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Bedford Institute
of Oceanography

# Biennial Review 1975/76

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# Biennial Review 1975/76

Bedford Institute of Oceanography
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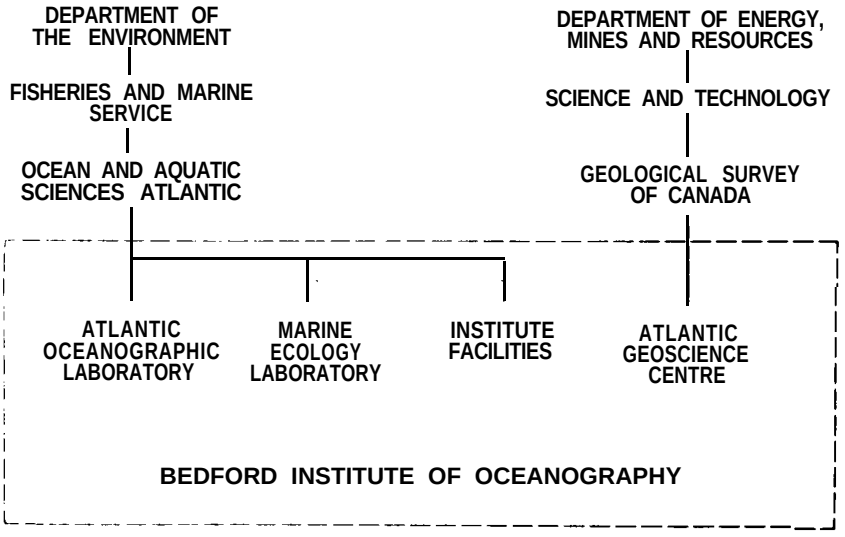
**GOVERNMENT OF CANADA**




**Acknowledgements**

The efforts of the people who helped prepare this edition of the Biennial Review are gratefully acknowledged. In particular I thank Gillian Elliott who edited many of the manuscripts; Roger Belanger, Norman Fenerty, and Heinz Wiele who took most of the photographs and prepared Section D; Arthur Cosgrove, John Lord, and Robert Sibley who prepared all of the line drawings; and Christine Behan who typed most of the manuscripts.

*Michael P. Latremouille*
*Editor*

# Contents

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# Foreword

*This, the fifth edition of the Biennial Review, carries on a policy of 10 years' standing: to make available an overview of the activities of the Institute in a single publication at 2-year intervals. The business of the Institute is the production of new knowledge about the marine environment and of new technology to observe and measure that environment. The products of this business reach their consumers in bits and pieces by the usual routes of scientific articles, reports, charts, conferences, and correspondence, but only in the Biennial Review does the interested reader have ready reference to all of its various products.*

*In addition to basic research devoted to the aquisition of new know/edge and to the understanding of the oceans, coastlines, and estuaries, the Institute continues to emphasize environmental problems and marine resources. Hydrographic charting and geoscience mapping account for a large proportion of the effort. There has been increased emphasis on work in the Arctic and on the continental shelves, the latter assuming greater importance as a result of Canada's decision to extend her fisheries jurisdiction to 200 miles (320 kilometres) offshore.*

*Collaboration with other organizations, both in Canada and abroad, was maintained at a high level. During the period there was increased use of Institute facilities by Canadian industry, including Huntec ('70) Ltd. during the development of an underwater deep-tow seismic system, and Hermes Electronics Ltd. during the development of oceanographic data buoys. The Institute has continued to provide support to several Canadian universities, and has joint projects with some. The University of British Columbia, for example, is running an experiment on the Institute's moored stable platform. We have engaged in a number of international joint activities such as the following. In 1976, Institute staff participated in a* CSS Baffin *cruise off the west coast of Africa under the auspices of the Canadian International Development Agency. French scientists took part in a physical oceanography cruise on* CSS Hudson *to the Labrador Sea, and a member of the Institute participated in a UK cruise on RRS* Discovery *to the Mid-Atlantic Ridge. A joint program with the German Hydrographic Institute, Hamburg, was undertaken to compare sampling and analytical methods pertaining to trace organic pollutants in sea water; there was co-operation with scientists from the Woods Hole Oceanographic Institution and the joint USA-USSR POLYMODE experiment in a deep sea mooring program; and Institute staff participated in two legs of the Deep Sea Drilling Project.*

*BIO continued to be active in the organization of international conferences. Benthonics '75, the first international symposium on benthonic foraminifera of continental margins, held in Halifax, N.S., was sponsored and mainly organized by the Institute, the Geological Survey of Canada, and Dalhousie University, Halifax. Our staff played a leading role in the organization of a joint meeting of the American Association of Stratigraphic Palynologists and the Commission Internationale de Micropaléontologie Paléozoique in Halifax in 1976. Plans for two 1977 conferences, a NATO Advanced Studies Institute on Spatial Patterns in Plankton Communities and an Oil Spill Marine Environment Recovery Symposium, are proceeding.*

*In November 1975 the Institute organized a 3-day open house, which attracted some 15,000 people. During the summer months of each year the old hydrographic survey ship, CSS* Acadia *(built 1913, retired 1969), continues to be a tourist attraction. As in previous years, the Institute received many special visitors from Canada and abroad. Of particular interest were the visits of: a Chinese Fisheries delegation led by Hsiao Feng, Director, Aquatic Products Bureau, Ministry of Agriculture and Forestry; Dr. J. B. Hersey, Deputy Assistant Oceanographer for Ocean Science, Office of Naval Research, U.S.A.; Mr. H. H. Haunschild, the West German Deputy Minister of Research and Technology; and Professor A. P. Kapitsa, Chairman of the Far Eastern Scientific Centre, Vladivostok, USSR.*

*On May 7, 1975 the Minister of State for Fisheries, the Hon. Romeo LeBlanc (now Minister of Fisheries and Minister of the Environment), announced that expenditures of 18 million dollars had been approved for expansion of the Institute; the work is to be carried out in varying stages over the next 4 years. "The activities of the Bedford Institute are recognized as central to the implementation of the federal government's Oceans Policy", Mr. LeBlanc said. "The proposed expansion of the Institute's facilities for ocean-related research and development for use by both government and industry will help speed up the implementation process." At the end of 1976 the first of three new buildings, which is to house laboratories, was nearing completion, and a good start had been made on the second building, which will house laboratories plus a geological core storage facility,*

*During the period of this Review the Fisheries and Marine Service of the Department of the Environment (now the Department of Fisheries and the Environment) revamped its management framework. The principal part of the former Fisheries Research organization was placed within Fisheries Management and the remaining elements, including the Marine Ecology Laboratory (MEL), were assigned to Ocean and Aquatic Sciences (OAS), formerly the Marine Sciences Branch. A degree of decentralization from Ottawa was achieved by the appointment of regional Directors-General responsible to the Assistant Deputy Minister for Ocean and Aquatic Sciences in Ottawa. The Institute-wide technical support functions previously managed by the Atlantic Oceanographic Laboratory (AOL) became Institute Facilities, and the Director, AOL, Director, MEL, and Manager, Institute Facilities, now report to the Director-General, Atlantic Region, OAS.*

*The Institute itself, however, continues to function as a community, sharing many common facilities and services, and managed by a Committee of Directors. The chairmanship of this committee rotates amongst the three laboratory directors; the Director-General and the Manager of Institute Facilities attend as members. The combined budget for 1976 amounts to approximately 20 million dollars with a total employment of 675.*

*The Institute also houses a number of smaller groups whose activities have an affiliation with the programs of one of more of the main laboratories, They are:*

*Department of Fisheries and the Environment: Marine Fish Division, Resource Branch, Fisheries and Marine Service, Maritimes Region; Laboratory Services Division, Environmental Services Branch, Environmental Protection Services, Atlantic Region; Seabird Research Program, Canadian Wildlife Services.*

*Department of Energy, Mines and Resources: Resource Management and Conservation Branch, Regional Office,*

*Industry: Huntec Seabed Project Office, Huntec ('70) Ltd.; Canadian Ocean Data System (CODS) Shore Base, Hermes Electronics Ltd.*

*The accounts on the following pages describe the programs of the Atlantic Oceanographic Laboratory, the Marine Ecology Laboratory, the At/antic Geoscience Centre, and Institute Facilities.*

*Wm. L. Ford*
*Director-General*
*Ocean and Aquatic Sciences - Atlantic*

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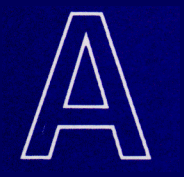


# Atlantic Oceanographic Laboratory (AOL)
# Ocean and Aquatic Sciences, Atlantic
# Department of the Environment
# 1975/76

Acting Director - C. R. Mann

- Chemical Oceanography Division
- Coastal Oceanography Division
- Metrology Division
- Ocean Circulation Division
- Hydrography Division
- Finance and Administration

# Director's Remarks

During the past 2 years the Atlantic Oceanographic Laboratory (AOL) has gone through considerable change in organization and program. As a result of the Fisheries and Marine Service re-organization, the management of facilities for the Bedford Institute of Oceanography was split off from AOL. The responsibility for general administration of common facilities, such as the typing pool and the provision of power, remained with AOL.

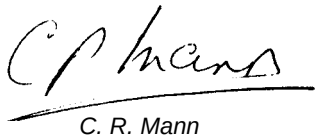
The divisional structure has been retained but four new division heads have been appointed: Dr. C. S. Mason has been appointed head of Coastal Oceanography; Dr. G. T. Needler, head of Ocean Circulation; Dr. D. McKeown, head of Metrology; and Mr. G. Bowdridge, head of Administration. The Air-Sea Interaction group has been moved from Metrology to Ocean Circulation. To give more emphasis and focus to Fisheries Oceanography it was agreed that the Marine Ecology Laboratory would build up a capability to undertake multidisciplinary studies in this area and that Coastal Oceanography would continue to support the program, particularly when large-scale studies of the physical oceanography of an area are necessary.

Several substantive shifts of program have been put into effect. As it is necessary to know more about the oceanography of the continental shelf for oil exploration and fisheries management, a program has been developed to study processes on the Scotian Shelf and the Labrador Shelf. Unfortunately, this has been at the expense of the deep sea program. The chemical program in the Gulf and estuary of the St. Lawrence has been reduced and this has released some resources for continental shelf and deep sea programs. The hydrographic program has continued with navigational and resource charting and will have added to it a Chart Construction unit, which is being decentralized from Ottawa. The laboratory has been given the responsibility for the major part of the Ocean and Aquatic Sciences regional vetting of dumping activities under the Ocean Dumping Act. The administration and issuing of permits is the responsibility of the regional office of the Environmental Protection Service.

The changes in organization and program, which came at a time of restraint, imposed considerable strain on the Laboratory; however, morale has been generally good in these trying times. It is apparent, though, that we must seek additional support if the Laboratory is to meet its obligations and fulfill its role in oceanographic research and hydrography.

During the past 2 years staff of the Atlantic Oceanographic Laboratory have undertaken advisory duties as members of task teams, groups of experts, advisory boards, etc., associated with industry, universities, Canadian governmental departments, both federal and provincial, and international organizations Examples of these organizations are: services within the Department of Environment (now Department of Fisheries and the Environment), Ministry of Transport, Nova Scotia Research Foundation, National Research Council of Canada, Huntec '(70) Ltd., Newfoundland Oceans Research and Development Corp., Bay of Fundy Tidal Power Review Board, Intergovernmental Maritime Consultative Organization, International Commission for the Exploration of the Seas, Intergovernmental Oceanographic Commission, and the

Scientific Committee on Oceanographic Research of the International Council of Scientific Unions. Close contact has been kept with the Department of Oceanography, Dalhousie University, and the Section d'océanographie de l'Université du Quebec à Rimouski. These duties are a natural expression of the research carried on at the Atlantic Oceanographic Laboratory. They also help to stimulate the program through contact with a wide spectrum of people interested in marine affairs.



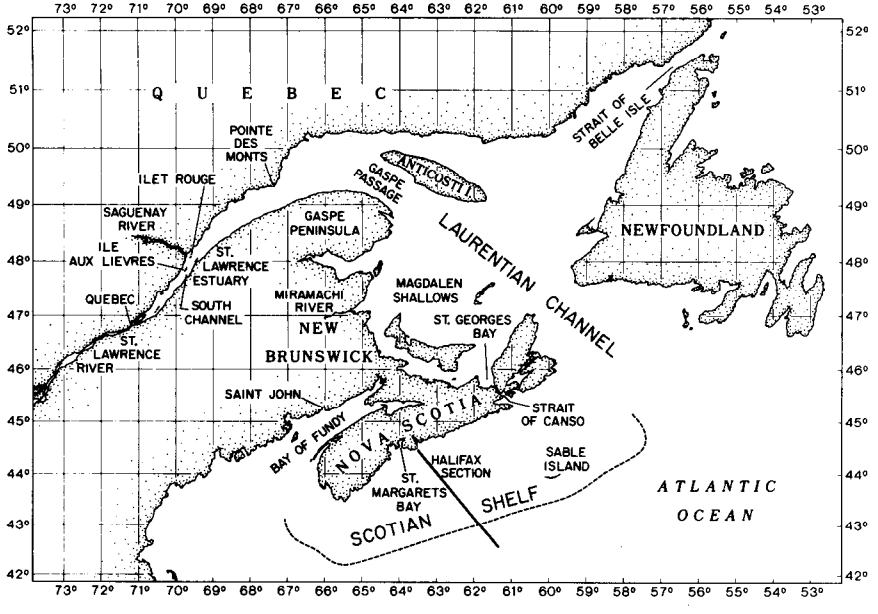
*C. R. Mann*
Acting Director
Atlantic Oceanographic Laboratory

# Chemical Oceanography

Chemical Oceanography Division conducts research on chemical behaviour in estuaries, on nutrients and biological/physical processes, on gas fluxes at the atmosphere-ocean boundary, on isotope variations and transport mechanisms, and on marine pollution by oil, organohalogen residues, and heavy metals.

In its present activities, the Division attempts to develop programs blending studies of a fundamental nature with those of obvious application to national and international concerns. A major project has been to examine fluxes of various constituents through the St. Lawrence estuary. The various chemical, physical, and biological factors influencing behaviour and transport of chemical species, particularly in the interactive zone between Quebec and Pointe des Monts, have been extensively studied. Concurrently, we have been concerned about industrial discharges of mercury to the coastal regions.

Our areas of interest have extended from the Arctic to Sable Island and across the North Atlantic to the western shores of Africa. Research tasks have ranged from attempts to understand the reason for 'open water' conditions in the Arctic to fisheries related studies of upwelling and organic content off Senegal. In the North Atlantic itself, a 5-year study of the occurrence and distribution of oil residues was completed.




*The Gulf of St. Lawrence and Scotian Shelf.* (AOL 4152)

The Division has played a substantial role in international matters. Specifically, we have been involved in Law of the Sea Developments, the Intergovernmental Oceanographic Commission, the Scientific Committee on Oceanic Research, the Intergovernmental Maritime Consultative Organization, the World Meteorological Organization, and the International Council for the Exploration of the Sea.

*A. Walton*

## Inorganic Chemistry

**Heavy Metals in the St. Lawrence Estuary.** Two cruises were conducted in the St. Lawrence estuary and the Saguenay fjord to determine the metal fluxes through these areas. Some of the metals discharged by the St. Lawrence River at Quebec are trapped in the estuary and some are recycled so that the degree of temporal variation in the input of trace metals to the marine environment is diminished. Much of this behaviour is due to the oceanographic and geological characteristics of the estuary; of particular interest is the quasi-stationary cloud of suspended particulate material in the low salinity regime of the estuary (shown in the satellite photograph). This 'turbidity maximum' is fairly common to estuaries whose fresh and saline waters are neither completely mixed nor wholly separated (stratified). The St. Lawrence turbidity maximum appears to play an important role in the removal and recycling of trace metals in the estuary and it is for this reason that its mode of formation and geochemical significance are being further examined. In the Saguenay fjord similar removal of trace metals from the water column, notably of iron and mercury, occurs. The Saguenay River contains relatively large amounts of both these elements and half of the iron and most of the mercury appear to be retained within the sediments of the fjord. In contrast to iron, which is predominantly natural in origin, the mercury is derived mostly from industrial activities in the region. This has resulted in severe sedimentary pollution of the fjord, which will probably only be alleviated by burial of the contaminated sediments. Contamination of the water, which was evident in 1973, had by 1975 been ameliorated as a result of reductions in the flux of mercury into the fjord and by natural flushing processes.

**Scotian Shelf.** A study of the distribution and behaviour of metals in the North Atlantic off Nova Scotia has revealed that the composition of continental shelf waters is only slightly modified by land run-off and other continental effects. Systematic spatial variations in water composition do occur within 400 kilometres of the coast but they are primarily related to natural geochemical processes and water circulation. The large-scale influences of anthropogenic metal emissions are of minor importance and are extremely difficult to detect.

**Sediment Geochronology.** A research effort is underway to determine recent sedimentation rates and geochronologies in coastal sediments. This knowledge is of fundamental importance in the understanding of aquatic and sedimentary geochemical processes and should provide valuable insights into the effects of man's impact on the coastal marine environment during the last 150 years.

The experimental method is based on the measurement of the activity of an excess of the naturally occurring radionuclide, $^{210}Pb$, as a function of depth in the sediment column. $^{210}Pb$ activities are determined by the alpha

*Satellite ERTS imagery of the St. Lawrence estuary. Note the lighter high-turbrdity areas*

particle counting of $^{210}Pb$ using a surface barrier detector. The background ($^{226}Ra$ supported) contribution to the total $^{210}Pb$ activity is measured by the radon gas-emanation technique.

The present analysis of sediment cores, collected in April 1976 during the CSS *Hudson* cruise in the Saguenay fjord, should contribute significantly to the interpretation of mercury and other trace element chemical profiles that have been measured in these sediments. This work can be extended to the measurement of other alpha-emitting radionuclides, such as those in the transuranic series, thereby providing a quantitative grasp of problems associated with estuarine geochemical processes, sediment transport, and radioactive contamination of the marine environment.

**Intercalibration.** The Inorganic Chemistry Section is participating in three international intercalibration experiments aimed at ensuring the validity and comparability of trace metal data from marine science institutions throughout the world. One of the two experiments being conducted under the auspices of the International Council for the Exploration of the Sea (ICES) is specifically dedicated to the problem of mercury concentrations in sea water.

*J. M. Bewers. P. A. Yeats. A. Walton. J. N. B. Smith*

## Stable Isotope Studies

**Oxygen and Carbon Isotope Variations in the St. Lawrence Estuary and Saguenay Fjord.** Traditionally, salinity changes and variations in concentrations of dissolved constituents of assumed conservative behaviour have been used to study mixing processes in estuaries. An independent approach, using $^{18}O/^{16}O$ ratios in water, may also be used to study these processes. It has an advantage in that it measures directly the mixing of the $H_2O$ component of the seawater fluid. A detailed study of the mixing in the St. Lawrence estuary based on samples collected in 1974 indicated that the range of $^{18}O/^{16}O$ ratios varies linearly from the surface waters of the St. Lawrence River [-10.3 parts per thousand SMOW (Standard Mean Ocean Water)] throughout the estuary to the saline waters of the Gulf of St. Lawrence (-2.0 parts per thousand SMOW). This relationship confirms the conservative behaviour of $^{18}O/^{16}O$ ratios for the estuarine regime and enables calculations to be made of the mixing ratio of fresh and saline waters.

Surface water samples collected along the Upper St. Lawrence estuary and the Saguenay fjord have also been analyzed for their $^{13}C/^{12}C$ ratios in the total dissolved $CO_2$ in order to examine the mixing behaviour of $^{13}C/^{12}C$ ratios in fresh and saline waters in an estuarine environment.

**Carbon Isotope Variations in Red Sea Brines.** As an integral part of the Canada - Federal Republic of Germany bilateral agreement, we collaborated with Dr. M. Schoell of the Federal Institute of Geosciences and Natural Resources, Hanover, F.R.G., in a joint project on carbon isotope studies of total dissolved $CO_2$ in Red Sea brines. The samples were collected during the *Valdivia* expedition to the Red Sea in 1972 and the mass spectrometer determinations of the $^{13}C/^{12}C$ ratios were carried out at BIO. The purpose of this study was to investigate the genetic relationships among the various brine pools in the Red Sea (Atlantis II, Discovery, and Chain Deeps) based on $^{13}C/^{12}C$ ratios and the concentration of the total dissolved $CO_2$. Our data indicate that the brines in the Discovery and Chain Deeps are derived from the Atlantis II brines and that the low $^{13}C/^{12}C$ ratios (-20 parts per thousand PDB) and $CO_2$ concentrations (10 to 20 millilitres per litre) observed in the Discovery and Chain Deeps result from carbonate precipitation under closed system conditions. (Note: PDB is a carbonate standard prepared from a belemnite rostrum collected from the Cretaceous Peedee Formation of South Carolina.)

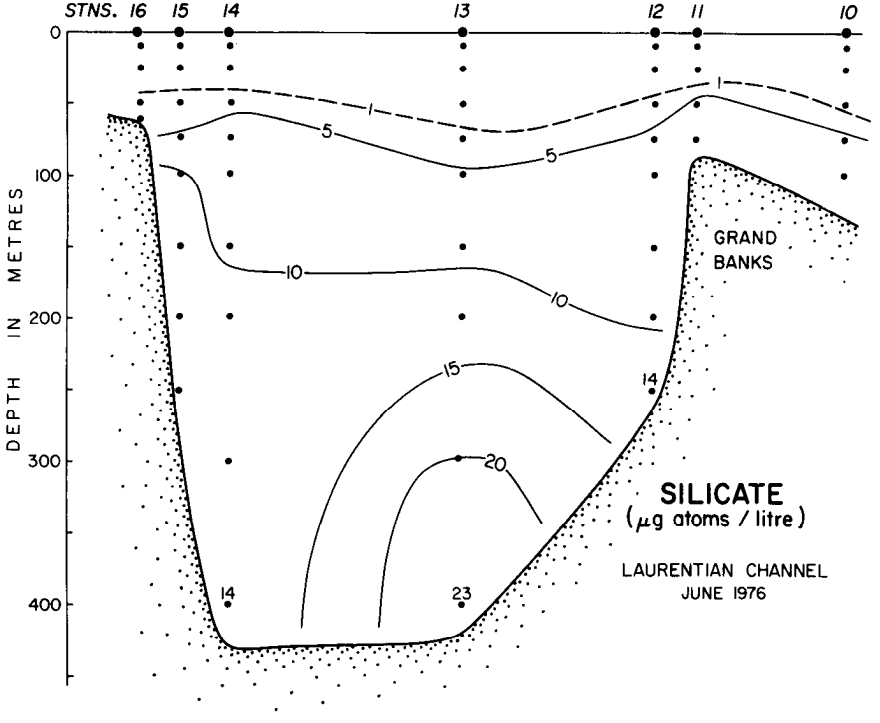
**Intercalibration and Laboratory Developments.** In order to evaluate the quality of isotope ratio measurements obtained at the BIO stable isotope laboratory, we participated in two international intercalibration experiments sponsored by the International Atomic Energy Agency, Vienna, Austria, and the Institute of Nuclear Sciences, Department of Scientific and Industrial Research, Lower Hutt, New Zealand. The results of these experiments were discussed at the International Stable Isotope Conference, Lower Hutt, New Zealand, 1976, and at the Consultants Meeting on Stable Isotope Standards and Intercalibration in Hydrology and Geochemistry, Vienna, Austria, 1976. The intercalibration experiments indicate that the BIO data are in good agreement with those of well-established laboratories in other parts of the world.

A combustion system for the analysis of the carbonaceous materials has been constructed and an evaluation of the procedures is complete. The system will be used to analyze the $^{13}C/^{12}C$ ratios of the total organic carbon in Gulf of St. Lawrence sediments in order to study the contribution of land-derived organic matter in the area.

*F. C. Tan, P. M. Strain, A. Walton*

## Nutrient Studies

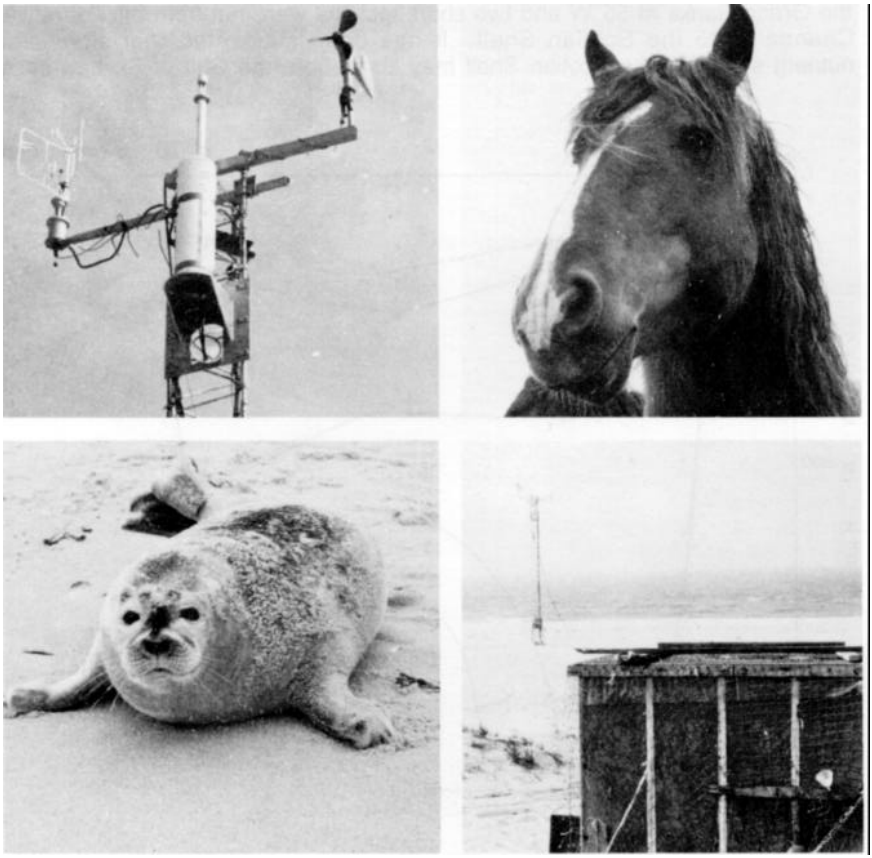
**Nutrients and Biological Productivity in the Gulf of St. Lawrence.** Previous work consisting of single transects of Cabot Strait indicated that there is a net inward flow of nitrate and silicate into the Gulf of St. Lawrence during the summer. To examine this feature in more detail the Cabot Strait Section was transected four times at 18-hour intervals in June 1976. These data will provide better information for the tidal influence on the transport calculation. Samples were taken also for total bound-nitrogen analysis in order to determine if the observed seasonal variation in nitrate concentration in the Strait is compensated for by an increase in organic nitrogen and ammonia. During this cruise a section was run through the slope water onto the Grand Banks at 55°W and two short sections were run from the Laurentian Channel onto the Scotian Shelf. It has been suggested that significant nutrient supply to the Scotian Shelf may come from the Gulf of St. Lawrence.




*Cross-section of dissolved silicate near the entrance to the Laurentian Channel; 44°37.0'N. 57°30.0'W to 45°20.5'N, 54°58.0'W. (AOL 4125)*

**Arctic and Northern Areas.** The Nutrient Studies Section participated in the first phase of the Labrador Sea program undertaken by the Ocean Circulation Division. One of the objectives of this program is to observe the winter formation of deep North Atlantic water. As might be expected, silicate, phosphate, and nitrate values are quite uniform in the deep convective regions. A maximum in the silicate distribution occurs between 2500 and 3000 metres.

In August 1976, during Phase I of the Atlantic Geoscience Centre Arctic Survey, both CTD (conductivity-temperature-depth) and bottle casts were run on two sections across Lancaster Sound at 82° and 91°W. The latter section repeated one run by the University of Washington in 1973 (Codispoti, L. A., and Owens. T. C., *Limnol. Oceanogr., 20:* 115-119, 1975) to verify the suggestion that Bering Sea water flows out of the Arctic through the Arctic Archipelago. Unfortunately, the most southerly stations could not be re-occupied because of ice conditions.



*The Instrumented tower was set up in position on the south beach of Sable Island, NS. while two curious residenfs looked on*

**Scotian Shelf Monitoring Section.** Nutrient sampling was undertaken for two cruises in 1975: Cruises 75-003 and 75-028. During Cruise 75-003 observations were recorded on the twelve Halifax-section stations as well as five other stations between the Scotian Shelf and Bermuda. Cruise 75-028 reoccupied the Halifax section for the monitoring program. [The Halifax section extends from the entrance to Halifax Harbour out to the shelf break (see figure)].

*A. R. Coote*

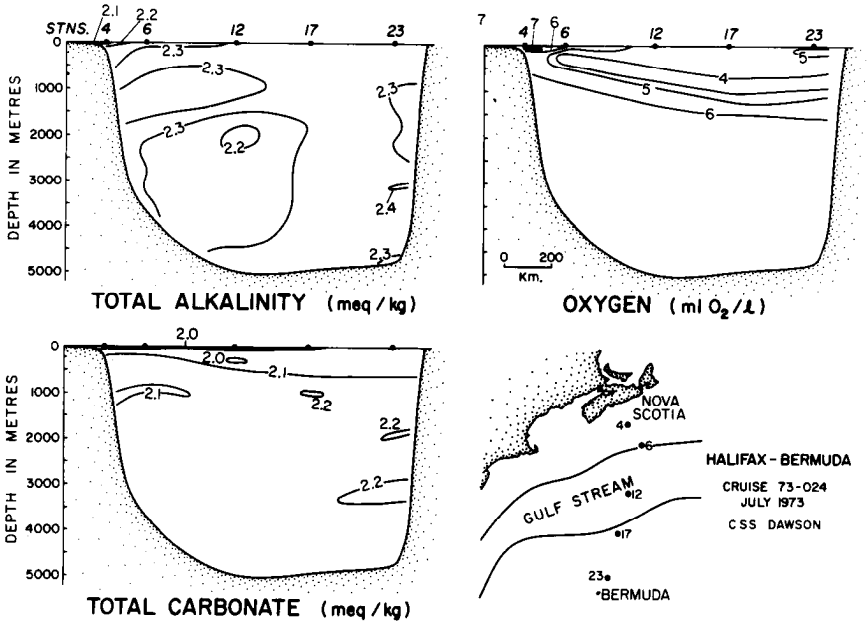
## Physical Chemistry

**Air-Sea Interaction.** Gas fluxes between the ocean and atmosphere are important chemical oceanographic parameters and in the case of $CO_2$ the measurement is particularly relevant to possible climate modification arising from increased $CO_2$ concentrations in the atmosphere from fossil fuel combustion. An instrument that measures $CO_2$ concentration fluctuations by infrared absorption was developed under contract: these fluctuations and the vertical wind velocity are used to obtain the $CO_2$ fluxes. A 5-week field program on Sable Island (Nova Scotia) carried out in the early summer of 1976 resulted in the first direct measurement of a gas flux between the sea and air. Sable Island is a long (41 kilometres), narrow (1.6 kilometres), crescent-shaped island oriented roughly in an east-west direction. The equipment was set up on the south beach to take advantage of the prevailing southerly winds. The various sensors ($CO_2$, wind velocity, temperature, humidity) were mounted on a lo-metre high tower about 30 metres from the water's edge (see photograph). The sensors were connected by cables to an instrument hut about 150 metres farther inland where the power supplies and recording systems were located.

**$CO_2$ System in Sea Water.** Studies of the chemistry of the $CO_2$ system and of dissolved $O_2$ in the Gulf of St. Lawrence carried out in previous years were continued and augmented by similar studies in the open North Atlantic from Cabot Strait to the Gulf Stream region south of the Grand Banks and in the region between Nova Scotia and Bermuda. The Halifax, N.S. - Bermuda Section (see figure) includes Coastal Slope, Gulf Stream, Sargasso Sea, and North Atlantic Deep waters. In addition to delineating water masses, the data illustrate the inverse relationship between $CO_2$ and dissolved $O_2$ concentrations arising from the production and utilization of $CO_2$ and $O_2$ by marine life. The $CaCO_3$ saturation level was about 2000 metres and there was no indication of an 'ocean calcium problem' as has been reported in the Pacific Ocean. Together these studies provide a fairly complete overview of the $CO_2$-system chemistry of the waters of Canadian continental shelf areas and their relationship to the adjoining open Atlantic.

**Dissolved Gases.** Analytical methods based on stripping the total dissolved $CO_2$, Ar, N, and $O_2$ from sea water followed by their separation and quantification by gas chromatography have been devised and tested during a cruise in the western North Atlantic. Although the analytical instrumentation functioned properly at sea, there were some problems with calibration. When these are overcome it will be possible to automate the shipboard analysis and processing of data on dissolved gases in sea water.

*E. M. Levy, E. P. Jones*




*The Halifax - Bermuda section. (AOL 4134)*

## Organic Chemistry

**Gulf of St. Lawrence.** Analyses of C, H, N and lignin in surface sediments show a marked change in moving from coves and fjords to the open Gulf. Sediments with an organic content of predominantly terrestrial origin are indicated by the presence of lignin accompanied by high organic carbon concentrations and high C:N ratios. Lignin values of greater than 9 parts per thousand, corresponding to as much as 12 per cent of the organic matter in the sediment, were found in the Upper Saguenay and in Corner Brook Harbour, Newfoundland. C:N ratios of 6 to 12:1 were measured in the Laurentian Channel and other open waters while ratios of up to 40:1 were measured in areas near pulp and paper mills. It would appear that there is minimal transport of terrigenous organic material from the land to the sea.

**Senegal.** Chemical analyses were undertaken as part of the Canadian International Development Agency (CIDA) - sponsored cruise off Senegal. The work was carried out in two broad areas: general oceanographic studies concentrated upon upwelling, and specific studies in organic chemistry. In the former, measurements of temperature, salinity, oxygen, and nutrients enabled the construction of charts delineating zones of depletion and enhancement of the above variables, which indicate areas of upwelling. The organic studies emphasized the measurement of particulate (POC) and dissolved (DOC) organic carbon. The measurement of POC enables the estimation of the organic matter available to filter feeding organisms while the measurement of DOC estimates the organic matter not directly but potentially available.

*R. Pocklington, J. D. Leonard*

## Marine Pollution

**Organohalogen Compounds.** Investigations have continued on the determination of organohalogen compounds in the marine environment. The concentrations of PCBs in surface waters of the Gulf of St. Lawrence [average 0.8 nannograms per litre] were similar to the concentrations of these compounds as reported by others in the open ocean. DDT and DDE were not detected (detection limit: 0.2 nannograms per litre).

A study is currently underway to determine these compounds in marine sediments. Sediments from a variety of Atlantic areas are being solvent extracted and the resulting extracts analyzed by gas chromatography. The aim is to determine background levels of organohalogens and the reasons for their variability.

**Oil.** The investigation of petroleum residues in the North Atlantic continued with measurements of both floating particulate residues and of dissolved/dispersed forms. The highlight of this study has been the analyses of the quantitative data concerning the distribution of floating particulate petroleum residues during the period 1971-1974. These data demonstrated that floating residues were virtually non-existent in the waters to the north of the Gulf Stream/North Atlantic Current system whereas they were almost ubiquitous in more southern waters: the highest concentrations were encountered in the western Sargasso Sea. The spatial distribution of residues was interpreted in terms of inputs from shipping and tanker traffic, and of the surface circulation. Because of this striking geographical separation, the distribution of tar in the North Atlantic was described via a two-box model. The northern region was assumed to contain no tar: in the other, tar was found to be lognormally distributed with an overall geometric mean of 0.16 milligrams per square metre for the 4-year period. Based on these data, the total amount of tar on the surface of the North Atlantic was estimated to be 5200 tons while the mean 'residence time' was calculated to be about 2 months.

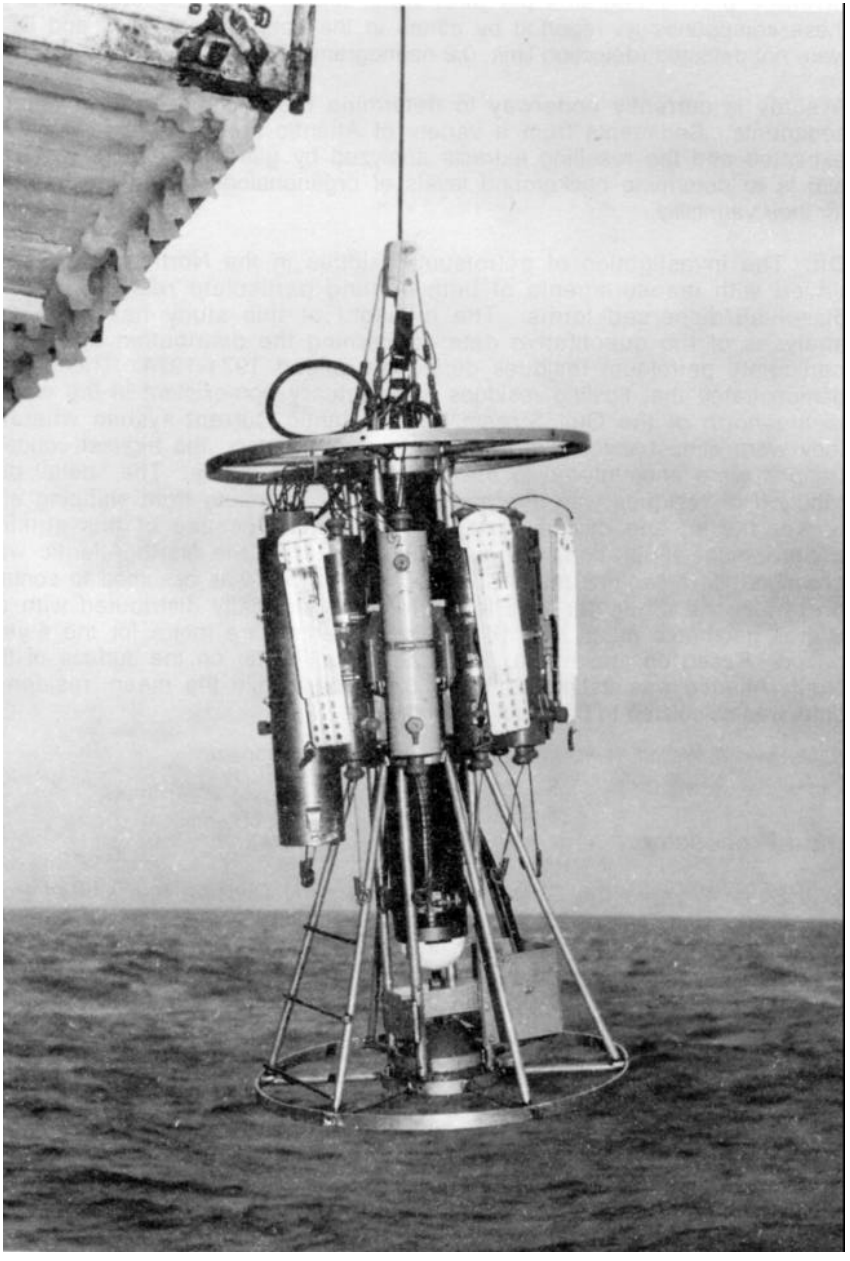
*E. M. Levy, A. Walton, R. Pocklington, R. D. Smillie, J. D. Leonard*

## Data Processing

In the last 2 years the Chemical Oceanography Division has shifted from processing raw instrument results using the BIO CDC 3150 computer to data processing in the laboratory or in the field, and is using greater amounts of time sharing on Dalhousie University's (Halifax) CDC 6400 computer to expedite data analysis.

