAFO Div. 4T-4Vn, Gulf of St. Lawrence	Mackerel egg survey
P354	Jul. 3-8	Y. Lafontaine, Quebec	NAFO Div. 4T, Gulf of St. Lawrence	Mackerel egg survey
P355	Jul. 13-23	J. Hunt, BSB	Georges Bank	Cod/haddock distribution
P356	Jul. 28-30	M. Lewis, BSB	Bedford Basin	Gear Trials
P357	Aug. 4-27	G. Robert, BSB	Georges Bank	Scallop survey
P358	Aug. 31-Sep. 10	D. Pezzack, BSB	NAFO Div. 4x, 5Ze	Lobster trawling
P359	Sep. 14-27	B. Hickey, FDB	NAFO Div. 4W, Scotian Shelf	Square/diamond mesh codend comparative fishing
P360	Oct. 5-14	M. Etter, BSB	Scotian Shelf	Shrimp distribution and abundance survey
P361	Oct. 19-Nov. 13	J. Sochasky/ D. Gordon, BSB	Bay of Fundy	Larval herring abundance
P362	Nov. 16-27	D. Cairns, Gulf	Bay of Chaleur	Herring acoustics

C.S.S. F.C.G. SMITH

- The maiden voyage of the catamaran C.S.S. *F.C.G. Smith* occurred in 1986. The ship is owned by the federal Department of Fisheries and Oceans and is operated by DFO's Scotia-Fundy Region. The vessel is primarily used by the Canadian Hydrographic Service as an acoustic sweep vessel in the coastal areas of the maritime provinces.

- Principal statistics - built in 1985 . . . length 34.8m . . . breadth overall 14m . . . single hull breadth 4m . . . draft 2.1m . . . freeboard to working deck 1.3m . . . 370 tonnes displacement . . . 12 knot full speed . . . 10 knot service speed . . . 7 day endurance . . . scientific complement of 4 . . . integrated sweep transducers, auto-pilot and laser-ranging positioning system . . . onboard data processing up to 500,000 depth measurements logged daily.

- 97 (102) sea days and 4,387 (4,869) n. miles steamed in 1986 (1987).

VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
86-009	Jun. 6-Sep. 22	A. Adams, CHS	13 ports - Gulf of St. Lawrence/Cabot Strait	Sweep surveys
86-024	Sep. 29-Oct. 31	A. Adams, CHS	Halifax Harbour, Lunenburg, Liverpool, Yarmouth, N.S.	Sweep surveys
87-013	May 4-Oct. 23	G.W. Henderson, CHS	Bay of Fundy Cape Breton, P.E.I., N.B., Gulf Shore	Sweep surveys
87-004	Oct. 26-Nov. 6	R.M. Eaton, CHS	Halifax Harbour and Bedford Basin	Gear tests

Participation in Other Research Cruises

- During 1986, a number of Scotia-Fundy Science organizations participated in cruises on vessels not operated by DFO, including cooperative research with other countries. These cruises are listed below:

US. DSR/V "ATLANTIS II" RESEARCH SUBMERSIBLE ALVIN A116

VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
A116	Aug. 2-15	D. Piper, AGC (Canada)	Laurentian Fan, Grand Banks	Define the manner in which the 1929 submarine earthquake modified the ocean bottom and determine the extent of the damage

COAST GUARD SHIP "NAHIDIK"

VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
	Sep. 4-12	P. Hill, AGC (Canada)	Eastern Mackenzie Delta, Richards Island and Kugmallit Bay, Beaufort Sea	Determine sedimentary processes and deposits in the nearshore and inner shelf zones and map the extent of the late Wisconsinan and Holocene sediments

U.S.S.R. RESEARCH VESSEL "TOROK"

VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
T01	Oct. 17-Nov. 20	M. Showell (Canada)	Scotian Shelf	Determine abundance of juvenile silver hake

NOAA R/VALBATROSS IV

VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
AL IV 86-03	Jun. 9-Ju13	J. Neilson (Canada)	Georges Bank	Cooperative juvenile gadoid survey

RV EDWIN LINK'S DSRV JOHNSON SEA LINK (SUBMERSIBLE)

VOYAGE YEAR NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
	Aug. 4-13	J. Neilson (Canada)	Georges Bank	Cooperative juvenile gadroid survey

Organization

The Bedford Institute of Oceanography (BIO), the Halifax Fisheries Research Laboratory (HFRL) and the St. Andrews Biological Station (SABS) are research establishments of the Government of Canada operated by the Department of Fisheries and Oceans (DFO), both on its own behalf and, in the case of BIO, for the other federal departments that maintain laboratories and groups at the Institute. There are two such departments: The Department of Energy, Mines and Resources (DEMR); and the Department of the Environment (DOE). The former maintains two units at BIO: the Atlantic Geoscience Centre of the Geological Survey of Canada; and the Canada Oil and Gas Lands Administration Laboratory. The Department of the Environment also maintains two units at BIO: the Seabird Research Unit of the Canadian Wildlife Service; and the Regional Laboratory of the Atlantic Region's Environmental Protection organization.

BIO also houses the office of the Northwest Atlantic Fisheries Organization (Executive Secretary - Captain J.C.E. Cardoso). In leased accommodation at BIO are the following marine-science related private companies: ASA Consulting Ltd., Brooke Ocean Technology, Seakem Oceanography, Seastar Instruments Ltd., and Seimac Ltd.

Presented below are the major groups and their managers as at March 1, 1988. In addition to the three research establishments, several staff are located in an office building in Halifax, the Hollis Building (HB). Telephone numbers are included: note that all BIO, Halifax Laboratory and Hollis Building numbers should be prefixed by (902) 426-

DEPARTMENT OF FISHERIES AND OCEANS

Scotia-Fundy Region
Regional Director-General
J.-E. Haché HB/2581

Regional Director Science
S.B. MacPhee BIO/3492
Marine Assessment and Liaison Division
H.B. Nicholls, Head BIO/3246
Scientific Computing Services
D. Porteous, Head BIO/2452

Biological Sciences Branch
M.M. Sinclair, Director HB/3130
Marine Fish Division
W.D. Bowen, Chief BIO/8390
Invertebrates, Marine Plants and Environmental Ecology Division
J.D. Pringle, A/Chief HFRL/6138
Biological Oceanography Division
T.C. Platt, Chief BIO/3793
Enhancement, Culture and Anadramous Fisheries Division
N.E. MacEachern, Chief . . . HB/3573
Fish Aquaculture and Applied Physiology (and Director, St. Andrews Biological Station)
R.H. Cook, Chief . . . . SABS/ (506) 529-8854

Physical and Chemical Sciences Branch
J.A. Elliott, Director BIO/8478
Marine Chemistry Division
J.M. Bewers, Head . . BIO/2371
Coastal Oceanography Division
C.S. Mason, Head BIO/3857
Metrology Division
D.L. McKeown, Head BIO/3489
Ocean Circulation Division
R.A. Clarke, Head BIO/2502

Hydrography Branch
Canadian Hydrographic Service (Atlantic)
T.B. Smith, A/Regional Director BIO/3497
T.B. Smith, Assistant Director BIO/2432
Field Surveys Division
T.B. Smith, Head BIO/2432
Chart Production
S.L. Weston, Superintendent BIO/7286
Hydrographic Development
R.G. Burke, Head BIO/3657
Navigation Group
H. Boudreau BIO/2572
Data Management and Planning
R.C. Lewis, Manager BIO/2411
Tidal Section
S.T. Grant, Head BIO/3846