The CIDA-sponsored survey cruise off Senegal demonstrated the Division's ability to carry out an extensive project in a remote region, and to produce results quickly. Salinity, temperature, organic carbon, hydrogen and nitrogen, and nutrient results were calculated using the HP 2100A computer aboard the CSS *Baffin* and transmitted by radio link to BIO for key punching and storage on disc at Dalhousie University (Halifax). A set of interactive computer programs allowed rapid examination, editing, and interpretation of the data. Finally, computer plots of the data at desired depths were produced using the CDC 3150. The entire project was completed within 2 months of the cruise.

On a cruise in the St. Lawrence estuary early in 1976 the Rosette sampler fitted with sensors for salinity, temperature, pressure, and optical attenuance was coupled to the shipboard HP 2100A to display data in 'real' time.



*The Rosette sampler (AOL 3946)*

Computer plots continue to be the major use of the CDC 3150. Cross-section plots and area plots have been generated for most variables measured by the Division. Work to simplify data entry to these programs continues. Programs for reducing the output of the Division's analytical instruments have been operational for several years. The paper tape data loggers will shortly be replaced by more modern methods of storing data and calculating results.

*J. L. Barron*

## National and International Activities

As in previous years, considerable effort was contributed to international scientific activities, including the Joint IOC/WMO Pilot Project on Marine Pollution Monitoring, the GESAMP (Group of Experts on the Scientific Aspects of Marine Pollution) Working Group on the Impact of Oil on the Marine Environment, and the proposed IOC/WMO/UNEP (United Nations Environment Program) program for Monitoring Background Levels of Selected Pollutants in Open Ocean Waters.

The co-ordination of the Canadian contribution to the IOC/WMO Pilot Project has been carried out in the Division with the extensive co-operation of other government departments, including the Ministry of Transport (MOT) and the Department of National Defence (DND).

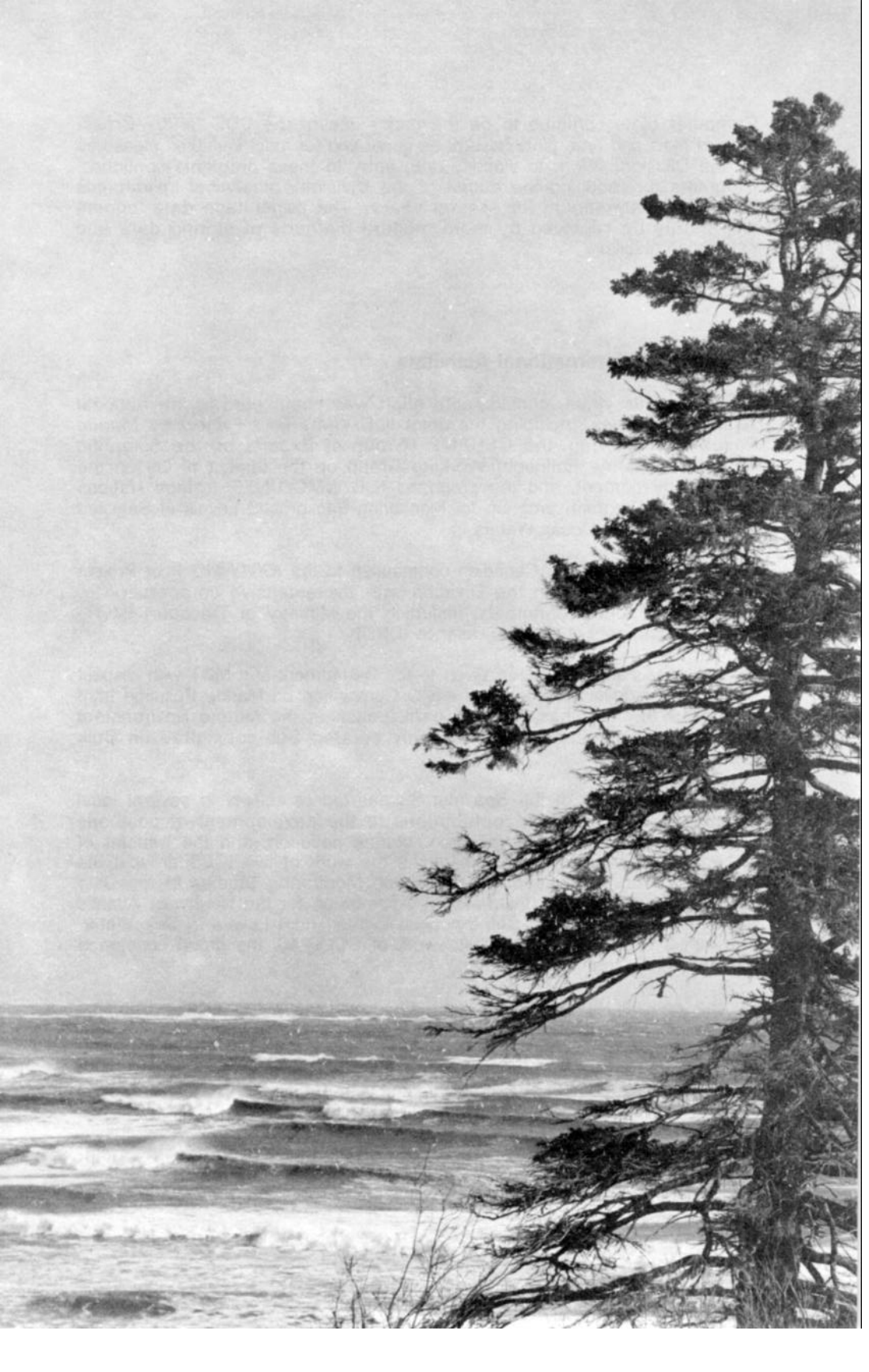
Scientific assistance has been given to the Department and MOT with respect to the further development of the IMCO Convention on Marine Pollution from Ships (1973). This has included participation in the Marine Environment Protection Committee and its recently created Sub-committee on Bulk Chemicals.

Our interest in Law of the Sea matters has led to activity in several local working sessions and to contributions to the development of positions regarding marine scientific research, marine pollution, and the transfer of technology. The Division participated in the work of two ICES groups: the Working Group on Pollution Baseline and Monitoring Studies in the Oslo Commission and ICNAF (International Commission for the Northwest Atlantic Fisheries) Areas, and the Sub-group on Contaminant Levels in Sea Water. Substantial effort was given to the work of SCOR-46, the group concerned with river inputs to ocean systems.

On the national scene, recent legislation, particularly the Ocean Dumping Control Act, has brought further significant responsibilities. In addition to the necessary scientific review carried out by the staff for all dumping applications, a representative served on the Regional Ocean Dumping Advisory Committee (RODAC) during its first year of operation.

Considerable support has been given to actions leading to the establishment, by the National Research Council of Canada (NRCC), of the Committee for Marine Analytical Chemistry. It is hoped that the marine standards program being pursued by NRCC will lead to the further development of marine chemistry in Canada.

*A. Walton, E. M. Levy, J. M. Bewers, R. Pocklington*



# Coastal Oceanography

Coastal Oceanography continues to direct most of its research activities towards understanding the physical processes of our coastal region. As in past years, we have been concerned with a broad spectrum of problems since much of the work is aimed at improving our abilities to provide answers for fisheries management, pollution control, and coastal engineering activities. Many of our projects are interdisciplinary and involve joint studies with other groups both inside and outside the Institute.

Research has been continuing on currents and internal waves in nearshore regions, such as the Saguenay fjord, Magdalen Shallows, and St. Margaret's Bay; on the wave climate of the North Atlantic and coastal regions; and on sediment transport, at the mouth of the St. Lawrence and Miramichi Rivers.

The major new field program is the Shelf Break Dynamics Study at the edge of the continental shelf, south of Halifax. We are monitoring the mixing of nutrient-rich offshore water onto the shelf. Another new project is the development of an impact assessment program for ocean dumping.

The following articles summarize our activities during 1975/76. Since the last review we have reorganized and the Division is now staffed entirely within AOL.

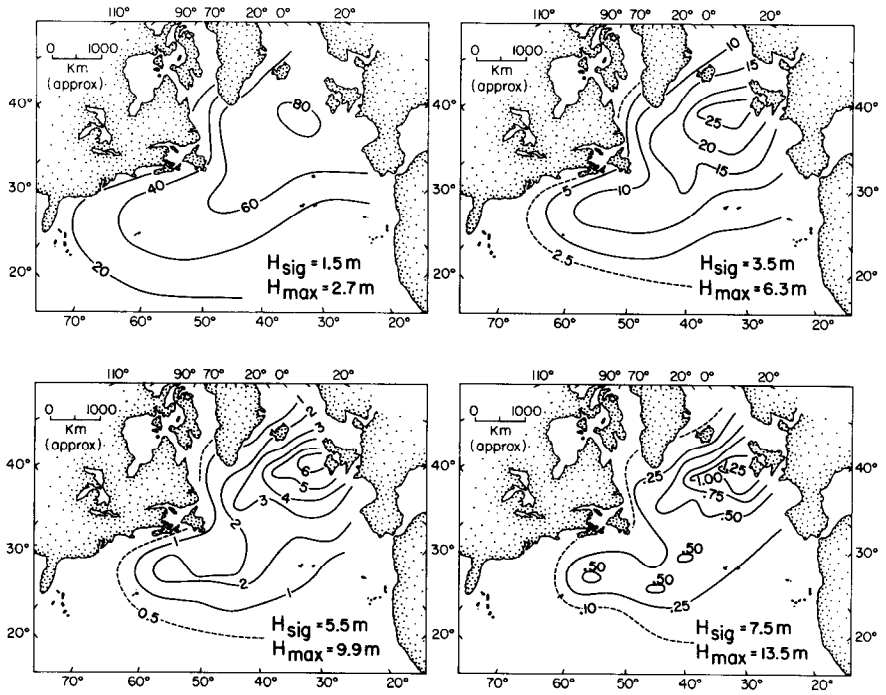
*J. A. Elliott*

## Offshore Studies

**North Atlantic Wave Climate.** Wave activity is one of the greatest problems in the exploitation of the ocean as a whole and of the North Atlantic in particular. In the oil industry, the design of drilling platforms, their operation, and the recovery of oil are governed by waves. The surface transportation of cargo across the Atlantic, the design of harbours and deep-sea terminals, and the development of onshore and offshore reactors demand an accurate knowledge of the sea state. For all these operations it is important to anticipate the operational interruptions and dangers to life and equipment which can arise from wave action. To assist in estimating these factors, percentage exceedance distributions were developed for significant wave heights (mean of the highest one third of the waves) of 1.5, 3.5, 5.5, and 7.5 metres and their respective maximum values of 2.7, 6.3, 9.9, and 13.5 metres. As can be readily seen on the figure, the area of the North Atlantic having the lowest probability of interruption is along the coast of North America and across the southern part of the ocean, while the area with the highest probability is west of Ireland; for the 1.5 metre significant height waves the probability of exceedance at Ireland is four to five times greater, while for waves with significant heights in excess of 5.5 metres, it is 12 times greater.

*H. J. A. Neu*

**Canadian Coastal Wave Climate.** Continued interest of various commercial and governmental developments in the variability of the sea state along the Canadian Atlantic coast has encouraged further studies into the wave



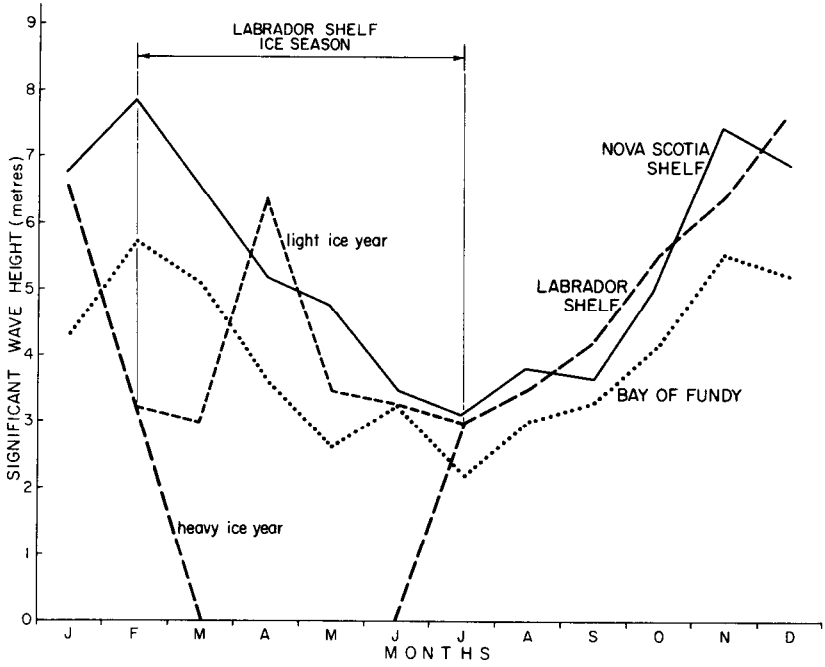

*Percentage of time wave height exceeds the given wave height (H) in the North Atlantic (1970 data).* (AOL 4135)

climate of this area. Earlier studies on the maximum wave heights of the North Atlantic for 1970 have been continued for 1971 and 1972. The variability over the entire 3-year period has been investigated in greater detail for the Labrador Sea, Scotian Shelf, and Bay of Fundy. The results, using mean monthly significant wave heights, are shown on the figure. Wave height variation in the Labrador Sea is similar to that found on the Scotian Shelf and in the Bay of Fundy only in the months from July to January. The remainder of the year it is affected by two factors, which are non-existent in the other regions; namely, ice and the spring shift in the location of the Icelandic low pressure centre that causes more northerly winds rather than the usual westerlies. When this shift occurs in a light ice year, conditions on the Labrador Shelf in the spring can be as severe as they are in the winter particularly in the month when the shift takes place (this varies somewhat from year to year). Maximum wave conditions on the Labrador Shelf are in general much the same as those on the Scotian Shelf.

For the Scotian Shelf, this analysis was extended to cover a 5-year period (1970-74) and it was found that 1971 was a period of average wave activity while 1972 had more severe wave conditions. For the 5 years, the 100 year significant wave height varied between 16 and 20 metres; the mean was 16.5 metres. Studies also commenced on the statistical variability of wave parameters during storms on the Scotian Shelf. A particular storm from 15 to 16 February 1972, which was monitored with a wave staff off Halifax Inlet, has been analyzed; 'wave-by-wave' and spectral analysis techniques

were compared and theoretical wave height and period distributions were verified. This will be expanded to all wave observations along the Atlantic coast.

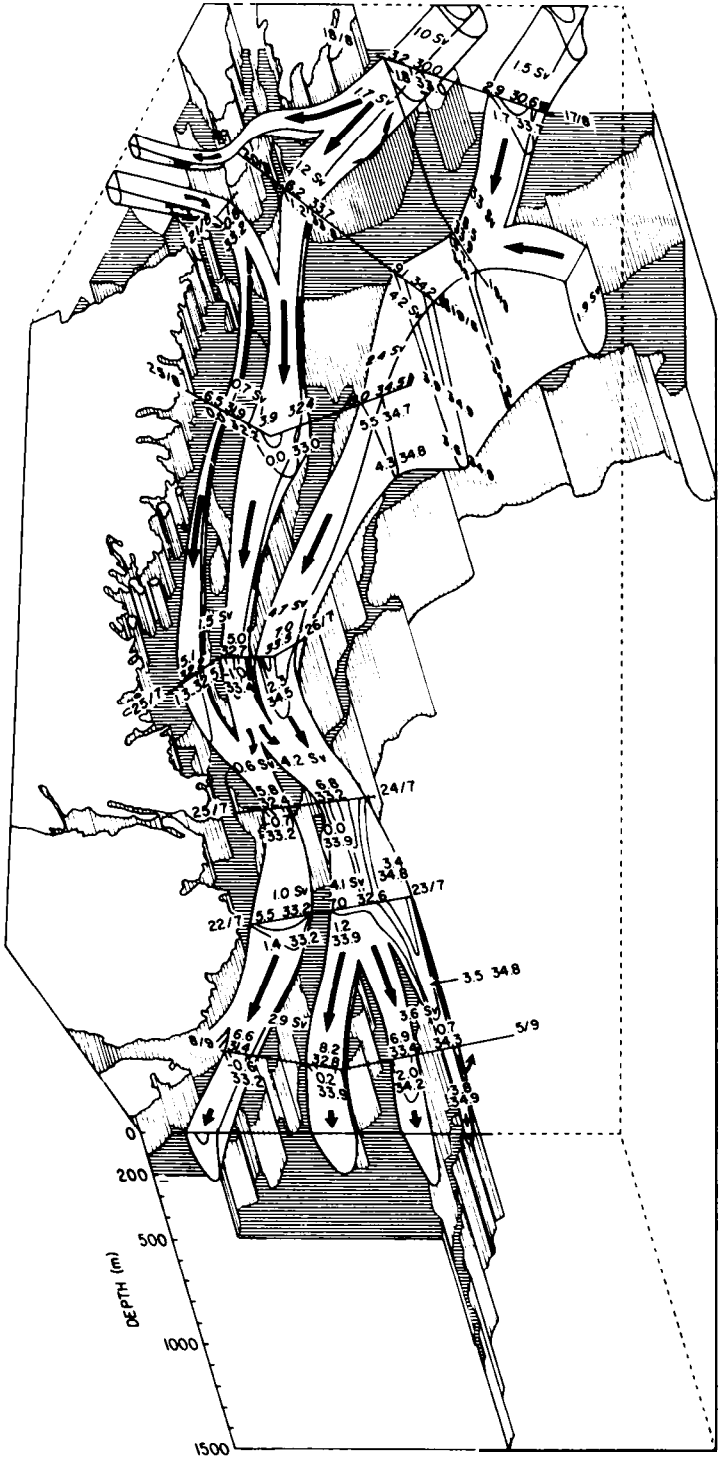
*H. J. A. Neu, P. E. Vandall*




*The annual variation in wave height for the Labrador Sea, Scotian Shelf, and Bay of Fundy. (AOL 4145)*

**Environmental Review of the Labrador Coast.** The search for oil along the Canadian Atlantic coast has expanded to the Newfoundland and Labrador continental shelf. Since 1971, an increasing number of exploratory drillings have been made with enough success to warrant further northward exploration. This development has prompted a review of all available environmental information on this region.

The region is characterized by heavy winter ice, followed in spring and summer by numerous icebergs and frequent fog. Wave conditions are as severe as any along the Canadian Atlantic coast, and contain significant wave heights of up to 8 metres and maximum wave heights of nearly 15 metres. The peak periods are about 12 seconds. Current patterns are dominated by the southward flowing Labrador current, which basically consists, as shown in the figure, of three major filaments originating from different sources and having their identity maintained by the coastal bathymetry and the prevailing dynamic field. Average currents rarely exceed



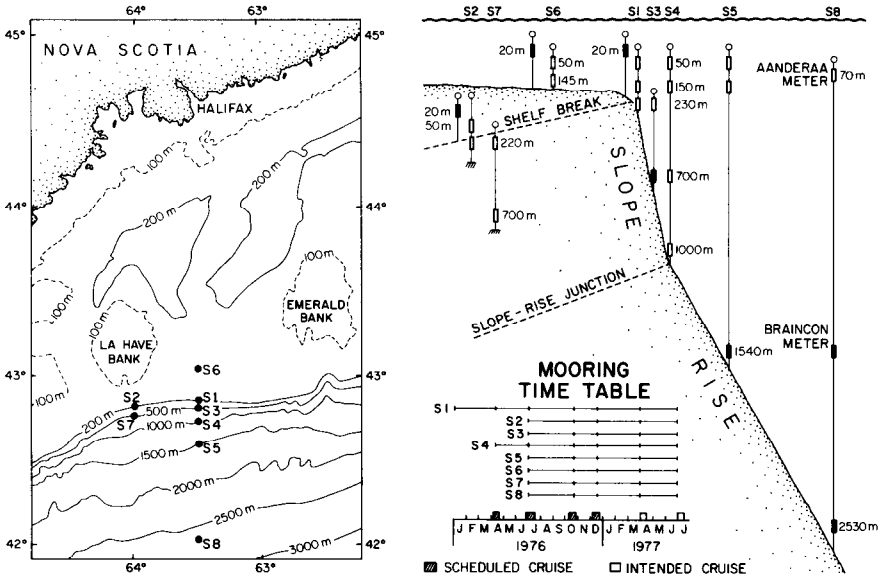

*The Labrador Current in perspective. (AOL 3896)*

0.5 metres per second but locally can reach up to 3.5 metres per second. The figure is based on 1928 temperature and salinity data from the *Marion* and *General Greene* expedition.

Freshwater run-off imposes seasonal changes in the Labrador current, with the Hudson Bay peak run-off over-riding all other sources.

*J. B. Matthews, H. J. A. Neu, P. E. Vandall, F. J. Jordan*

**The Shelf Break Dynamics Program.** The Coastal Oceanography Division is presently conducting an experiment to investigate the circulation and dynamics at the edge of the Scotian Shelf. The motivation for this study is twofold. Sparse measurements and theoretical results indicate that strong currents and energetic low frequency waves may be associated with the sharply varying topography at the shelf break. Furthermore, the shelf break region is the locus for important mixing and exchange processes between oceanic and coastal waters. Those data that are available from the outer Scotian Shelf and slope indicate that low frequency motions dominate the circulation. Therefore a long term program of moored current meter measurements is required to obtain an adequate description of the most important physical processes at the shelf break. A second reason for studying shelf break processes is the tremendous biological implications of the interaction between coastal and offshore waters. A recent series of seasonal cruises across the Scotian Shelf (in association with Dalhousie University, Halifax) consistently showed maxima of nutrient concentration and biological activity near the shelf break. By collaborating with the Dalhousie biologists, it is hoped that data collected during the Shelf Break Program will shed some light on the physical and biological causes for these distributions.




*Current meter moorings for the shelf break dynamics experiment.* (AOL 4132)

At present, the shelf break experiment is composed of five basic elements: an array of current meter moorings on the continental shelf and slope; a series of hydrographic surveys covering 63°W to 64°W from the shelf (~ 43°N) to the slope water boundary (~ 41°N); a detailed examination of the slope water boundary; the collection and analysis of meteorological data; and biological experiments. The locations of the current meter moorings are shown in the figure. The central site, S1, is located on the 250 metre isobath south of Halifax. A schedule for replacement on that basis is also given in the figure.

*P. C. Smith. B. D. Petrie*

## Gulf of St. Lawrence Studies

**The Western Gulf of St. Lawrence.** Studies of the geostrophic currents in the Gulf of St. Lawrence provide us with a general view of the circulation pattern of the Gulf. To gain a further understanding of the dynamics and the variability of the current system, time dependent motion observed by direct current measurements has to be taken into account. Existing current meter data taken in 1967, 1969, and 1970 from stations in the Gaspe Passage and the Magdalen Shallows have been analyzed. The most prominent feature in the lower St. Lawrence estuary is an intense current flowing along the shore of the Gaspe Peninsula with a maximum velocity of 90 centimetres per second. Its core occasionally shifts to the mid-channel and causes a counter current near shore. As the current reaches the mouth of the Gaspe Passage, it spreads out over the Magdalen Shallows. The currents in the Magdalen Shallows have typical speeds of 20 centimetres per second in the upper layer and 5 centimetres per second near the bottom. The directions are highly variable and there are no apparent correlations between data taken at stations more than 20 kilometres apart. The time scale of the residual (or average) currents is approximately 3 days. To understand the behaviour of these time dependent currents, a two-layer model based on the principle of diffusion of vorticity was formulated. This model explains how quasi-geostrophic currents are generated, propagated, and dissipated. The results of regression analyses on the data show general agreement with the theory.

*C. L. Tang*

**Wind Driven Inertial Currents in the Magdalen Shallows.** An analysis of current meter data collected in the Magdalen Shallows during the autumn of 1970 has been carried out. Inertial oscillations were a prominent feature of the average currents and were found to occur in bursts of 2 to 3 days duration with irregular intervals between the bursts. The transient nature of this behaviour was consistent with the pulse-like nature of the wind stress and a significant linear correlation was found between the magnitude of the wind stress and the rms (root-mean-square) residual current.

The theoretical behaviour of the system was also investigated and showed that the transient response to a typical wind stress pulse was also pulse-like, with a relatively small phase lag; this is similar to the experimental observations. The results suggest that about 50 per cent of the average current speed was due to the local wind except in the vicinity of the Gaspe current where current speeds were much higher and showed little correlation with the local winds.

*B. L. Blackford (Dalhousie University)*

**Mesoscale Inhomogeneities in the Magdalen Shallows.** In July 1972 the newly developed Batfish CTD (conductivity-temperature-depth profiler) was towed through a grid in the Magdalen Shallows, Gulf of St. Lawrence. The instrument performed well; it produced a dense coverage of data along the path of the ship in a minimum of time. Variations in the level of the pycnocline were found over the whole grid, which suggest the presence of meanders and gyres superimposed on a mean circulation. However, each leg of the grid took several hours and it is likely that at least part of the signal was due to internal tides.

*S. J. Reid*

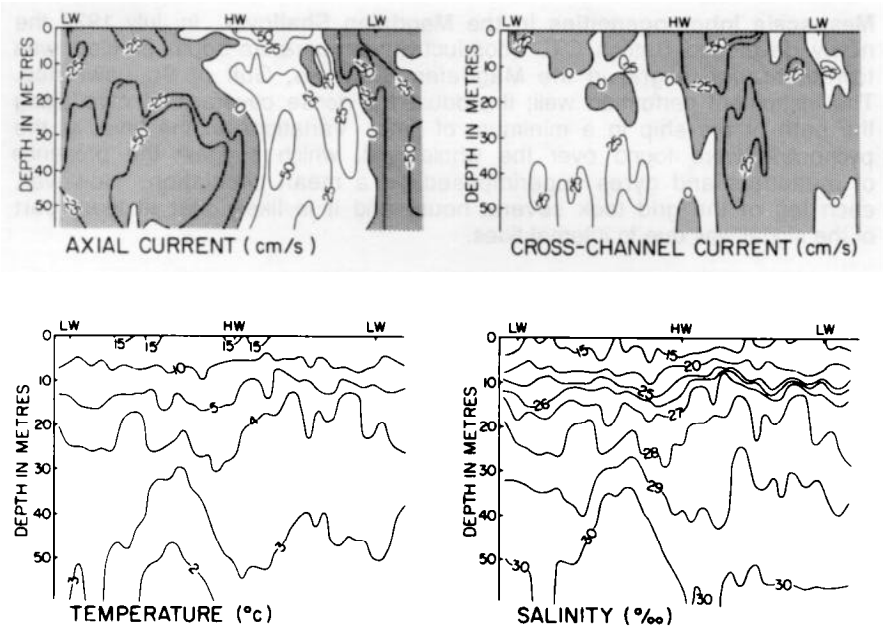
**The St. Lawrence Estuary.** The St. Lawrence estuary, where it is joined by the Saguenay, is a complex system of channels, banks, and sills. The data from an intensive period of observations using two ships in this area at the beginning of July 1973 have now been processed. There is evidence of a movement of deep water from the Laurentian Channel through the South Channel and across a sill into the upper parts of the estuary. Perhaps more important is the observed development of a large mass of relatively homogeneous water over and downstream of this sill, which lies from Ilet Rouge to Ile aux Lievres. The water mass has a salinity of about 28 parts per thousand through a depth of 40 metres or more and appears to contain a large proportion of water from the cold intermediate layer and below. This circulation could be a major part of the nutrient pump in this region.

*S. J. Reid*

## Nearshore Studies

**Saguenay Fjord.** The Saguenay fjord joins the St. Lawrence estuary about 180 kilometres below Quebec City. The fjord is approximately 120 kilometres long, varies in width from 1 to 6 kilometres, and is divided into several elongated deep basins by shallow sills. The long-term mean surface circulation (upper 20 metres) appears to be as in other highly stratified deep fjords. The fresh water discharged into the fjord at its head gradually becomes more saline as it is mixed with sea water from below; the volume ratio of sea water to fresh water may reach 30:1. When compared to other shallow silled fjords, the Saguenay fjord appears to be anomalous in that its deep basins are always well oxygenated. In fact, oxygen values in the outer basins are usually higher than at comparable depths seaward of the main sill.

Work undertaken by the Bedford Institute of Oceanography in July 1975 focussed on the lower reaches of the fjord, particularly the region between the two main sills. A section line consisting of six stations was occupied six times at varying phases of the tide. Profiles of temperature, salinity, and horizontal currents were obtained at two locations. Data from one of these locations (i.e., on the second sill) are shown in the figure. During both the flood tide and the ebb tide the salinity, at say 40 metres, increased and the temperature decreased, which indicates a movement of increasingly dense water across the sill. The 30 parts per thousand isohaline reached a high point of 35 metres during the flood tide and a large volume of water with a salinity greater than 30 parts per thousand apparently




*Current speeds, temperature values. and sainity concentrations over a tidal cycle on the second sill of the Saguenay fjord, July 17- 18, 1975 (AOL 4112)*

flowed across the sill. The salinity and temperature were also measured at stations on both sides of the sill and through the deep basis to the main sill of the Saguenay. Within the fjord, the 30-parts-per-thousand isohaline had a mean depth of about 70 metres, approximately the top of the second still. Thus, the water moving over the second sill contained a large proportion of water having an equilibrium depth below it. This process must be of great importance to the renewal of deep water in the fjord. The mechanism leading to this exchange appears to be the slope of the sea surface necessary to force the tidal flow across the sill. The elevation of the isopycnals against the sill appears to be just that required to compensate in the deep water for the pressure disturbance at the surface. The same process is present in an even more pronounced form at the sill at the mouth of the Saguenay over which the water is only 20 metres deep. Here, water with a temperature of 0°C, which in most parts of the St. Lawrence estuary is found below 40 metres, was observed close to the surface on the outer side of the sill on the flood.

*G H Seibert. S. J Reid. R. W. Trites*

**Generation of Internal Waves By Tidal Flow Over Sills.** Internal waves at the tidal frequency are a common feature of oceanographic observations in coastal regions. The region near the mouth of the Saguenay river appears to be the generation point for these internal waves and it is also an important upwelling region.

A study of internal wave generation mechanisms has been carried out and a simple theoretical model for a possible non-linear generation mechanism

was developed. The distorted free surface in the vicinity of the sill is assumed to be the driving force for internal waves. The model predicts that internal waves should be generated at twice the tidal frequency as well as at the tidal frequency. The amplitude of the component at twice the tidal frequency is predicted to vary as the square of the surface tidal stream over the sill. The model also predicts a steady component of elevation of the internal interface in the vicinity of the sill. These model predictions have been compared to field observations from two natural fjord systems and also to experimental data from a laboratory wave tank experiment. The agreement between theory and experiment was encouraging. The results suggest that the generation mechanism incorporated in the model may be an important factor in producing the intense upwelling and internal waves in the Saguenay - St. Lawrence River system.

*B. L. Blackford*

**St. Margaret's Bay Phytoplankton Study.** Support was given to this year-long project in the form of an array of four moorings with a total of nine current meters that were deployed for a 9-week period in the spring of 1975. Analysis of the data has been carried out in our Data Shop. Preliminary results indicate good correlation between phytoplankton patchiness on a given day and high frequency (> 0.2 cycles per hour) fluctuations in current during the preceding several days.

*D. J. Lawrence*

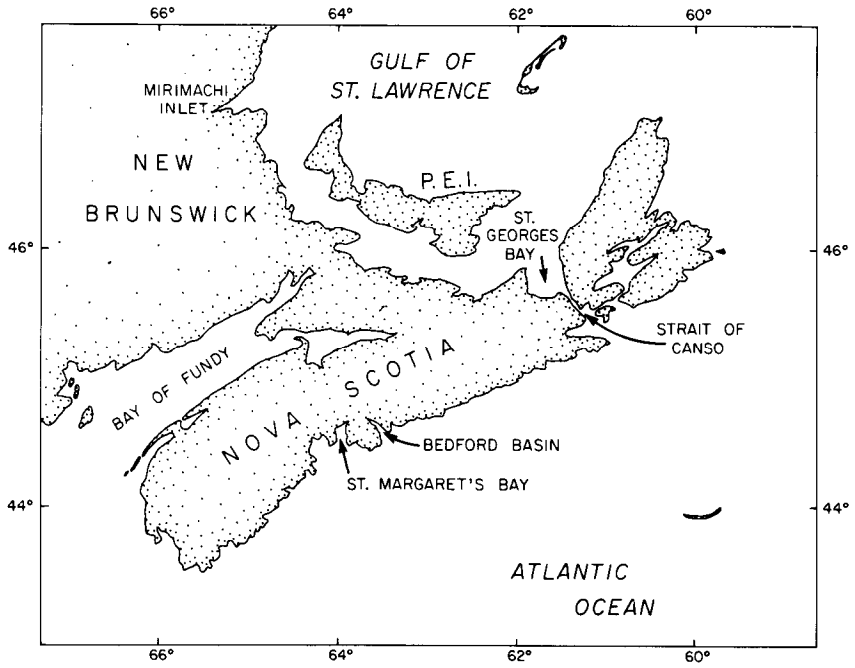
**Strait of Canso Environmental Survey.** This survey, commissioned by the Ministry of Transport and carried out by the Department of Public Works, looked at environmental conditions, specifically, waves, tide heights, and currents, in the Strait as they relate to navigation and superport dock design. The Division assisted with the survey and archived the current meter data.

Although the currents proved to be tolerable from an engineering standpoint, for dock design, there were several interesting and unexplained features. Perhaps the most outstanding was the reconfirmation of earlier observations (Lawrence et al. 1973, BI-R-73-6) that strong (40 centimetres per second) unidirectional flows could persist for several days at sites within the Strait. These are uncorrelated with local winds but may have their origins in larger scale wind fields over the Scotian Shelf. The survey found no significant energy in currents with periods of 30 to 2 minutes, a part of the spectrum hitherto unexplored in the Strait.

*D. J. Lawrence*

**St. Georges Bay.** A current meter mooring and a hydrographic program were conducted in St. Georges Bay in 1974 and 1975 in conjunction with an MEL biological study. The mean circulation in the Bay is dominated by an anticyclonic gyre and a narrow and at times intense flow into the western side of the Bay. Poor horizontal and vertical correlations of the currents make accurate estimates of fluxes into and out of the Bay unattainable. A reduced field program of current profiling and temperature measurements was continued during the summer of 1976.

*B. D. Petrie*




*Atlantic coastal areas.* (AOL 4226)

**Studies of Particulate Matter in Estuaries.** Our Granulometrics Laboratory carries out analyses used in the study of particulate matter in the sea, with special reference to suspended and bottom sediments in coastal areas. Particle size analysis is the principal work of the laboratory. A Coulter Counter is used for all routine analysis and emphasis has been placed on the analysis of both the naturally occurring usually flocculated particle distributions and the ashed deflocculated constituent inorganic mineral grains. During the last year a routine method of analyzing bottom sediment samples has been developed to enable direct comparison between material in suspension and on the bottom. This has required the construction of a modified Coulter Counter glassware unit with a larger sample capacity and better electrical insulation.

Most of the samples processed during the last 2 years have been from estuaries and from rivers flowing into estuaries. The results of most analysis are being filed to form baseline data for future needs and as well used in ongoing research. Many outside requests for information have been answered, mostly concerning general techniques of particle size analysis and specific environmental problems in the Atlantic Provinces.

We have completed the analysis and interpretation of the material collected in 1973 and 1974 in the Miramichi inlet. The main goal has been to understand the detailed organization of natural particle size distributions and their dynamic formative processes. In the river water the organic particles are generally flocculated and the inorganic grains unflocculated. In the estuary, tidal action and the two layer flow cause an increase in

concentration accompanied by flocculation of the organic material with some of the inorganic material. Salinity, concentration of inorganic grains, and the organic-inorganic ratio appear to be controlling factors in flocculation, but their relative importances have only been partially established.

Particulate matter distribution and dynamics in the St. Lawrence estuary are being studied in conjunction with the McGill University Marine Sciences Centre (Quebec). Preliminary analysis of physical, biological, and sedimentological measurements from two cruises show a zonation of water masses based on salinity, total suspended sediment concentrations, and plankton ecology. River water contains freshwater plankton and abundant organic flocs. Strong mixing and development of two layer flow in the upper estuary are associated with fine-grained partly unflocculated suspended sediment with high total concentrations, especially in the area of the turbidity maximum. The freshwater plankton die out in this region and appear to contribute to the high organic detrital load. The area below the Saguenay is characterized by upwelling of highly saline particle-free water from the cold intermediate layer of the Gulf of St. Lawrence and by the appearance of fully marine plankton.

*K. Kranck*

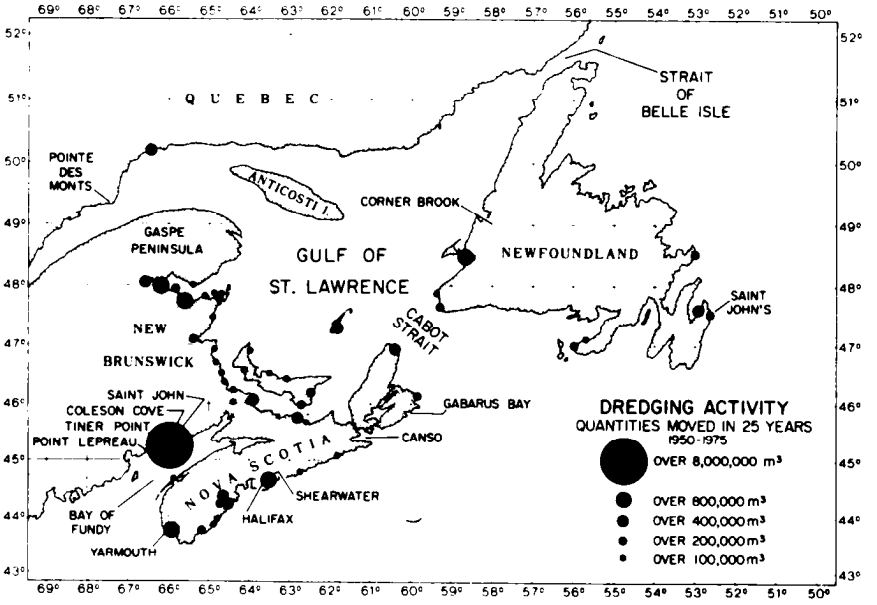
## Support Studies

**Ocean Dumping Control Act.** Early in 1976, Parliament proclaimed an Act establishing control over the dumping of materials by vessel into coastal waters. Since then Coastal Oceanography has supplied the Regional Ocean Dumping Advisory Committee (RODAC) with advice concerning the physical characteristics of proposed dump sites and with estimations of the physical effects of dumping operations. In addition, responses from representatives of biological, geological, and chemical oceanography, and hydrography have been co-ordinated for presentation to RODAC. To date approximately 70 applications have been reviewed. All but three proposed to dump dredged sediment, in quantities ranging from 1500 to 200,000 cubic metres (see figure). Two applications concerned the disposal at sea of ships and one proposed the placing of radioactive sand on a tidal flat as a tracer for sediment movement. Plans are underway for field studies of phenomena associated with ocean dumping, particularly those such as turbidity and siltation, which may degrade fisheries productivity. The feasibility of a program using sea-bed drifters to estimate bottom transports is being studied.

*D. S. Bezanson, H. J. A. Neu*

**Environmental Impact Statements.** At the request of federal and provincial agencies, a large number of environmental investigations and assessments were made. The major projects were the Lepreau Atomic Power Station (New Brunswick), the intake and outfall design of the cooling water system of the Coleson Cove steam power plant (New Brunswick), Miramichi Channel Improvement (New Brunswick), Gabarus breakwater design (Nova Scotia), Strait of Canso Public Wharf development (Nova Scotia), the second Halifax Container Pier, and the Tiner Point deep-sea oil terminal (New Brunswick).

The last project is located near Saint John, New Brunswick, in the Bay of Fundy. After considerable research it was concluded that the forces




*Dredging activity in Atlantlc Canada. (AOL 4149)*

acting in this area of the Bay of Fundy, particularly those of currents and waves, are appreciably larger than those chosen by the consultant for the design and operation of the wharf. Furthermore, the surging character of the currents, which makes berthing difficult and even hazardous, has been completely overlooked in the design and model studies. It therefore follows that the proposed fixed wharf design carries with it a greater environmental risk from a large-scale oil spill than does a 'soft' berth such as a single-point mooring.

*H. J. A. Neu*

**Remote Sensing of Surface Salinity.** Preliminary studies were carried out, to determine the feasibility of using passive UHF (ultra-high frequency) radiometry for remote salinity measurements. Most of the background work was carried out by SED Systems Ltd. of Saskatoon with the evaluation being done at BIO. Results indicated that optimal response to salinity is obtained at frequencies between 200 and 400 megahertz with skin depths in the order of centimetres. This response is largely due to the conductivity of the water, so an independent measurement must be made for temperature in order to determine salinity. Using an infrared (IR) radiometer for temperature measurements, the salinity measurements at best would be accurate to - 0.5 per cent. This accuracy coupled with operational limitations severely limits the usefulness of the technique and an attempt is being made to find an alternate method.

*P. E. Vandall*

**Other Support Activities.** As in past years, Coastal Oceanography has continued to give support to other groups within the Institute by maintaining current meters, salinity-temperature-depth (STD) profilers, moorings,

and other equipment, and providing the data reduction for the current meters and the STD profilers.

The Division was responsible for two oceanographic surveys for outside users: one a seasonal sampling of the 'Halifax Section' in support of ICNAF (International Commission for the Northwest Atlantic Fisheries), the other an 'ice forecast cruise' each November in the Gulf of St. Lawrence to collect data needed by the Atmospheric Environment Service as input for their ice forecast calculations.

# Hydrography

The 1975/76 period has been a highly productive one for Hydrography Division. For example, the Division carried out, in conjunction with its traditional work as part of the Canadian Hydrographic Service, several projects of economic interest to Canada including:

-tidal surveys along the edge of the continental shelf to provide input to a current study of electricity generation from the possible harnessing of the Bay-of-Fundy tides:

-Loran-C navigation of the Canadian west coast in response to the pending plan to transport oil from Alaska to western U. S. ports;

-eastern Arctic cross-sectional charting of possible pipeline sites and corridor charting for transportation of natural gas and oil;

-Labrador Sea Natural Resource Charting in support of oil exploration and fisheries and navigation chart compilation (see also Regional Reconnaissance, AGC);

-charting of the Miramichi Waterway, N.B., as input to a study that will determine the feasibility of dredging the channel to accommodate deeper-draught vessels.

Another significant event of 1975/76 was the decision of Canadian Hydrographic Service management in Ottawa to decentralize the Service by transferring the cartographic function to the Bedford Institute of Oceanography. The transfer will take place over 3 years with the first group coming in 1977.

Unfortunately, 1975/76 also gave us a share of bad luck. One of the Institute's vessels chartered for hydrographic work, the MV *Christmas Seal,* caught fire at sea a mere 3 hours from Halifax on the morning of May 13, 1976. All hands were rescued but the wooden vessel burned and sank. A replacement, the MV *Northern Seal,* came on charter about 2 weeks later thus permitting us to lose little time on our program.

A summary of the work done during 1975 and 1976 by the sections of the Division - Charting, Hydrographic Development, Navigation, and Tidal - follows.

*R. C. Melanson*

## Charting

The Charting Section plans and conducts field surveys of navigable waters within the Atlantic Region for the production of navigational charts and related publications. To carry this out, eight field establishments in 1975 and seven in 1976 operated in the areas shown in the accompanying figures. The main charting areas were concentrated in the St. Lawrence estuary, Labrador Coast and Sea, and the Canadian Eastern Arctic. The following tables give a brief outline of the projects carried out by the various establishments in 1975 and 1976.

*The MV Christmas Seal in trouble. See text for details. (Courtesy of Wamboldt-Waterfield, Halifax)*

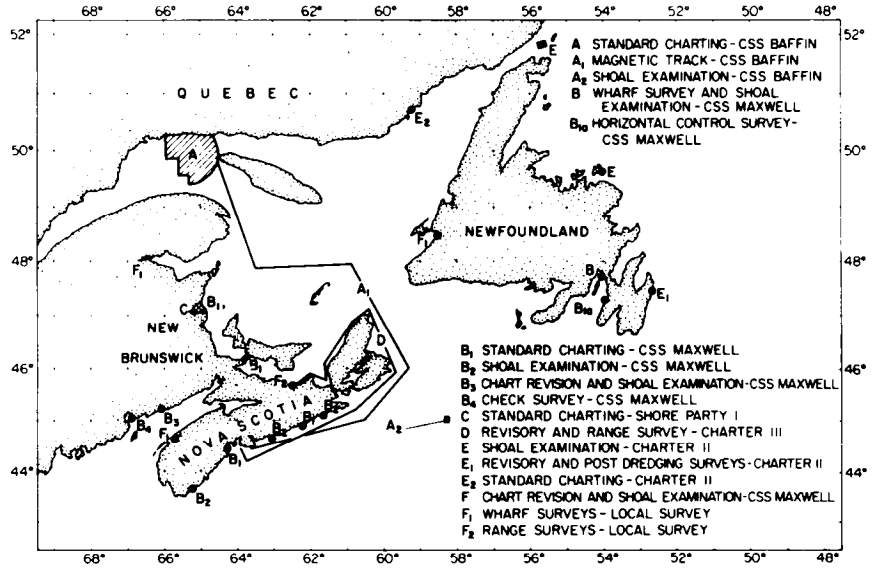
With the exception of our Arctic program, we have enjoyed two productive years as evidenced by the number of projects completed. In the Arctic, relatively bad ice and weather conditions severely hampered survey operations and led to early termination of some projects.

1975 field program

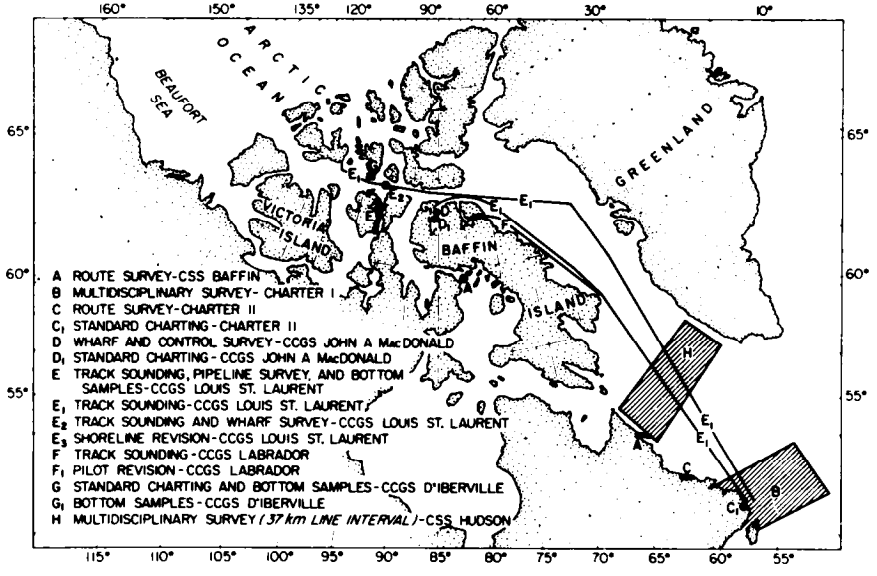
| Establishment and dates | Area | Type of Survey |
|---|---|---|
| CSS *Baffin*<br>April 30 - Oct. 17 | St. Lawrence estuary | Navigational charting and magnetics |
| | Cape Chidley | Route survey |
| | Foxe Basin | Route survey |
| | Banquereau Sank | Shoal examination |
| *CSS Hudson*<br>Sept. 14 - Oct. 12 | Davis Strait and Labrador Sea | Regional multidisciplinary survey (bathymetry, gravity, magnetics, and seismics at 37 kilometre line intervals in co-operation with AGC) |
| Charter Vessel I<br>June 19 - Oct. 14 | Labrador Sea | Natural resource chatting, multidisciplinary survey (bathymetry, gravity, magnetics, and seismic profiles) |

| | | |
|---|---|---|
| Charter Vessel II<br>June 27 - Oct. 11 | Fairway Shoal, Strait of Belle Isle | Shoal examination (standard charting) |
| | Stag Harbour, Tickle, Nfld. | Shoal examination |
| | St. John's, Nfld. | Chart revision and post dredging survey |
| | Tête-à-la-Baleine | Standard charting (route) |
| | Alexis River, Ship Harbour, Labrador | Standard charting |
| | Windsor Harbour Island to Cape Makkovik, Labrador | Route survey |
| CSS *Maxwell*<br>April 30 - Oct. 31 | Come By Chance, Nfld. | Wharf survey and shoal examination |
| | Miramichi Bay, N.B. | Standard charting |
| | Cape Tormentine, N.B. to P.E.I. | Standard charting |
| | Saint John, N.B. | Chart revision and shoal examination |
| | Petit Passage, N.B. | Check survey |
| | Eastern Shore | Shoal examination and standard charting |
| | South Shore, N.S. | Shoal examinations |
| | Argentia, Nfld. | Control survey |
| | Western Shore, N.S. | Standard charting |
| Shore Party<br>May 12 - Aug. 1 | Miramichi Bay, N.B. | Standard charting |
| Charter Vessel III<br>May 26 - Oct. 29 | Halifax to Pictou, N.S. | Chart revision and range surveys |
| CCGS<br>*John A. MacDonald*<br>July 7 - Aug. 18 | Strathcona Sound, Arctic | Wharf and control surveys |
| | Strathcona Sound, Arctic | Standard Charting |
| CCGS<br>*Louis S. St. Laurent*<br>Aug. 18 - Oct. 3 | Peel Sound, Arctic | Track sounding, pipeline surveying, and bottom sampling |
| | Strait of Belle Isle to Byam Martin Island, Arctic | Track soundings |
| | Resolute Area, Arctic | Track sounding and wharf survey |
| | Franklin Strait, Arctic | Shoreline revision |
| *CCGS Labrador*<br>Aug. 25 - Sept. 8 | Cape Dyer, Lancaster Sound, Arctic | Track soundings |
| | Clyde Inlet, Arctic | Pilot revision |
| *CCGS d'Iberville*<br>Sept. 8 | Intrepid Passage, Arctic | Standard charting and bottom sampling |
| | Admiralty Inlet, Arctic | Bottom sampling |

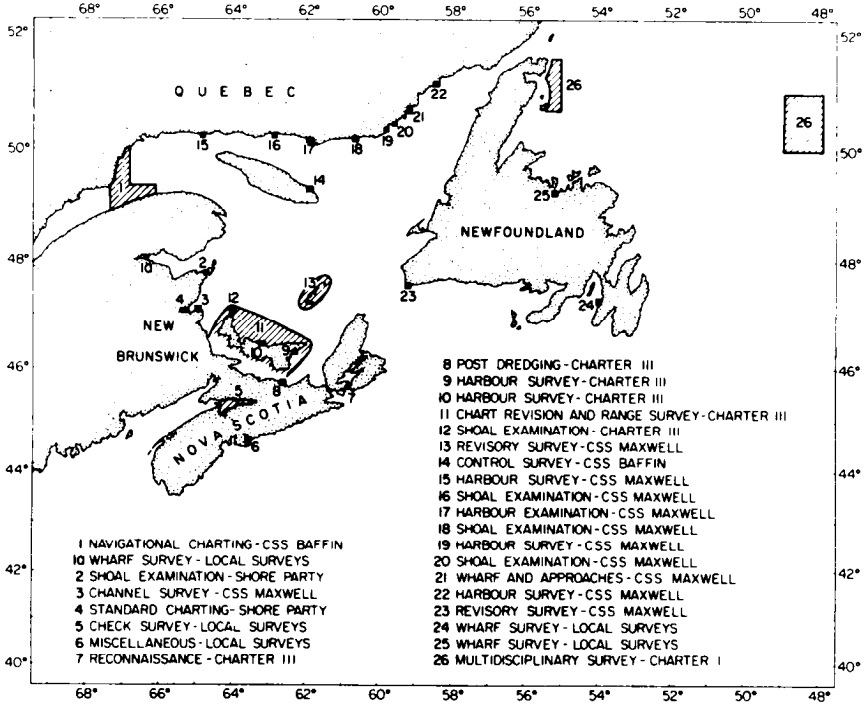
In addition to the above, a number of projects of a minor nature were completed by our Local Surveys Group. With the exception of our Eastern Arctic programs, where CSS *Baffin* was forced to leave Foxe Basin early due to adverse weather and the *CCGS Labrador* twisted off her starboard tail shaft, the season was successful. Oil residue samples were also collected on our Arctic program for Chemical Oceanography, AOL.



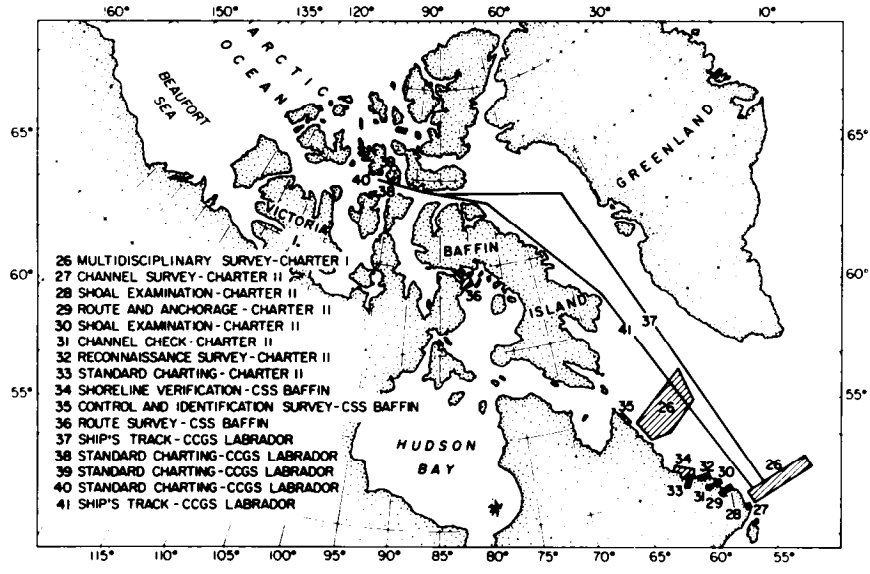

*Hydrographic survey operations in the Atlantic Provinces in 1975. (AOL 4219)*




*Hydrographic survey operations in the eastern Arctic in 1975. (AOL 4219)*




*Hydrographic survey operations in the Atlantic Provinces in 1976. (AOL 4219)*




*Hydrographic survey operations in the eastern Arctic in 1976. (AOL 4219)*

1976 field program

| Establishment and dates | Area | Type of survey |
|---|---|---|
| *CSS Baffin* May 17 - Sept. 30 | St. Lawrence estuary | Navigational charting and magnetics |
| | Cape Chidley, Labrador | Positioning and identifying off-lying rocks |
| | Foxe Basin, NWT | Route survey |
| Charter Vessel I June 28 - Sept. 30 | Labrador Sea | Natural Resource Charting - bathymetry, gravity, and magnetics |
| Charter Vessel II June 22 - Oct. 8 | White Bear Arm, Labrador | Channel survey |
| | Cartwright Harbour | Shoal examination |
| | Sandwich Bay | Route and anchorage |
| | Groswater Bay | Shoal examination |
| | Goose Bay Narrows | Channel check |
| | Webec Harbour to Cape Makkovik, Labrador | Reconnaissance |
| | Kaipokok Bay, Labrador | Standard charting |
| *CSS Maxwell* May 5 - Oct. 29 | Miramichi, N.B. | Channel survey |
| | Magdalen Islands | Revisory survey |
| | Anticosti Island, Que. | Control for 1977 Hi-Fix Chain |
| | Rivière-au-Tonnerre, Que. | Harbour survey |
| | Piashti Bay, Que. | Shoal examination |
| | Natashquan Harbour, Que. | Harbour examination |
| | Gethsemani, Que. | Shoal examination |
| | Harrington Harbour | Harbour survey |
| | St. Mary's Island | Shoal examination |
| | Tête-à-la-Baleine | Wharf and approaches |
| | St. Augustin, Que. | Harbour survey |
| | Old Fort Bay, Que. | Harbour survey |
| | Port-aux-Basques, Nfld. | Revisory surveys |
| Shore Party May3-June11 | Miramichi, N.B. | Standard charting |
| | Shippegan, N.B. | Shoal examination |
| MV *Northern Seal* June 5 - Oct. 25 | St. Peters Inlet, N.S. | Reconnaissance |
| | Caribou, N.S. | Post dredging |
| | Souris, P.E.I. | Harbour survey |
| | Rustico, P.E.I. | Harbour survey |
| | P.E.I. and Caribou, N.S., to Shediac, N.B. | Chart revisions and surveys |
| | North Point, P.E.I. | Shoal examinations |
| *CCGS Labrador* July 19 - Oct. 15 | Track North | |
| | Freemans Cove, NWT | Standard charting |
| | South Bathurst Island | Standard charting |
| | Track South | |
| Local Surveys | Dalhousie, N.B. | Wharf survey |
| | Minas Basin, N.S. | Check survey in conjunction with AGC |
| | Halifax Harbour | Miscellaneous |
| | Argentia, Nfld. | Wharf survey |
| | Botwood, Nfld. | Wharf survey |

In addition to the navigational charting in 1976, oil tows were collected in the Arctic for Chemical Oceanography, AOL, bottom samples were taken around P.E.I. for Chemical Oceanography in conjunction with Ocean Dumping, and the anchors for Metrology's (AOL) offshore tower in the entrance to Halifax Harbour were positioned.

Our Eastern Arctic program was again hampered by exceptionally heavy ice in our priority survey area south of Bathurst Island. For the second consecutive year, CCGS *Labrador* sustained ice damage and was forced to operate on a restricted program.

*T. B. Smith*

## Hydrographic Development

The Hydrographic Development Section investigates and implements instrumentation and techniques designed to increase the efficiency and accuracy of hydrographic surveys.

An evaluation of Calcomp, Gerber, Xynetics, and Kongsberg Flatbed Plotter systems has culminated with the purchase of a Xynetics 1100 system. The Flatbed Plotter will be used to generate grids, projections, lattices, title blocks, and bathymetry from automated surveys. Magnetic forces generated by a Sawyer linear motor are used to position the plotting head. This approach eliminates the requirement for the mechanical drives found in conventional systems. The accompanying figure shows the plotting head and the table controls.

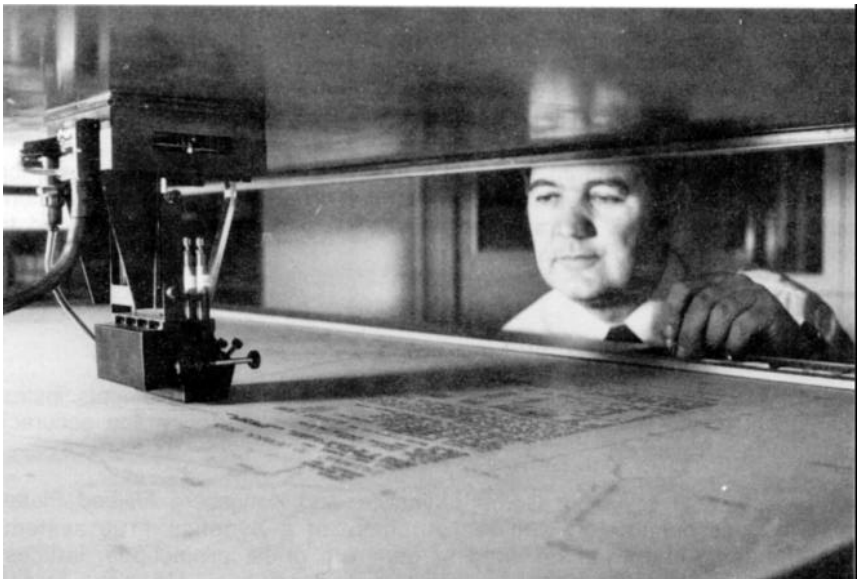
Hydrography has acquired two Hewlett Packard 9815A programmable calculators for survey calculations. A number of programs have been written, including routines for geodetics, projection conversions, electronic positioning, and general purpose survey calculations.

For surveys that do not lend themselves to automation, work is underway on a small portable field digitization system using a Hewlett Packard 9815A Programmable Calculator and a 8765A XY Digitizer. Depth and position will be recorded on miniature tape cartridges for subsequent processing and plotting on a Hewlett Packard 2100 computer system.

A new Hewlett Packard 21MX computer system has replaced the PDP8L hydrographic data processing system on the CSS *Baffin.* Significant improvements in both processing speed and ease of data manipulation have been realized. A Real-Time Executive Operating System permits several programs to be run concurrently. The processing software, which has been written by our personnel, employs removable disc cartridges for data storage.

A study to determine the best techniques for digitizing field data using the existing BIO facilities has been commenced. The major components to be used in the study include a Gradicon Digitizer Table, a Xynetics 1100 Flatbed Plotter, a Hewlett Packard 2100 Computer System, and a Tektronix 4010 CRT terminal. The organizational structure recommended in this study will complement the existing organization and will permit consolidation of several individual projects. The study will include recommendations on survey planning and field data storage and retrieval systems.

*R. G. Burke, G. R. Douglas*



*The new Xynetics plotter. (AOL 4186)*

## Navigation

Precise positioning has always been needed by hydrographers and geophysicists. Now other oceanographers are putting new instruments to use that demand precision navigation to realize their full potential. Deep-towed side-scan sonar and high-resolution seismics are used to 'look' at the seabed, and the porpoising Batfish is used to map the water structure in three dimensions; they all need a relative positioning accuracy of the order of 100 metres to scale the record, to correlate successive grid lines, and to return to interesting discoveries. In addition, oceanographers want to compare accurate dead-reckoning with good radio navigation to measure the surface current. This positioning must be available anywhere on the Canadian continental shelf, and should be presented to the user in a form that is easy to merge with the scientific data.

At present a great deal of effort is needed both during the cruise and in post-processing to achieve good navigation; sometimes the resources have not been available and the results have suffered. And no human operator can combine data from several systems immediately, yet this integration, which improves accuracy, has to be done in real-time unless an enormous amount of data is to be stored. We are, therefore, developing an automated navigation system, named 'Bionav', that will: reduce the complex operator chores involved in precise navigation by giving them to a computer; improve positioning by including all available information in the solution; give a best available position on-line, with a final value a few hours later; and display the data in the form needed for running the survey, and record it in the form to best merge with the scientific data.

Bionav will be based on Satnav (the U. S. Navy Navigation Satellite System),

augmented by ship's log and gyro, by radio aids such as Loran-C and Decca, and, later, by added information from ship's motion (heave, etc.) and wind and weather. It will combine all this information statistically using error models based on observations of each subsystem. We are continually collecting and analyzing this accuracy data.

While Bionav is being developed, we continue to integrate manually Satnav-with-log-and-gyro, and passive ranging Loran-C (the latter being the only radio aid available over much of Atlantic Canada). We have improved our Loran-C user programs and added remote displays for way point and line-keeping navigation to our earlier geographic position conversion. Engineering Services (see Institute Facilities) at BIO has built interfaces and displays for this development.

We continue to develop off-line programs for many navigation problems. One of the most widely used sets draws hyperbolic or circular lattices for any radio navigation aid (navaid) on either a large flatbed plotter at the Institute, or on the ship-borne computer and drum plotter.

One problem with a long range navaid such as Loran-C is that the signal path may pass over land as well as over salt water; the accuracy of a radio aid depends critically on knowing the velocity of the radio wave and this is predictable over water but not over land. Much of our work is along the Labrador Coast, and there we have used a portable Decca transmitter sited to give all over-water paths to the survey area to measure corrections for Loran-C land paths. Elsewhere we have calibrated Loran-C and Decca chart lattices of offshore areas by means of Satnav, and we have made tests on the maximum effective range of Loran-C.

Other work on navigation instruments included fitting Doppler speed logs on our icebreaker ships (the bow thruster causes severe acoustic problems) and testing differential Omega and VLF navigation.

*R. M. Eaton*

## Tidal Section

This section directs the tidal, tidal current, and water levels work carried out by the Canadian Hydrographic Service in the Atlantic Region.

The past 2 years have seen some significant advances in the collection and analysis of tidal data. The Aanderaa water level gauge, an exceptionally versatile instrument, has become a standard tool for the measurement of both offshore and inshore tides. It has been used successfully in almost every type of marine environment on our coast, from the edge of the shelf to the upper reaches of the Bay of Fundy, as well as in the high Arctic. A number of tidal records of one-year duration were recently obtained in the Arctic, at sites previously inaccessible for tidal measurement. The analysis of the tidal data has been enhanced by the use of spectral analysis techniques in addition to the customary harmonic analysis, and the development of specialized software for rapid offshore gauge data processing.

Tide gauges have been supplied to the hydrographic field parties and other users in the marine community for tidal support. In addition, an Endaco

remote-reading current meter has been acquired for hydrographic use to obtain short-term observations of the current regime in harbours and channels in support of shipping.

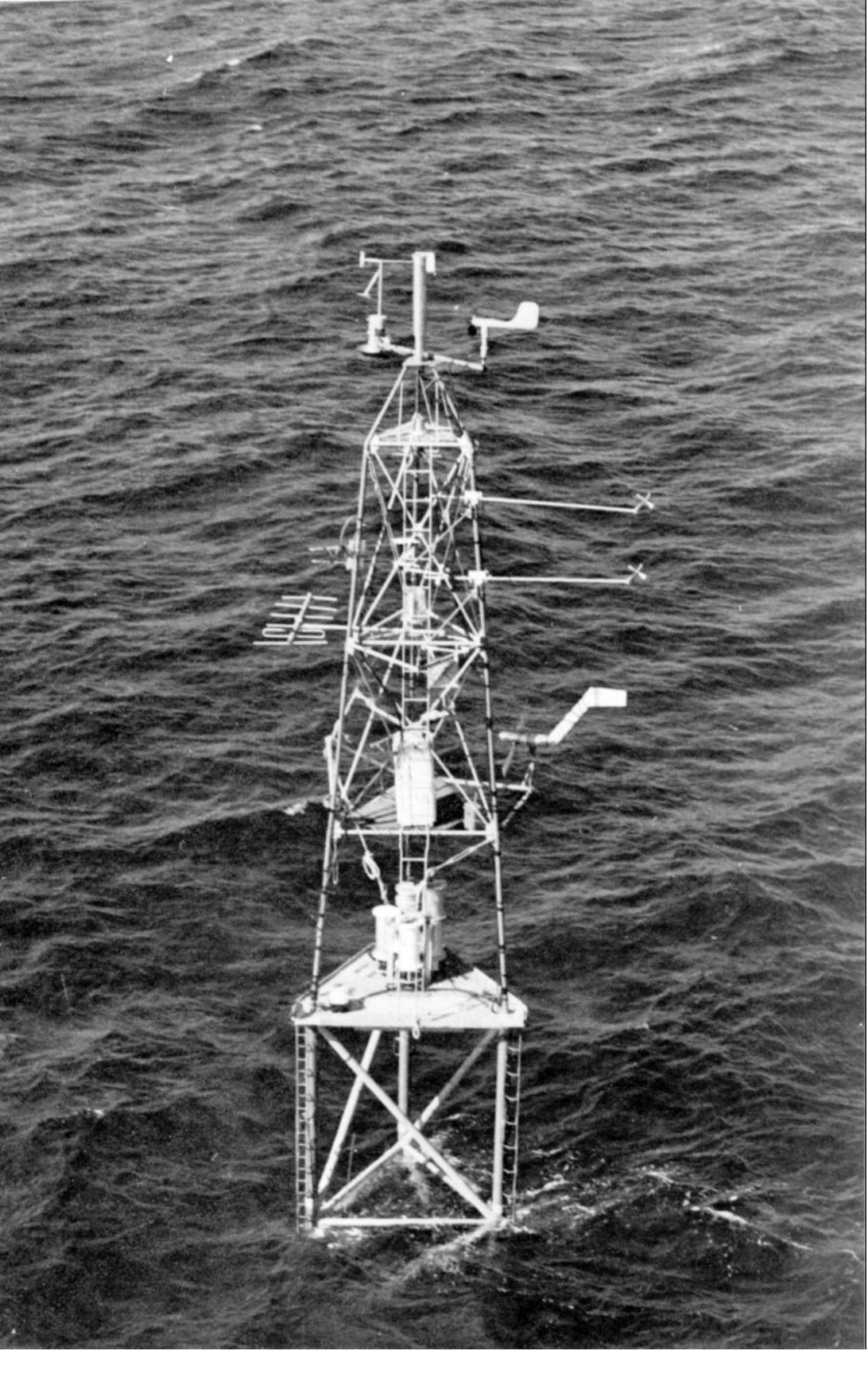
Planning of the Permanent Gauging Network on the East Coast and Eastern Arctic has been undertaken by the Tidal Section and the Water Survey of Canada office in Halifax. This co-operative work has resulted in some new advances in permanent gauging, particularly in the installation of a movement-free transducer pin at Cape D'Or, N.S. In the Eastern Arctic, testing of a submersible gauge proved that it overcomes previous data-collection problems in ice-covered areas.

*Hydrographic station on North Shore, Gulf of St Lawrence, (AOL 3998)*

A project to measure and analyze the tide along the Continental Shelf from the Scotian Shelf to south of Cape Cod, and in the Gulf of Maine and Bay of Fundy, was begun during 1976. This work, funded by the Atlantic Tidal Power Review Board, is being undertaken in conjunction with the numerical modelling of the Bay of Fundy/Gulf of Maine system by Dr. D. A. Greenberg of Marine Environmental Data Service (MEDS). The tidal

data are analyzed and then used to calculate the open boundary conditions and proper calibration of the model. To date, the field program has been successful. A spin-off of this work has been the development of a reliable 'pop-up' tide-gauge mooring. The mooring is a small bottom-mounted package without ancillary ground support: as a result it is more likely not to be damaged by bottom-trawlers operating in its vicinity.

*D. L. DeWolfe*



# Metrology

Metrology Division develops and tests new oceanographic equipment, techniques, and standards in support of the scientific research at the Institute. Current projects include the development of oceanographic and biological sensors, bottom sampling equipment, and improved marine navigation and geodetic techniques. The work is carried out in close collaboration with scientists and technologists at the Institute and within Canadian industry and the university community. Examples of co-operative effort with industry include: scientific management of the Canadian Ocean Data System program, contracted to Hermes Electronics Ltd.; collaboration with Huntec ('70) Ltd. in the development of a system for remote sensing of the geotechnical properties of marine sediments; and assistance to Guildline Instruments Ltd. in the development and testing of a family of CTD (conductivity-temperature-depth) instruments.

In April 1976, the Air-Sea Interaction Group was transferred to the Ocean Circulation Division and at the same time, the Metrology Division was reorganized into three sections: Electronic Design, Mechanical Design (including the Instrument Machine Shop), and Applied Physics (including the Standards Laboratory). Work within Metrology is still organized on a project basis, that is, each project group is formed from divisional staff with the required skills.

*D. L. McKeown*

## Oceanographic Sensors

**Physical Oceanography.** Development of CTD (Conductivity-Temperature-Depth) systems has continued in collaboration with the National Research Council of Canada (NRCC) and Guildline Instruments Ltd., Smiths Falls, Ontario. This work includes methodical laboratory calibration of the instruments in conjunction with sea trials, development of computer-based data acquisition systems, and applications to horizontal profiling with the Batfish towed body as well as more conventional vertical profiling from a stationary vessel.

Several CTDs have gone through cycles of laboratory calibration and sea trials to assist Guildline in improving the instruments. These cycles have included both analogue and digital versions of the equipment. Various discrepancies between instruments and problems specific to a particular unit have been referred back to NRCC and Guildline for correction One consequence of this work was the publication of a new formula for the conversion of conductivity measurements to salinity (Bennett (1976) see Section F of this Review).

Considerable effort has been expended to create a computer-based data acquisition system involving both 'software' and 'hardware' for use with the standard ship-borne HP-2100A minicomputers. Initially, a prototype digitizing system was developed for the analogue CTD. Engineering Services (Institute Facilities) then produced a second system based on a Fluke digital voltmeter. Metrology collaborated in the interfacing of this system with the CTD and computer and evaluated its performance. It is now

permanently installed on CSS *Hudson* and CSS *Dawson,* Data acquisition programs were also written for use with the digital CTD. All computer programs including a number of utility programs were documented in various Bedford Institute of Oceanography Computer Notes (see Section F). Metrology personnel joined several cruises to train oceanographers of the Coastal Oceanography and Ocean Circulation Divisions of AOL and the Atmospheric Environment Service (Department of Environment) in the use of these systems.

Programming activities are continuing with the immediate aim of producing data acquisition programs compatible with the HP-2100A RTE (Real Time Executive) system now being introduced at the Institute as the operating system for data processing on the minicomputers. An outcome of the programming effort has been the development and documentation of a new programming language, ONCAL (ON-line CALculator). This computer language provides a very powerful tool for interfacing real-time sensors to a ship-borne minicomputer and for processing the incoming data. Aside from CTD data acquisition, ONCAL is being used for some biological sensor developments, acoustic positioning work, and on-line navigational computations.

The CTD continues to be used with the Batfish undulating towed body to obtain continuous horizontal and vertical information on temperature and salinity variations in the top 400 metres of the ocean. Metrology has been supporting Coastal Oceanography's Shelf Break Dynamics project and Ocean Circulation's Labrador Sea experiments through the use of this equipment. In the former project, the horizontal resolution achieved with the Batfish has revealed complexities in the internal wave field not observable with the conventional station spacings of vertical CTD casts.

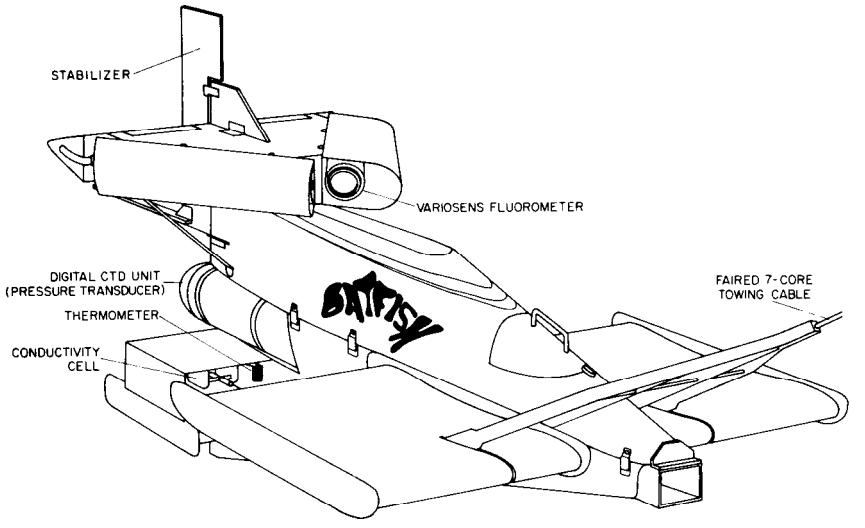
During the past 2 years the Metrology Division has been working with Professor Kroebel and his colleagues at Kiel University, F.R.G., to examine and evaluate their Multisonde, which measures conductivity, temperature, depth, sound velocity, red and blue light attenuation, and the differential light attenuation betewen the two colours. This instrument is of considerable interest to the Institute as light attenuance measurements should make possible the determination of both the concentration of suspended particulate matter and to some degree the differentiation between different types of suspended matter. Unfortunately, the instrument presently suffers from problems of contamination of the optical components by oil and other impurities on the sea surface. Operation of the Multisonde in conjunction with Guildline CTDs has proved valuable in highlighting discrepancies and weaknesses in the design of both instruments that we hope will lead to their eventual improvement.

*A. S. Bennett, J. P. Thorburn, M. Stepanczak, J. J. Betlem, G. R. Dubois*

**Biological Oceanography.** Little attention has been paid until recently to the instrument needs of biological oceanographers. To overcome this deficiency, Metrology has embarked on a program to develop *in situ* biological sensors and establish proven techniques for their use at sea. For example, a Variosens fluorometer system and a Zooplankton Counter are being developed for integration with the Guildline CTD and installation on the Batfish towed-body.

A modified version of the Variosens fluorometer has been interfaced with

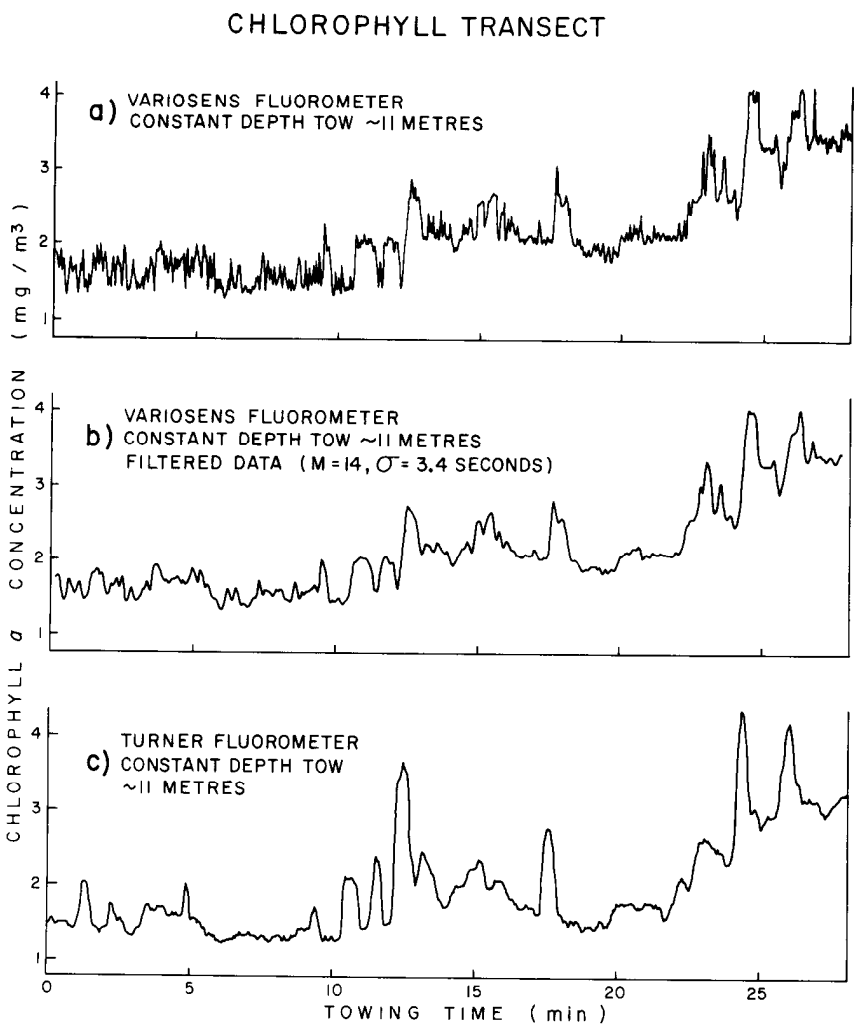
the CTD and installed on Batfish (see figure) to measure in *situ* chlorophyll a fluorescence, the pigment most often used by biologists to estimate the concentration of phytoplankton. This measurement along with conductivity, temperature, and towed body depth is processed on-line by an HP-2100 minicomputer to provide real-time information on phytoplankton distribution and variability.