Management Services Branch
E.J. Maher, Director HB/7433
Marine Services
J.H. Parsons, Chief . BI017292
Engineering and Technical Services
D.F. Dinn, Chief BIO/3700
Facilities Management
A. Medynski, Chief HFRL/7449
Material Management
G. Hewett, A/Chief HB/3568
Information Systems
C. Elson, Chief HB/9315
BIO Library Services
J.E. Sutherland, Chief BIO/3675
Halifax Library, Services
A. OxIey, Chief HFRL/6266
Administrative Services
J. Broussard, A/Chief HB/7037

Comptroller's Branch
G.C. Bowdridge, Director BIO/6166
Accounting and Treasury Operations
S. Lucas, Chief HB/3552
Financial Planning and Analysis
L.Y. Seto, Chief BIO/7060
Operational and Work Planning Division
R.A. Huggins, Chief HB/2271

Communications Branch
J. Gough, Director HB/5762
Science Communications
M.Roy BIO/6414

DEPARTMENT OF ENERGY, MINES AND RESOURCES

Atlantic Geoscience Centre
(Geological Survey of Canada)

M.J. Keen, Director	BIO/2367
D.I. Ross, Assistant Director	BIO/3448
Eastern Petroleum Geology	
M.E. Best. Head	BIO/2730
Environmental Marine *Geology*	
R. Taylor, A/Head	BIO/7730
Regional Reconnaissance	
R. MacNab, A/Head	BIO/5687
Program Support	
K.S. Manchester, Head	BIO/3411
Administration	
C. Racine, Head	BIO/2111

DEPARTMENT OF ENVIRONMENT

Seabird Research Unit
(Canadian Wildlife Service)

E.H.J. Hiscock, Administrative Coordinator	BIO/3274

Regional Laboratory
(Environmental Protection)

H.S. Samant, Chief	BIO/6237

Projects

WE present below a listing of the projects and individual investigations (1, 2, 3, etc.) being undertaken by the Department of Fisheries and Oceans Scotia-Fundy Region laboratories and by the Atlantic Geoscience Centre of the Department of Energy, Mines and Resources. For more information on these projects and those of other components at the BIO, feel free to write to the: Regional Director of Science, Scotia-Fundy Region, Department of Fisheries and Oceans, c/o Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2.

BIOLOGICAL SCIENCES BRANCH

A. MARINE FISH AND MARINE MAMMAL STOCK ASSESSMENTS AND ASSOCIATED RESEARCH

1. Herring Assessments and Associated Research
(T.D. Isles)
2. Haddock Assessments and Associated Research
(W.D. Bowen)
3. Cod Assessments and Associated Research
(W.D. Bowen)
4. Pollock Assessment and Associated Research
(C. Annand)
5. Silver Hake Assessments and Associated Research
(D. Waldron)
6. Redfish Assessments and Associated Research
(R. Halliday)
7. Flatfish Assessments and Associated Research
(J. Neilson)
8. Continental Shelf Margin Studies Including Argentine Assessment
(R. Halliday)
9. Dogfish Assessment and Related Research
(C.Annand)
10. Population Ecologv and Assessment of Seals
(W.D. Bowen)
11. Fisheries Management Studies
(W.D. Bowen)
12. Stock Assessment Methods
(G. White)
13. National Sampling Program
(K. Zwanenburg, J. Hunt)
14. International Observer Program
(D. Waldron)
15. Groundfish Surveys
(S. Gavaris)
16. Groundfish Age Determination
(J. Hunt)
17. Ichthyoplankton Research
(P. Hurley)
18. Fisheries Recruitment Variability
(K. Frank)
19. Otolith Studies
(S. Campana)
20. Tagging Studies
(W.T Stobo)
21. Groundfish Distribution and Community Studies
(J.S. Scott)
22. Bioenergetics of Marine Mammals
(P.F. Brodie)
23. Acoustics Research
(U. Buerkle, L. Dickie)
24. Parasitology of Scotian Shelf Fishes
(J.S. Scott)
25. Oceanography and Fish Distribution
(I. Perry)
26. Juvenile Fish Ecology and Surveys
(J. Neilson)
27. Alternate Approaches to Resource Assessment and Management: Size-Dependent Processes in Fish Production Systems
(S. Kerr)
28. Alternate Approaches to Resource Assessment and Management: Mathematical Analysis of Fish Production Systems
(W. Silvert)
29. Statistical Consulting and Special Projects
(R. Mohn)

B. INVERTEBRATE AND MARINE PLANT STOCK ASSESSMENTS AND ASSOCIATED RESEARCH

1. Alternate Approaches to Resource Assessment and Management: Fish-Fishermen Interaction
(R. Mohn)
2. Scallop Research
(R. Mohn)
3. Shrimp Research
(R. Mohn)
4. Invertebrate Recruitment Studies
(M. Sinclair)
5. Juvenile Scallop Biology
(M.J. Dadswell)
6. Scallop Stock Assessment and Related Research
(G. Robert)
7. Offshore Clam Research and Assessment
(T.W. Rowell)
8. Inshore Clam Stock Assessment and Related Research
(T. Amaratunga, T.W. Rowell)
9. Crab Assessment and Research
(R.W. Elner)
10. Marine Plant Stock Assessment and Related Research
(G.J. Sharp)
11. Lobster Stock Assessment - LFAs 34-39
(A. Campbell)
12. Lobster Stock Assessment and Related Research - Cape Sable Island to Bay St. Lawrence, N.S. (LFAs 27-33)
(R.J. Miller, J.D. Pringle)
13. Lobster Stock Assessment and Related Research - Offshore (LFAs 40,41)
(D.S. Pezzack)
14. Lobster Research - Habitat and Trapping
(R.J. Miller)
15. Lobster Research - Larval Biology
(G.C. Harding, J.D. Pringle, R.W. Elner)
16. Lobster Research - Juvenile and Adult Biology
(A. Campbell)
17. Inshore Molluscan Habitat Studies
(T.W. Rowell)
18. Mussel Assessment and Biological Studies
(T. Amaratunga, G.J. Sharp)

C. ENVIRONMENTAL ECOLOGY

1. Acid Rain Research
(W.D. Watt)
2. Freshwater Fish Habitat Assessment and Related Research
(W.D. Watt)
3. Organic Carbon Bioavailability
(PD. Kaizer)
4. Trophic Relations in Near-Shore Kelp and Seagrass Communities
(K.H. Mann)
5. Interactions Between Physical and Biological Processes in the Marine Environment
(K.H. Mann)
6. Deep-Ocean Food Webs
(B.T Hargrave)
7. Contaminant Fluxes in Arctic Ocean Food Webs
(B.T. Hargrave)
8. Distribution and Activity of Benthic Organisms
(D.L. Peer)
9. Benthic and Pelagic Exchanges
(K. Muschenheim)
10. Chemical Tracers in Food Webs
(P. Keizer)
11. Evaluation of Estuarine and Continental Shelf Habitats
(D.C. Gordon)
12. Field and Laboratory Studies of Diapause in Copepods
(N. Watson)
13. Fish Habitat Assessment Advice
(D.C. Gordon)
14. Sublethal Effects of Hydrocarbon Exploration on Scallops
(D.C. Gordon)