*The Batfish equipped with a Variosens fluorometer and a CTD (conductivity-temperature-depth) unit. (AOL 3946)*

The fluorometer data have been verified by comparing them to data obtained with water supplied by a towed pump to a Turner III fluorometer aboard ship, a well established experimental procedure. A chlorophyll transect, sampled by the two instruments at a constant depth of approximately 11 metres in coastal waters off Yarmouth, Nova Scotia, is shown in the figure. Traces a and c show the raw data obtained with the Variosens and Turner Ill fluorometers respectively. Trace b shows the Variosens data filtered digitally to obtain the optimum statistical agreement with the Turner data. Analysis has shown that the Variosens fluorometer will respond to temporal variations 20 times faster than the pump/Turner fluorometer system.

To complement the phytoplankton measurement program, a zooplankton counter is being developed in collaboration with NRCC. NRCC is designing and constructing the instrument and the Metrology Division is testing and calibrating it in the laboratory and at sea. The underwater sensor, presently installed on Batfish along with the Variosens fluorometer and Guildline digital CTD, counts and sizes copepods with diameters of 0.5 to 5 millimetres that pass through a conductivity cell. Digitized data are transmitted to the surface for on-line processing by a minicomputer or storage on a cassette recorder.



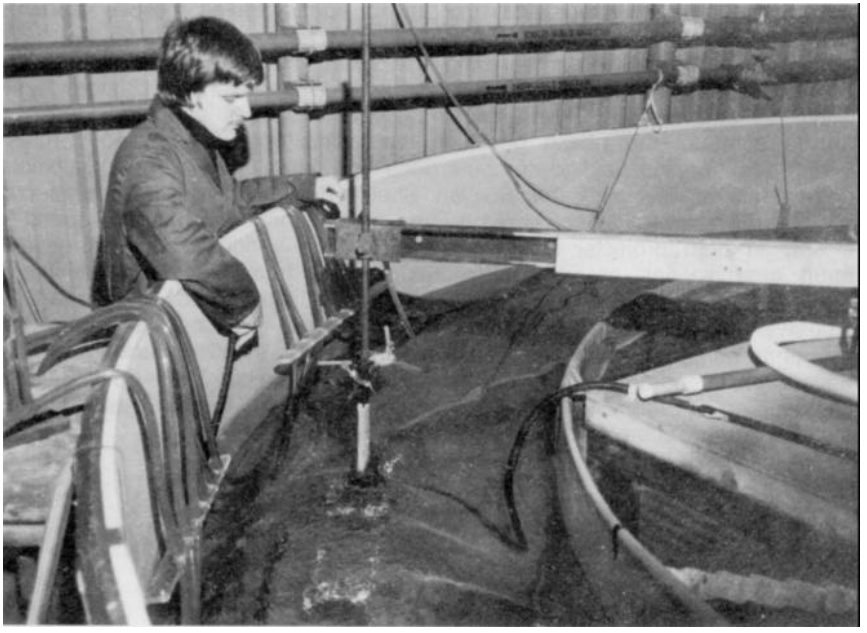

*Chlorophyll transects obtained from the Variosens fluorometer mounted on Batfish and from a towed pump - fluorometer system. (AOL 3946)*

An annular test tank was constructed (see figure) to provide a facility for calibrating the zooplankton counter. The counter sensor can be rotated in the tank at speeds of 0 to 3 metres per second. The cell has been tested in the laboratory and at sea but further testing, rigorous calibration, and verification of data are required before it can be used routinely at sea.

*A. W. Herman, J.-G. Dessureault, E. E. Phillips*

## Marine Geodesy

The Marine Geodesy program is aimed at development of techniques for precise positioning in the marine environment and topographic mapping of the sea surface.



*Testing the zooplankton counter in an annular tank. (AOL 4147)*

Since 1968 the Institute has been using the Transit satellite navigation system for positioning research and survey vessels. Geodetic positioning techniques utilizing these satellites are now being applied to positioning problems at sea. The Division has completed development of a computer program package for geodetic networks of fixed stations and installed it at Dalhousie University in Halifax, University of New Brunswick, Institut fur Angewandte Geodasie in Frankfurt, Royal Norwegian Council for Scientific and Industrial Research in Oslo, and Universidade Federale de Rio de Janeiro.

Midway between a fixed geodetic network and a network of marine stations such as oceanographic vessels and offshore drilling rigs, some of which may be moving, lie the slowly deforming networks such as the manned ice camps of the Arctic Ice Dynamics Joint Experiment (AIDJEX). During the past 2 years the Division, in collaboration with AIDJEX investigators, has critically examined the problem of determining the absolute and relative motions of these ice camps using the Transit satellite system. Both calibration and field data were collected and analyzed.

These investigations and techniques are also being applied to the problem of creating a more accurate and reliable navigation system aboard ships by integrating several navigation systems currently operated by the Institute. This work is being done in co-operation with the Navigation group of Hydrography Division (AOL).

A new tool, which may benefit geodetic and marine science, is the satellite-borne radar altimeter. Following initial experiments aboard SKYLAB,

the U. S. National Aeronautics and Space Administration (NASA) launched the GEOS-3 satellite: one of the objectives was to demonstrate the utility of satellite altimeters for measuring the relief of the ocean surface. The eventual goal with later satellites is to provide sea surface topography to within 10 centimetres. Two Canadian GEOS-3 projects accepted by NASA are to compute the ocean geoid in the vicinity of Canada and compare it with other geoids, and to compute tides and mean sea level from altimetry data. Hudson Bay and the Scotian Shelf - Bay of Fundy were selected as the main investigation areas. The investigators, who are co-operating closely in both projects, include personnel from various Canadian government organizations as well as representatives from Dalhousie University, University of New Brunswick, Shell Canada Limited, and the Institut fur Angewandte Geodasie. To supplement the NASA tracking data during the 4 month primary data acquisition period, Doppler satellite tracking stations have been temporarily established at Churchill, Manitoba, Poste-de-la Baleine, Quebec, and Fredericton, New Brunswick; permanent Earth Physics Branch stations are in Calgary and Ottawa.

*D. E. Wells*

## Bottom Sampling

**Underwater Electric Drill.** The Division has been involved since its inception in the development of drilling devices for obtaining hard rock cores from the sea floor. By 1975 an underwater electric drill powered from the ship via an umbilical cable and deployed and recovered on a separate strong cable had been developed. The drive mechanism required that the outer wall of the drill barrel be threaded throughout its length. While system reliability was good and station time minimal, two problems were evident. Operational depth was limited by the two-cable handling configurations and certain bottom materials, especially those encountered in the Arctic, which caused clogging of the thread with consequent jamming of the mechanism and high wear. During the past year, both these problems have been addressed.

Since 1973, investigations have been underway to find an almost neutrally buoyant single cable containing both a strength member and electrical conductors. Kevlar, a new synthetic material with low stretch and nearly neutral buoyancy, became available in 1974. Two samples of a Kevlar cable with integral electrical power and signal leads have been tested. Problems of insulation breakdown have arisen and modifications and improvements are being made by the manufacturer.

The drive mechanism has been simplified so that there is no longer a requirement to thread the outside of the drill barrels. There is now a threaded fitting at the top of the drill barrel that runs up and down a threaded plastic liner surrounding the barrel. The outside surface of the barrel is now completely smooth with the exception of a vertical keyway. Field trials during 1976 have indicated that the tendency of the mechanism to clog and jam has disappeared and component wear has been considerably reduced.

*G. A. Fowler, P. F. Kingston, W. J. Whiteway, R. Cassivi*

## Co-operative Programs

The Institute of Geological Sciences (IGS) in Edinburgh and BIO share an interest in the development of techniques for bottom sampling. In 1974, BIO participated in trials of a new British unmanned submersible, CONSUB. In 1975 the IGS Vibracorer (to core unconsolidated sediments) was modified by the Metrology Division and tested aboard CSS *Hudson,* then purchased by the Atlantic Geoscience Centre. In 1976, IGS tested the BIO underwater electric drill during a joint IGS/Norwegian Continental Shelf cruise in the North Sea.

*J. Brooke, G. A. Fowler*

## Mooring Techniques

Investigations into new mooring methods and materials continue. At present, effort is being concentrated on the replacement of stainless steel wire with Kevlar synthetic rope. While the strength of this material is adequate, techniques for applying end fittings quickly are still being developed to retain the overall strength of the rope. Some test moorings have been placed in the ocean and results are being evaluated.

*J. Brooke, G. A. Fowler*

## Acoustic Positioning

**Long Baseline System.** During the past few years, the Metrology Division has been developing a long baseline acoustic positioning system utilizing acoustic transponders and beacon pingers (for more detail see the 1973/74 Biennial Review). Its prime purpose is to provide information on the three dimensional position of an oceanographic instrument in the water column or on the sea floor. On two occasions the system has been used to navigate a bottom crawling vehicle, the Sea Rover, up to the side of a sunken oil barge. It has also provided an indication of the particular cargo tank being surveyed by the vehicle while alongside. Another application of the system has been the establishment of the trajectory that a current meter mooring follows during deployment. Two simulated current meter moorings were laid while the paths that the subsurface float and anchor followed were monitored acoustically. While acoustic releases have proved very reliable on moorings, they do on occasion fail. In this event, the recovery of the instruments and data poses a problem. Coastal Oceanography Division has been exploring the possibility of cutting the mooring wire just above the anchor by towing a pair of buoyant trawl doors along the sea floor. As part of this investigation, the long baseline system was employed to define the path of the doors relative to the towing vessel.

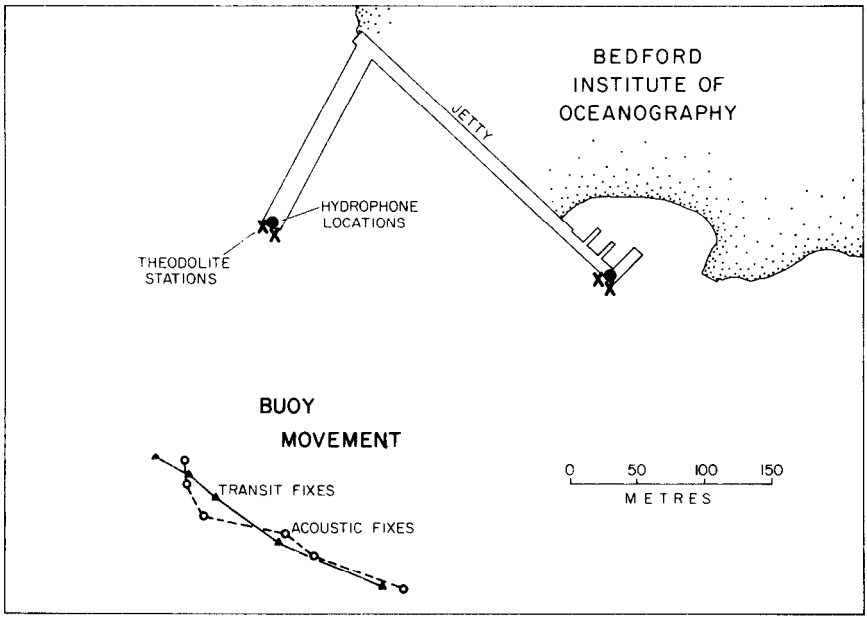
*D. L. McKeown, B. B. Hartling*

**Short Baseline System.** An acoustic current drogue and companion shore-based tracking system have been developed and a ship-borne hydrophone array with companion electronic detection equipment is being developed to give the range and bearing of the ship from an acoustic marker.

In winter months, many coastal inlets are covered by a sheet of ice and the surface water movement is not influenced by wind. A system employing

current drogues containing acoustic pingers is being developed to enable oceanographers to study water movement under these conditions. Initially, trials of various float configurations were conducted in a test tank at Dalhousie University, Halifax. A particular drogue configuration was established and its reaction to currents of various velocities determined. Samples of the float were released and allowed to travel under an ice sheet in Bedford Basin, Nova Scotia, to confirm that they would ultimately appear in open water at the other end of the ice.

An assemblage of hydrophones, amplifiers, electronic detectors, and recording equipment was created to track floats. A series of receiving stations was established along the jetty of the Institute and several floats were tracked acoustically. A surface marker was attached to each so that



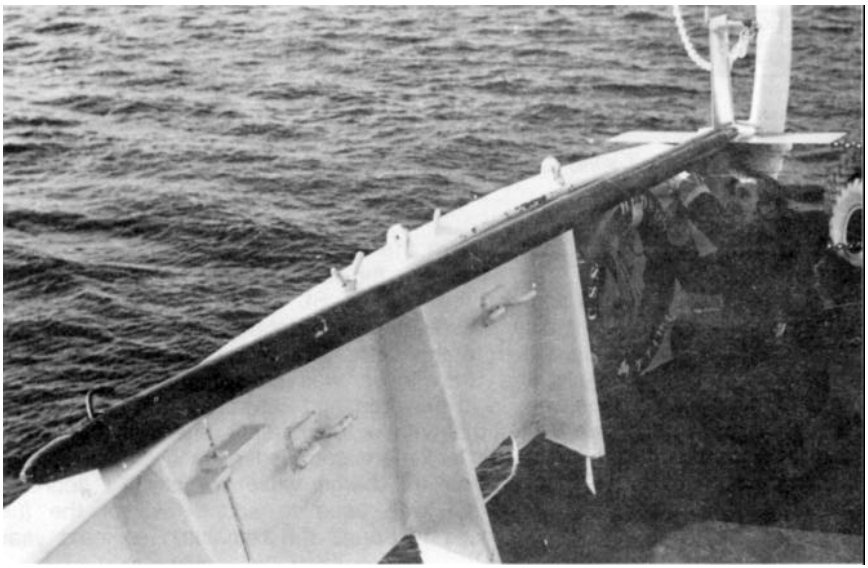

*Acoustical tracking of floating buoys in Bedford Basin from the BIO jetty. (AOL 4133)*

its position could be periodically checked by a pair of theodolites. An example of the results of this experiment is shown in the accompanying figure.

In some instances at sea, the long baseline acoustic positioning system is unsuitable. A less accurate but simpler system for positioning is to install a number of hydrophones on the hull of a ship and to deduce the range and bearing from the ship to an acoustic source by calculating the difference in arrival times of the signals at various hydrophone pairs. Two forms of hydrophone arrays have been installed. The first consists of two standard shipboard echo sounder transducers plus a third towed hydrophone abeam of the ship. The second consists of a single hull mounted transducer plus a pair of hydrophones mounted in a 5 metre long towed

body. Electronics are being developed to periodically calibrate the hydrophone array, digitize the time differences, and transfer the data to a minicomputer where ranges and bearings are computed. The design of a microprocessor to replace the computer has been completed. The next stage in the development will be an intercomparison between the long baseline system with its known positioning accuracy and the short baseline system under development. The system has already demonstrated its worth by aiding in the location of a lost current meter mooring in St. Georges Bay, Nova Scotia.

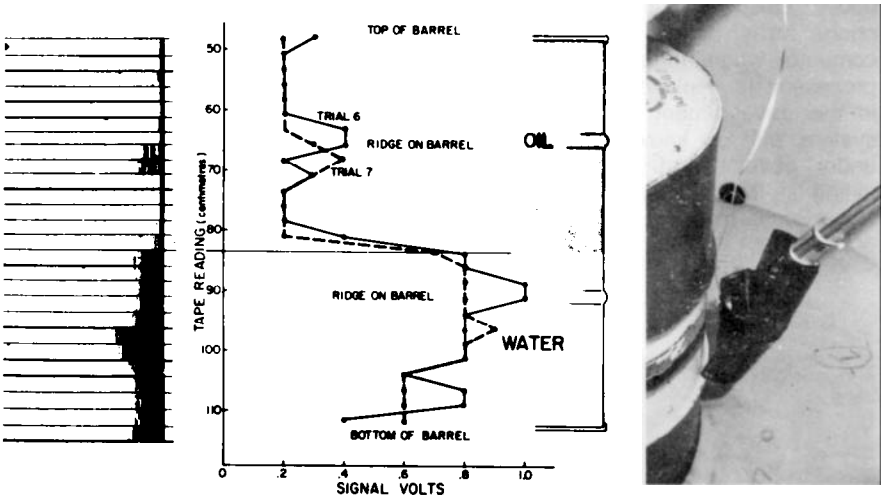
*P G. Jollymore. D L. McKeown*



*Hydrophone array for a short-baseline acousttc positioning system (AOL 4168)*

## Detection of Oil-Water Interfaces

When an oil tanker or similar vessel sinks, some portion of the cargo often escapes. There is then the problem of determining how much oil remains in each tank. The measurement technique must be non-destructive and suitable for use by divers in shallow water, or by submersibles or remote controlled vehicles in deep water. The Metrology Division is developing an acoustic measuring technique. A standard high frequency echo sounder (200-300 kilohertz) is used to sound horizontally through the tanks at various heights. When the acoustic pulse passes into water within the tank, strong reverberations occur; when the pulse passes into an oil the acoustic reverberations rapidly diminish due to the high acoustic attenuation of the oil. Laboratory experiments on a 45 gallon drum filled with Bunker C oil indicated that the method would work. The only item the diver or submersible need handle is a small acoustic transducer.




*Laboratory experiment verifying that the proposed acoustic system could detect an* oil-water *interface. (*AOL 3207)

The detection method was tested in the field by measuring the levels of Bunker C in the tanks of an oil barge, the *Irving Whale,* lying at a depth of 67 metres on the bottom of the Gulf of St. Lawrence. At this depth, divers would have to employ saturation diving techniques to conduct the investigation. As an alternative to this approach, a simple bottom-crawling remotely controlled vehicle, the Sea Rover, was constructed to deploy the acoustic transducer. The vehicle is powered and controlled from the surface via an umbilical cable. It is fitted with a television camera and acoustic navigation equipment. The cargo tanks are sounded by allowing a buoyant package to rise vertically alongside the barge while acoustically sounding the tank horizontally. This system was used to sound two of the fuel tanks of the *Irving Whale:* we hope to sound the remaining six next year.

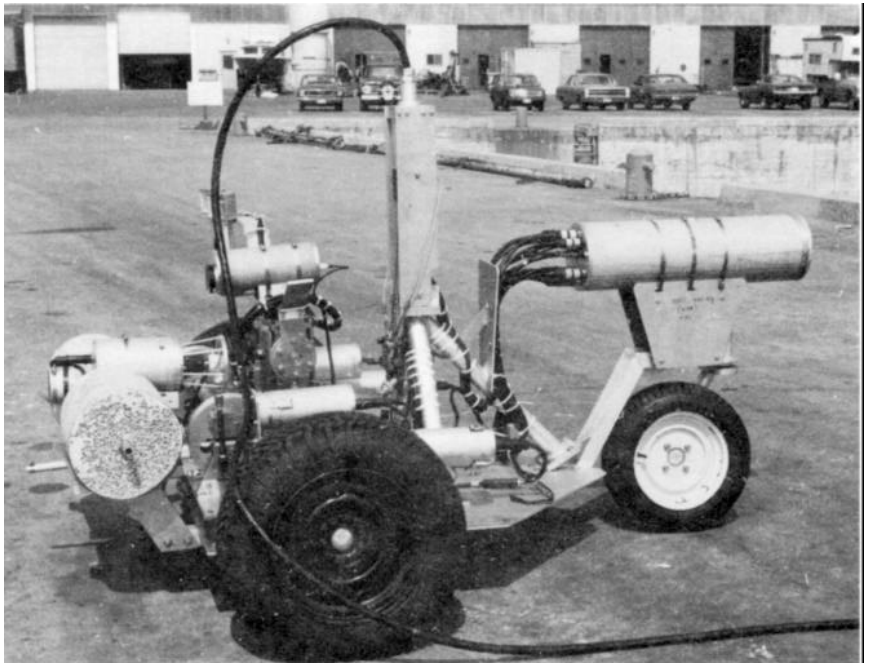
*K. R. George, D. L. McKeown, S. W. Young*

## Contract Management

The Division has been involved with the technical and administrative management of three major projects.

A new Air-Sea Interaction (see Ocean Circulation Division) stable tower has been designed, constructed, and deployed during the past 3 years. It is presently located off the entrance to Halifax Harbour and is fitted with air-sea interaction instruments. The work was carried out by a local consulting engineering company who succeeded in maintaining overall costs within 5 per cent during the contract period.

Hermes Electronics Ltd. of Dartmouth, N.S., have begun the development of the Canadian Ocean Data System (CODS) based on a program they put forward to the Department of Supply and Services as an unsolicited proposal. The scientific management is being conducted under the direction of a senior engineer of the Division. The ocean data system is based on the concept of acquiring meteorological and oceanographic data by a

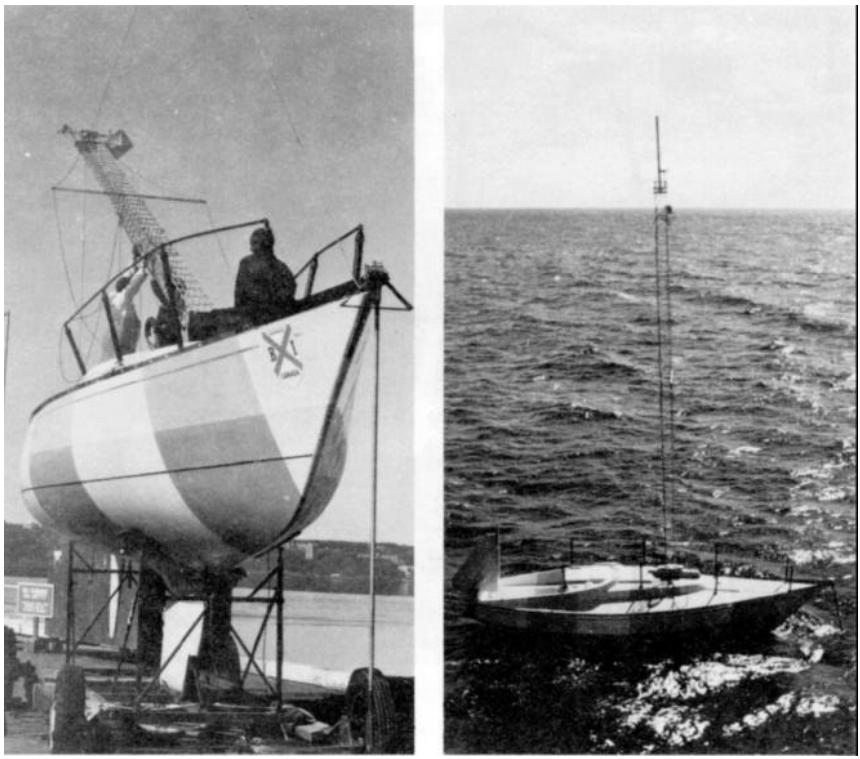


*Sea Rover: a bottm-crawling, remotely controlled vehicle. (AOL 3708)*

number of surface buoys and transmitting this information to shore stations by a radio link. The preliminary investigation includes not only the design of the buoys and associated sensors, telemetry, and data processing systems, but also the testing of prototype buoys and establishment of user needs. At present, a number of prototype buoys are moored near the Air-Sea Interaction stable tower. Their data, including buoy motion, are being assessed relative to those obtained from instrumentation on the tower. An immediate outcome of the program has been the development of a drifting buoy. Eighteen of these buoys will be deployed in the Southern Pacific Ocean in February of 1977 for preliminary evaluation

Late in 1974, the Division tested the high resolution deep tow seismic system developed by Huntec ('70) Ltd. As a consequence of these trials the Atlantic Geoscience Centre (AGC) commenced a co-operative effort with Huntec to develop techniques for remotely classifying seafloor sediments using the system. To this end, Huntec provided a research team stationed at the Institute to further develop the equipment and create the necessary signal processing techniques. A member of the Division is assisting AGC in the management of this program and engineering support has been provided to conduct towing trials and advise on system improvements.

*J. Brooke, D. L. McKeown*



*Yacht hull used as an oceanographic buoy in preparation and on site. (AOL 4070)*

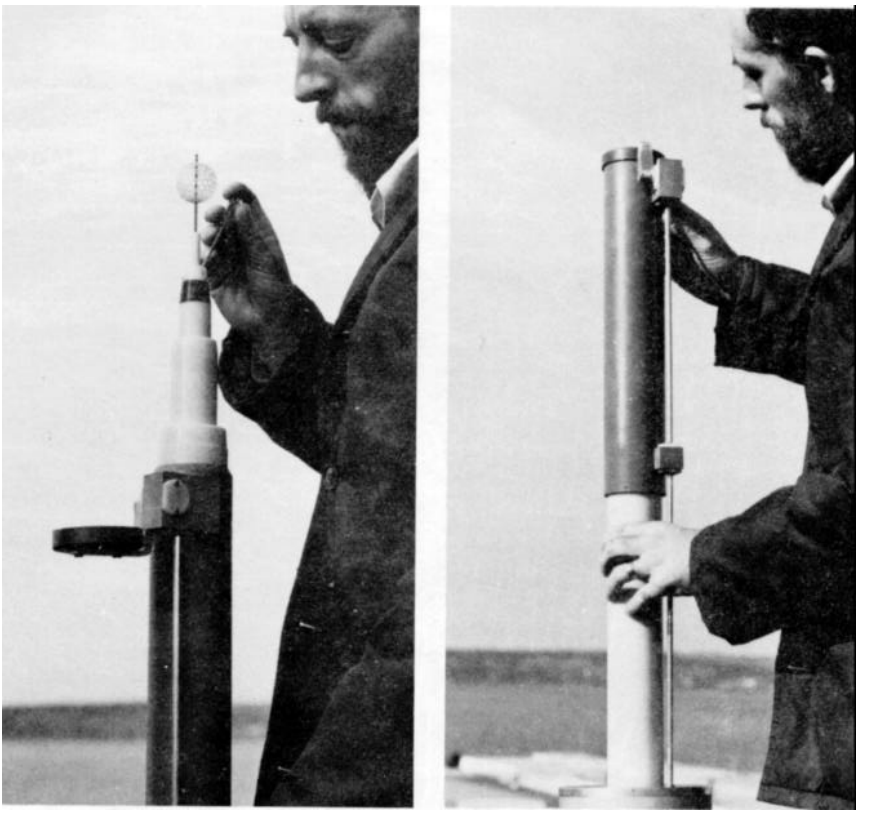
## Experimental Buoys

As a consequence of its involvement in the management of the Hermes Electronics Ltd. ocean data system contract, the Division has become interested in the design of surface buoys. In particular, it was decided that an investigation would be conducted into the performance of a standard production line yacht hull as an oceanographic buoy. While such a concept has been suggested in the past, the proposal has never been fully investigated. The major advantage of such a buoy is that a bare production hull with a deck bonded on is up to 30 per cent cheaper than other buoys, and is readily available. A hull has been purchased, equipped with meteorological and motion sensors, and moored near the CODS buoys and Air-Sea Interaction stable tower. The sensor suite includes typical yacht instrumentation. The objective is to determine whether or not realistic data can be obtained from such a buoyancy package and sensors.

*J. Brooke, J.-G. Dessureault, D. R. Harvey*

## Miscellaneous Support Programs

Our Standards Laboratory has continued to develop oceanographic standards and calibrate electronic, mechanical, and oceanographic instruments. The Instrument Machine Shop continues to devote about one-half of its



*The new thrust anemometer in its operating position (left) and in its protective cover (right). (AOL 4140)*

effort towards development of instruments and construction of prototype equipment for the entire Institute.

The Division has been active in providing interfaces between our HP-2100 minicomputer and a number of experimental systems at BIO. Fifteen general purpose acoustic pingers were purchased, tested, and calibrated, and are now available on general issue from Engineering Services (Institute Facilities). A general purpose data logger was developed and used in scientific experiments.

The Division has provided support to the National Institute of Oceanography (NIO), Goa, India through the Canadian International Development Agency by procuring oceanographic instruments and training NIO staff in their operation aboard Institute vessels and at Goa.

**Thrust Anemometer.** A new thrust anemometer has been developed for the Air-Sea Interaction group (see Ocean Circulation). It is easier to fabricate, disturbs the air flow less, has lower drift and greater sensitivity, and exhibits less cross-coupling error than the anemometer now being used.

*J.-G. Dessureault, D. F. Knox*

# Ocean Circulation

The main activities of the Ocean Circulation Division include: field studies of the large-scale patterns of oceanic properties such as momentum, heat, and salt, and their statistical variations; theoretical and numerical modelling of oceanic processes; theoretical, laboratory, and experimental studies of small-scale processes at the air-sea interface and in the upper ocean; and development of mooring technology and instruments capable of measuring small-scale processes.

In general our program is aimed at understanding the physical processes in the ocean's interior and at its upper interface with the atmosphere. While this still includes large-scale experimental programs aimed at describing the mean distribution of properties such as heat, salt, and momentum, more of the Division's resources have been utilized in experiments aimed at examining the details of time dependent processes. The latter have taken two basic forms. Firstly, we have started to maintain current meters with temperature sensors in one place for periods as long as a year and a half in order to examine the statistical properties of the oceanic 'eddy' fields and their influence on the mean flow. Secondly, the Division has carried out experiments, like the one in the Labrador Sea (described later), where the details of a particular process, in this case of deep convection and deep water formation, have been examined. To better interpret oceanic data, the Division has increased its efforts in the field of numerical modelling. With increased awareness of the complexity of the processes in the ocean interior, numerical models have become more important, not only for directly simulating what is known of an oceanic system, but as tools for examining the individual roles of various processes in model systems that, unlike the ocean, can be varied to allow one or another physical mechanism to be dominant.

During the past year the Air-Sea Interaction group has joined the Division. Together with our previous work on microstructure, the Division's efforts on understanding and parameterizing small-scale processes will be increased. Only from programs of this type will oceanographers obtain the information required to describe the sources and sinks of energy, momentum, etc., which are necessary for a large-scale description of the ocean.

Co-operation continues with other institutions, nations, and international organizations. French scientists participated in the Labrador Sea project, scientists from the Woods Hole Oceanographic Institute and the joint USA-USSR POLYMODE experiment co-operated in the deep sea mooring program, and our Air-Sea Interaction group participated in the Joint Air-Sea Interaction Experiments (JASIN). Such co-operation continues to emphasize the international aspect of oceanography and the need of oceanographers to exchange ideas and results in international as well as national forums.

*G. T. Needler*

## Labrador Sea

The Labrador Sea is of prime interest to Canadian oceanographers not only because of its importance as a producer of deep water masses but

also because of its influence through the Labrador Current on the oceanography of the continental shelves to the south. From data obtained by BIO and other institutions, the Labrador Sea is believed to have a weak interior cyclonic circulation bounded by stronger boundary currents at the continental slopes. The central Sea is very weakly stratified due to the doming of the isopycnals in the centre in response to the weak cyclonic circulation. It has been argued that through the action of small cyclonic eddies (possibly wind generated) this weak stratification can be broken down and the deep waters of the Labrador Sea water formed to depths of 1500 metres by the action of surface cooling. Examination of the hydrographic stations occupied from year to year at Ocean Weather Station Bravo indicates that Labrador Sea Water was created in large quantities by deep convection over much of the basin during a few years like 1967 and that in other years only small quantities were produced in very small short-lived events. The records suggest that the temperature of the deep water below seasonal influence rises slowly over several years, decreases rapidly during particular winter seasons such as 1967, and then starts a new slow rise.

From February to April 1976, physical and chemical oceanographers from BIO, Dalhousie University, Halifax, and the Musée Nationale d'Histoire Naturelle, Paris, conducted an investigation of some of the dynamical processes taking place in the Labrador Sea toward the end of the winter cooling season. The experiment was designed to investigate deep convection events, if such events could be found, and also to investigate the structure of the offshore branch of the Labrador Current. Due to heavier than normal ice conditions, it was only possible to place three current meter moorings on the Labrador Continental Slope in the offshore branch of the current and unfortunately one of these lost its subsurface buoyancy during the mooring operation and did not return useful data. Preliminary analysis of the mooring data does however provide some measure of the current velocities at the edge of the Labrador Current and of its low frequency variations.

During the March 1976 experiment, the western side of the Labrador Sea had very little stratification; the CTD (Conductivity-Temperature-Depth) stations 100 kilometres offshore from the ice edge showed only an adiabatic temperature gradient to 1500 or 1600 metres. Toward the centre of the sea the water was almost neutrally stable although there appeared to be some interleaving of waters with slightly different T-S (temperature-salinity) properties throughout the water column. At a later date the water column was found to be neutrally stable to depths greater than 2000 metres, the depth limit of the CTD. Neutrally buoyant floats with vanes that respond to vertical currents were set at depths of 200 to 600 metres in the neutrally stable water and the Batfish was used to obtain the temperature and salinity fields in the upper 200 metres. The data suggest that the floats moved parallel to a boundary between an extremely homogeneous rotating water column of 10-20 kilometres horizontal extent and a slightly warmer less mixed water mass. The vertical velocities in the boundary region are as high as 3 centimetres per second and oscillate between being directed upwards and downwards; it is conjectured that these strong periodic vertical velocities kept the column well mixed. The extent of the column of deep homogeneous water was greater than observed previously.

*R. A. Clarke, J. R. N. Lazier*

*Preparing to launch a neutraii buoyant float (AOL 3946)*

## The Deep Gulf Stream

During the past few years, the Division has maintained several moorings for short periods in the deep water near or underneath the Gulf Stream. Although some of the moorings were used strictly for the development of better mooring systems, many were for the purpose of determining the strength and direction of the deep flow, it being assumed that the Gulf Stream retained its nature as a coherent current to the bottom and that one could use deep current measurements and knowledge of the density field to calculate the transport of the Stream itself. However, the unsteady nature of the deep currents both in direction and strength is now well known and the study of transient oceanic motions, often referred to as 'eddies', has become of great interest to oceanographers from many nations. There is now strong evidence that in most of the deep oceans the eddies are as important in transporting heat, momentum, vorticity, etc., as are the weak mean currents themselves.

In the spring of 1975, the Woods Hole Oceanographic Institution as part of the joint US-USSR POLYMODE experiment laid an array of moorings along 55°W as far north as the northern side of the Gulf Stream. Taking advantage of the meridional coverage given by this array, we laid three deep moorings 20, 50, and 90 kilometres west of one of the Woods Hole moorings and more or less under the historical axis of the Gulf Stream in December 1975. The moorings each have current meters at about 4000 metres and 4800 metres depth and these will be reset twice to give a total record length of about 18 months. The analysis of the data should give considerable information about the transient flow under the Gulf Stream including, it is hoped, stable estimates of many statistical quantities including the mean flow. The average deep flow for the first 8 months of data was to the northwest instead of to the east like the surface Gulf Stream.

*G. T. Needler, R. F. Reiniger, R. M. Hendry*

## Denmark Strait Overflow

The Greenland-Scotland Ridge inhibits the free flow of cold dense water from the Norwegian Sea into the deep basins of the North Atlantic. Some Norwegian Sea water 'overflows' in a near-bottom layer at several locations along the ridge to become a major component of the deep and bottom water in the North Atlantic.

For a month in August-September 1973, the Division investigated the region between Greenland and Iceland as part of the Overflow '73 Expedition sponsored by the International Council for the Exploration of the Sea. Part of this investigation included the placement of 11 current meters in a plane cutting the overflow just south of the sill. From these instruments a time series of the transport of overflow water (temperature < 2°) has been computed. It shows that the overflow varied between 1-7 x $10^6$ cubic metres per second with a mean of 2.5 x $10^8$ cubic metres per second and that it was characterized by bursts of large transport occurring at intervals of several days and lasting for periods of about a day.

Since there is always cold dense water north of the sill at depths much shallower than sill depth, the question arises: why is there such great variability in the flow south of the sill? A likely mechanism lies in the time dependent forcing of the overflow by variations in the atmosphere, although previous attempts to verify this mechanism have been unsuccessful. In our case, although the atmospheric pressure gradients across the Strait and along the Strait were dominated by fluctuations with a period close to the total length of observation, the high frequency part of the record of pressure difference between the atmospheric pressure north and south of the sill shows considerable correlation to the variable transport. Although the response of the current to the pressure difference is in the direction necessary if a flow of water through the Strait is to compensate for changes in sea level due to the direct adjustment of the sea surface to the atmospheric pressure difference, the physical significance of this correlation is not at present understood because it is difficult to understand why the adjustment would be by the flow of water through the constriction of Denmark Strait rather than through other, totally open, areas.

*C. K. Ross*

## Numerical Modelling of Oceanic Systems

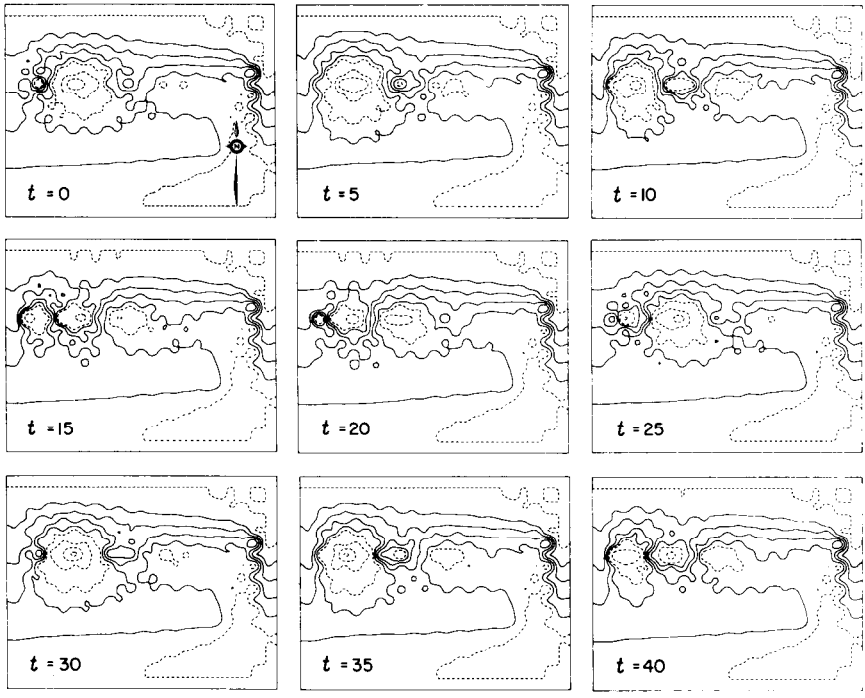
The importance of numerical modelling of oceanic processes in the advance of physical oceanography cannot be overemphasized. The oceans are large, complex systems and data gathering in such systems is expensive and often only sparsely done. Theoretical work based on classical analysis has in the past provided an understanding of the linear dynamics of model oceans, but classical analysis is hopelessly inadequate in the face of non-linear processes, irregular boundaries, and complicated time-dependent forcing and interactions, all of which are important components of the real oceanic circulation. Numerical modelling has extended classical analysis because in principle it can cope with all the difficulties mentioned, but in practice it also has limitations. Among these are the speed and storage capacity of the computers, since time-dependent computations of the large-scale stratified ocean circulation must be detailed enough to resolve the 'eddy' structure of the oceans, and this can require many hours of computation

on large computers. Thus much of the numerical modelling of the ocean has been done by groups associated with laboratories with large and fast computers for numerical weather prediction. The recent initiation of such a program in AOL has followed the installation of a CDC 7600 computer by the Atmospheric Environment Service (AES) in its weather prediction centre at Dorval, Quebec, in 1974. This system became fully operational in 1975.

At AOL, oceanic modelling has been started using a model obtained from scientists at the University of California, Los Angeles, which is similar to the primitive equation model developed for the ocean at the Princeton Geophysical Fluid Dynamics Laboratory, although we have to extensively modify the original computer coding. With the addition of a new staff member in late 1975 progress has been made in studying the boundary and topographically induced large-scale circulation in a semi-enclosed ocean. The accompanying diagrams show an example of the transport stream function during one complete cycle of an oscillation induced on a zonal current by steps in the bottom topography.

All our present developments are aimed at perfecting a realistic stratified model for the Labrador Sea; the objective is to develop a model for use in conjunction with the observational program (described earlier) for the Labrador Sea. The future understanding of the physics of the oceans interior depends greatly on the success of such co-operative efforts between observational programs and numerical modelling.

*C. Quon, K. T. Tee*




*Mass transport of a topographically induced oscillating flow. The period of oscillation is 27.4 time steps. (AOL 4172)*

## Shelf Dynamics

To properly plan the use of the coastal areas for recreation, food, mineral exploration, and transportation requires an understanding of the circulation and exchange processes on the continental shelf and a determination of the relative importance of the various forces in causing the oceanic variability on the shelf. In co-operation with the Coastal Oceanography Division, the Scotian Shelf is being examined to determine the importance of the sources of variability, such as transient wind effects, exchange with the offshore waters, tidal phenomena, and river run-off in the framework of the irregular bathymetry and coastline. The space and time scales of all these sources vary greatly, and cause very complex responses on the shelf.

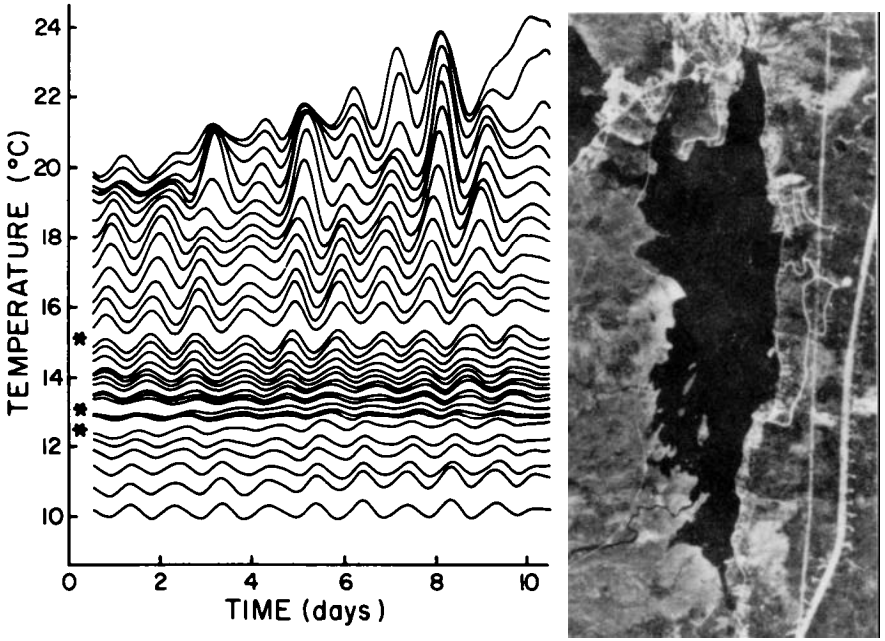
Existing data sets such as coastal tide-gauge and meteorological records have been searched for coherent fluctuations. Along the Nova Scotia coast sea-level changes at synoptic time scales are highly correlated with variations in the long-shore wind component and there are systematic seasonal differences in response to a given wind stress. This local response pattern is in contrast to findings in other shelf areas where the non-local resonant influence on propagating shelf waves accounts for much of the variability. The predominance of the locally forced response on the Scotian Shelf is an indication of the difference in the time scales of free shelf waves and the meteorological forcing and further implies that friction associated with water movements is of importance at synoptic time scales. A theoretical model for this region is being developed.

*H. Sandstrom*

## Structure in Lakes

Measurements of the migrating structure in the thermocline of Lake William, Nova Scotia, were continued in the summer of 1975 using a vertical array of 44 temperature sensors. Some of the temperature records for the first 10 days of observation are shown in the figure. The vertical spacing between these records is 20 centimetres, except where an asterisk indicates sensor malfunction and except for the bottom four sensors, which are further apart. The curves have been smoothed in order to exclude the short period temperature changes and to emphasize the strong daily oscillations evident in all the records. The interesting feature in the diagram is that the daily oscillation is not in phase through the water column; there is a change of nearly 360° that is continuous with depth. This change of phase through the thermocline causes the vertical temperature gradient to be alternately higher then lower than the average gradient. Because the phase change in the oscillation is a smooth function of depth, the anomalous gradients or structure appear to move upward through the water column with time.

A theoretical analysis of the wind forced internal oscillations of a long narrow viscous stratified lake, similar to Lake William, predicts temperature oscillations very similar to those illustrated in the figure. The theory indicates that the total phase change across the thermocline depends directly on the ratio of depth to length of the lake and on the degree of stratification, that is, the change of temperature from the top to the bottom. The phase change also depends inversely on the frequency of the wind that is forcing the motion in the interior of the lake. Thus the phase changes observed in the temperature records in Lake Williams are a result of the shape of the lake,




*Ten days of temperature records from Lake William. NS. (AOL 3188)*

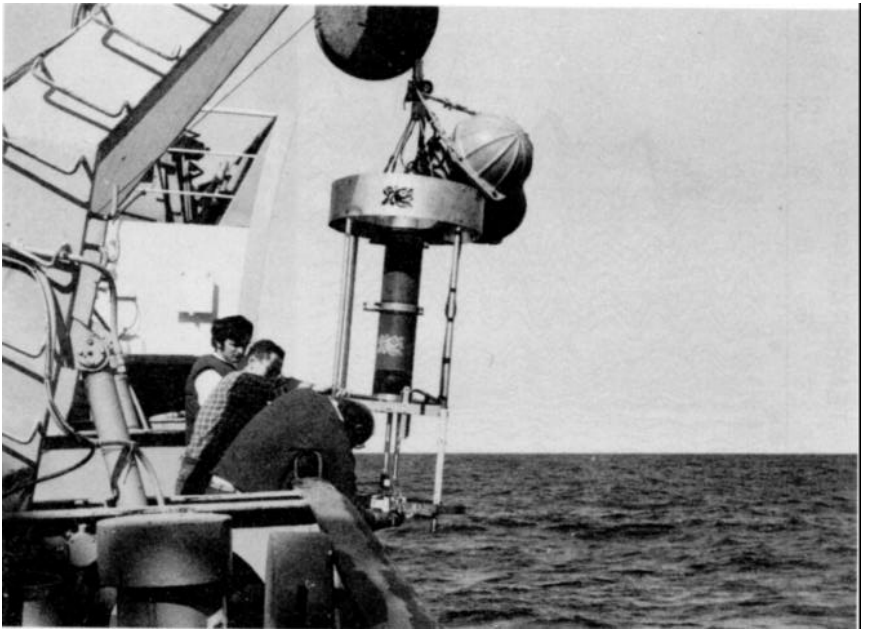
the strength of the stratification, and the strong daily variation in the wind. The theory also shows that the phase of the oscillation varies smoothly with depth because of the viscosity in the water. If viscosity is not included the phase change occurs in infinitesimally thin layers and the anomalous vertical temperature gradients do not appear to move through the water column with time.

It is hoped that in the future the conclusions of the lake study may be used to gain further understanding of the formation and nature of some of the vertical structure observed in the ocean. Such a hope is encouraged by recent measurements off the California coast where observations have been made of vertical temperature structure with behaviour similar to that observed in Lake William.

*J. R. N. Lazier*

### Microstructure Studies

Throughout the oceans there are numerous bands or layers of complex structure, often composed of vertical gradient steps no larger than a centimetre. The small-scale structures are an important part of the mixing and dissipation process in the oceans. The Division has continued its experimental study of these structures using a vertical profiler called OCTUPROBE. During the fall of 1975, a cruise following a track similar to that of past years was made to the Gull Stream region, and a new version of the temperature measuring system was evaluated. The data obtained have sufficiently good signal-to-noise ratio that it has been possible to compute the shape of the temperature spectrum in detail to scales of less than a centimetre.



*OCTUPROBE (OCeanic TUrbulence PROBE) 1. (AOL 3819)*

The spectra from data covering a wide variety of conditions have a fairly constant shape and agree well with the shape predicted for sharp temperature steps that have been smoothed by thermal diffusion.

The temperature data collected during the 1974 GATE (see 1973/74 Biennial Review) experiment in the tropical Atlantic are presently being analyzed to provide input to a mathematical model that will provide an estimate of the vertical heat flux through the surface thermocline in the GATE study area. The variety of data collected in this experiment will allow comparison of flux estimates obtained by several techniques.

Part of the Division's program has been to investigate various generating sources of small-scale structure. During both the 1974 GATE cruise and the 1975 Gulf Stream cruise, data were collected using an array of thermometers with probe spacings from 1 centimetre to 1 metre. These data are being analyzed to construct a three-dimensional picture of the structure. During another cruise in the fall of 1976 to a site near Emerald Basin (Scotian Shelf), we collected data to monitor the 'life cycle' of small-scale structures, along with various parameters that may be responsible for their generation including the small-scale vertical shear of the water velocity.

*J. A. Elliott, N. S. Oakey*

## Wind Stress Measurements

Air-Sea interaction processes are important in the generation of wind-driven currents and the formation of air and water masses. Both the wind

stress and heat flux at the sea surface have been computed by scientists in the Division and elsewhere from records of turbulent fluctuations in the wind and the temperature at a fixed point a few metres above the surface. The turbulent fluxes are most active during storms, however, and direct measurements are not yet available for such conditions due to the difficulty of operating delicate sensors near large waves. In order to make such measurements, a suitable platform is required. Ships are generally not usable because the presence of the ship deflects the wind flow and so alters the processes to be measured, and also because it is difficult to remove the effects of ship motion from the measurements. Oil drilling rigs are more stable but places suitably free from flow interference are too far removed from the surface for useful measurements. To overcome these problems a stable tower designed to withstand waves up to 18 metres high was constructed and, in July 1976, moored in 58 metres of water near the approaches to Halifax Harbour, where the full fetch of the North Atlantic is available for southerly or easterly winds. The tower can support instruments for measurements of wind drag and heat exchange at the sea surface, and of wave height. The tower is a steel structure 47 metres long, with 6 large floatation tanks occupying the lower half of this length. The upper part extends 12.3 metres above the mean water level. It is secured by 12 diagonal anchor lines and one vertical line, which are held in tension by the excess buoyancy of the structure.

The surface wind drag and heat exchange are measured by a BIO thrust anemometer and micro-thermistor mounted on top of the tower. An accelerometer measures tower motion, strain gauges measure tension in the six upper support cables, and a 12 metre resistance-wire wave staff measures sea state. The data are telemetered to the BIO building in a multiplexed, frequency-modulated form and equipment on the tower can be controlled by radio from BIO. Power is obtained from automobile batteries charged by a 24 watt windmill generator. The stable tower experiment is planned to run for 2 years, starting in the fall of 1976.

In addition to the BIO equipment a similar system is being operated on the tower by members of the Institute of Oceanography, University of British Columbia. This system has a propeller and vane anemometer, along with temperature and humidity sensors, to measure wind stress, heat flux, and evaporation. It also includes digital tape recorders and transmits data through the BIO telemetry system. The UBC part of the experiment will run from September 1976 until May 1977.

A weather telemetry package was operated on the stable tower by the Atmospheric Environment Service, Toronto, during the Canadian Ocean Data Buoy trial period, September and October 1976. This system operated independently of the other turbulence-measuring systems.

We also participated in the Arctic Ice Dynamics Joint Experiment (AIDJEX) in the Beaufort Sea and measured wind drag on pack ice and on ice ridges in the springs of 1975 and 1976. An intercomparison of the BIO and UBC systems for eddy flux measurements was carried out at Sable Island in the fall of 1975. In the summer of 1976 preliminary measurements of $CO_2$ flux at Sable Island were made in co-operation with the Chemical Oceanography Division. A study was completed of wind profiles and turbulence over Bedford Basin.

*S. D. Smith, F. W. Dobson, E. G. Banke, R. J. Anderson, D. L. Hendsbee, A. H. Meshal*

*The stable tower moored near the approaches to Halifax Harbour. (AOL 4092)*

## Wave Growth

Experimental research on wave generation has continued but has been confined over the past 2 years to data analysis, further calibrations, and the planning of future experiments. The results are being digested from two major field experiments: the Joint North Sea Waves Project (JONSWAP), held in 1973 in Germany, and the Bight of Abaco experiment, held in the Bahamas in 1974. In both experiments, the BIO wave follower, a hydraulically powered servo-device designed to keep air flow sensors at a fixed height above the moving sea surface, was deployed at sites suitable for observing a growing wind-wave field. (See also the *essay "Ocean Waves" by F. W. Dobson in Ocean Science Reviews, Part E of this Biennial Review).*

Three month-long joint data analysis workshops have been held - one on the JONSWAP data and two on the Bight of Abaco data. The principal result of the JONSWAP experiment is somewhat negative: it was shown that contamination from waves not generated locally prevented the estimation of wave growth rates and wave-induced air drag. The Bight of Abaco experiment has yielded, after careful elimination of instrumental problems, the most complete set of information collected to date on the horizontal and vertical structure of the air pressure fluctuations above growing wind waves. The analysis is now in its final stages and the results are highly encouraging.

*F. W. Dobson, J. A. Elliott, E. G. Banke*

B

# Marine Ecology Laboratory (MEL)
# Ocean and Aquatic Sciences, Atlantic
# Department of the Environment
# 1975/76

Acting Director - T. C. Platt

- Biological Oceanography Program
- Environmental Quality Program
- Equipment Development Program
- Fisheries Oceanography Program
- Administration

# Director's Remarks

The period under review has been one of considerable change and some uncertainty for the Marine Ecology Laboratory (MEL). In the absence of a permanent director, three scientists took their turn in an acting capacity.

Major re-organization of the Fisheries and Marine Service has brought about a change in our reporting lines and in our relationship to other regional laboratories. Unlike the other laboratories of the old Fisheries Research Board system, the Marine Ecology Laboratory is now a part of Ocean and Aquatic Sciences, Atlantic, and therefore closely allied with the Atlantic Oceanographic Laboratory. This will undoubtedly have a beneficial effect on our future research. At the same time, we have no intention of losing our strong ties with the other former FRB laboratories in the region, which are now part of Fisheries Management.

As a result of the new organizational structure, several programs and responsibilities were transferred from MEL to Fisheries Management. These include the management and financial control of a major project for stock assessment on the continental shelf using the acoustic fish counter developed by MEL; the shellfish aquaculture program of Mr. R. Drinnan: and the operation of the substation at Ellerslie. P.E.I.

During the review period there have been several staff changes. Dr. B. S. Muir transferred to Fisheries Management in Halifax to become Director of the Resources Branch; Dr. E. M. Hassan left to join the Ministry of State for Science and Technology in Ottawa; Dr. A. D. Jassby took a position at the Lawrence Radiation Laboratory, Berkeley; and Dr. S. J. Crabtree resigned to enter medical school. We were pleased to welcome back Dr. S. R. Kerr who spent the past 4 years working with the Ministry of Natural Resources in Ontario.

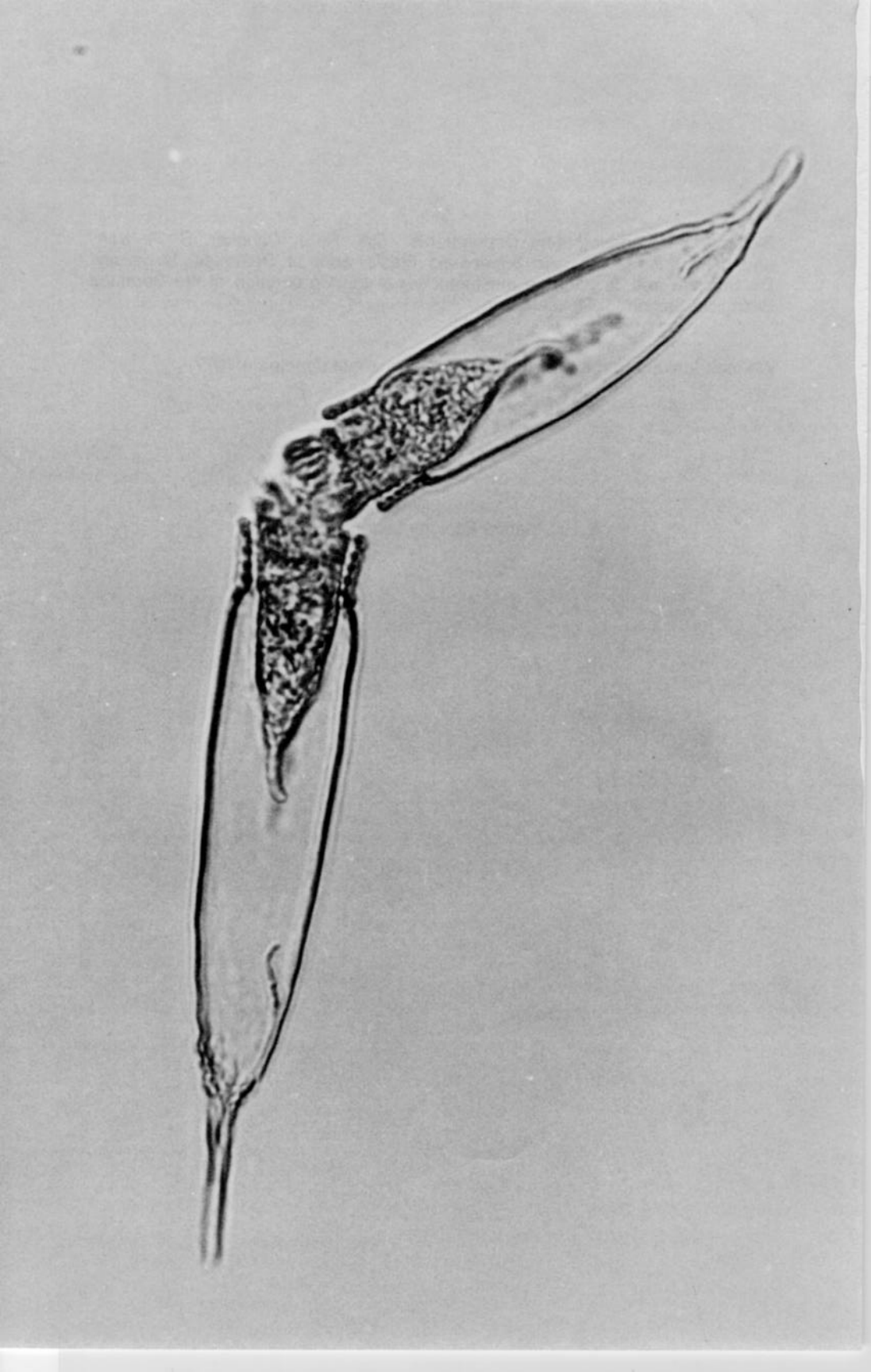
Construction of the new MEL wing is proceeding more or less on schedule and we look forward to taking occupation early in 1977. For the first time in many years, the Laboratory will be housed under one roof. We are also working on plans to renovate our fish holding laboratory and improve our seawater system.

Research scientists at the Marine Ecology Laboratory continue to be affiliated in various ways with outside organizations. Dr. K. L. Denman was an honorary lecturer in oceanography at Dalhousie University, Halifax: Dr. T. C. Platt taught a course there in "Interpretation of Oceanographic Data"; Drs. B. T. Hargrave, D. C. Gordon, Jr., T. C. Platt, and D. M. Ware were Research Associates at Dalhousie University and supervised graduate students of the

Biology and Oceanography Departments. Drs. R. J. Conover, S. R. Kerr, and J. Vandermeulen also supervised thesis work at Dalhousie University. Dr. Sutcliffe and Dr. Gordon are members of the Corporation of the Bermuda Biological Station for Research.

We look forward to the appointment of a permanent director in 1977.

*T. C. Platt*
Acting Director
Marine Ecology Laboratory



# Biological Oceanography

The Biological Oceanography group investigates the mechanisms operating within the planktonic ecosystem. Ultimately, we hope our studies will enable us to predict, initially in the plankton community and later in the commercial fisheries themselves, changes in biological production both from year to year and from locality to locality. In the following paragraphs our research activities during 1975 and 1976 are highlighted.

## Ecology and Physiology of Phytoplankton, Zooplankton, and Fish

**The Dependence of Photosynthesis on Light for Natural Assemblages of Coastal Phytoplankton.** As part of our general objective to refine the capability for marine biological prediction, considerable effort was directed to a reassessment of the relationship between the rate of photosynthesis and the amount of available light for phytoplankton growth. A critical review of the options for mathematical representation of this fundamental relationship was prepared and the available equations were rewritten into a form (requiring two parameters) that permits a direct comparison of their ability to describe experimental data. Nearly 200 experiments were conducted in laboratory incubators using natural coastal phytoplankton assemblages; these formed an ideal data set for comparison of the equations. After the most suitable equation was chosen, its parameters were fitted for each experiment and examined for variations with depth and season and in response to environmental covariates such as temperature and sunlight. Considerable seasonal variation was observed. On the average, the efficiency of the plankton at using the available light was only about 50 per cent of the theoretical physiological maximum rate. The stability of the parameters was also examined on time scales of hours and days. The assimilation of $CO_2$ in the dark was studied for the Bedford Basin (Nova Scotia). It varied from 20 per cent (summer) to 200 per cent (winter) of the assimilation in the light. Annual fixation in the dark was estimated to be 50 grams of carbon per square metre or about 25 per cent of the estimated annual photosynthetic production.

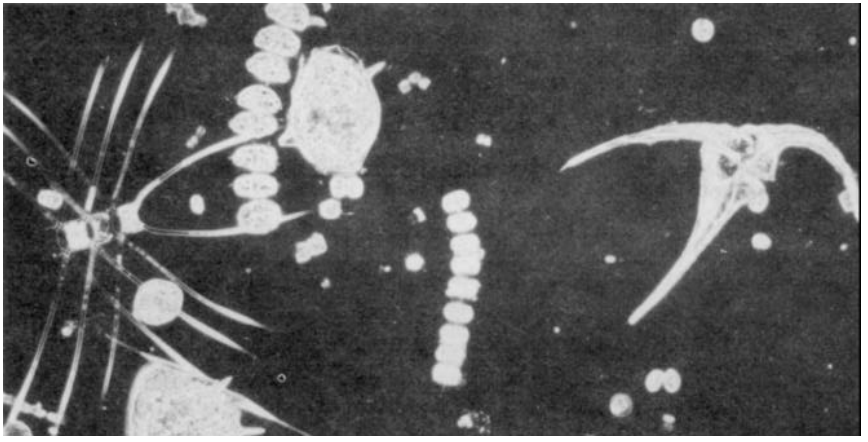
*T. C. Platt, A. D. Jassby*

**Theory of the Pelagic Food Chain.** A steady-state theory has been developed for the structure of the pelagic ecosystem, specifically for the distribution of organisms by size in the pelagic zone of the open ocean. It is based on accepted relationships for the weight-dependence of metabolism and growth. The theory explores the flow of biomass from the smallest to the largest organisms through a series of size-classes arranged on an octave scale. This formalism leads to simple analytic expressions for the structure of the pelagic ecosystems that are testable by direct measurement. The main conclusion, that biomass in a given size-class decreases in a regular manner with increasing size, is in substantial agreement with data collected in the subtropical oceans by colleagues in this laboratory.

*T. C. Platt, K. L. Denman*

**Size Fractionation of Phytoplankton Production.** Phytoplankton algae range in form and size from the unicellular flagellates (3 micrometres) to

the filamentous diatoms (less than 1000 micrometres). Studies in diverse marine environments using a variety of techniques lead to the general conclusion that the nannoplankton (less than 65 micrometres) often contribute more than 70 per cent of both biomass and production of phytoplankton and are subject to substantially less temporal variations than those of the bigger size classes.



*Marine phytoplankton*

Qualitative and quantitative enumeration of phytoplankton samples collected during the past few years from the coastal waters of Nova Scotia and of the Bay of Fundy have demonstrated the importance of nannoplankters. Live samples have been fractionated physically and the various size fractions examined for: variations in their biomass and photosynthetic carbon assimilation rates; the qualitative and quantitative abundance of the major groups of phytoplankton, i.e., phytoflagellates, diatoms, and dinoflagellates; and their relative photosynthesis when treated with germanium dioxide, an inhibitor of photosynthetic activity of diatoms.

*S. R V Durvasula. T C Platt*

**Some Relations Between Zooplankton and Food Supply.** Seasonal studies in Bedford Basin (Nova Scotia) suggest that ammonia excretion by zooplankton is closely correlated with the amount and chemical composition of the particulate matter that serves as its food supply. Carbohydrate had a minimal effect on zooplankton protein but protein in the food supply increased nitrogen excretion by the animals. Respiration of zooplankton was largely unaffected by potential food supply, but directly correlated with temperature and size of the animals. Predictive multiple regression equations account for up to 95 per cent of the variance in the case of zooplankton excretion, but are less reliable for zooplankton respiration.

The distribution of digestive enzymes in the zooplankton was also closely correlated with the chemical composition of the available particulate matter. Moreover, zooplankton feeding performance may also be related to the

abundance of enzymes. In nature, zooplankton probably acclimate to an increase in their food supply by inducing the necessary enzymes and by making other behavioural adjustments, which we still do not understand completely. Hence, they can make optimal use of the available food resources no matter how concentrated these are, and their feeding response does not saturate' as has been suggested by many laboratory studies. However, zooplankton do not seem to favour certain food particles and they probably will reject these no matter how long they are exposed to them, at least when another food source is available.

*R. J. Conover. P. M.* Mayzaud

**Tower Tank Experiments.** Two attempts were made to establish populations of larger zooplankton animals in the Dalhousie University Aquatron. The pteropod *Spiratella retroversa* survived there for at least 3 weeks dur-

*An underwater photograph of* Spiratella retroversa *about 7 millimetre in diameter.*

ing which time we investigated its swimming and feeding patterns. The animals tended to remain in the upper 4 metres of water by swimming less than 25 percent of the time even though they carry a shell weighing at least as much as their living tissue. The rest of the time they sank slowly, about 15 centimetres per minute, and fed, probably using ciliated tracts on wings, foot lobes, and mantle. Although we do not yet fully understand how the animals regulate their buoyancy, we have observed that they always hold their wings in a characteristic position when feeding.

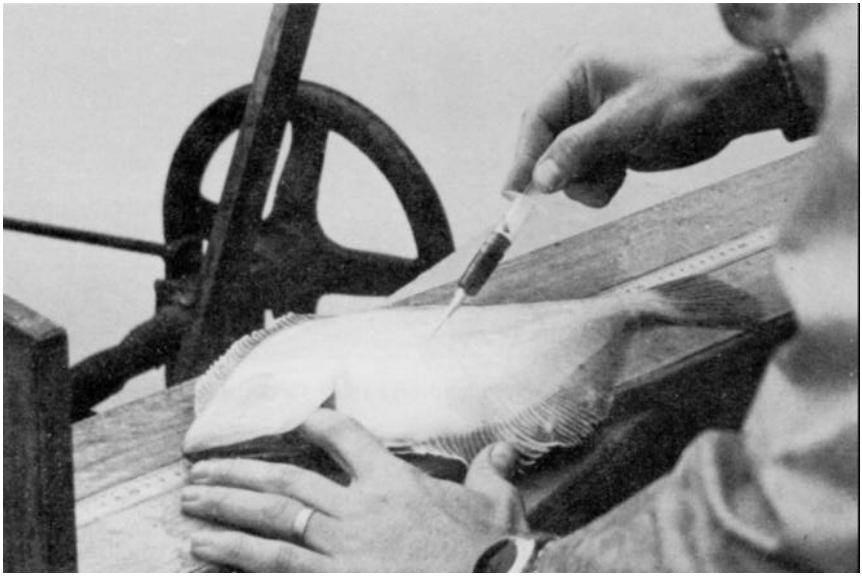
For over 3 months the arrow worm *Sagitta elegans* was also maintained in the same system, along with a population of neritic (coastal) copepods on

which we presume it was feeding. These extremely delicate animals almost always oriented themselves vertically, head up or down. We saw no regular pattern of migration or period of feeding. The majority of the animals remained in the deeper part of the tank at all times. The population was reproducing and apparently healthy when the experiment was accidently terminated.

*R J Conover. M A Paranjape*

**Physiological Adaptation in Phytoplankton and Fish.** The objective of this study is to learn how various physical and biological environmental parameters (e.g., light intensity and wavelength, total solar radiation, temperature, salinity, and food supply) interact on different time scales to affect the uptake, utilization, and distribution of energy in these organisms. Current interest is focused on acclimation of the levels of key enzymes regulating the rate of $CO_2$ fixation and the subsequent distribution of fixed carbon within the organism during photosynthesis, and on enzymatic aspects of the control of glucose utilization and production by the liver. The information gained from these studies should permit identification of indicators of the levels of various physiological processes in the field.

*J C Smith*



A *blood sample being taken from an Amencan plaice (AOL 4174)*

**Hematological Studies of Fish.** Relationships between several blood parameters, body weight, sex, feeding levels, and a number of physical environmental variables have been observed in the American plaice. Analytical

models of the fish cardiovascular system have been developed from these observations. From these it is possible to predict that blood viscosity and hemoglobin oxygen affinity are functions of body weight in this species. These hypotheses are currently being tested.

*J. C. Smith*

## Variability in the Plankton and their Environment

**Spatial Variability of Phytoplankton Populations.** Marine organisms, whether they be phytoplankton or whales, are seldom distributed uniformly through the ocean. Rather they tend to be in layers, clumps, patches, or long ribbon-like bands. These regions of higher concentration are ecologically advantageous: they make feeding by higher level organisms more efficient and thereby allow the oceans to support a greater amount of life than if all organisms were evenly distributed. Because of this very important influence on the productive capacity of an ecosystem, the Marine Ecology Laboratory has been carrying out extensive theoretical and experimental studies on the spatial variability of phytoplankton. The spatial heterogeneity of phytoplankton distributions is the topic of an essay in this volume so the following will be restricted to studies undertaken in the last two years not covered in that essay. Because phytoplankton have little or no capability for directed movement, motions within their environment (current, turbulent eddies, internal waves, etc.) are important in determining their distribution in time and space. Thus, in many of these investigations the Marine Ecology Laboratory is assisted by physical oceanographers from the Atlantic Oceanographic Laboratory.

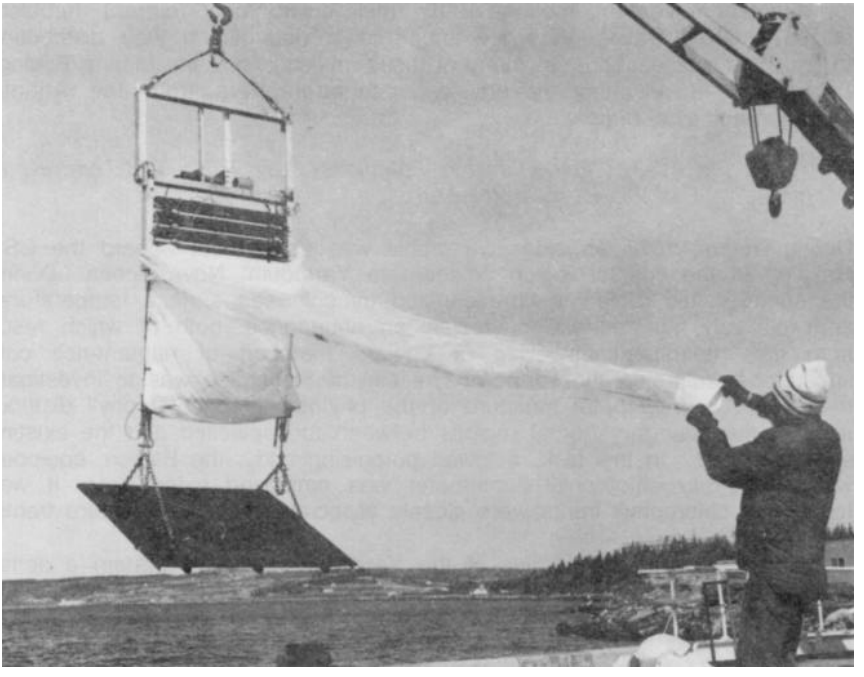
*(See also the essay "Phytoplankton Patchiness" by T. C. Platt and K. L. Denman, Part E of this Biennial Review.)*

During August 1975 an extensive cruise was carried out aboard the CSS *Maxwell* in the coastal region adjacent to Yarmouth, Nova Scotia. During the summer this region is characterized by cold sea surface temperatures and relatively high surface phytoplankton abundance, both of which result from the intermittent upwelling or upward transport of nutrient-rich cold subsurface waters to the surface. The aim of the cruise was to investigate the spatial and temporal structure of the phytoplankton chlorophyll distributions in the boundary frontal regions between the upwelled and the existing surface waters. In this task, a towed porpoising body, the Batfish, equipped with an *in situ* chlorophyll fluorometer was employed extensively. It was found that chlorophyll fronts were closely associated with temperature fronts.

In conjunction with the studies of the Yarmouth upwelling system a series of day and night missions for the air-borne remote sensing of surface chlorophyll were carried out. Two ships (CSS *Maxwell* and MV *Harengus)* provided 'ground truthing' for a Canada Centre for Remote Sensing (CCRS) DC 3 aircraft carrying several instruments capable of remote sea surface chlorophyll measurements. Instrumentation included a filter photometer, a silicon diode spectrometer, a laser fluorometer, an infra-red line scanner, a low light level TV, and an inertial navigation system. Participants from BIO, Ocean and Aquatic Sciences (Pacific Region), Canada Centre for Inland Waters, York University (Toronto), and CCRS were involved in the planning and management of the experiment. About 800 line kilometres were flown over the test area southwest of Yarmouth; this area contained

low and medium concentrations of chlorophyll (1-5 miligrams per cubic metre). Preliminary results showed that all sensors operating in the visible range correlated well with 'ground truth' measurements. Detailed results including sensor intercomparison will be available soon.

A study of the primary production system at the edge of the Nova Scotian continental shelf south of Halifax is being carried out in conjunction with the shelf break dynamics program (Coastal Oceanography, AOL). In July 1976 a cruise aboard the CSS *Hudson* was carried out jointly with Coastal Oceanography and Metrology. During this period extensive nutrient sections both perpendicular and parallel to the shelf edge were obtained. They showed the slope water, rich in nutrients, intruding up onto the shelf. Batfish surveys showed high phytoplankton chlorophyll only on the shelf and about 10 kilometres out from the shelf edge in a narrow band associated with a zone of presumed mixing that was implied from interleaving in the vertical temperature structure. Numerous experiments on available light versus the rate of photosynthesis were also carried out in an attempt to delineate differences in the growth rate of the phytoplankton that live in the various physical/chemical environments.



*The multple net trawl (AOL 3922)*

To put the results of these various field experiments into the framework of prediction of the biological production in the sea, we have developed two theories for the existence of horizontal patchiness in phytoplankton popula-

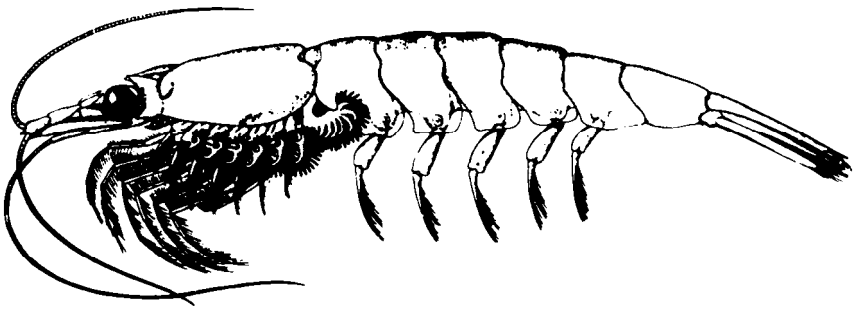
tions. In these theories the growth of the phytoplankton and the horizontal dispersion of the phytoplankton by varying ocean currents interact in such a way that the development and persistence of patches in a certain range of sizes is preferred. From our field observations and those of other investigators, patches of roughly 1 kilometre appear to dominate; this is consistent with our theoretical predictions.

*K L. Denman. T C. Platt. A. W Herman (Metrology). P E Vandall (Coastal Oceanography)*

**Study of Zooplankton Sample Variability.** An analysis of three zooplankton sample variation experiments on the Scotian Shelf suggests that there is a periodic fluctuation in numbers of many zooplankton species over 26 hours at any fixed geographic station. Such fluctuations appear to be related to the tidal cycle. The studies also demonstrate that an estimate of the mean concentration of many zooplankton species obtained over a period of 26 hours at a single station is as reliable an estimate as the mean obtained from many stations sampled over a large geographical area. If future experiments confirm this, the time and expense of gathering zooplankton data in the field can be greatly reduced by improving sampling strategies.

Improved net design will also facilitate prudent sampling. During the last 2 years an electronically-controlled opening and closing 1 square metre tucker trawl with 10 nets was designed and built. Information is transferred from the net to the ship on temperature, net depth, net speed through the water, pitch and roll of the net, light intensity in the water, and salinity. The net has incorporated in its design a depressor which allows towing of the net at speeds up to 3.5 metres per second, thus enabling us to capture fast-moving macrozooplankton and small fish. The development of this net has simplified and improved studies of the vertical distribution of zooplankton, and has aided the study of acoustic scattering layers.

*D. D. Sameoto, L. O. Jaroszynskl*



*Krill (2 to 4 millimefres long)*

**Acoustic Scattering Layers and Zooplankton Vertical Migration.** The species composition and behaviour of acoustic scattering layers in the Gulf of St. Lawrence and the Scotian Shelf was studied. The aim of the work was to develop an acoustic system that can be used as a quantitative sampling tool for macrozooplankton and juvenile fish. It is now possible to

receive the acoustic signals and process them aboard ship to obtain immediately an estimate of the density of macrozooplankton such as krill. This system, combined with the new multiple net, enabled us to obtain accurate estimates of the acoustic target strength of krill; these are necessary if we are to make fast *in situ* measurements of the krill's biomass.