D. ANADROMOUS SPECIES ASSESSMENTS, SALMON ENHANCEMENT AND ASSOCIATED RESEARCH

1. Salmon Assessment Research
(T.L. Marshall)
2. Non-Salmonid Assessment Research
(B.M. Jessop)
3. Salmon Enhancement Research
(Enhancement Biology)
(B.M. Jessop)
4. Enhancement and Fish Passage Engineering
(H. Janson)
5. Fish Culture Engineering
(H. Janson)
6. Hatchery Operations and Production
(G. Robbins)
7. Fish Culture Research
(G. Farmer)
8. Anadromous Species Statistical Data Collection and Analysis
(S.E O'Neill)
9. Special Projects
(D.J. Scarratt)
10. Invertebrate Nutrition
(J. Castell)
11. Fish Nutrition
(S.P. Lall)
12. Fish Disease Research
(G. Oliver)
13. Parasitology
(G. Oliver)

14. Molluscan Culture Research
(K. Freeman)
15. Aquaculture Co-ordination
(R.E. Drinnan)
16. Fish Health Service Unit
(J.W. Cornick)

E. FISH AQUACULTURE AND APPLIED PHYSIOLOGY

1. Division Chief, FAAP
(R.H. Cook)
2. Salmon Genetics Research Program
(R.H. Cook)
3. Finfish Physiology and Aquaculture Development (Salmon)
(R.L. Saunders)
4. Invertebrate Biology and Aquaculture Development Research
(D.E. Aiken)
5. Ecophysiology of Cod and Haddock
(K.G. Waiwood)
6. Marine Finfish Aquaculture
(K.G. Waiwood)
7. Aquaculture Ecology
(D.J. Wildish)
8. Effects of Low pH on Salmonid Development
(R.H. Peterson)
9. Environmental Requirements for Early Fish Development
(R.H. Peterson)
10. Impacts of Acid Rain on Salmonid Ecology
(G.L. Lacroix)

F. BIOLOGICAL OCEANOGRAPHY

1. Bioptical Properties of Pelagic Oceans
(T. Platt)
2. Respiration, Nutrient Uptake and Regeneration of Natural Plankton Populations
(W.G. Harrison)
3. Physical Oceanography of Selected Features in Connection with Marine Ecological Studies
(E. Home)
4. Physiology of Marine Microorganisms
(W. Li)
5. Role of Picoplankton in the Marine Ecosystem
(D.V. Subba Rao)
6. Biological Oceanography of the Grand Banks
(E. Home)
7. Carbon Dioxide and Climate: Biogeochemical Cycles in the Ocean
(T. Platt)
8. Analysis of Pelagic Ecosystem Structure
(A.R. Longhurst)
9. Carbon and Nitrogen Utilization by Zooplankton and Factors Controlling Secondary Production
(R.J. Conover)
10. Secondary Production and the Dynamic Distribution of Micronekton on the Scotian Shelf
(D.D. Sameoto)
11. Biological Stratification in the Ocean and Global Carbon Flux
(A.R. Longhurst)
12. Nutrition and Biochemistry in Marine Zooplankton
(E.J.H. Head)
13. Feeding Studies on Zooplankton Grown in an Algal Chemostat
(E.J.H. Head)
14. Scotian Shelf Ichthyoplankton Program: Data Acquisition Over Large Spatial and Long Temporal Scales
(R.J. Conover)
15. Feeding Dynamics of Eastern Arctic Zooplankton and Miconekton
(D.D. Sameoto)
16. Shore-Based Studies of Under-Ice Epontic and Pelagic Plankton Communities
(R.J. Conover)
17. Summertime Shipboard Studies in the Eastern Canadian Arctic
(E.J.H. Head)
18. Biogeochemistry of Metal and Nutrient Cycling by Pelagic and Benthic Bacteria
(P.E. Kepkay)

PHYSICAL AND CHEMICAL SCIENCES BRANCH

A. OCEAN CLIMATE

1. Humidity Exchange over the Sea (HEXOS) Programme
(S.D. Smith, R.J. Anderson)
2. Microstructure Studies in the Ocean
(N.S. Oakey)
3. Near-Surface Velocity Measurements
(N.S. Oakey)
4. 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)
5. The Spin-Down and Mixing of Mediterranean Salt Lenses
(N.S. Oakey, B.R. Ruddick (Dal))
6. Laboratory Measurements of Velocity Microstructure in a Convective System Using Photographic Techniques
(J.M. Hamilton)
7. Labrador Sea Water Formation
(R.A. Clarke. NS. OakeY, J.-C. Gascard (France))
8. Modelling of the Labrador Sea
(C. Quon, R.A. Clarke)
9. Labrador Current Variability
(R.A. Clarke, V. Larichev)
10. Age Determinations in Baffin Bay Bottom Water
(E.P. Jones, J.N. Smith, K.M. Ellis)
11. Moored Measurements of Gulf Stream Variability: A Statistical & Mapping Experiment
(R.M. Hendry)
12. Newfoundland Basin Experiment
(R.A. Clarke, R.M. Hendry, A. Coote)
13. Problems in Geophysical Fluid Dynamics
(C. Quon)
14. Norwegian/Grenland Sea Experiment
(R.A. Clarke, J.A. Swift (Scripps), J. Reid (Scripps), N. Oakey, P. Jones, R. Weiss (Scripps))
15. Baseline Hydrography; North Atlantic at 48°N of Labrador Current Waters
(R.M. Hendry)
16. Studies of the North Atlantic Current and the Seaward Flow of Labrador Current Waters
(J.R.N. Lazier, D. Wright)
17. Ship of Opportunity Expendable Bathythermograph Programme for the Study of Heat Storage in the North Atlantic Ocean
(F. Dobson)
18. Thermodynamics of Ocean Structure and Circulation
(E.B. Bennett)
19. Flow through the Strait of Belle Isle
(B.D. Petrie, C. Garrett (Dal), B. Toulany)
20. Shelf Dynamics - Avalon Channel Experiment
(B.D. Petrie)
21. Batfish Internal Waves
(A.S. Bennett)
22. Data Management & Archival
(D.N. Gregory)
23. Eastern Arctic Physical Oceanography
(C.K. Ross)
24. Water Transport through and in the Northwest Passage
(S.J. Prinsenberg, E.B. Bennett)
25. Saguenay Fjord Study
(G.H. Seibert)
26. Seasonal and Interannual Variability in the Gulf of St. Lawrence
(G.L. Bugden)
27. Foxe Basin Mooring Observation Program to Study Tidal Current. Mean Circulation. and Water Mass Formation and Transport
(S. Prinsenberg)
28. The Gulf of St. Lawrence - Numerical Modelling Studies
(K. Tee)
29. Tidal and Residual Currents - 3-D Modelling Studies
(K.T. Tee)
30. Circulation and Air/Sea Fluxes of Hudson Bay & James Bay
(S. Prinsenberg)
31. Developing an Efficient Method for Modelling Three-Dimensional Shelf and Slope Circulations
(K.T Tee)
32. CTD's and Associated Sensors
(A.S. Bennett)
33. Real-Time Data Acquisition
(A.S. Bennett)
34. CTD Sensor Time Constant Measurements
(A.S. Bennett)
35. Mooring Systems Development
(G. Fowler, R. Reiniger, A. Hartling, J. Hamilton)
36. Handling and Operational Techniques for Instrument/Cable Systems (J.-G. Dessureault, R.F Reiniger)
37. Climate Variability Recorded in Marine Sediments
(J. Smith)
38. The Carbonate System & Nutrients in Arctic Regions
(E.P Jones)
39. Distribution of Sea Ice Meltwater in the Arctic
(F.C. Tan)
40. Paleoclimatological Studies of Lake Melville Sediment Cores
(F.C. Tan, G. Vilks (AGC))
41. Development of an Operational Mooring Design for N&r-Surface Current Measurements-
(J. Hamilton)
42. Intergyre Exchange
(R. Hendry)