*D. D. Sameoto, S. A. Paulowich*

## Cetacean Bio-acoustics

In the future biological oceanographers may use acoustics to map routinely the distribution and size of zooplankton and fish. Although the nature of sound transmission within the ocean is well understood, the optimum characteristics of a generalized sonar transmitter are to a large extent unknown. Baleen whales that must locate and consume tons of zooplankton and fish each day may show us how to solve this problem. Therefore, a program was developed to prove the existence of and subsequently to study the sonar of these animals. Although we had recorded with hydrophone arrays short repetitive sounds suitable for a whale sonar in the presence of Blue, Fin, Humpback, and Minke whales, we considered it desirable to capture a whale and maintain it temporarily in confinement to prove the existence of its biological sonar.

*This humpback whale (about 10 metres long) was studied for the existence of biological sonar Note the flippers underwater, which are each about 3 metres long.*

In June 1975 a young male humpback whale (a baleen whale) was trapped in a fishing net on the southeast coast of Newfoundland. The recordings of short repetitive sound pulses on a seven-hydrophone array were similar

to a series of clicks recorded previously in the presence of free-swimming humpbacks. The whale was tagged with orange and yellow streamers and released. In July 1976, with techniques developed the previous year, a young female humpback was entrapped on the east coast of Newfoundland. Temporary blindfolds were attached and the animal was allowed to swim through a maze during acoustic recording. This was the first experiment designed to test for the presence of sonar in a baleen whale. The whale was tagged with yellow and purple streamers and a 27 megahertz radio transmitter before she was released and tracked.

*P. C. Beamish*

# Environmental Quality

The general aim of the Environmental Quality program is to learn how artificially-induced environmental changes affect marine ecosystems. Within this broad objective, we have chosen research projects to provide information which is relevant to the Canadian Atlantic region, and which establishes general principles governing the behaviour of contaminants in the marine environment. These projects include studies of the distribution and transport of contaminants; studies of their uptake, metabolism, and clearance by marine organisms, and of their effect on marine life; and provision of expert technical advice and opinion on these topics to international, governmental, and other bodies. The contaminants currently being investigated include chlorinated hydrocarbons, petroleum hydrocarbons, and heavy metals.

*R. F. Addison*

## Basic Ecological Studies

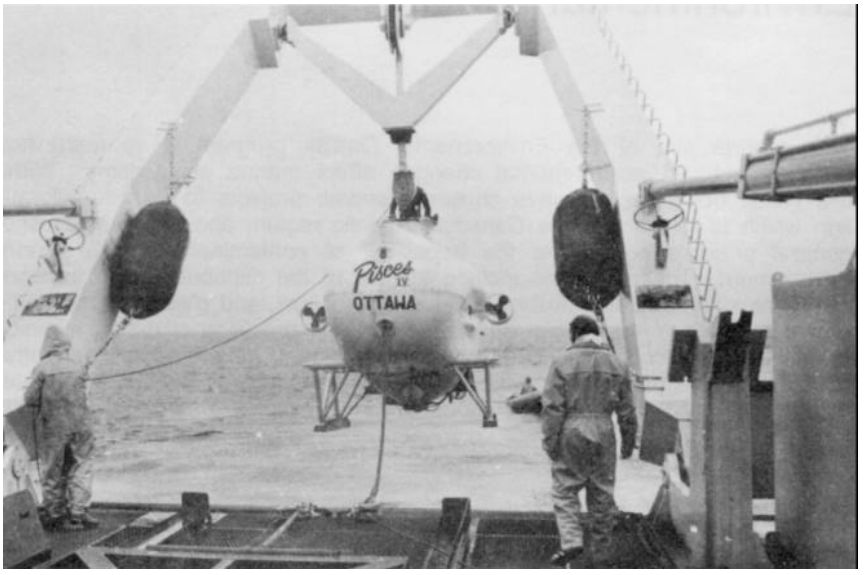
Many contaminants are readily absorbed to small particulate material. To understand how contaminants are transported and distributed, we require general information about the behaviour of such particles in the sea.

**The Role of Sediments and Benthic Communities in the Cycling of Natural Organic Matter and Pollutants in Marine Ecosystems.** Sediments, the sediment-water interface, and suspended particulate matter are sites of adsorption and metabolism of organic matter in all aquatic systems. The flux of material into sediments and the accumulation and transfer in benthic organisms are being evaluated as indicators of the rate of supply from overlying water.

Sedimented material and measures of its organic content were monitored for 2 years at various depths in the Bedford Basin, Nova Scotia. Traps at successively deeper depths did not collect similar types of material, which implies that horizontal transport occurred intermittently, possibly by resuspension of sediments at shallower depths and transport to deeper water. Using a submersible in St. Margaret's Bay, Nova Scotia, layers of turbid water were observed above the surface of soft mud sediments in the centre of the Bay and abrupt changes in concentration of suspended material occurred over a short time. Vertical movement of particulate matter from the water column to the sediment surface may predominate only when horizontal currents are not important.

Organic matter is metabolized within sediments and is utilized in benthic food chains. The rate of this activity should reflect the flux of organic material to the sediment surface. To demonstrate the importance of pathways of supply of organic matter, the roles of primary production and the mixed layer depth (of the water column) in controlling the amount of sedimentation have been quantified for various water bodies. For deep thermoclines (greater than 20 metres), extensive biological decomposition of material occurs at the surface and input to sediments is reduced. The stability of the water column and the associated changes in vertical mixing rate appear to be critical in determining deposition.

*B. T. Hargrave, G. A. Phillips*




*This submersible was borrowed from the Institute of Ocean Sciences Patricia Bay, Victoria. B C., for use in a study of St Margaret's Bay. N.S*

## Chlorinated Hydrocarbons

The major chlorinated hydrocarbon contaminants in Atlantic Canada are the insecticide DDT and its metabolites, and a group of industrial chemicals, the polychlorinated biphenyls (PCBs). Our work on these materials has dealt principally with the processes by which they are transported between certain reservoirs of the marine environment, and with their degradation by, and effects on, marine organisms.

**Adsorption of Organochlorine Compounds to Particles.** Adsorption (per unit weight) of $^{14}$C-DDT from sea water by particles ranging in size from bacterial cells to large sand grains was inversely related to particle diameter and directly related to the concentration of DDT in sea water if saturation levels were not exceeded. A review of the behaviour of many pollutants entering water indicated that association with natural suspended material occurs in inverse proportion to solubility. Particle size and concentration determine the surface area available for adsorption. Flocculation also occurs; the size of the units is determined by the inorganic nuclei around which the organic matter is clumped. Prediction of the dynamics of transport and dispersal of many pollutants in water is thus equivalent to prediction of the dynamics of dispersal of fine particulate matter.

*B. T. Hargrave, G. A. Phillips*

**DDT Residues in St. Margaret's Bay Benthic Fauna.** Detectable concentrations of organochlorines exist in the benthic fauna of St. Margaret's Bay. However, total DDT levels in whole organisms (excluding fatty rich tissue), grouped as demersal fish, and invertebrates living in and on the sediments, were not significantly different. Atmospheric supply is the most probable

source of the low levels of DDT measured and the diverse feeding patterns present in the benthic detritus-based food web may account for the equalized residue concentrations between the various feeding types.

*B T. Hargrave, G. A. Phillips*

**Uptake and Clearance of DDT by Marine Invertebrates.** Work to obtain transfer rate constants for organochlorines (DDT and PCBs) from sea water to pelagic marine life continues. Present information allows us to predict the amount of DDT in copepods for a given concentration of DDT in sea water. As the extent of uptake probably depends on the surface area of the organism, a method of measuring surface area was developed. Parallel studies are being conducted with euphausiids. Since plankton may also accumulate organochlorines through feeding, the efficiency of uptake of organochlorines from food by plankton is being determined. This information will enable us to construct a model of organochlorine dynamics in zooplankton which will be tested by a survey of organochlorine concentrations in phytoplankton, zooplankton, and larval fish in St. Georges Bay, Nova Scotia.

*G. C. H. Harding. W. P. Vass*

**Metabolism of DDT by Fish.** DDT and many other chlorinated hycrocarbons are very soluble in fat, but relatively insoluble in water. It is believed that in order to excrete appreciable amounts of DDT, an organism must convert it to water soluble derivatives. The major metabolites of DDT in fish are its dehydrochlorination product, DDE, and its dechlorination product, DDD. Although DDD is formed only at about one-tenth the rate of DDE, it may be an intermediate in the eventual conversion of DDT to water-soluble compounds. At the rate at which DDT residues would clear via these degradations is much slower than the rate at which DDT residues would be accumulated through feeding, it is not surprising that DDT residues in various aquatic organisms increase as the organisms age.

*R F Addison, M. E. Zinck. D. E. Willis*

*Liquid scintillatlon counting of radioactively labelled insecticides during metabolic studies (AOL 4166)*

**Metabolism of DDT by Copepods.** The capacity of copepods to degrade DDT was examined. No metabolites of DDT were observed, and the kinetics of the DDT uptake suggested that most DDT accumulated by these organisms was localized on external surfaces, and was metabolically inactive.

*D. C. Darrw, G. C. H. Harding*

**Enzyme Induction Studies in Fish with Chlorinated Hydrocarbon Insecticides.** Many chlorinated hydrocarbons induce production of microsomal mixed function oxidase (MFO) enzymes in terrestrial mammals and in insects. The MFO system is believed to be a protective mechanism by which the organism can detoxify various foreign chemicals or render them water soluble, and hence excretable. We have investigated the extent to which MFO systems in fish are inducible by chlorinated hydrocarbons. DDT and DDE fad to fish at levels high enough to produce tissue concentrations well above those routinely encountered in 'wild' samples did not induce MFO enzymes. Injection of aldrin (a cyclodiene insecticide) caused a slight induction, but feeding of dieldrin (a metabolite of aldrin) did not. Injection of various metabolites of DDT (all known to be produced by fish) resulted in no MFO induction. The MFO system in fish is, therefore, not readily inducible by the DDT group, or its metabolites, and degradation of DDT is not enhanced by prolonged exposure of fish to DDT or related compounds.

*R. F. Addison, M. E. Zinck, D. E. Willis*

## Petroleum Hydrocarbons

Much of our work on the behaviour of petroleum hydrocarbons in the marine environment was stimulated by the *Arrow* spill of Bunker C oil in Chedabucto Bay, Nova Scotia, in 1970, and by the increased activity in oil exploration off the east coast and in the Labrador Sea.

**Sampling and Analytical Methods for the Determination of Hydrocarbons in Environmental Samples.** We are developing methods for determining hydrocarbons in marine sediments and organisms. The principal approaches continue to be fluorescence spectroscopy and gas chromatography. Improvements in sample and data handling have increased the number of samples that can be analyzed, and the quality of the data.

*P. D. Keizer. J. Da/e*

**Distribution of Hydrocarbons in the Marine Environment off Eastern Canada.** Most of the hydrocarbons observed on the Scotian Shelf and in the Gulf of St. Lawrence, St. Lawrence estuary, and Bedford Basin appeared to be biogenic in origin. Concentrations of n-alkanes ranged from about 20 to 1000 nannograms per litre. Discernible levels of petroleum-derived hydrocarbons were observed only in Bedford Basin. A detailed temporal study of hydrocarbons in the water column of Bedford Basin was conducted between January 1975 and April 1976. The highest concentrations occurred during the winter and early spring months. Analysis and interpretation of these data are continuing.

During 1973 we collected a series of sediment samples on the Scotian Shelf from areas where exploratory drilling had been undertaken. Hydrocarbon analysis of these sediments has just been completed and the data are now

being evaluated. These data will provide baseline measurements of hydrocarbons and may also provide some evidence on the effects of drilling.

*P D. Keizer, J. Dale*

*The interaction of worms and oil-polluted sediment was studled. (AOL 4185)*

**Ecological impact of Oil Spills.** Since the residence time of oil in sea water is short (of the order of days) and concentrations are generally quite low (parts per billion), our studies of the ecological impact of oil spills have shifted to marine sediments. Quite high concentrations can be attained in sediments and they can persist for many years. We have studied the interactions between the deposit-feeding polychaete *Arenicola marina* and oil-polluted sediment. The worms seem very sensitive to fresh oil but appear to become more tolerant to oil as it weathers. The discovery that the worms appear to remove oil from the sediment while passing it through their guts suggests that the activity of deposit-feeding organisms might be an important factor in the weathering of oil in sediments.

*N. J Prouse, D. C. Gordon*

**Impact of 1970 Chedabucto Bay Oil Spill.** Since 1973 a concerted effort has been made to understand the eventual fate of the stranded Bunker C fuel oil remaining on Chedabucto Bay beaches and shorelines following the 1970 *Arrow* spill. Such stranded Bunker C oil is restricted to a relatively narrow tar strip on the surface of the sediments along the high water line. This gradually reenters the beach interstices and the water column via tidal flushing. The main route of re-entry is via the interstitial water in the beach,

and only in trace amounts via the water column. Sediments in this system act as a sink, with hydrocarbon concentrations in the milligram per gram (parts per thousand) range. Concentrations of Bunker C released from oiled beach sediments by flowing water alone are generally within the microgram per litre (pans per billion) range, similar to those measured in the water column over the oiled study site. Initial estimates suggest that after 6 years of weathering as much as 20 per cent of the originally stranded Bunker C fuel oil is still ashore as tar strips and sediment-bound hydrocarbons. Total removal of the

*Stranded Bunker C oil at Chedabucto Bay, NS. (AOL 4037)*

sediment-bound petroleum hydrocarbons by tidal flushing alone will probably require in excess of 170 years. Inclusion of the tar layer at the top of the beach may well extend the decay time by an order of magnitude.

Soft-shelled clams *(Mya arenaria)* and the rooted eelgrass *(Zostera* sp.) from oiled sediments have high levels of petroleum hydrocarbons in their tissues. Mussels *(Mytilus edulis)* from the same site have only traces of oil contamination, and we were unable to detect any oiling of the beach kelp *(Fucus vesiculosus).*

Over the past 2 years attention has turned towards documenting the chemical changes in sediment-bound Bunker C, and evaluating its effects on benthic organisms. Bunker C from the tar layer, re-entering the interstitial environment of oiled beaches through tidal leaching, shows almost immediate total reduction of its n-alkane portion, but the aromatic fraction appears resistant to biological degradation.

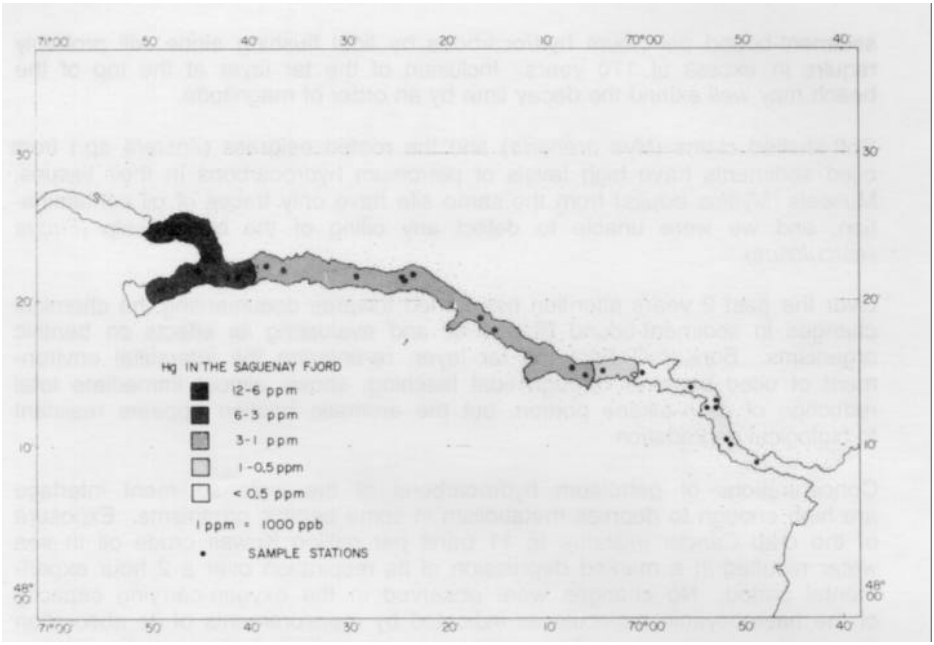
Concentrations of petroleum hydrocarbons at the water-sediment interface are high enough to depress metabolism in some benthic organisms. Exposure of the crab *Cancer irroratus* to 11 parts per million Kuwait crude oil in sea water resulted in a marked depression of its respiration over a 2 hour experimental period. No changes were observed in the oxygen-carrying capacity of the haemocyanin molecule as indicated by measurements of its absorption spectrum, subunit composition, serum copper content, or oxygen dissociation curves. The respiration changes observed may reflect interferences with neuronal control or tissue metabolism. ATP production (a measure of metabolic activity) in some unicelluar algae *(Monochrysis lutheri)* has been found to be sensitive to napthalene, with a 35 per cent reduction in total ATP available, and soft-shelled clams *(Mya arenaria)* from chronically oiled sediments show a marked depression in their metabolic handling of carbon.

Clams *(Mya arenaria)* from oiled sediments contain high levels of Bunker C derived petroleum hydrocarbons, which are cleared only slowly and incompletely. In higher animals, aromatic hydrocarbons are metabolised by an aryl hydrocarbon hydroxylase enzyme (AHH) system, which is inducible by polycyclic hydrocarbons. However, no AHH activity was found in mussels, oysters, and clams, either non-oiled or after 4 days exposure to either a Kuwait crude oil or to a Bunker C fuel oil. Furthermore, mussels and clams from chronically oiled (since 1970) Chedabucto Bay sediments were found to lack the necessary enzyme systems for other detoxification mechanisms. This implies that the only defense of oiled bivalves to such hydrocarbon contamination is slow clearing. The accumulation of these compounds unchanged in mollusc tissues presents a point of entry into the food chain.

*J. H. Vandermeulen, T. P. Ahern*

## Distribution of Heavy Metals in the Gulf of St. Lawrence

**Heavy Metals in the Sediments.** Heavy metal studies in the Gulf of St. Lawrence have been undertaken to: determine baseline levels; identify areas of heavy metal accumulation; determine the proportion of the total heavy metal concentration that is available to the biota: determine natural and industrial sources; and understand the pathways by which the heavy metals enter or leave the sediments.




*Concentrations of mercury in Quebec's* Saguenay *fjord. (AOL 3296)*

High concentrations of mercury exist in the surface sediments of the Saguenay fjord. High levels also occur in subsurface sediments of the fjord (up to 12 parts per million) and river (up to 218 parts per million), in suspended particulate matter (1-50 parts per million) in the fjord, in water (0.7-0.38 parts per billion), and in certain species of fish (0.5-10 parts per million). These levels appear to reflect industrial discharges, and it is estimated that about 112 tonnes of industrial mercury reside in the sediments of the fjord and River. A further 12 tonnes of industrial mercury have probably escaped the fjord and are deposited in the sediments of the adjacent St. Lawrence estuary. These amounts are similar to estimated industrial discharges of mercury to the system prior to 1971.

After 1971, federal government regulations were imposed to restrict mercury discharges by industry. Analyses of water sampled in 1973 suggest the mercury input at that time was about 7.8 tonnes of mercury per year of which only 2.8 tonnes per year could be accounted for by natural and allowable industrial discharges. Examination of other factors suggests that only the inclusion of the mercury losses not accounted for by local industries could explain the 1973 mercury flux through the system. At these levels, the contamination of the fjord would continue and the productive fishery in the adjacent St. Lawrence estuary might be affected. If all industrial inputs to the system were curtailed, the mercury concentrations in the water would probably return to natural levels in about 3 or 4 years, and the recovery of the fisheries in the Saguenay might occur within 2 years.

The distribution of Zn, Cu, Pb, Co, Ni, Cr, and V (elements which often accompany industrial waste discharges) in the fjord sediments was investigated. The fjord muds were enriched in Zn and Pb when compared to sediments from the St. Lawrence estuary and open Gulf of St. Lawrence, and Cu,

Co, Ni, Cr, and V concentrations were at, or near, natural levels. Only the non-detrital portion is available to the biota in the fjord (between 14-29 per cent of the total Zn, 14-21 per cent of the total Cu, 12-25 per cent of the total Pb, 8-25 per cent of the total Co, 11-29 per cent of the total Ni, 2-9 per cent of the total Cr, and 5-23 per cent of the total V). The distribution of non-detrital Pb, Zn, and Cu (but not Co, Ni, Cr, or V) is apparently controlled by the seaward dispersal of Hg-rich terrestrial organic matter derived from industrial sources. Although the contribution of Pb, Zn, and Cu derived from industrial wastes is small now, the absolute quantity being supplied may lead to an excessive accumulation in the future, as has been the case of Hg in the past.

The detrital fraction contains the bulk of the trace element concentrations (70-98 per cent) and the elements are located in sulphide (Pb, Cu, Zn, Co, Ni), oxide (Cr, V), and ferromagnesian minerals. The elements in this fraction naturally accumulate at the same rate as their host (or carrier) minerals in response to the present depositional conditions.

*D. H. Loring, R. T. T. Rantala*

## Other Studies

**Degradation and Effects of Alkylhydroxamic Acids.** Alkylhydroxamic acids are a group of fatty acid derivatives that have been proposed for use as ore floatation agents in Canada. Previous work showed that these materials were highly toxic to salmonids. A $^{14}C$-labelled octanohydroxamic acid was accumulated rapidly by trout and was cleared rapidly when the trout were placed in clean water. Radioactivity was distributed ubiquitously among tissues, with large amounts present in the bile, which suggests that much of the accumulated material was excreted. Incubations of liver homogenates showed that hydroxamic acid was rapidly converted to the corresponding carboxylic acid, which would presumably enter the normal metabolic processes of the organism. Since trout exposed to octanohydroxamic acid eventually died, the detoxification process (hydroxamate to carboxylate) does not proceed sufficiently rapidly to protect the fish.

The probable site of action of octanohydroxamic acid is the nervous system. Trout poisoned with this material show a reduced respiration rate and apparently die from asphyxiation.

*D. C. Darrow, R. F. Addison*

**Dartmouth Lakes.** Through representation on the Dartmouth Lakes Advisory Board, effort is directed to protect the lakes in the City of Dartmouth from the undesirable effects of development and urban growth. During 1976, a Secchi disk program has been conducted, in which volunteers monitored weekly the transparency of each lake.

*D. C. Gordon. Jr*

# Fisheries Oceanography

The Fisheries Oceanography group studies the functioning of complete ecosystems, but the major emphasis is on the terminal parts of the food webs. Our aim is to understand all the processes leading to the production of fish. We are actively engaged in: the determination of fish stocks; an investigation of production mechanisms from both theoretical and experimental viewpoints; devising methods for the prediction of fish production; and looking at climatic and oceanographic influences on fish stocks and production.

*R. W. Sheldon*

## Hydro-acoustic Assessment of Fish Stock Size

A 'rational' management of fish stocks requires an estimate of the size of stock from which the catch is taken. To date, estimates of fish stock sizes are based on indices such as random trawl surveys or on statistics such as catch per unit effort. Hydro-acoustic echo processing methods offer the potential for directly estimating the numbers of fish in a particular area and hence offer an extremely important tool for fisheries management.

The Marine Ecology Laboratory, in conjunction with the Fisheries and Marine Service at St. Andrews, New Brunswick, and St. John's, Newfoundland, has developed a computerized echo processing system that can assess numbers of fish that occur singly or in schools. In addition to real time estimates of fish densities, all information concerning fish echoes, such as depth and size, is stored on magnetic tape for subsequent evaluation. The last two years have seen three important developments. Previously, incoming signals were sized using a two-bit system that provided four levels; a 12-bit analogue-digital converter has now been incorporated, enabling assessment of the incoming signal to be made at one of 1024 levels. To eliminate the uncertainty of the actual target strength of the fish due to directivity effects of the transducer beam, a two-beam system is used in which a transducer receives echoes on two different hydrophone arrays. This permits an analytical rather than a statistical estimate of the target strength. The third development is the incorporation of an integration mode, which enables estimates of the abundance of schooling fish (such as capelin or herring) to be made. The same hardware is used for echo counting and for integrating so a choice of either count or integrate mode can be made.

Progress has been made in the development of computer programs to identify sequences of echoes produced by individual fish and also to identify single fish within schools of fish. Such programs also enable schools at different depths to be separated and also schools that differ in target strength and (presumably) species to be identified.

*R. G. Dowd, R. Shotton*

## Bio-energetics and Recruitment in Exploited Fish Populations

In most marine fish populations there is often considerable variation in the numbers of young fish or recruits that enter the fishery each year.

indeed, in some cases the abundance of recruits can vary by a factor of a hundred or more between successive year-classes. Since it is widely recognized that an accurate prediction of recruitment is essential to the management of a fishery, our theoretical and applied studies in this area are continuing. We have been developing a general model of optimal feeding behaviour and examining its possible significance to the recruitment process. We have shown, in theory, for a fish of a given size and a given available food supply that there is a unique speed at which the fish ought to swim if it is to maximize its growth rate. Since it can also be argued that the fastest growing fish in a year-class will be in better physiological condition, and hence more efficient in finding food and avoiding predators, it follows that it ought to have a higher survival rate than slower growing individuals. Thus, our model suggests, among other things, that variations in recruitment can arise from natural fluctuations in a number of growth modifying factors such as the initial number of fish in each year-class, food availability, and hydrographic conditions. The general applicability of the model is currently being evaluated by comparing the theoretical interrelationship between growth and survival with the observed rates for juvenile mackerel in St. Georges Bay, Nova Scotia.

*D. M. Ware, T. C. Lambert, J. K. McRuer, A. D. MacDonald*

## Ecology of Larval Fish

A feasibility study of St. Georges Bay was initiated in 1973 to determine whether it was a suitable environment, from a fisheries point of view, to examine the early life history of Atlantic mackerel and other selected fish populations. Since the initial results were favourable, the foremost objective of the program, beginning in 1974, was to clarify the relationship between the spawning cycle of mackerel and the production of the larval food supply. Two other objectives were a study of the size variation in pelagic (in the surface waters) fish eggs in relation to similar changes in the zooplankton community and the feasibility of detecting mackerel egg patches so that their developmental and subsequent loss rates could be studied *in situ*. Each of the objectives was selected to determine the importance of different factors on the growth and mortality of mackerel during their early life history.

We have shown that the average particle size of zooplankton is inversely correlated with water temperature, and is positively correlated with the decline in mackerel egg size during the spawning cycle. Thus, there is a generally favourable match between the size of a newly-hatched larvae and its food supply. Secondly, we have found for 3 consecutive years that the measured egg loss rates (which average about 40 per cent of the population per day) are consistent with a theoretical model we have developed concerning the adaptive significance of egg size on recruitment. In view of these findings, we are currently expanding our study of the differences in egg size between species, during their respective spawning cycles, in relation to attendant changes in particle size in the zooplankton community as a whole.

The program has expanded in 1976 and St. Georges Bay is now being visualized as a typical system: the biological production and, to some extent, physical characteristics are typical of other coastal embayments in the southern Gulf of St. Lawrence. The scope of the work now encompasses

*Mackerel.*

the entire pelagic community. During the next few years we hope to quantify the particle size dynamics of the plankton over all seasons, and to determine whether or not there is a near-shore production gradient established during the summer, which could be of ecological significance to larval fish.

*D. M. Ware, T. C. Lambert. J. K. McRuer*

## Dynamics of Fish Production Systems

This program uses existing, or readily acquired, data to predict the structural responses of fish production systems to stressors; that is, anything that causes changes to the natural ecological system. Emphasis is at the community level of response, and upon the effects of fishery exploitation. Results to date indicate: that discernible properties and behaviours do in fact emerge at the multi-stock or production system levels of analysis; that fisheries exhibit multiple stable configurations, bounded by abrupt transition zones; that individual stock dynamics are in part interpretable in these terms; and that certain newer methods of analysis, such as catastrophe theory, can usefully supplement the more conventional techniques.

*S. R. Kerr*

## The Structure of Pelagic Ecosystems and the Relationships Between Plankton and Fish Production

Recent observations on the concentration of organisms in the sea relative to their size has confirmed that the structure (i.e., the relationship between numbers and sizes of animals and plants) for the pelagic food web that we tentatively developed some years ago is correct. It is a remarkably

simple structure. The production of any group of organisms varies simply according to its size, and the stock (or weight concentration) of all organisms is similar and is independent of size. In simple (but only approximately correct) terms, this means that if we took all the fish in an area and ground them up into phytoplankton-sized pieces and then dispersed them back into the sea, the concentration of 'fish bits' would be the same as that of the phytoplankton.

It is clear from this that if we measure the concentration of phytoplankton in any area we can estimate the concentration of fish. Furthermore, if we can measure the growth rate of the fish - not a difficult task - we can then estimate the potential production of the fish. This in turn can be related to the potential maximum fish catch.

We have done this for two areas. In the Gulf of Maine we used data on fish landings to estimate the potential plankton production. For the area off Peru we used plankton data to estimate the potential production of the anchoveta fishery. In both cases our estimates were close to the known values.

*R. W. Sheldon, W. H. Sutcliffe, Jr.*

## Mollusc Studies

A program to develop indices of production potential of Maritime inlets was begun during the summer of 1974. Initial trials have concentrated on the development of holding systems suitable for a variety of species. In the initial experiment three bivalves (mussels, *Mytilus edulis;* soft-shell clams, *Mya arenaria;* and razor clams, *Ensis directus)* were placed near Luke Island in St. Margaret's Bay. Trays of cylindrical containers successfully maintained the two clam species over two winters and virtually eliminated the mortality due to predator pressure evident on nearby beaches. The soft-shell clams attained a mean shell length of 40 millimetres in two seasons. The razor clam experiments were less successful since these mobile molluscs were capable of escaping from the containers.

Mussels were successfully held in suspended culture on ropes for 2 years although drift ice and storms resulted in the need for constant maintenance to the support system. Also, the relatively unprotected mussels suffered some losses due to natural settlements of starfish. Despite these problems, the mussels grew to more than a minimum commercial size within two growing seasons.

Production indices (rate of production compared to number of molluscs there) for different environments cannot be based on growth and mortality measurement for indicator species unless it can be assured that differences due to inherent physiological (genetic?) influences among the stock specimens can be distinguished from those due to environmental effects. Earlier work with mussels in Bedford Basin and St. Margaret's Bay (Nova Scotia) gave assurance of major bay-to-bay differences in production parameters but gave indications as well that there were different growth 'strains' within the single stock used. Accordingly, experiments were begun in 1976 to examine these anomalies more critically.

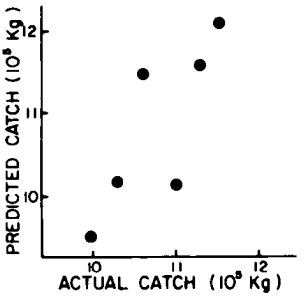
Mussels from St. Margaret's Bay, Bedford Basin, and Malpeque Bay (Prince

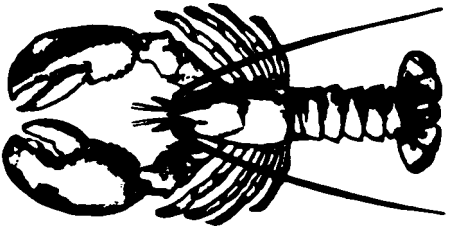
Edward Island) were placed in suspended cages in each of the three locations. This three-way transfer experiment was begun in the spring and regular observations were made during the growing season. Preliminary results suggest that there may be quite remarkable differences in hardiness of stocks from the three areas. Observations will be continued through a second growing season.

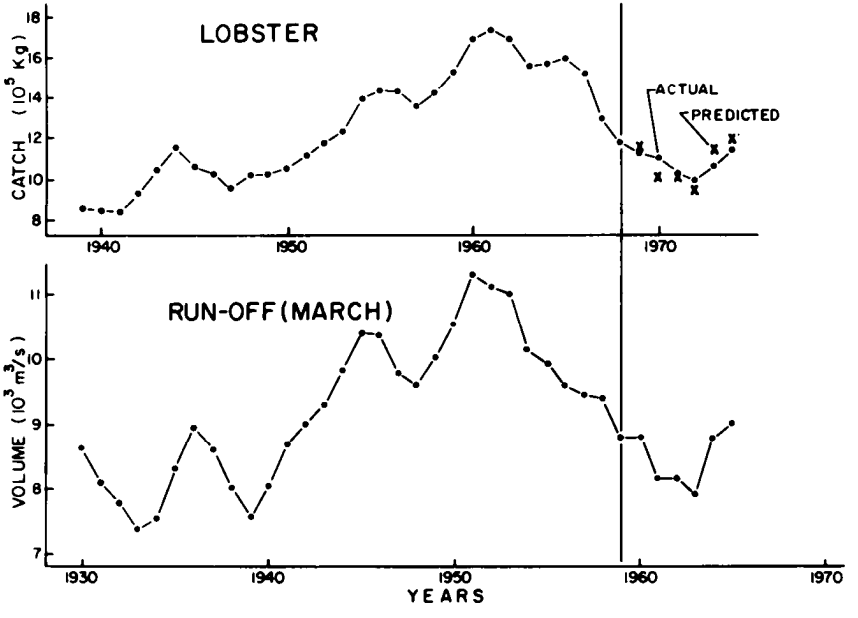
*K. R. Freeman*

## Flounder Studies

Examination of the possibility that a vertebrate could be used as an index organism began in late 1974 with a comparative growth study of winter flounder (Pseudopleuronectes americanus), a ubiquitous Maritime species. The initial experiment, which was completed in the spring of 1975, gave a






*Lobster catch for Quebec compared to March run-off from the St. Lawrence River and its major tributaries 9 years before. (AOL 4194)*

strong indication that flounder from St. Margaret's Bay and Malpeque Bay tend to retain the growth characteristics of the parent stock irrespective of holding site and feeding regime following capture. In other words, there is a strong indication that these fish may be genetically distinct with regard to growth capacity. Unfortunately, holding facilities of the laboratory near Malpeque Bay were not suitable for summer-time growth, but, following improvements, further attempts to confirm the observed dissimilarity in flounder growth will be made next year.

*K. R. Freeman*

## Fish Production and Its Relationship to Climatic and Oceanographic Variation

The species comprising the bulk of the commercial catch in the Gulf of Maine are found to have either positive or negative response to local oceanographic climate as indicated by the temperature. These responses apparently balance out so that the net effect is a relatively level catch in total for about 20 years (1940-1959) until the advent of large foreign fleets in the 1960s. A theoretical model of three shelf species incorporating environmental influences may explain some of the historical aspects of these fisheries.

Forecasts made 5 years ago of the commercial catch of lobster and halibut for Quebec, based on run-off of the St. Lawrence River, are in good agreement with the actual catch so far. The figure shows the lobster catch for Quebec and the run-off from the St. Lawrence River and its major tributaries 9 years before in the month of March. On the right of the lobster curve is shown the predicted catch (based on run-off figures) compared to the actual catch from 1968-1974 (3 years running means). The plot of predicted versus actual catch shows the high correlation.

*W. H. Sutcliffe, Jr.*

## Bio-energetics of Marine Mammals

When studying the energetics of large whales, one is limited to observations that can be made from chance sightings and strandings. Few investigators have the opportunity or facilities to mount expeditions or to study fresh material at the few remaining pelagic or land whaling stations.

The metabolic rates attributed to large cetaceans are often quite inconsistent with the available food resources and burden the animals with rates so high that it would appear their greatest source of natural mortality is spontaneous combustion! The extremely large body size of some cetaceans enables them to behave uniquely; food can be stored for extensive periods of migration and fasting. If one applies parameters normally used to describe terrestrial mammals, such as daily food consumption as a percentage of body weight, the results can be very misleading.

The importance of establishing the correct energy budgets for large cetaceans is that they help to assess the potential of other resources from the same system. If the energy demands for the cetaceans are exaggerated, the productivity of the prey supporting these stocks is also exaggerated. Thus,

the prey available for commercial exploitation following the reduction of the predator (e.g., through whaling) is overestimated.

*Whale and trawler compete for capelin*

It is surprising that theoretical energetic studies might have considerable relevance to the commercial understanding of living cetaceans, but the increasing demand for marine resources, ranging from Antarctic krill to North Atlantic capelin, might have a considerable effect on the populations of marine mammals. For this reason there is an increasing emphasis placed on studying and managing marine resources as ecosystems rather than as individual stocks.

The results of studies at the Marine Ecology Laboratory are in good agreement with work from Japan and England. The indications are that the energy demands of large marine mammals have been exaggerated and this in turn has lead to overestimates of the amounts of their prey. These results have aroused particular interest in Japan where techniques are being developed for harvesting the Antarctic krill.

*P. F. Brodie*

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# Atlantic Geoscience Centre (AGC) Geological Survey of Canada Department of Energy, Mines and Resources 1975/76

Director - B. D. Loncarevic

- Eastern Petroleum Geology Subdivision
- Environmental Marine Geology Subdivision
- Regional Reconnaissance Subdivision
- Program Support Subdivision
- Administration

# Director's Remarks

As we enter the last quarter of the twentieth century, the world seems to have paused. For a brief moment, open warfare has been suspended and the big guns are silent. Hysteria over the energy crisis seems to have subsided, though we have yet to solve the underlying problem of resource conservation and allocation. We seem to have accepted inflation as inevitable, though logically it must lead to a collapse of the present economic order. To our list of problems we have added the unresolved Conference on the Law of the Sea; this, in spite of the warnings that increasing conflicts in this area can lead to serious international confrontation.

We are delaying the day of reckoning, not because we hope that the problems will go away but because we need a greater understanding of the nature of complex world systems before we can control them. Progress is being made in this direction with important roles to be played by geoscientists. It is thus appropriate that the most important recent event in this area in Canada was the Geological Survey of Canada Futures Conference convened in Ottawa in the fall of 1974 to try to understand the nature of the forces that will shape our work over the next 10 to 25 years.

In preparation for this conference, AGC held a number of informal evening discussions throughout the summer of 1974. Some of the points brought out at that time were: (a) the isolation of scientists will end, individuals will become more involved in group or co-operative projects, and groups will become more visible in the public arena; (b) as society becomes more interdependent, and technologically more sophisticated, the public policy will have to be based on greater and greater input of scientific data and advice; (c) measurements based on digital data processing will lead to an increasingly quantitative approach to geology; this, in turn, will lead to an increasing emphasis on the development of conceptual models based on non-linear mathematics and statistical simulation experiments; (d) as we undertake more and more sophisticated resource inventory, our procedures will approach and eventually become indistinguishable from mineral exploration.

With specific reference to offshore regions, it was also recognized that our concern in the marine areas will be more worldwide because: (i) marine science and technology will be perceived as an important tool of foreign policy. In all bilateral science and technology discussions with other countries, 'oceanography' has received particular attention; (ii) it is now likely that an International Seabed Authority will be established. Canada will want to have an active, perhaps even leading, role in this Authority; (iii) Canada will receive an increasing number of requests from less developed countries for technical training and assistance as many of them recognize their new responsibilities resulting from the Law of the Sea.

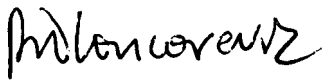
The major hurdle AGC faced in the last few years was learning to live with diminished funding while at the same time retaining a high degree of enthusiasm and momentum for its work. The exercise has been frustrating for managers who find an increasing number of plans and projects are still-born. In spite of the external factors, which could easily have made AGC a dispirited organization, the scientific staff have responded by increasing

productivity in a large number of diversified projects, by improving the quality of their work as evidenced in our publications, and by determining to do the best job possible in dealing with ever increasing responsibilities.