B. MARINE DEVELOPMENTS AND TRANSPORTATION

1. Bay of Fundy Tidal Power - Studies in Physical Oceanography
(D.A. Greenberg)
2. Oil Trajectory Analysis
(D.J. Lawrence)
3. Winter Processes in the Gulf of St. Lawrence
(G. Bugden)
4. Modelling Historical Tides
(D.A. Greenberg)

5. Storm surges
(D.A. Greenberg, T.S. Murty (IOS Pat Bay))
6. Point Lepreau Environmental Monitoring Program
(J.N. Smith)
7. Marine Emergencies
(E.M. Levy)
8. A Novel Vibracorer for Surface, Subsurface Remote, or ROV Supported Operation
(G. Fowler)

C. OFFSHORE ENERGY RESOURCES

1. Studies of the Growth of Wind Waves in the Open Seas
(F.W. Dobson)
2. Wave Climate Studies
(W. Perrie, B. Toulany)
3. Iceberg Drift Track Modelling
(S.D. Smith)
4. Labrador Coast Ice
(S. Prinsenberg, I. Peterson)
5. Gulf of St. Lawrence Ice Studies
(G. Bugden)
6. Wind Sea Dynamics
(W. Perrie, B. Toulany)
7. Current Measurements Near the Ocean Surface
(PC. Smith, D.J. Lawrence, J.A. Elliot, D.L. McKeown)
8. Modelling of Ice and Icebergs Flowing along the Labrador and Baffin Island Coasts
(M. Ikeda)
9. Large-Scale Circulation in the Labrador Sea and Baflin Bay
(M. Ikeda)
10. Labrador Ice Studies - Field Program
(I. Peterson)
11. Storm Response in the Coastal Ocean: The Oceanographic Component of the Canadian Atlantic Storms Program
(P.C. Smith, W. Perrie, F.W. Dobson, D.A. Greenberg, D.J. Lawrence)
12. Dynamical Origins of Low-Frequency Motions over the Labrador/Newfoundland Shelf
(D. Wright, J. Lazier, B. Petrie)
13. Labrador Ice Margin Studies
(C. Tang, M. Ikeda)
14. Current Surges and Mixing on the Continental Shelf Induced by Large Amplitude Internal Waves
(H. Sandstrom &J.A. Elliot)
15. Oceanography of the Newfoundland Continental Shelf
(B.D. Petrie, D.A. Greenberg)
16. Study of Current Variability and Mixed Layer Dynamics on the Northeastern Grand Banks
(C.L. Tang. B.D. Petrie)
17. Anemometers for Drifting Buoys
(J.-G. Dessureault, D. Belliveau)
18. Thermistor Chains on Drifting Buoys
(G.KA. Fowler, J.A. Elliot)
19. Bottom Referenced Acoustic Positioning Systems
(D.L. McKeown)
20. Ship Referenced Acoustic Positioning Systems
(D.L. McKeown)
21. Doppler Current Profiler
(N.A. Cochrane)
22. Development of a Lagrangian Surface Drifter
(D.L. McKeown. G. Fowler)
23. Bottom-Mounted Acoustic Current Profiler
(N. Cochrane, J. Whitman, D. Belliveau)
24. Techniques to Recover or Refuel the Submarine (DOLPHIN Under Way (J.-G. Dessureault, R. Vine (ETS))
25 Petroleum Hydrocarbon Components
(E. Levy)
26. Petroleum Residues in the Eastern Canadian Arctic
(E. Levy)
27. Enhanced Biodegradation of Petroleum in the Marine Environment
(E. Levy, K. Lee)
28. Trace Elements in the Marine Environment
(P. Yeats)
29. Application of Measurements of Hepatic Microsomal Mixed Function Oxidase (MFO) Activity in Winter Flounder as a Petroleum Pollution Monitoring Tool
(R.F Addison, D.E. Willis, Dalhousie Contractors, J.E Payne)
30. Petroleum Hydrocarbon Stress to Juvenile Fish
(J.H. Vandermeulen)
31. Contaminant Cycling in Estuarine Waters
(J.H. Vandermeulen)
32. Measurement of Ocean Waves During CASP
(F.W. Dobson)
33. A Trawl Proof Bottom Mount for Oceanographic Instruments
(J.-G. Dessureault)
34. Towing in Ice
(R.A. Clarke)
35. Georges Bank
(J. Loder, N. Oakey, K. Drinkwater, E. Home)
36. Oceanic CO_2
(E.P Jones)
37. Sublethal Tainting-Scallops
(R. Addison)

D. LIVING RESOURCES

1. Circulation off Southwestern Nova Scotia: The Cape Sable Experiment (P.C. Smith, D. LeFaivre (Quebec), K. Tee, R. Trites)
2. The Shelf Break Experiment: A Study of Low-Frequency Dynamics and Mixing at the Edge of the Scotia Shelf
(P.C. Smith, B.D. Petrie, J.P. Louis (NRC PDF))
3. Theoretical Investigations into Circulation and Mixing on Georges Bank: Mixing and Circulation on Georges Bank
(J. Loder, D. Wright)
4. Circulation and Dispersion on Browns Bank: The Physical Oceanographic Component of the Fisheries Ecology Program
(PC. Smith)
5. Long-Term Monitoring of the Labrador Current at Hamilton Bank
(J.R.N. Lazier)
6. Long-Term Temperature Monitoring
(D. Dobson)
7. Flemish Cap Experiment
(C.K. Ross)
8. Heat and Salt Budget Studies for the Grand Banks Region
(J.W. Loder, K.F. Drinkwater, B.D. Petrie)
9. Development of a Remote Sensing Facility in the Atlantic Oceanographic Laboratory
(C.S. Mason, B. Topliss, L. Payzant)
10. Horizontal and Vertical Exchange on the Southeast Shoal of the Grand Bank
(J.W. Loder. C.K. Ross)
11. Bottom and Surface Drifters
(D. Gregory)
12. Towed Biological Sensors
(A.W. Herman, M. Mitchell, S.W. Young, E.F. Phillips, D. Knox)
13. The Dynamics of Primary & secondary Production on the Scotian Shelf
(A.W. Herman, D. Sameoto, T. Platt)
14. Vertical Profiling Biological Sensors
(A.W. Herman, M.R. Mitchell, S.W. Young, E.F. Phillips, D.R. Harvey)
15. Zooplankton Grazing and Phytoplankton Dynamics
(A.W. Herman, A.R. Longhurst, D. Sameoto, T. Platt, G. Harrison)
16. Moored Biological Sensors
(A.W. Herman. M.R. Mitchell. S.W. Young. E.F. Phillips)
17. Satellite Estimations of Primary Productivity
(B. Topliss)
18. Optical Properties of Canadian Waters
(B.J. Topliss)
19. Biological Arctic Instrumentation
(A. Herman, D. Knox)
20. Automatic Winch Control for Towed Plankton Samplers
(M. Mitchell, J.-G. Dessureault, A. Herman, S. Young, D. Harvey)
21. Multi-Frequency Acoustic Scanning of Water Column
(N.A. Cochrane)
22. Fish Ageing from $^{210}Pb/^{226}Ra$ Measurements in Otoliths
(J.N. Smith)
23. Growth Rates of the Sea Scallops (Placopecten Magellanicus) Using the Oxygen Isotope Record
(F.C. Tan, D. Roddick)
24. Bioavailability of Non-Living Organic Carbon
(P.D. Keizer, D.C. Gordon, P. Schwinghamer, P.J. Cranford, P. Kepkay)
25. Residual Current Patterns on the Canadian Atlantic Continental Shelf as Revealed by Surface & Sea Bed Drifters
(R.W. Trites)
26. Water Mass Analysis for the NAFO Area
(R.W. Trites. K. Drinkwater)
27. Effects of Hudson Bay Outflow on the Labrador Shelf
(K. Drinkwater)
28. Larval Transport and Diffusion Studies
(R. Trites, T.W. Rowell, E.G. Dawe)
29. Climatic Variabilitv in the NAFO Area
(R. Trites, K. Drinkwater)
30. Environmental Variability - Correlations, Patterns, and Response Scales
(R. Trites)
31. Baffin Island Fjords
(R.W. Trites)
32. Variability and Origin of the Cold Intermediate Layer on the Labrador and Newfoundland Shelves
(S.A. Akenhead, J.R.N. Lazier, J.W. Loder, B.D. Petrie)

E. BIOGEOCHEMISTRY

1. Physical Dynamics of Particulate Matter
(K. Kranck)
2. In-Situ Sampling of Suspended Particulate Matter
(G. Fowler, B. Beanlands, W. Whiteway)
3. Estuarine and Coastal Trace Metal Geochemistry
(P.A. Yeats, D.H. Loring, J.A. Dalziel)
4. Sediment Geochronology and Geochemistry in the Saguenay Fjord
(J.N. Smith)
5. Organic Carbon Transport in Major World Rivers: The St. Lawrence, Canada
(R. Pocklington, F. Tan)
6. Arctic and W. Coast Fjords
(J. Smith)
7. Isotope Geochemistry of Major World Estuaries
(F.C. Tan, J.M. Edmond)
8. Review of Chemical Oceanography in the Gulf of St. Lawrence
(J.M. Brewers, E.M. Levy, D.H. Loring,

R. Pocklington, J.N. Smith, P.M. Strain, F.C. Tan, P.A. Yeats)
9. Radioccological Investigations of Plutonium in an Arctic Marine Environment
(J.N. Smith, K.M. Ellis, A. Aarkrog)
10. Trace Metal Geochemistry in Estuarine Mixing Zones
(P. Yeats, J.M. Bewers, J. Dalziel)
11. Trace Metal Geochemistry in the North Atlantic
(P.A. Yeats)
12. Natural Marine Organic Constituents
(R. Pocklington) -
13. Comparison of Vertical Distribution of Trace Metals in the North Atlantic and North Pacific Oceans
(P.A. Yeats)
14. Radionuclide Measurements in the Arctic
(J. Smith)
15. Carbon Isotope Studies on Particulate and Dissolved Organic Carbon in Deep Sea and Coastal Environments
(F.C. Tan. P. Strain)
16. Joint Canadian/FRG Caisson Experiments
(D.H. Loring, R. Rantala, F. Prosi)
17. Use of Chemical Tracers to Establish the Structure of Marine Food Webs
(PD. Keizer, P. Schwinghamer, P.J. Cranford, D.C. Gordon)
18. Benthic Nutrient Exchange
(P. Keizer, B. Hargrave)
19. Development of Methods for Studies of the Atmospheric Input of Organochlorines to the Northwest Atlantic and Arctic (R.F. Addison, M.E. Zinck. G.C. Harding)
20 Trace Metal Transport in the Western Boundary Currents
(P. Yeats)
21 Low Molecular Weight Hydrocarbons: Potential Contributions to the Carbon and Energy Requirements of Offshore Scallops and Prey of Juvenile Galoids on Georges Bank
(E. Levy, F. Tan, K. Lee)

F. TOXICOLOGY, CONTAMINANTS, AND HABITAT

1. Canadian Marine Analytical Chemistry Standards Program
(M. Bewers, P. Yeats, D. Loring)
2. International Activities
(J.M. Bewers, P.A. Yeats, D.H. Loring)
3. ICES Intercalibration for Trace Metals in Sediments
(D. Loring)
4. Heavy Metal Contamination of Sediments and Suspended Matter on the Greenland Shelf
(D.H. Loring)
5. Risk Assessment of Toxic Chemicals
(J.F. Uthe, C.L. Chou, N. Prouse)
6. Habitat Assessment & Related Research - Acid Rain
(H.C. Freeman and G.B. Sangalang)
7. Risk Assessment of Organic Chemicals to Fisheries
(V. Zitko, M. Babineau, H. Akagi)
8. Biochemical Indicators of Health and Aquatic Animals
(K. Haya, B.A. Waiwood, L.E. Burridge)
9. MFO Induction by PCBs and PCB Replacements
(R.F Addison)
10. Organochlorine-s in Seals
(R.F Addison)
11. Sublethal Contaminents: Long-term Fate and Effects of Petroleum Hydrocarbon Pollution in Aquatic Systems
(J.H. Vandermeulen)
12. Heavy Metal Contamination in a Greenland Fjord
(D. Loring)
13. Interaction of Toxicity and Mutagenicity in Contaminated Environmental Samples
(J.H. Vandermeulen)
14. Isolation & Identification of Critical Hormones in Lobster
(H.C. Freeman)
15. Organochlorine Dynamics in the Marine Pelagic Ecosystem
(G. Harding, K. Drinkwater, R. Addison)

HYDROGRAPHYBRANCH

A. HYDROGRAPHIC FIELD SURVEYS

1. Coastal and Harbour Surveys:
Passamaquoddy Bay, N.B.
(M.G. Swim, J. Ferguson)
Cobscook Bay, Maine, U.S.A.
(J. Ferguson)
Grand-Manan Island, N.B.
(V. Gaudet. M.G. Swim)
Bylot Island, N.W.T.
(V. Gaudet)
Strait of Belle Isle
(V. Gaudet)
Labrador Coast
(V. Gaudet)
Singer Inlet (Ungava Bay)
(V. Gaudet)
2. Sweep Surveys - Ports and Harbours of the Atlantic Coast
(A. Adams)
3. Revisory Surveys:
Riverport, N.S. and Approaches
(G. Costello)
Avon River. N.S
(M.G. Swim)
Neguac Bay, N.B.
(R. Mehlman)
Restigouche River (Boundary Survey)
(R. Haase)
Sydney, North Sydney, St. Peters Canal, Baddeck, N.S., St. Bride's, Argentia, Long Pond, Harbour Grace, Port Union, Bonavista, Clarenville, Bay Bulls, Nfld.
(S. Dunbrack)

B. TIDES, CURRENTS AND WATER LEVELS

1. Ongoing Support to CHS Field Surveys and **Chart Production**
(S.T. Grant, C. O'Reilly, O. Nadeau, C.P. McGinn, G.B. Lutwick, F. Carmichael)
2. Operation of the Permanent Tide and Water Level Gauging Network
(S.T. Grant. C.P. McGinn. G.B. Lutwick, F. Carmichael, O. Nadeau)
3. Review and Update of Tide Tables and Sailing Directions
(S.T. Grant, C. O'Reilly)
4. Scientific and Engineering Project Support:
Calibration and Maintenance of Submersible Gauges
Water Level Analysis of NW P.E.I. for AGC and McMaster University
Development of AU-Weather Digital Barometer Installation of Dial-A-Tide Telephone Answering System for Halifax Calibrations of Wimpol Tide Gauges for the Miramichi, N.B.
(S.T Grant, C. O'Reily, O. Nadeau, C.P. McGinn, G.B. Lutwick, F. Carmichael)