In the short run, we have met the challenges of inflation by: (1) examining expenditures at every step and eliminating waste; (2) selecting those projects where the maximum return for investment of our resources will be obtained; and (3) deferring projects of a lower priority. In the long run, we are trying to equip ourselves to deal with the ongoing fiscal situation by doubling our efforts at defining our long term objectives, and by paying increased attention to longer range realistic planning.

The challenge to AGC is not unique. It is a common problem facing most research organizations today: how to define the role and goals of research in a society which is constantly changing its own values and purpose? It appears that society and governments are unwilling (or unable) to support long term research unless some short term benefits are clearly visible. The resources that were available for long term research are being depleted and used to fight brush fires and to answer yesterday's questions. At the same time, regulatory agencies are proliferating as we move closer and closer towards a centrally planned economy. Since these agencies are formed in response to statutory requirements, the resources for their operation have to be found, and this frequently further erodes the research base. Science is particularly vulnerable today, not only as a result of decreased funding and public disenchantment, but because of the risk that the situation may lead to internal disillusionment. Yet, surely, we must welcome the situation as a challenge, as a mechanism for establishing the creative tension so necessary for great advances. The inquisition did not stop Galileo nor could it suppress the truths that he discovered. Darwin's theories flourished in spite of (and not because of) public enthusiasm. Even the theory of "Continental Drift" is today acceptable to scientists who only two decades ago were labelling it "utter nonsense".

There is still unlimited opportunity to advance scientific research in the service of society. As long as scientists can maintain a forward perspective they can continue to make contributions. Canada still needs marine research and the oceans are still an important avenue for bringing the people of the world together.



*B. D. Loncarevic*
Director
Atlantic Geoscience Centre

# Eastern Petroleum Geology

Eastern Petroleum Geology directs its main effort towards understanding the geological structure and history of the sedimentary basins of eastern Canada in both the onshore and offshore areas. This program facilitates the assessment of resources, especially oil and gas potential. Scientific studies are underway in each of the major basins outlined on the map (overleaf). The emphasis of the work may vary according to the hydrocarbon potential of each area. Biostratigraphers, lithostratigraphers, geophysicists, and petroleum geologists combine their efforts in an integrated basin analysis program. In addition, scientists also pursue more independent lines of research to the benefit of their particular discipline and ultimately, to the basin analysis objectives. The following are examples of some of our activities and results.

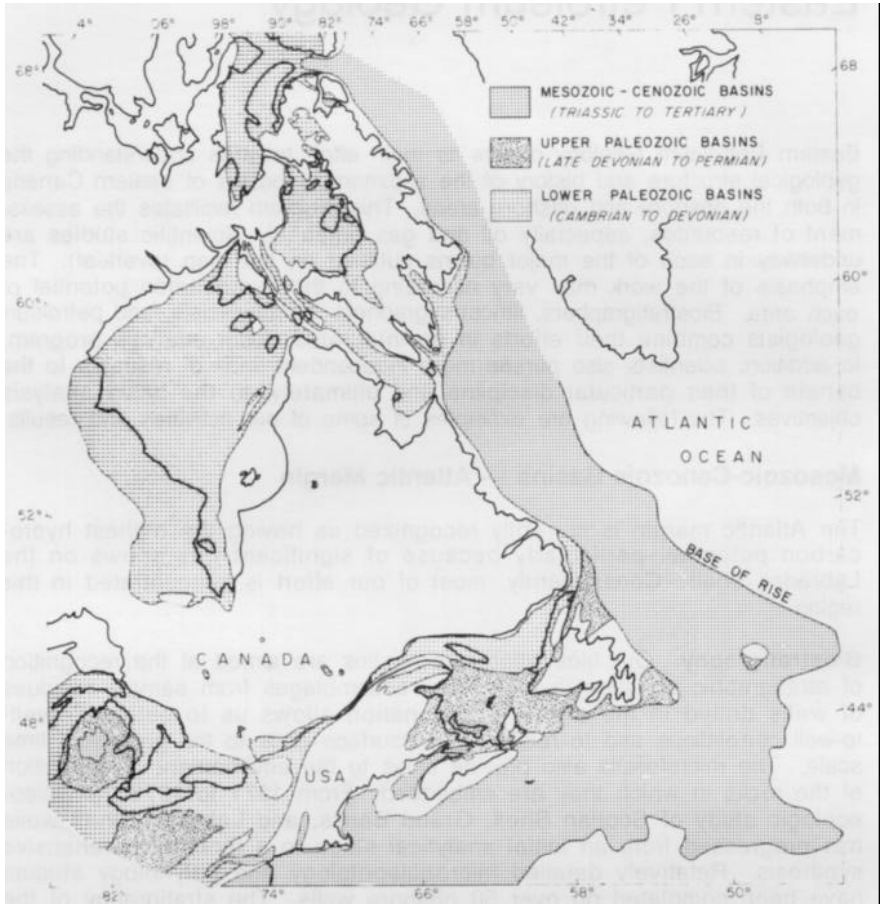
## Mesozoic-Cenozoic Basins - Atlantic Margin

The Atlantic margin is currently recognized as having the highest hydrocarbon potential, particularly because of significant gas shows on the Labrador Shelf. Consequently, most of our effort is concentrated in this region.

**Biostratigraphy.** Our biostratigraphic studies are aimed at the recognition of stratigraphic zonation in microfossil assemblages from sample residues of wells drilled in the area. This zonation allows us to establish well-to-well correlations and to relate the subsurface beds to the geological time scale. The microfossils also provide clues to the environment of deposition of the rocks in which they are embedded. From 1971 to 1976 the paleoecologic study of Scotian Shelf, Grand Banks, and Labrador Shelf wells has progressed from an initial analytical stage to a more comprehensive synthesis. Relatively detailed micropaleontology and palynology studies have been completed on over 50 offshore wells. The stratigraphy of the Grand Banks and Scotian Shelf covers Triassic, Jurassic, Cretaceous, and Cenozoic rocks; on the Labrador Shelf, Paleozoic, Cretaceous, and Cenozoic rocks are involved. Recent studies have provided a multiple biozonation for the Labrador Shelf with emphasis on its North Atlantic character: a multiple Jurassic zonation for the Grand Banks with emphasis on its “Old World” affinity; a detailed Cretaceous-Cenozoic palynology zonation for the Grand Banks - Scotian Shelf; and foraminiferal-ostracod zonation for the Scotian Shelf.

Participation in the Deep Sea Drilling Project, Legs 41 and 44, has provided excellent Cretaceous microfaunas and microfloras from deep water facies. The integration of these data with Grand Banks - Scotian Shelf biostratigraphy and paleo-ecology is a major stimulus for further North Atlantic basin studies.

Studies of kerogen (organic matter) type and colouration in residues from well cuttings as an adjunct to our palynology studies have given some interesting preliminary results. These studies show that, in general, on the Grand Banks and Scotian Shelf most of the rocks encountered in exploratory wells are thermally immature and have poor potential for generating hydrocarbons. The younger sediments in these wells mostly contain immature




*Sedimentary basins of eastern Canada and adjacent areas.* (AOL 3573)

amorphous kerogen, which is of marine origin and the most favourable type for the generation of oil. Deeper in the wells, where temperatures might have been high enough to generate oil from the amorphous material, mostly herbaceous and woody kerogen of terrestrial origin occurs. This material requires much higher temperatures to generate oil and gas. On the Labrador Shelf, the organic colouration studies indicate that herbaceous and woody material near the bottom of some wells approached maturity and therefore formed gas. Amorphous material in younger sediments is often in the immature-mature transitional stage, and, if areas on this shelf are found with mature amorphous material, oil might be expected.

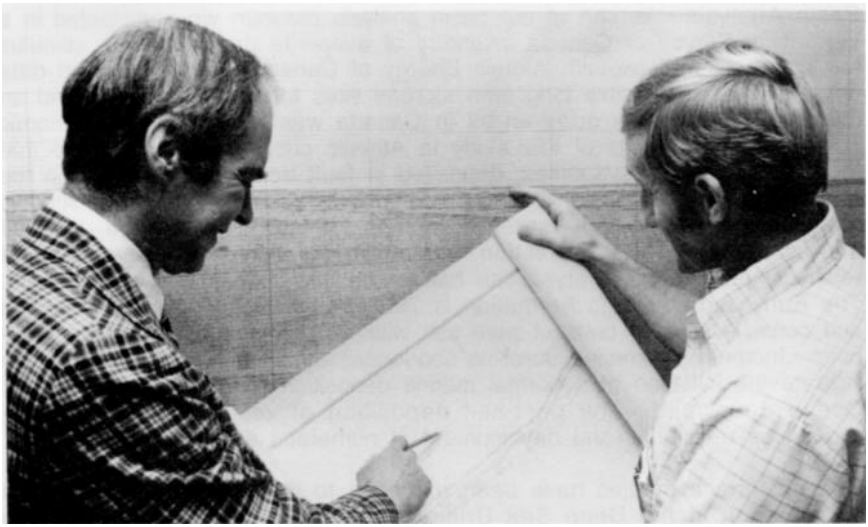
The evaluation of hydrocarbon potential using organic type and colour does not take into account factors such as hydrocarbon geochemistry, porosity of sediments, presence of reservoir seals, or structural considerations. However, without the right kind of organic material, which has been heated strongly enough and for a sufficient length of time, large amounts of oil and gas should not be expected from the rock even though other factors may favour the presence of large hydrocarbon accumulations.

**Basin Analysis.** As part of our basin analysis program we participated in a Geological Survey of Canada inventory of evaporite deposits. The stimulus for the study was twofold: Atomic Energy of Canada Limited required data on salt beds as possible long term storage sites for nuclear wastes, and an inventory of evaporite occurrences in Canada was requested for economic consideration. Results of this study in Atlantic offshore areas indicate that the Early Mesozoic evaporites, deposited in fault troughs that formed in the early stages of continental breakup, comprise two formations on the Atlantic margin of Canada. The Osprey Formation, of Late Triassic age, is 2054 metres thick in the type section. It consists of thin to massive beds of relatively pure coarsely crystalline halite with interbeds of red-brown shale. The Early Jurrasic Argo Formation is 780 metres thick in the type section and consists of thick beds of pure salt with minor red and grey shale interbeds. Increasingly marine Jurassic sequences overlying the Argo Formation indicate the initiation of a normal marine depositional regime as the Atlantic Ocean developed. The post-salt deposition of very thick sedimentary sequences resulted in the development of numerous salt flowage structures.

Our subsurface studies have been extended to the North Atlantic through participation in the Deep Sea Drilling Project (DSDP) and we are also participating in workshops related to the naming of sedimentary formations of the North Atlantic. The Mesozoic sedimentary sequences of the western

*Geological Time Scale*

| ERA | AGE (M.Y.) | PERIOD | EPOCH | STAGES |
|---|---|---|---|---|
| CENOZOIC | 1.8 | QUATERNARY | HOLOCENE<br>PLEISTOCENE | |
| | | TERTIARY | PLIOCENE<br>MIOCENE<br>OLIGOCENE<br>EOCENE<br>PALEOCENE | MAASTRICHTIAN<br>CAMPANIAN<br>SANTONIAN<br>CONIACIAN<br>TURONIAN<br>CENOMANIAN |
| | 65 | CRETACEOUS | LATE<br>EARLY | ALBIAN<br>APTIAN<br>BARREMIAN<br>HAUTERIVIAN<br>VALANGINIAN<br>BERRIASIAN |
| MESOZOIC | 140 | JURASSIC | LATE<br>MIDDLE<br>EARLY | |
| | 195 | TRIASSIC | LATE<br>MIDDLE<br>EARLY | |
| | 230 | PERMIAN | LATE<br>EARLY | STEPHANIAN<br>WESTPHALIAN<br>NAMURIAN |
| | 280 | CARBONIFEROUS | LATE<br>EARLY | VISEAN<br>TOURNAISIAN |
| | 345 | DEVONIAN | LATE<br>MIDDLE<br>EARLY | |
| PALEOZOIC | 395 | SILURIAN | LATE<br>EARLY | |
| | 435 | ORDOVICIAN | LATE<br>EARLY | |
| | 500 | CAMBRIAN | LATE<br>MIDDLE<br>EARLY | |
| | 570 | | | |
| PRECAMBRIAN | | | | |

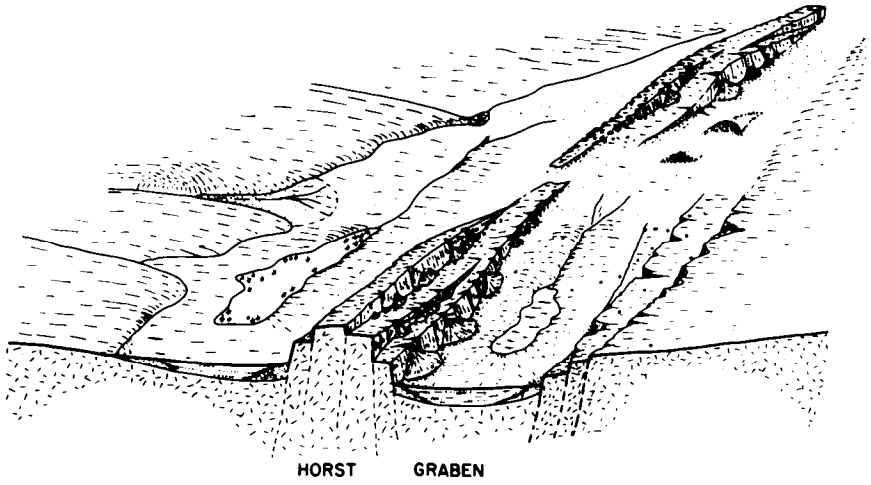


*Geologists discussing a seismic record. (AOL 4165)*

and eastern central North Atlantic Basin have very similar ages, faunal assemblages, and petrographic composition, even though they are separated by the volcanics of the Mid-Atlantic Ridge. Seven sedimentary formations can be recognized in the central North Atlantic Basin. Study of the microfacies of the Jurassic sedimentary sequences narrowed the span of lithostratigraphic and biostratigraphic units. The indication is that the older sediments recovered by DSDP in the central North Atlantic are not older than the middle of the Late Jurassic. These sediments were deposited in an epibathyal environment, above the carbonate compensation depth (CCD). The sea bottom subsided below the CCD in Aptian time. The euxinic conditions in the Aptian-Cenomanian resulted from stagnation of bottom and intermediate water due to the disruption of the deep water circulation, which was related either to separation of the continental plates between the Grand Banks and Spain - Portugal (120 million years ago), or to erogenic movement in the Gilbraltar - northwest Africa region, or to initiation of the breakup of Africa from South America. The bottom circulation was reestablished in the Late Cretaceous.

Data from three wells on the Labrador Shelf (Leif M-48, Bjarni H-81, and Gudrid H-5) have now been released and have facilitated the analysis of geophysical data. Seismic profiles in the vicinity of these wells show the basement to be faulted, although the faults do not disturb the overlying sediments to any great extent. The faults are normal and many have westward-dipping fault planes, which indicates downthrow towards the present coast. These faults are related to a basin-forming episode that occurred in earliest Cretaceous time. Extrusion of subaerial basalt lava flows accompanied the faulting. Both Leif M-48 and Bjarni H-81 penetrated these lavas, which have radiometric dates of 139 to 120 million years. Gudrid H-55 penetrated the entire Mesozoic sedimentary sequence and an unconformity-bound Westphalian dolomite, and terminated in Precambrian crystalline basement.

The study of these wells shows that after a phase of discontinuous elastic continental sedimentation, sediments were deposited in a milieu of rapidly deepening water followed by gradual shallowing conditions. Thus continental sand and shallow neritic sediments of Lower Cretaceous to Paleocene age are overlain by deep water deposits of middle Eocene to lower Miocene age. Succeeding sedimentation occurred under progressively shallower environments, terminating with shallow water Pleistocene sands. Both Bjarni H-81 and Gudrid H-55 encountered thick, gas-bearing reservoirs. In Bjarni the reservoir is the Lower Cretaceous continental sand, which is 98 metres thick, though only about 81 metres can be regarded as hydrocarbon reservoir. In Gudrid, the reservoir is a crystalline dolomite of Westphalian age between the Mesozoic-Cenozoic sediments and the Precambrian basement. This dolomite is 131 metres thick and over 98 metres can be regarded as hydrocarbon reservoir.




*Artist's concept of horst and graben features. (AOL 4144)*

## Upper Paleozoic Basins

Surface and subsurface studies of the Upper Paleozoic basins in the Atlantic Provinces rely heavily upon the use of biostratigraphic zonations from fossil spores. Recently a major study has been directed towards an inventory of the Upper Paleozoic evaporite deposits as part of the Canada-wide evaporfte study. These investigations have outlined a number of areas in New Brunswick, Nova Scotia, and western Newfoundland that may be suitable for nuclear waste storage. The history of these evaporite deposits begins with the continental collision of Africa with North America and Europe during the late Paleozoic Acadian orogeny; this resulted in uplift, folding, faulting, and granitic intrusion. As the orogeny waned the highly fractured basement subsided forming a complex series of northeast-trending horst and graben structures. During the late Tournaisian and early Visean the area continued to subside resulting in the accumulation of playa lake deposits of the upper part of the Horton Group followed by the advance of

the Windsor sea, which may have been an extension of the Visean sea of northwest Europe. The restricted circulation of the Windsor sea in Eastern Canada resulted in the accumulation of thick deposits of evaporites in the lower part of the Windsor Group. During the upper-middle Visean and into the late Visean, the depositional environment of the Windsor sea became shallow and marine, with elastics and carbonates being deposited. From late Visean to Permian, renewed compression, uplift, and erosion removed large areas of Horton and Windsor Group rocks. This erogenic uplift changed the depositional environment of the area from marine to continental, which led to the accumulation of thick deposits of elastics, coal, and minor limestones.

## Lower Paleozoic Basins

A synthesis of the Lower Paleozoic geology of Atlantic Canada, with emphasis on the Appalachian belt, has been carried out to provide a basis for interpreting the plate tectonic evolution of the region. The interpretations by other workers and the results of the present study indicate that the early tectonic history of the Appalachian belt was very complex and involved the opening and closing of two co-existing seaways of oceanic dimensions. The oceans were separated by a crustal block the size of Japan referred to as the Avalon Platform. The seaways were floored by Cambrian and Early Ordovician continental crust (Ophiolite), and Ordovician and Silurian island arc volcanics developed above subduction zones. Almost the entire belt was deformed, intruded, uplifted, and eroded following the final closure of the oceans in Middle to Late Devonian times. To the northwest of the

*Preliminary examination of rock cores from eastern offshore wells (AOL 4121)*

Appalachian belt, Cambrian and Early Ordovician carbonates transgressed northwestward over the North American continent. These deposits record a carbonate bank much larger but in many respects similar to the present-day Great Bahama Bank. Carbonates, evaporites, and elastic sediments were deposited in a variety of depositional settings over wide areas of eastern North America during Late Ordovician, Silurian, and Early Devonian times. Much of Eastern Canada was uplifted and eroded during the Late Paleozoic, except in parts of the Appalachian belt where terrestrial and shallow marine sediments accumulated in a number of 'successor' basins.

## Resource Evaluation

All aspects of our work contribute to a data base for estimating the hydrocarbon potential of the eastern Canadian sedimentary basins. This is a co-operative effort with several agencies within the Government of Canada that provide representatives to a Subcommittee on Geological Potential. (The methodology used was discussed in the 1973-74 Biennial Review.) The Subcommittee completed a reassessment of major frontier areas with particular emphasis on the Labrador Shelf, Mackenzie Delta, and Arctic Islands. A method for determining pool size distributions was developed for use in an economic evaluation. In the past year a coal petrology section was added to the Subdivision. This involved setting up a new coal petrology laboratory with facilities for Vitrinite reflectance measurements (a way of determining the grade of coal). Consultation is provided to the coal exploration programs undertaken by the Nova Scotia Department of Mines and the Cape Breton Development Corporation. A preliminary revision of the coal resources in Nova Scotia has been prepared based on recent results of the Provincial coal drilling program; this was part of the energy policy study of the Department of Energy, Mines, and Resources. A detailed evaluation has been made of thermal and metallurgical resources in the Sydney coalfield. As part of Eastern Petroleum Geology's hydrocarbon geochemistry program, Vitrinite reflectance is being carried out on samples from offshore wells to determine their degree of organic metamorphism.

# Environmental Marine Geology

The ultimate objective of the Environmental Marine Geology program is to improve the understanding of those physical, chemical, and biological processes that control the development and stability of marine geological features and resources. Improved knowledge of critical processes is thus applied to problems of coastal zone development and management, environmental quality assessment, and geological assessment of natural resources. The program is organized among four scientific groups: Paleo-ecology, Organic Geochemistry, Inorganic Geochemistry, and Coastal Geodynamics. The research includes: ecological and paleo-ecological studies of post-Pleistocene foraminifera and Mollusca; hydrocarbon geochemical analyses of offshore exploratory well samples to evaluate hydrocarbon potential; inorganic geochemical studies to determine the mechanisms of metal dispersion and precipitation in nearshore Recent marine sediments; sedimentary and geomorphological studies of beach and nearshore environments to determine the factors that control the evolution and stability of coastal features; and multidisciplinary studies of coastal and estuarine systems to determine the environmental sensitivity and develop models for effective management.

## Paleo-ecology

The main research activities of this group are the ecology and paleo-ecology of post-Pleistocene foraminifera. To determine those environmental factors that may have influenced the distribution of fossils found in subsurface sediments, efforts have been directed at better understanding the present-day ecology of foraminifera.

**Biology and Experimental Ecology.** Studies of the habitat, life cycle, and benthonic community relationship of foraminifera have produced several significant findings valuable for application in paleo-ecology. It was found that only the asexual phase of the life cycle occurs in the high-energy tide-pool habitat. It was also noted that calcareous species have a major bloom in population that coincides with the early fall phytoplankton bloom.

Detailed examination of the tests (skeletal remains) by means of scanning electron microscopy revealed that many benthonic foraminifers are ingested by other invertebrates and that a record of this process is preserved by small gouges, scratches, and etchings on the test surfaces. This evidence from fossil populations can thus be used to estimate the degree of bioturbation of sediments and to determine the relationship between foraminifera and larger invertebrates.

Preliminary studies were begun for a series of in *situ* experiments that will measure the mobility of foraminifera populations. Because a number of forces may be responsible such as storm waves, rafting, and inherent locomotive capabilities, preliminary core samples were examined and dated to establish probable storm events. Several dating techniques were employed including $^{14}C$, pollen zones, paleomagnetic intensity and declination, and changes in fossil species; at present we are trying to resolve the discrepancies found between methodologies and replicate cores.

**Regional and Environmental Studies.** Paleo-ecological field studies have extended from the Arctic to the Maritimes. From detailed studies of foraminifera and molluscs found in core and grab samples collected from the Beaufort Sea a history of sea-level changes and sedimentary processes during the Holocene (last 10,000 years) has been deduced. In the Bay of Chaleur contemporary foraminifera distribution patterns are primarily related to the depth of water and salinity, while the inorganic sediments are related to hydrodynamic energy levels. A major problem in reconstructing the Late Pleistocene-Holocene paleo-oceanography has been the difficulty in applying classical dating techniques.

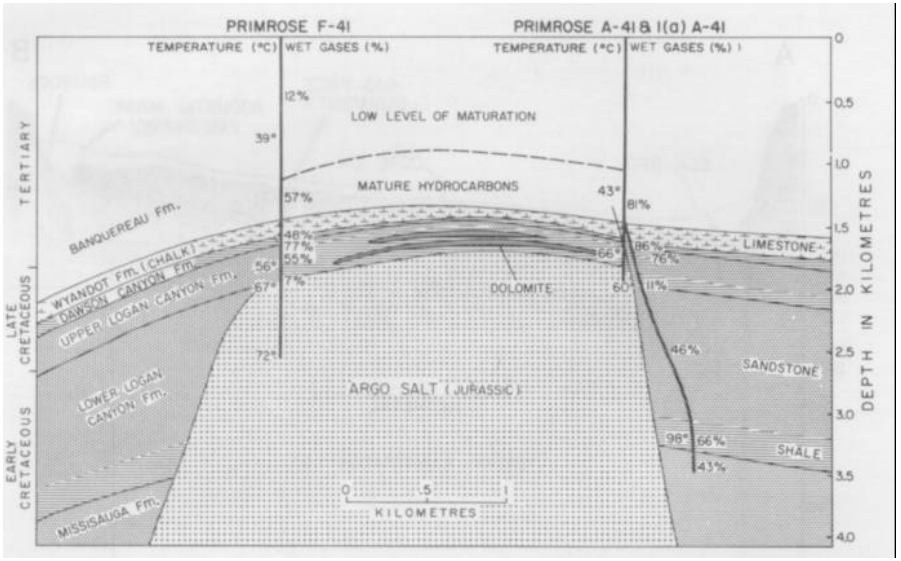
Over the past 2 years a number of cores have been collected from various small basins on the continental shelves off Labrador and Nova Scotia and within the Gulf of St. Lawrence and the Bay of Fundy. An occurrence now recognized as common in many of these cores is the high concentration of methane gas (up to 20,000 parts per million). The paleo-ecologists and organic geochemists have been attempting to deduce the reasons for this gas accumulation. So far it has been established that: (1) methane is only found in sediments containing more than 90 per cent clay-sized material; (2) high concentrations of methane have only been found in sediments containing inner-shelf or estuarine faunas; (3) although organic carbon is a prerequisite for methane production, there is no relationship between the concentration of organic carbon and gas; and (4) the methane gas is produced as a result of bacterial degradation of organic matter under post-depositional anaerobic conditions.

**'Benthonics '75'.** The first international symposium on benthonic foraminifera was held in Halifax in August 1975. The symposium, sponsored by the Atlantic Geoscience Centre and Dalhousie University, Halifax, welcomed about 200 participants and heard 80 detailed papers. Many of the 11 organized sessions focused on some aspect of modern marine environmental relationships and Quaternary paleo-oceanography as revealed by the biology and distribution of Recent benthonic foraminifera. There was also a significant emphasis on biostratigraphic and paleo-ecologic relationships in Mesozoic and Cenozoic sediments. Two volumes of the symposium papers and proceedings will be published as a special edition of *Maritime Sediments.*

## Organic Geochemistry

Investigations of the ancient organic constituents found in samples obtained from offshore hydrocarbon exploration wells have been the main activity of the organic geochemistry group. Some effort has been directed at environmental geochemistry problems and special problems involving engineering properties of Recent marine sediments.

**Hydrocarbon Exploration Geochemistry.** The long term goal of providing information to assist in evaluating the oil and gas potential of offshore areas of the east coast of Canada was realized during the past 2 years. Analyses for organic carbon and gaseous hydrocarbons were completed for over 3000 samples from 24 exploratory wells many of which are located in the 'frontier' areas of exploration such as the Labrador Shelf. These wells, in addition to those drilled a few years earlier on the Scotian Shelf and Grand Banks, have also been studied in some detail by

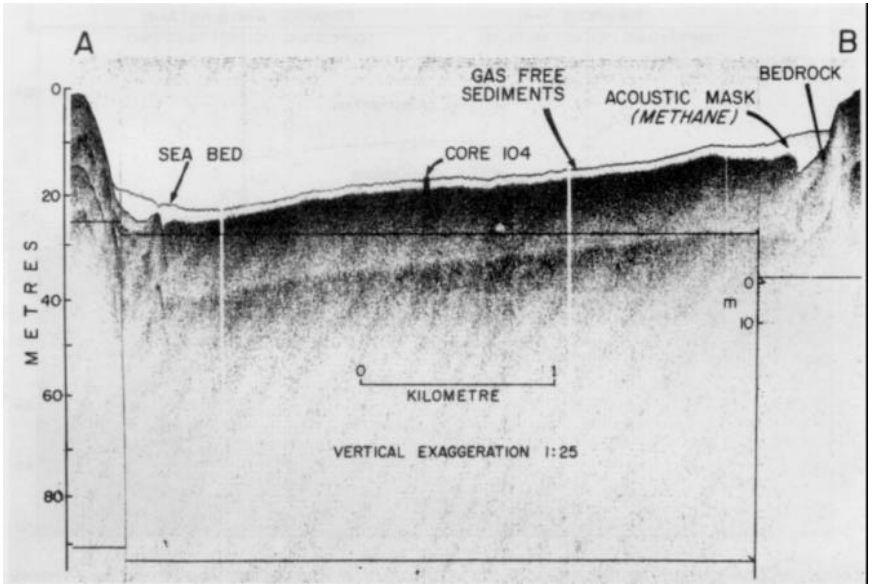



*Cross-section depicting the shallow occurrence of wet gases in the Primrose Prospect (Sable Island, NS) due to high heat gradients caused by the underlying Argo Jurassic salt dome (AOL 4771)*

extracting the heavy hydrocarbons (those having more than 15 carbon atoms in the molecule). By examining the proportion of various hydrocarbon and non-hydrocarbon fractions, by quantitative analysis of the saturated hydrocarbons, and by statistical evaluation of a wide variety of geological and geochemical data, models of organic matter deposition, diagenesis, and maturation into hydrocarbons have been developed to explain the observed occurrences. Major problems have been identified for further regional research and model synthesis. These problems include determination of the original type of organic matter (marine or non-marine) deposited in the ancient basins, a means of identifying the oxidation level of the paleo-environment, an accurate estimate of paleothemal gradients, and a means of measuring hydrocarbon migration.

**Organic Geochemistry and Recent Sediments.** As noted above, there has been an interdisciplinary research effort to determine the reasons for methane generation in Recent sediments. In addition to the paleo-environmental factors that control the favourable conditions for methane generation it has been found that the genesis of bacterially fermented methane is closely associated with the diagenesis of soluble sulphates. Methane production does not begin unless the concentration of soluble sulphates is considerably below average background levels.

It has long been recognized that organic matter in soils influences the ‘strength’ of soils, or more technically the shear strength, compressibility, and liquifaction. These geotechnical properties in marine sediments have now been demonstrated to be directly related to the presence of natural organic compounds. Experiments showed that removal of these compounds caused the marine sediments to become less cohesive and to ‘shrink’ with shearing. Experiments with natural humic compounds showed that these compounds can retard deterioration of cement-concrete structures in the marine environment.




*A continuous seismic profile in St. Margaret's Bay, NS. The acoustic mask is the result of methane in bubble form in the sediment. (AOL 4116)*

## Inorganic Geochemistry

The mechanisms that control the deposition of metals in Recent marine sediments are determined by the geochemical behaviour of these metals in sea water and with suspended particulate matter. Elucidating some of these mechanisms is the main emphasis of the research projects being carried out in this group.

**Trace Elements and Solution Stability.** As a result of the search for a suitable method with which to determine trace element concentrations in sea water a relationship was found between the relative amount of 'reactive' (or labile) metal and pH. This relationship appears to be related to metal hydrolysis and may be a significant mechanism in regulating trace metal equilibrium in some natural water. It has also been found that when abundant organic matter is present in natural waters the simple 'ideal solution' characterisics no longer hold; rather the reactivity of metals is strongly correlated with the amount and type of organic matter.

Experiments with suspensions of natural muds and sands demonstrated that fine-grained sediments have a greater capacity to remove trace metals from solution than coarser grained sands. However, it is by no means certain that the reaction mechanism is one dependent on simple surface absorption. Other mechanisms now being investigated are: ion exchange, co-precipitation, and metal-organic compound chelation.

Some preliminary experiments have been performed on methods of analysis of chelated $Cr^3$ . These studies may lead to a detailed investigation of the geochemistry of chromium in sea water and marine sediments, and to some understanding of how this metal can be used to indicate redox conditions of metal precipitation in the sea.

## Coastal Geodynamics

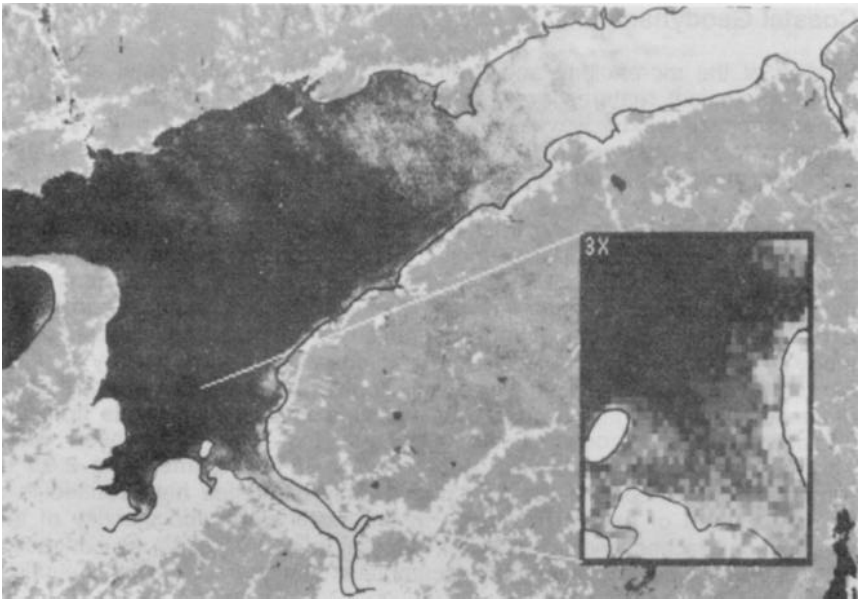
Studies of the morphology and sedimentary character of coastal and nearshore geological features are normally undertaken by measuring dynamic forces such as winds, waves, tides, and currents, and then relating these variables to the observed responses in beaches, submerged bars and ridges, sediment movement, and surface features such as ripples and sand waves.

**The Magdalen Islands.** An intensive study of the processes affecting the morphology and sediment movement on the Magdalen Islands was carried out in 1974 and 1975. This study related wave and weather conditions during two seasons (summer and fall) to the observed responses in beach and nearshore morphology and sediment movement rates. Because the study was carried out on a west-facing coastline and a nearby (3 kilometres away) east-facing coastline, the contrasting environments are quite dramatic. The west-facing coast was exposed to prevailing winds from the westerly quadrant throughout the year with the result that mean wave energy levels were greater by factors of 2.25 in summer and 2.95 in winter, as compared with the east coast. This difference has resulted in a general pattern of extreme changes in the morphology and stability of the west coast beaches and in sediment by-passing on that coast as contrasted with ridge-welding and sediment accumulation on the east coast beaches.

The importance of these studies goes beyond the immediate application to the coastal management of the Magdalen Islands because the environments studied there in detail have permitted the development of certain process-response models that can now be applied to many other coastal zones in the Gulf of St. Lawrence.

**Minas Basin and Bay of Fundy.** Studies have been undertaken to evaluate several aspects of sediment dynamics. One of the obvious questions that stimulated the research in this area is what would be the effect of tidal power development on the geologic processes now dominating the system? To answer even some aspects of this question, projects have been undertaken to measure: the amount of mud that has accumulated in front of the Windsor causeway since its construction in 1970 and to relate this phenomenon to processes of siltation in a tidally altered estuary; the flux of suspended sediments between the Minas Basin and the Bay of Fundy; the rate of coastline erosion as a means of estimating the rate of supply of new sediments to the system; and the detail in physiography and structure of bottom sediments in an effort to deduce the history of sedimentation in the Basin. These studies have required the implementation of several innovative techniques such as the use of remote sensing to map the distribution of suspended matter throughout the Minas Basin.

**Feasibility of Offshore Mineral and Aggregate Resources.** A review of available information concerning the possible economic value of heavy mineral, sand, and gravel deposits was undertaken. This review was designed to determine the types of new information that would be required in order to make a resource assessment; the areas where survey information should be compiled on a priority basis; and the environmental feasibility studies that should be conducted in areas of potential exploitation. It was generally concluded that nearshore areas containing sands and gravels are most likely to become attractive to exploration and development because of their valuable resource of construction aggregate.




*Satellite photograph showing suspended matter in the Minas Basin, NS.*

## Multidisciplinary Studies

Since 1973 the Environmental Marine Geology Subdivision has initiated two major multidisciplinary studies involving co-operative field and laboratory investigations by all staff. The purpose of these studies has been to broaden the scientific scope of investigations in complex environmental systems thus allowing for a greater depth of understanding of the interactive physical, chemical, and biological processes.

**Completion of Canso Strait Studies.** Several scientific reports have been published that describe the effects of changing environments on fossil-forming organisms. The direct effect of the construction of the Canso Causeway has been the restriction of Atlantic biotopes to areas south of the Causeway. In the longer term, and with increased industrialization of the Strait area, severe alteration of the viable benthonic communities has occurred. An order of tolerance to environmental pollution was established in which the most tolerant forms were the foraminifera, followed by the molluscs; the least tolerant were the ostracods. By contrast, a deep burrowing shrimp, *Axius serratus,* thought to be extremely rare was discovered in large numbers in polluted regions of the Strait of Canso.

**Commencement of Miramichi Estuary and Bay Studies.** This study focuses on the development of a broad-shallow-bay type inlet. This inlet, which faces the Gulf of St. Lawrence, has a well developed barrier island system extending across the seaward end. Because of the intimate relationship between the growth and stability of a barrier island system and the overall evolution of the estuary-bay system, the study is designed to reveal this

interaction. In addition, the study will emphasize seasonal aspects of variation in hydrological and sedimentological processes taking place throughout the system. Seasonal sampling and observations were begun in September 1975 and continued with a unique winter field season in which operations were conducted over the ice-covered bay and estuary using sampling sheds mounted on “ice-runners”.

*A portable laboratory being towed onto the ice of Miramichi inlet, NB.*

# Program Support

The major responsibility of the Subdivision is to provide central support facilities and assistance in AGC field projects. In 1975, a normal year, our staff averaged almost 20 per cent of their time in the field. In both the laboratory and field, they maintained, calibrated, and operated equipment, and collected, processed, and stored field data and geological samples. Another aspect of the work is the development of systems and equipment to improve the efficiency and capabilities of AGC projects. Recent examples of our activities are discussed below.

**Instrument Operation and Maintenance**

The acquisition and modification of a number of standard 6 metre freight containers to serve as portable laboratories both at sea and in the field have greatly improved logistics and equipment installation and operating conditions. During February 1976 a successful 2 week field sampling project was carried out on the ice of Miramichi Bay (New Brunswick) using a portable laboratory towed onto the ice by snowmobile.

During a multidisciplinary cruise on the CSS *Baffin* off Senegal, January to April 1976, arrangements with a local company to provide shipboard 24 hour a day contract maintenance on our geophysical instrumentation were so successful that they were continued for the 4 month multidisciplinary cruise on the *Martin Karlsen* during the summer of 1976.

*Nearshore survey launch in operation. (AOL 4106)*

A co-operative project with the German Hydrographic Institute in Hamburg, F.D.R., was carried out during the spring of 1976 in which two AGC Askania GSS-2 sea gravimeters and two D.H.I. Askania GSS-3 sea gravimeters were calibrated over the European gravity range from Eibsee in southern Germany to Hammerfest in northern Norway, a range of 23 degrees of latitude and 2100 milligals. The purpose of the project was to determine the linearity and value of the gravimeter calibration factor over a large gravity range, equivalent in size and value to that from Nova Scotia to the high Arctic islands. The calibration enabled the quality of future AGC gravity data to be greatly improved.