C. NAUTICAL CHART PRODUCITON

1. Production of:
- 5 New Charts
- 8 New Charts
(By Contract)
- 11 - New Editions
- 9 New Editions for LORAN-C
(By Contract)
- 11 Chart Correction Patches
- 110 Notices to Mariners

D. NAVIGATION

1. LORAN-C Calibrations in the Atlantic Area for Large and Small Scale Charts
(R.M. Eaton. N. Stuifbergen. B. MacGowan)
2. LORAN-C Error Accuracy Enhancement for Atlantic Canada
(N. Stuifbergen)
3. Testing and Developing the Electronic Chart
(R.M. Eaton)
4. BIONAV Maintenance
(H. Boudreau)
5. NAVSTAR-GPS Studies
(R.M. Eaton)

E. HYDROGRAPHIC DEVELOPMENT

1. DOLPHIN Trials
(R.G. Burke, C. Stirling, H. Varma, T. Berkeley)
2. FCG SMITH Data Processing Software
(S. Forbes, H. Varma)
3. Enhancing Automated Field Surveys
(K. White, S. Forbes, H. Varma)
4. Enhancing Computer-Assisted Chart Production Techniques
(S. Forbes, K. White, H. Varma)

F. SAILING DIRECTIONS

1. Publication of Sailing Directions, Newfoundland. Eighth Edition
(R. Pietrzak)
2. Revisions to Small Craft Guide, Saint John River, N.B.
(R. Pietrzak)

ATLANTIC GEOSCIENCE CENTRE

A. COASTAL GEOLOGY 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 Coastal Zone Geotechnics
(P.R. Hill)
6. Permafrost Processes in Arctic Beaches
(R.B. Taylor)
7. Coastal Morphology & Sediment Dynamics SE and East Cape Breton Island
(R.B. Taylor)
8. Nearshore Sediments and Non-Fuel Minerals
(G.B. Fader)

B. GEOLOGY OF 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. Sediments Dynamics at Head of the Bay of Fundy
(C.L. Amos)

4. The Recent Paleoclimatic and Palecoecologic Records in Fjord Sediments
(C.T. Schafer)
5. Transfer of Sediments from the Land Mass to the Continental Shelf (SEDFLUX)
(J.P.M. Syvitski)

C. GEOLOGY OF THE 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 Modem Turbidites
(D.J.W. Piper)
6. Engineering Geology of the Atlantic Shelf
(R. Parrott)
7. Marine Geotechnical Study of the Canadian Eastern and Arctic Continental Shelves and Slopes
(K. Moran)
8. Computer Based Map Series
(G.B. Fader)

D. EASTERN ARCTIC AND SUBARCTIC GEOLOGY

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
(P.J. Mudie)
8. Surficial Geology, Geomorphology and Glaciology of Hudson Bay
(W.H. Josenhans)

E. WESTERN ARCTIC GEOLOGY

1. Surficial Geology and Geomorphology, Beaufort Sea
(S.M. Blasco)

F. GEOCHEMISTRY

1. Environmental Geology of the Deep Ocean
(D.E. Buckley)
2. Diagenesis and Geochemical Cycling
(R. Cranston)
3. Early Diagenesis in Quaternary Marine Sediments of Eastern and Arctic Canada
(D.E. Buckley)

G. REGIONAL GEOPHYSICAL SURVEYS

1. East Coast Potential Fields
(R.F MacNab)
2. An Earth Science Atlas of the Continental Margins of Eastern Canada
(S.P. Srivastava)
3. Potential Fields Data-Base Operation
(K.G. Shih)
4. Regional Geophysics of the Mesozoic-Cenozoic of the Newfoundland Margins
(A. Edwards)
5. Interpretation of Potential Field Data
(J. Verhoef)
6. Basin Investigations
(B. Loncarevic)
7. Ocean Mapping
(R. MacNab)

E. INVESTIGATIONS OF DEEP GEOLOGICAL STRUCTURES

1. Comparative Studies of the Continental Margins of the Labrador Sea and the North Atlantic
(S.P. Srivastava)
2. Seismic Studies of Continental Margins of Eastern Canada and Related Areas
(I. Reid)
3. Arctic Ocean Seismic Refraction and Related Geophysical Measurements
(H.R. Jackson)
4. Seismic Refraction Along the Canadian Polar Margin
(H.R. Jackson)
5. Regional Geologic and Plate Tectonic History of the-Canadian Appalachians
(G. Stockmal)
6. Marine Deep Seismic Reflection Studies, Offshore Eastern Canada
(C.E. Keen)
7. Ocean Drilling Program Leg 105 in the Labrador Sea and Baffin Bay
(S.P. Srivastava)
8. Geophysical Study of the Gulf of St. Lawrence Region
(F. Marillier)

F. THEORETICAL GEOPHYSICAL MODELLING

1. Rift Processes and the Development of Passive Continental Margins
(R. Boutilier)

G. 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 in Basin Synthesis and Hydrocarbon Inventory
(A.C. Grant)
3. Compilation of Geoscientitic Data in the Upper Paleozoic Basins of Southeastern Canada
(R.D. Howie)
4. Stratigraphy and Sedimentology of the Mesozoic and Tertiarv Rocks of the Atlantic Continental Margin
(L.F. Jansa)
5. Reconnaissance Field Study of the Mesozoic Sequences Outcropping on the Ibcrian Peninsula
(L.F Jansa)
6. Sedimentary Basin Evolution of the Continental Margin of Newfoundland, Labrador, and Baffin Bay
(K.D. McAlpine)
7. Sedimentology of East Coast Formations
(D.J. Cant)
8. Lithospheric Stress in Canada (with Special Emphasis on Sedimentary Basins)
(J.S. Bell)
9. Lithologic Evolution in the Offshore Basins of Eastern-Canada
(A. Fricker)
10. Labrador Shelf Basin Atlas
(J.S. Bell)

H. HYDROCARBON RESOURCE APPRAISAL

1. Hydrocarbon Inventory of the Sedimentary Basins of Eastern Canada
(M.E. Best)
2. Rank and Petrographic Studies of Coal and Organic Matter Dispersed in Sediments
(P.A. Hacquebard)
3. Maturation Studies
(PA. Hacquebard)
4. Interpretation of Geophysical Data from the Scotian Margin and Adjacent Areas as an Aid to Basin Synthesis and Estimation of Hydrocarbon Potential
(B.C. MacLean)

I. BIOSTRATIGRAPHY

1. Identification and Biostratigraphic Interpretation of Referred Fossils
(M.S. Barss)
2. Palynological Zonation of the Carboniferous and Permian Rocks of the Atlantic Provinces, Gulf of St. Lawrence, and Northern Canada
(M.S. Barss)
3. Biostratigraphy of the Canadian Atlantic Shelf and Adjacent Areas
(R.A. Fensome)
4. Taxonomy and Ecology of Palynomorphs
(R.A. Fensome)
5. DSDP Late Cretaceous-Cenozoic Dinoflagellates
(G.L. Williams)
6. Biostratigraphic Zonation (Foraminifera, Ostracoda) of the Mesozoic and Cenozoic Rocks of the Atlantic Shelf
(P. Ascoli)
7. Quaternary Biostratigraphic Methods for Marine Sediments
(G. Vilks)
8. Quantitative Stratigraphy in Paleo-Oceanography and Petroleum Basin Analysis
(F.M. Gradstein)

J. GEOLOGICAL DATA BASES

1. Geological Survey Representative on Steering Committee for the Kremp Palynologic Computer Research Project
(M.S. Barss)
2. Information Base for Offshore East Coast Wells
(G.L. Williams)
3. Data Inventory
(LA. Hardy)
4. Coastal Information System Development
(D. Forbes)

K. GEOLOGICAL TECHNOLOGY DEVELOPMENT

1. Sediment Dynamics Monitor: RALPH
(D.E. Heffler)
2. Development of Vibracorer/Drill for Geotechnical, Geological, and Engineering Studies
(KS. Manchester)
3. seabed II
(K.S. Manchester)
4. Long Coring Facility Development (LCF)
(K.S. Manchester, W. MacKinnon)
5. Development & Implementation of ROV Technology
(K.S. Manchester)

L. SPECIAL GEOLOGICAL PROJECTS

1. Ocean Drilling Program Planning
(M.J. Keen)
2. Hudson Bay Bedrock Geology
(A.C. Grant)
3. Basin Atlas Project
(D.I. Ross)
4. Montagnais Geophysical Investigation
(A. Edwards)

Excerpts from the Log

LISTED below are some of the events that occurred during 1987. The selection was made by Brian Nicholls:

- A three day workshop was held at BIO in February to explore the usefulness of ecosystem models in environmental impact assessment. The workshop was attended by representatives from industry, university and federal government departments. They concluded that ecological modeling can be a very powerful tool for environmental impact assessment.

- The first held prototype of the Arctic Ice Monitoring System, AIMS 1, completed operational trials during February. The system was jointly developed by DFO Scotia-Fundy Region Science Sector's Physical and Chemical Sciences Branch (PCSB) and Seimac Ltd. It was set up to measure engineering parameters such as wave induced acceleration and to transmit the data to shore-based computers via the ARGOS satellite link.

- A computer-based telephone answering system that provides tidal information became operational during March. The system, "Dial-A-Tide", was developed by a local consulting firm with assistance from the Canadian Hydrographic Service at BIO.

- Atlantic Geoscience Centre (AGC) staff of DEMR participated in a two-week course in offshore mineral exploration and development organized by the International Centre for Ocean Development (ICOD) and the Mineral Policy Branch of DEMR for senior geologists from Third World countries. The course, held in Halifax in March, had thirteen participants from Pacific, Asian, South American and African nations. It included a demonstration of survey methods on a small vessel in Halifax harbour.

- BIO was host to the 9th Annual Canada - U.S. Scientific Discussions during the week of March 9. Canadian fisheries scientists from the Gulf, Newfoundland, Quebec and Scotia-Fundy Regions of DFO met with their counterparts from Woods Hole, Massachusetts to discuss a range of topics concerning the biology and management of coastal marine populations.

- A field study of the marginal ice zone off Labrador was carried out by PCSB during March as part of the multi-institutional sea-ice research program, the Labrador Ice Margin Experiment (LIMEX). This part of the program, involving the *CSS Baffin,* resulted in the collection of ice surface and under-ice data from eleven ice floes. A helicopter was employed farther inside the pack ice for aerial photography and CTD measurements.

- On May 13, at the five-yearly meeting of the International Hydrographic Organization (IHO) in Monaco, Adam Kerr, Regional Director of the Canadian Hydrographic Service at BIO, was elected one of the three directors of the IHO. This organization was founded early in this century to foster the exchange of chart information between maritime nations and to encourage standardization in chart design and symbology.

- On May 19, Stephen MacPhee replaced Barry Muir as Regional Director, Science, Scotia-Fundy Region.

- From May 19 to July 2, a staff member of AGC participated in Leg 115 of the Ocean Drilling Program involving a voyage of the *JOIDES Resolution* in the Indian Ocean. The objectives were to sample basalts for plate velocity and reconstruction studies and to determine Neogene history of carbonate productivity and dissolution in the equatorial waters of the area. Previously, another member of AGC participated in Leg 112 of the Ocean Drilling Program to the Peru continental margin.

- The Scientific Council of the Northwest Atlantic Fisheries Organization (NAFO) held its main meeting of the year at the organization's headquarters at BIO. The meeting was held during the period June 3-17. Regional staff from the Physical and Chemical Sciences and Biological Sciences Branches, including staff from the St. Andrews Biological Station and the Halifax Fisheries Research Laboratory, contributed to meetings of its various committees.

- A marine finfish aquaculture program was initiated at the St. Andrews Biological Station in which halibut is emerging as the leading candidate for research because of its high demand and market value. A research cruise was undertaken in the area of Sable Island Gully in July and 24 adult halibut were caught and returned to St. Andrews to become brood stock for larval rearing studies under this program.

- From July 2 to August 10, five personnel from AGC conducted a marine seismic reflection and geological sampling survey in the channels of the Lougheed Island/King Christian Island region of the Canadian Arctic Archipelago. Objectives were to determine the geological and geotechnical properties and regional character of the unconsolidated sediments, and to identify constraints to engineering developments in the inter-island channels with respect to hydrocarbon development.

- Four scientists from BIO, Peter Jones, Doug Wallace and Frank Zemlyak of PCSB and Peta Moody of AGC, participated in an international expedition onboard the German icebreaker. *F.S. Polarstern*, to the Nansen Basin of the Arctic Ocean. On August 5, *F.S. Polarstern* reached 86°11'N, the most northerly point of the first oceanographic section across a major basin in the Arctic Ocean and the most northerly point ever reached by a research vessel in the Arctic Ocean, surpassing that of the Nansen expedition of nearly a century ago by about 20 miles. The two-month long expedition gathered extensive oceanographic and geological data that showed considerable variations in the Arctic Ocean on a basin-wide scale.

- On Wednesday August 5, Mr. A.J. Kerr (Regional Hydrographer, Scotia-Fundy Region), Mr. Ross Douglas (Director-General, Canadian Hydrographic Service) and Rear-Admiral R. Moses (Director of the Atlantic Marine Center, U.S. National Ocean Survey, Norfolk, VA) visited *CSS Baffin* in Passamaquoddy Bay. The visit marked the successful conclusion of the joint Canada-U.S. survey program in this boundary area.

• A People's Republic of China delegation in the marine sciences and ocean resources field visited BIO during August. The leader of the group was His Excellency Yang Jun, Special Advisor to the State Council for Science and Technology and Deputy Head of the State Council Leading Group for Ocean Resources.

• *CSS Maxwell* and her crew, together with six hydrographers, transferred to the Newfoundland Region of DFO on September 3, 1987.

• Dr. W.K.W. (Bill) Li of DFO Scotia-Fundy Region Science Sector's Biological Sciences Branch (BSB) was the recipient in September of the 1986 APICS Fraser Gold Medal. This prize, which is awarded annually to an outstanding scientist (under 40 years of age) in the Atlantic Provinces, recognizes Dr. Li's contribution to the understanding of the physiological ecology of microbial populations in the sea.

• *CSS Baffin* carried out a successful hydrographic survey between September 2-22, 1988 in Norwegian Bay located in the Canadian Arctic Archipelago. Attempts over the past decade had been unsuccessful due to heavy ice cover. In addition, the Atlantic Geoscience Centre participated and collected valuable geological information.

• The Groundfish Subcommittee of the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) held its annual September meeting from 14-24 September 1987 at the St. Andrews Biological Station. Participants from all DFO Atlantic Regions provided peer review of stock assessments.

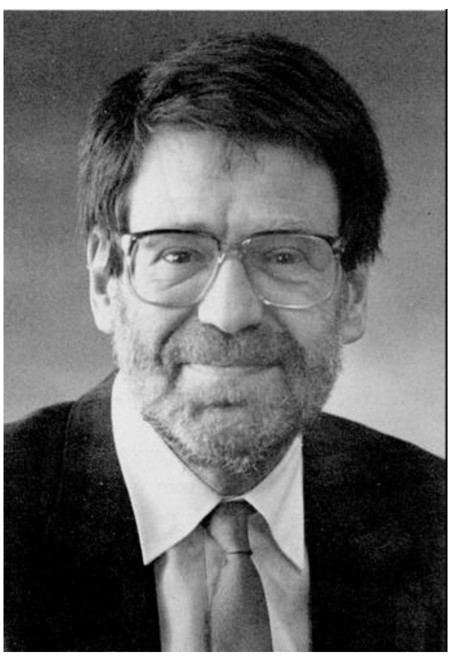
• Oceans 87, the joint MTS/IEEE annual conference and exposition, was held in Halifax during the period September 28 to October 1. The conference theme, "The Ocean: An International Workplace", was much in evidence with 53% of the papers from the USA and 14% from outside North America. The Scotia-Fundy Region was well represented with 25 papers and 13 session chairmen; AGC provided 11 papers and 2 session chairmen.

• On October 26, 1987 the Bedford Institute of Oceanography celebrated its 25th Anniversary. The formal program was well attended by past and present staff. Several official dignitaries attended; they included: The Lieutenant Governor of Nova Scotia, the Premier of Nova Scotia, Mayors of Dartmouth and Halifax, the Honourable M. Forrestall, P.C.M.P., the Deputy Minister of Fisheries and Oceans, the Assistant Deputy Minister - Science, Fisheries and Oceans, the Associate Deputy Minister of the Department of Energy, Mines and Resources and the Vice-President, Academic Research, Dalhousie University. In addition to the congratulations offered by these guests, a telex was received from the Minister of Fisheries and Oceans commending the Institute for its excellent achievements over the past 25 years.

• A "BIO 25th Anniversary Student's Day" was held on October 29. At the Institute's invitation, 450 high school students and their teachers from 21 schools across the province visited BIO to partake in lectures, tours and displays.

• From November 2 to 9, *CSS Dawson* carried out geological surveys on the inner continental shelf from Halifax Harbour east to Ship Harbour and in the vicinity of Sable Island. This project involved staff from AGC, Dalhousie University, Nova Scotia Research Foundation Corporation and Seastar Instruments Ltd. The objectives of the cruise were to ground truth earlier sidescan and seismic reflection surveys, to map the distribution of seabed materials on the inner shelf, and to improve our knowledge of offshore aggregate resources in the area.

• Completion of a herring survey on Georges Bank involving staff of the St. Andrews Biological Station using the *Lady Hammond* (Nov. 2-12) provided positive evidence for resurgence of the Georges Bank herring stock, which has been economically extinct since the mid- 1970's. Electrophoretic analysis of spawning herring indicates that it is the 'old' stock coming back, not another filling in



Tom M. Fenchel (left) received the A.G. Hunts
man Award in 1986 for excellence in research i
biological oceanography, while Xavier LePich
(right) received the award in 1987 for hi
contributions to marine geoscience.

the niche vacated by the 'old' stock. The 1987 programme also validated a prediction of spawning stock biomass in the Bay of Fundy derived from trends from previous surveys - claimed to be the first such prediction from larval survey data.

- At a special awards ceremonv held in Ottawa on December 10, the Honourable Tom Siddon, Minister of Fisheries and Oceans, presented ten members of DFO Regional Science Sector staff with special merit awards in recognition of their efforts towards the development and transfer of technology to the private sector. Those receiving the awards in recognition for their contributions to the *Dolphin* program were: R. Burke, J.-G. Dessureault, W. Goodwin, M. Lamplugh, D. McKeown, A. Parsons, G. Steeves, C. Stirling, D. Dinn and R. Vine.

- During the month of December, serious shellfish toxicity problems, affecting primarily mussels, occurred in and around Prince Edward Island. DFO Regional scientists were mobilized to work with staff or other agencies to identify the toxin(s) and investigate their pathways in the food web.

- A "Georges Bank Research Workshop", organized by the Scotia-Fundy Region Science Sector's Advisory Committee on Georges Bank Hydrocarbon Development, was held at BIO on December 16. The workshop involved over sixty participants from government, university and industry sectors. A total of 23 papers was presented.

Notes

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The Bedford Institute of Oceanography (BIO), the Halifax Fisheries Research Laboratory and the St. Andrews Biological Station are research establishments of the Government of Canada operated by the Department of Fisheries and Oceans (DFO), both on its own behalf and, in the case of BIO, for the other federal departments that maintain laboratories and groups at the Institute. There are two such departments, the Department of Energy, Mines and Resources and the Department of the Environment. The former maintains two units at BIO, the Atlantic Geoscience Centre of the Geological Survey of Canada and the Canada Oil and Gas Lands Administration Laboratory. The Department of the Environment also maintains two units at BIO, the Seabird Research Unit of the Canadian Wildlife Service and the Regional Laboratory of the Atlantic Region's Conservation and Protection.

DFO operates a fleet of research vessels, together with several smaller craft out of BIO. 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.

The broad objectives of the research undertaken by the three research establishments are:

(1) To perform applied research leading to the provision of advice on the management of our marine environment including its fisheries and offshore hydrocarbon resources.

(2) To perform fundamental long-term research in accordance with the mandates of the resident departments.

(3) To perform necessary surveys and cartographic work to ensure a supply of suitable navigational charts for the region from Georges 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.

Senior staff* - Bedford Institute of Oceanography:

S.B. MacPhee - *Regional Director, Science Sector, DFO Scotia-Fundy Region*
P. Bellemare - *Director, Hydrography Branch DFO Scotia-Fundy Region*
J.A. Elliott - *Director, Physical & Chemical Sciences Branch, DFO Scotia-Fundy Region*
M.M. Sinclair - *Director, Biological Sciences Branch, DFO Scotia-Fundy Region*
D.I. Ross - *Director, Atlantic Geoscience Centre, DEMR*
E.H.J. Hiscock - *Seabird Research Unit, Canadian Wildlife Service, DOE*
H.S. Samant - *Chief; Regional Laboratory, Environmental Protection, DOE*

Senior staff* - St. Andrews Biological Station:

R.H. Cook - *Chief Aquaculture and Invertebrate Fisheries Division*

Senior staff* - Halifax Fisheries Research Laboratory:

J.D. Pringle - *Chief Benthic Fisheries and Aquaculture Division*
J.A. Ritter - *Chief Freshwater and Anadromous Division*

(*As of Dec. 31, 1988)

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Energy, Mines and Resources | Énergie, Mines et Ressources

Environment | Environnement