## Data Systems

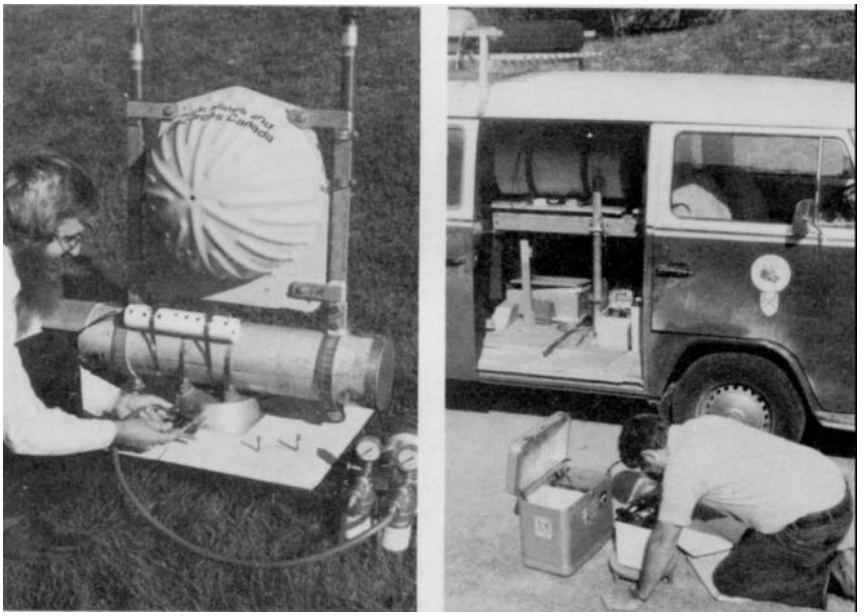
A geological sample curation policy and facilities have been recently established at AGC. The facilities, located in a separate building, consist of 225 square metres of dry heated storage and 56 square metres of refrigerated storage space. Recent geological samples collected by AGC

*Curation facilities for the storage of AGC's geological samples. (AOL 4167)*

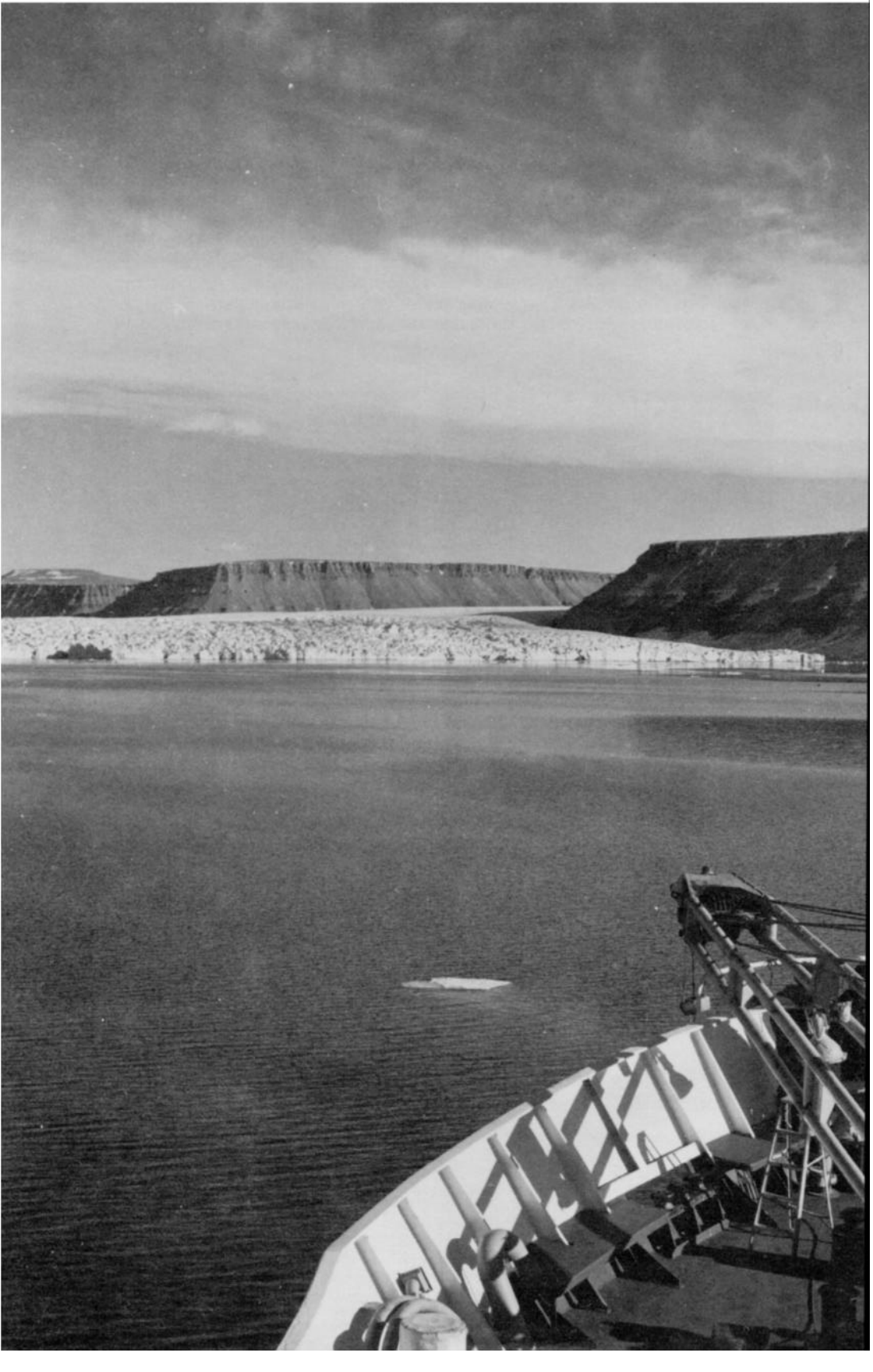
staff are now properly stored, inventoried, and subsampled with the resulting data being entered in a data retrieval system. Most of the older 1963 to 1971 cruise records and non-digital data have been microfilmed and the original data transferred to the Public Archives of Canada, Dartmouth, N.S., for permanent storage. This has freed space for more recent data and provided for more permanent storage. During 1976 considerable effort has gone into the design of a new geophysical data storage and retrieval system to replace our present 10 year old outdated GEOFILE system.

## Systems Development

To improve the capabilities of the air-gun seismic reflection system a Time Variable Gain (TVG) unit, a new seismic amplifier, and a variable speed paper transport unit to control the recorder chart-paper speed relative to the ship speed have been designed. Side scan sonar data processing has been expedited by the design of tape recording facilities for and the play-back and display of the data on a fibre-optic recorder. Another major project was the investigation of the ocean bottom seismometers (OBS) available. Two more OBS of a Cambridge University design are now being built.



*Preparation of an ocean bottom seismometer (left) and calibration of sea gravimeters over the European gravity range (right).*



# Regional Reconnaissance

The program of the Regional Reconnaissance Subdivision is oriented towards meeting the broad objectives of geodynamic research as it relates to the development of the continental shelves, margins, and adjacent ocean basins of Atlantic and Eastern Arctic Canada. In the third report of the Canadian Geodynamics sub-committee this research is summarized as the "determination of the volcanic, sedimentary and the metamorphic history, time-space relationships and geotectonic implications of the Appalachian . . . and Innuitian Fold Belts and their adjacent ocean basins".

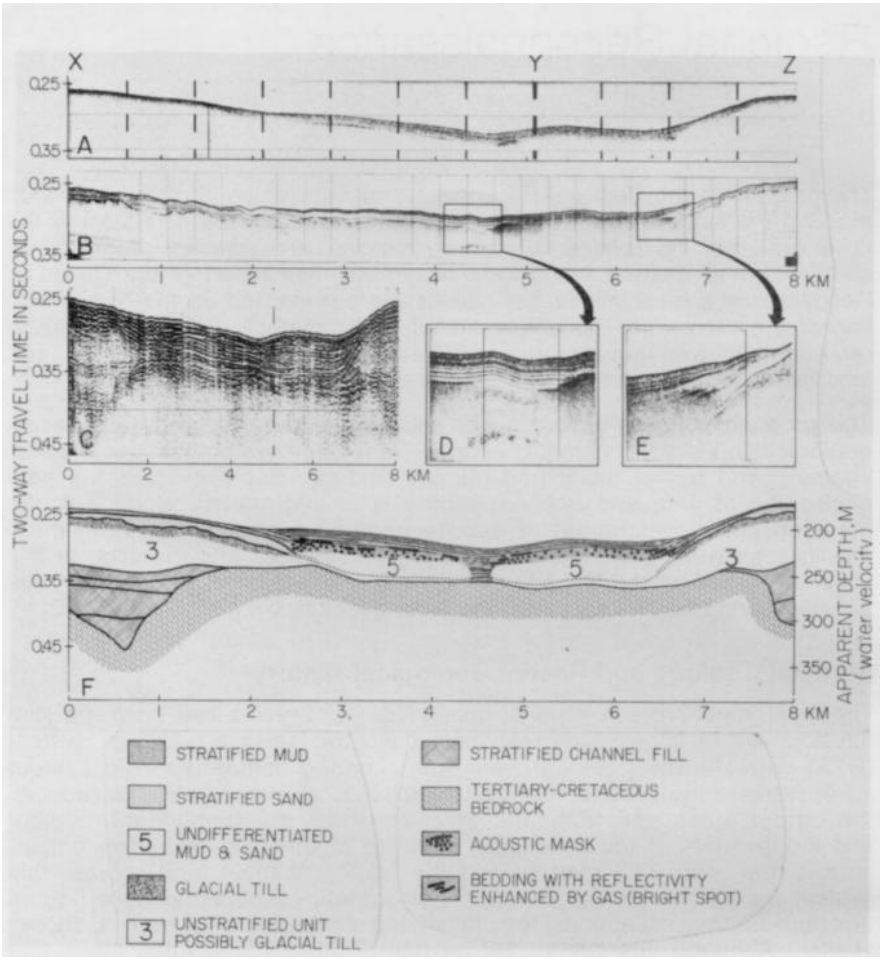
The program consists of four major activities: surficial geology and recent geological history, systematic bedrock mapping, systematic geophysical surveys, and ocean basin and margin studies. Each involves the field acquisition of data and regional synthesis of information, along with the initiation and development of new technology aimed at providing more definitive answers to questions on geological structure and evolution in this important region of the Canadian landmass. Achievements in each of these activities during the Review period are summarized below.

## Surficial Geology and Recent Geological History

The most important achievement during the last 2 years has been the joint development of a new high resolution deep tow seismic reflection system (DTS) with Huntec ('70) Ltd., a Toronto based company. This system incorporates a wide bandwidth (0-10 kilohertz) electro-acoustic transducer, the output pulse spectrum and level of which are highly reproducible and independent of towing depth. Because of the high resolution obtainable, better than 0.25 metres, and the fidelity of the sound source, this system permits us to use the acoustic signatures obtained from bottom and sub-bottom reflections for classifying sediment type from a survey vessel. Although this cannot yet be done routinely, the project has met with considerable success and has opened up new opportunities for research into sedimentary processes and dynamics. During 1975, the Huntec DTS was used on four major cruises of the CSS *Hudson* and acquired data on the Scotian Shelf, on the Grand Banks of Newfoundland, in the Gulf of St. Lawrence, and off southeast Baffin Island. In all cases new information on the nature of the surficial sediments in these areas was recorded. In 1976, with improvements based on the previous year's field work and the beginning of on-line digital recording, terrain studies were undertaken in the Arctic offshore regions and on the northern Labrador shelf.

The high resolution seismic data obtained with the Huntec DTS have been effectively combined with side-scan sonar, bathymetric, and conventional seismic data in the development of an integrated survey approach for the work on the Grand Banks. The accompanying figure shows a composite interpretation (F) using an echogram (A), a DTS (B), and air gun (C) seismic records. Sections (D) and (E) are enlarged areas of the DTS record (B); they illustrate the very fine stratigraphic detail resolved by the Huntec system.

As part of the background for studies on the Labrador Shelf, the recent geological history of the Labrador Sea has been studied in an attempt to




*An integrated approach to interpretation. See text.* (AOL 3821)

better determine the glacial history of Labrador and the importance of glaciation to the development of the banks on the Labrador Shelf. This work is now being focused on Saglek Bank (the northernmost bank of the Labrador Shelf) as part of a comparative study with the Hamilton Bank (a southern bank), a study of which was completed in 1974. Bathymetric data, with some sub-bottom data, have been obtained over Saglek Bank as part of the multiparameter survey program using a Raytheon 3.5 kilohertz hull-mounted sounding system. Additional reconnaissance high resolution seismic lines have been completed as part of the planning for 1977.

## Systematic Bedrock Mapping

The program of bedrock mapping has also benefitted tremendously from the Huntec DTS precise mapping instrument. Penetration obtained with the system is sufficient in most offshore areas to define the bedrock surface; in some areas significant penetration into the bedrock is obtained and bedding planes are often clearly identified. The precision with which

shallow bedrock surfaces can be mapped has provided new opportunities for direct sampling of these layers with the electric rock-core drill developed at BIO (see Metrology, AOL).

Three offshore regions have received major attention in the past 2 years. On the Grand Banks work has been concentrated on the central region from the Avalon peninsula out to Flemish Cap. Additional field work in this area and also on the Tail of the Banks is necessary to complete the mapping of the major portion of the Banks. Preliminary maps of the northeast Gulf of St. Lawrence and of the area off northeast Newfoundland have been completed in collaboration with the Regional Economic Geology Division, Geological Survey of Canada. The bedrock mapping and the completion of geophysical mapping off northeast Newfoundland were integrated to enable the onshore geological trends of northeast Newfoundland to be extended into the offshore and across the continental margin. The third area of bedrock mapping, off southeast Baffin Island, was begun as part of the 1974 *Hudson* cruise to the Arctic. Initial attempts to sample the bedrock with the BIO electric drill were largely unsuccessful, but the availability of the Huntec DTS to control site selection in 1975 and the resulting improved core recovery with the drill provided the incentive to attempt more work in this important region of the near Arctic. The small trial project in 1975 was part of a geophysical cruise in the Labrador Sea and Davis Strait and the project plan is to complete the mapping of the Baffin Island shelf south of Cape Dyer with additional field work in 1976 and 1977. The first phase of this work was completed successfully as part of *Hudson's* 1976 Arctic cruise.

## Systematic Geophysical Surveys

Our major project within this activity is the offshore multiparameter surveys carried out jointly with the Hydrography Division, AOL. This is a continuing project to obtain hydrographic and geophysical coverage of the continental shelf and margins of eastern Canada to standards specified by the two federal government departments concerned (the Department of Energy, Mines and Resources and the Department of the Environment). The data obtained are published as maps in the Natural Resource Series by the Canadian Hydrographic Service. The geophysical data are also used for regional geological interpretations.

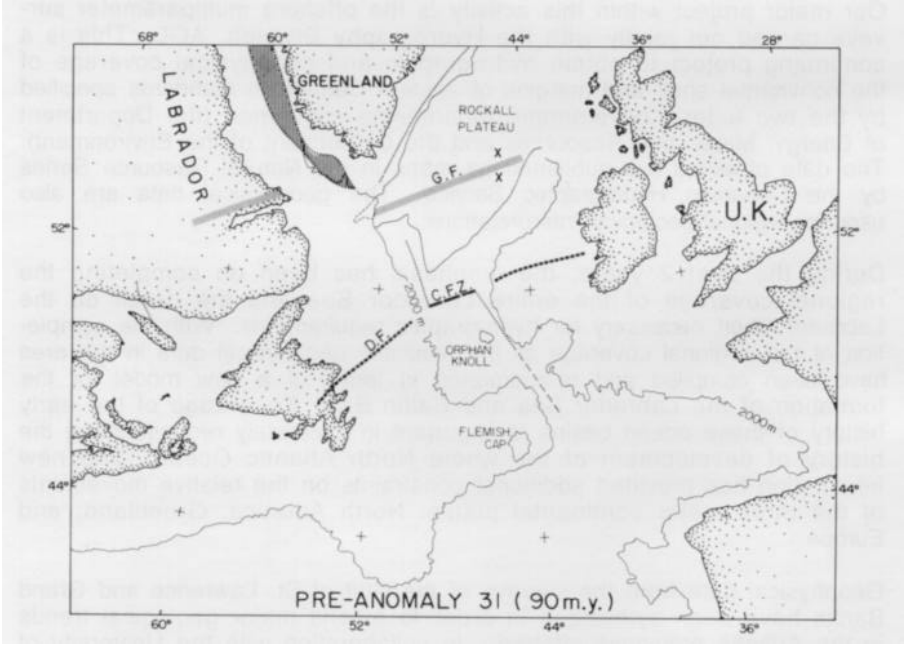
During the past 2 years, the emphasis has been on completing the regional coverage of the entire Labrador Sea and the detail on the Labrador Shelf necessary for hydrographic requirements. With the completion of this regional coverage all the available geophysical data in the area have been compiled and re-interpreted in terms of a new model for the formation of the Labrador Sea and Baffin Bay. Knowledge of the early history of these ocean basins is important in accurately reconstructing the history of development of the whole North Atlantic Ocean. The new information has provided additional constraints on the relative movements of the three major continental plates: North America, Greenland, and Europe.

Geophysical data from the surveys of the Gulf of St. Lawrence and Grand Banks have been synthesized in order to extend major geological trends in the Atlantic provinces offshore. In collaboration with the University of Rennes in France, the significance of trends in Newfoundland and on

*In the eastern Arctic.*

the Grand Banks has been studied and correlated across the Atlantic to Spain, thus, providing new control on the early reconstruction of this part of the Atlantic Ocean.

An important addition to the multiparameter survey program in 1976 was the addition of the Canadian International Development Agency (CIDA) funded program off the coasts of Senegal and The Gambia. This Subdivision provided the geophysical participation on the program in co-operation with the Hydrographic staff from the Central Region, Canadian Hydrographic Service. Maps of free air gravity and magnetic anomaly at a scale of 1:1 million have been produced and seismic data obtained with both air guns and the Huntec deep tow system are included in the report on the offshore geology of the area.




*A reconstruction of the North Atlantic Ocean. (AOL 4154)*

## Ocean Basin and Margin Studies

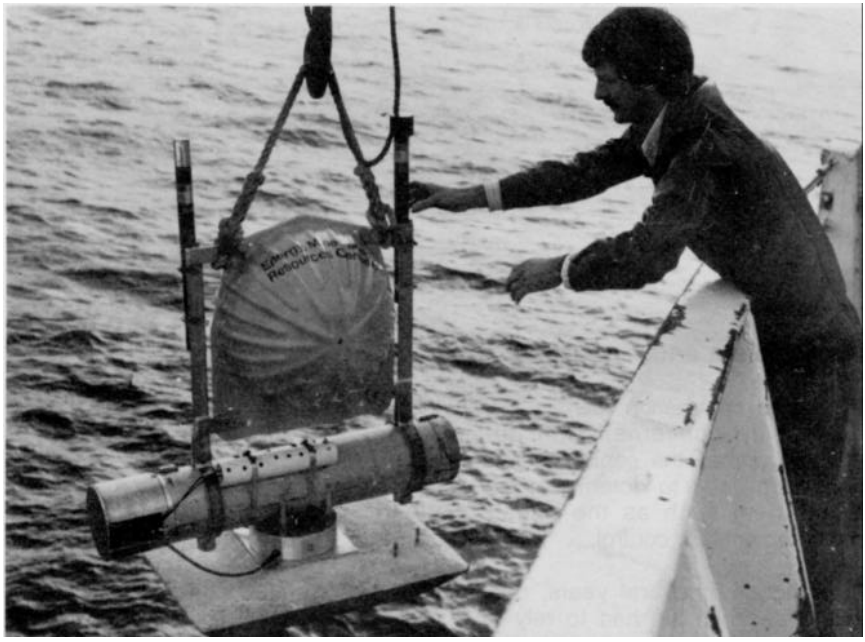
The prime information for this activity comes from seismic work since these studies are concerned with obtaining information on the deep crustal structure across the continent-ocean margin. Gravity and magnetic measurements are used to determine changes in structure that occur across major boundaries, such as the ocean-continent transition, using the seismic measurements for control.

Over the past several years, our crustal seismic measurements have been limited because we had to rely on equipment deployed on the sea surface for receiving seismic signals refracted within the upper layers of the earth. An effort has been made during the last 2 years to upgrade our measurement capability by acquiring a number of ocean bottom seismometers (OBS). These instruments will enable us to determine the extent to deep sedimentary basins on our margins, the variation in crustal structure across the margins, and small scale variability within the main crustal layers with far more precision than was previously possible.

During the program of acquisition and evaluation of ocean bottom seismometers we have participated on two major site surveys in the North Atlantic as part of the International Program of Ocean Drilling (IPOD). These site surveys have been carried out to define the crustal structure in the areas where deep crustal drilling is proposed for the drill ship *Glomar Challenger.* The surveys used OBS built for IPOD by the Lamont-Doherty Geological Observatory, N.Y. The first two OBS, purchased by AGC from the University of Hawaii, have been used on a joint experiment with the Earth Physics Branch, Department of Energy, Mines and Resources, off the west coast of Canada; as well as recording refraction data during the experiment, a large number of earthquakes were recorded.

Studies of the eastern margin of the Grand Banks and the adjacent Newfoundland Basin have essentially been completed with the successful short cruise on the *Martin Karlsen* at the end of the 1976 field season. This work has included studies on the petrology of the Newfoundland seamounts and the interpretation of magnetic data in the Newfoundland Basin. The effort here is to relate the origin of the Newfoundland basin to the early history of the Atlantic Ocean and the formation of the eastern margin of the Grand Banks.

Seismic data obtained in 1976 across the eastern Baffin Island continental margin show that the transition from continental to oceanic crustal structure



*An ocean bottom seismometer being deployed. (AOL 4095)*

occurs over a very short distance, approximately 30 kilometres. The refraction measurements define a deep sedimentary basin on the edge of the continental shelf off northern Baffin Island and show that Lancaster Sound is filled with about 10 kilometres of Mesozoic or Paleozoic sediments. Additional geophysical data on both the eastern and western margins of Baffin Bay have been obtained on the CSS *Hudson's* 1976 Arctic cruise (see part F, Major Cruises of 1975/76).

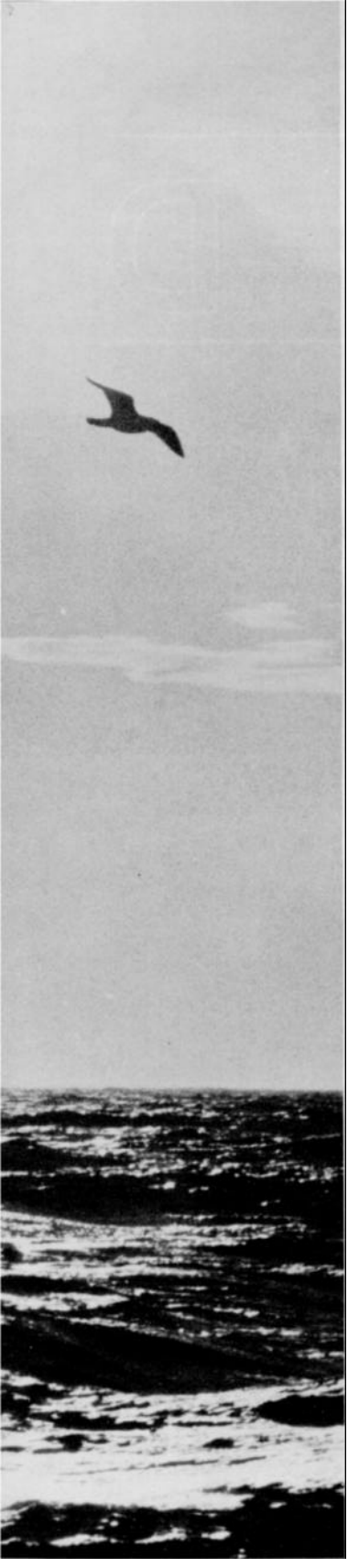
Studies on the continental margins have led to difficulty in defining the transition from continent to ocean in some areas. As well as leading to an effort to upgrade our measurement techniques to provide some information on the true nature of the crustal rocks beneath our continental margins, these discrepancies have resulted in renewed interest in undertaking comparative studies off different margins around the world.

D

# Institute Facilities (IF)
# Ocean and Aquatic Sciences, Atlantic
# Department of the Environment
# 1975/76

Manager - R. L. G. Gilbert

- Ships Division
- Engineering Services Division
- Computing Services
- Library Services
- Drafting and Illustrations
- Photography



# Manager's Remarks

The Gentleman Scientist of the eighteenth century carried out his research in almost total isolation. The Oceanographer or Marine Surveyor today requires an associated team of specialists to carry out his work. In order to collect basic data, ships are usually essential - and today's research or survey vessel is a very sophisticated piece of machinery, staffed by specialists and capable of diverse tasks even under extreme weather conditions. The instruments that collect the data and establish the position of the ship must be operated and maintained by specialists; the computers that process the data, both on the ship and on shore, are operated and maintained by their own skilled staff. The preparation of the results of the work demands the assistance of editors, draftsmen, and photographers if the best and clearest presentation is to be made; and today's library - the repository of all wisdom - is so complex that the librarian of 50 years ago would be totally incapable of working there.

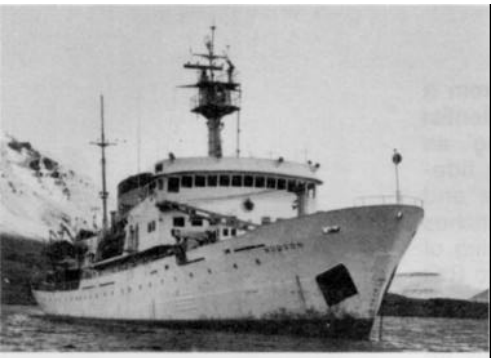
At the Bedford Institute of Oceanography, most of these services are provided to any user by a central group, Institute Facilities, in the belief that the technical support to carry out oceanographic research can most efficiently be provided by a facility common to all. The six units of Institute Facilities - Ships, Engineering Services, Computing Services, Library Services, Drafting and Illustrations, and Photography - support most of the research and survey work done by the Institute and also give considerable support to other, outside, agencies. In the sense that basic operations remain unchanged over the 2-year period covered by the Biennial Review, much of the work is routine; but perhaps the improvements, which are made continuously to facilities and services in support of the research, are the most significant part of the support. The bridge of CSS *Hudson was* rebuilt in the winter of 1975, and now includes a navigation centre, provides the officer of the watch with a good view of over-the-side operations for the first time, and significantly reduces the operating fatigue of all those who work there. The shipborne computers have been modified so that all three major ships now have essentially identical, considerably upgraded, systems. Items of equipment, which have been designed and built to

improve the quality of the field data, range from a sampling system designed to enable the scientist to collect water samples from 'interesting' as opposed to 'routine' parts of the sea to a tide-gauge that measures the state of the tide and relays the result to the survey ships and launches in the area. The Library made on-line searching of over a dozen scientific data bases accessible to BIO scientists. In 1976, an 16 million dollar building program to expand the BIO campus was begun and Institute Facilities staff have been extensively involved in design and contract negotiations for the new buildings, and also in modifications to existing facilities that will bring them up to the best modern standards of construction and operation. Another important development of 1976 was the designation of the BIO library as the future major Canadian oceanographic library. A librarian has now been hired to direct the development of this national collection.

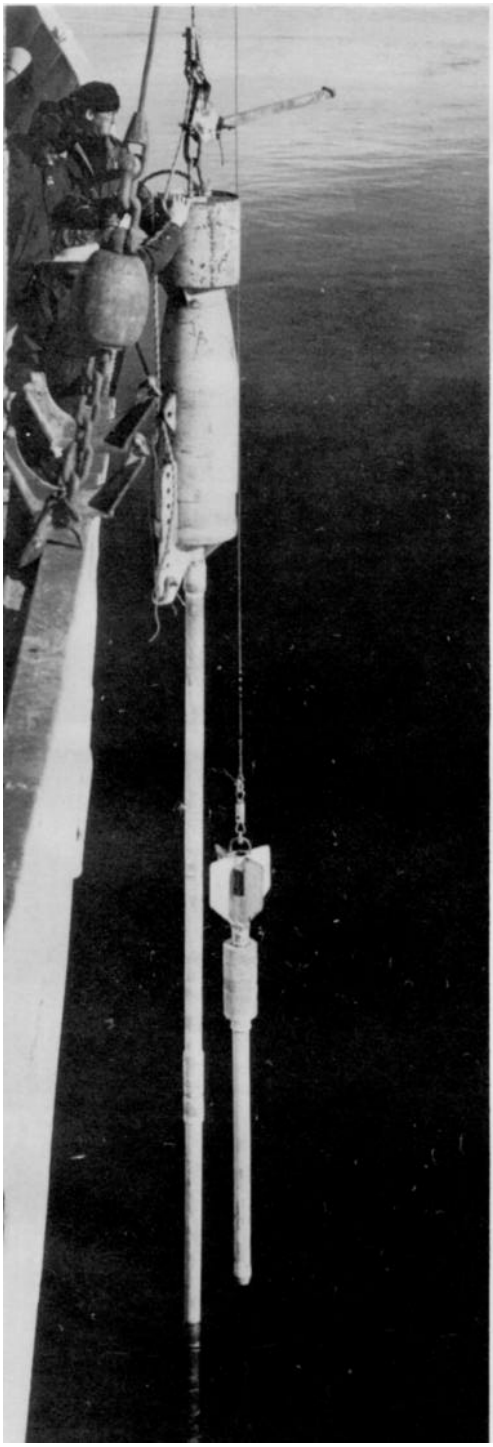
In this Review, for the first time, we have highlighted the work of Institute Facilities in a series of photographs. We hope the following pages will give you, the reader, an appreciation of our operation and of how it serves the scientific research programs described in other sections of this Review.

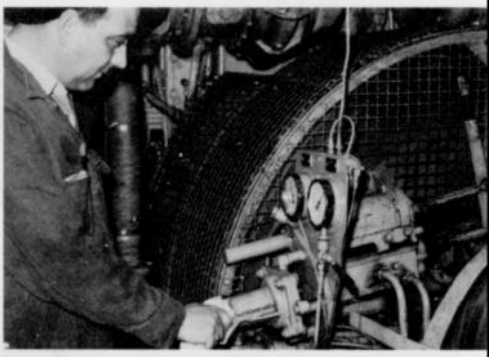
R. L. G. Gilbert
Manager
Institute Facilities

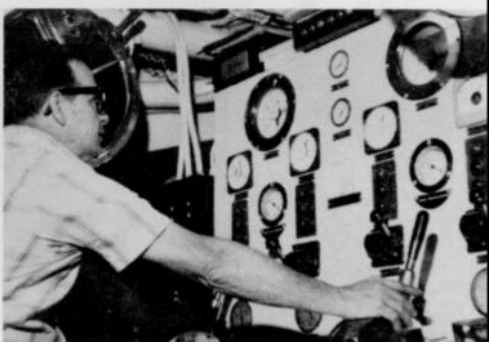
# Ships



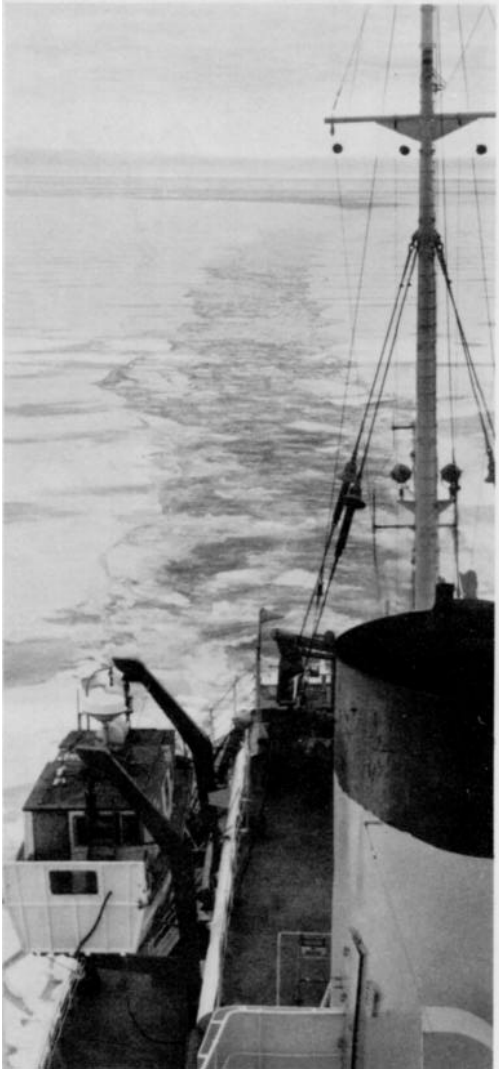
*The Bedford Institute of Oceanography operates a permanent fleet of four ships (shown at left) as well as a number of launches and chartered vessels in support of the Institute's research and survey activitivities. CSS* Hudson *(built 1963; length 90.4 metres; displacement 4793 tons) is used mainly for multidisciplinary offshore oceanographic surveys from arctic to tropical waters: she is ice strengthened, carries a ship's complement of 62 and up to 25 scientists, and can cruise 24,000 kilometres at 13.5 knots with 60 days endurance. CSS* Baffin *(built 1956; length 87.02 metres; displacement 4420 tons) is used for offshore hydrographic charting and geophysical studies and for survey work in coastal and arctic waters: also ice strengthened,* Baffin *can carry 28 scientists with a ship's complement of 77. She has a range of 22,400 kilometres at 13 knots with 45 days endurance. CSS* Dawson *(built 1967; length 54.54 metres; displacement 1975 tons) is used for oceanographic work in offshore and coastal waters; she has a bowthruster, as does Hudson, and controllable pitch propellers and is well suited to placing and retrieving moored instruments. Her cruising speed is 13 knots. CSS* Maxwell *(built 1961; length 30.5 metres; displacement 275 tons) is used mainly for hydrographic charting along the Atlantic coastal areas. She has a cruising speed of 10 knots.*

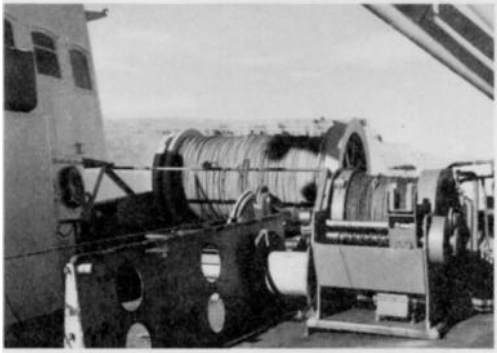







HUDSON





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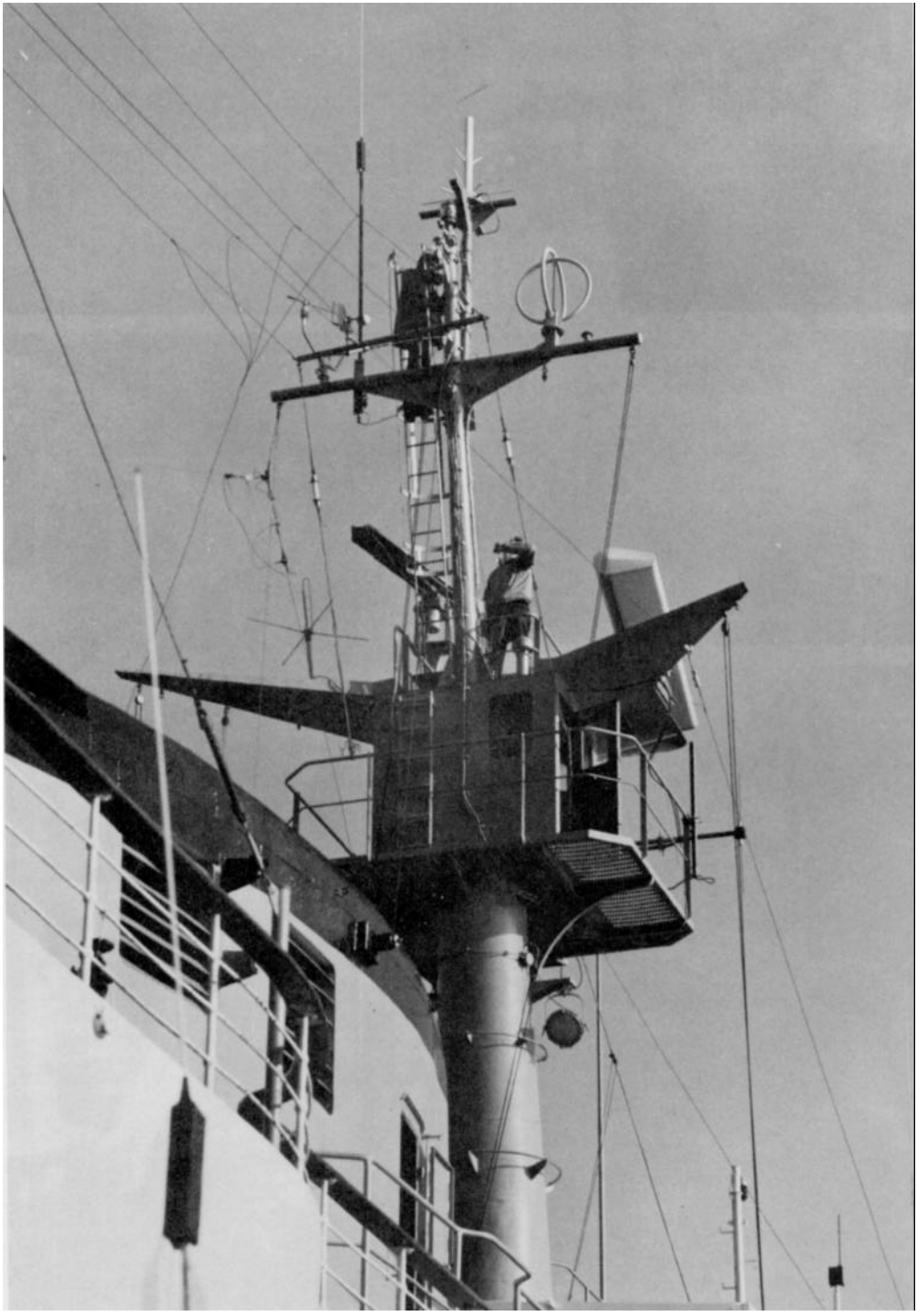

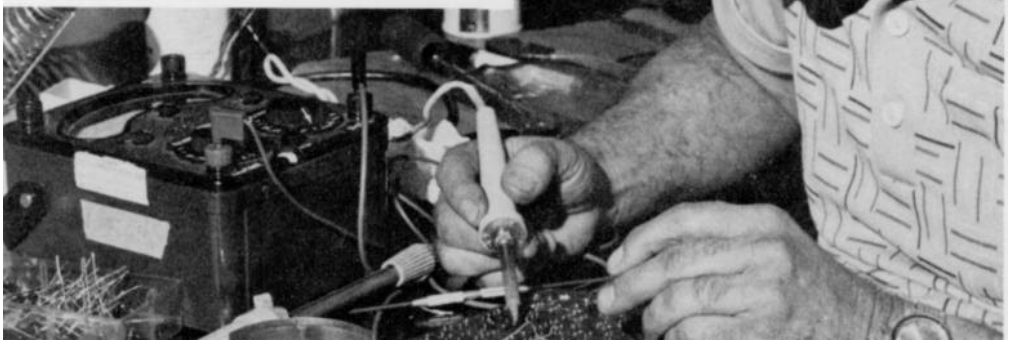

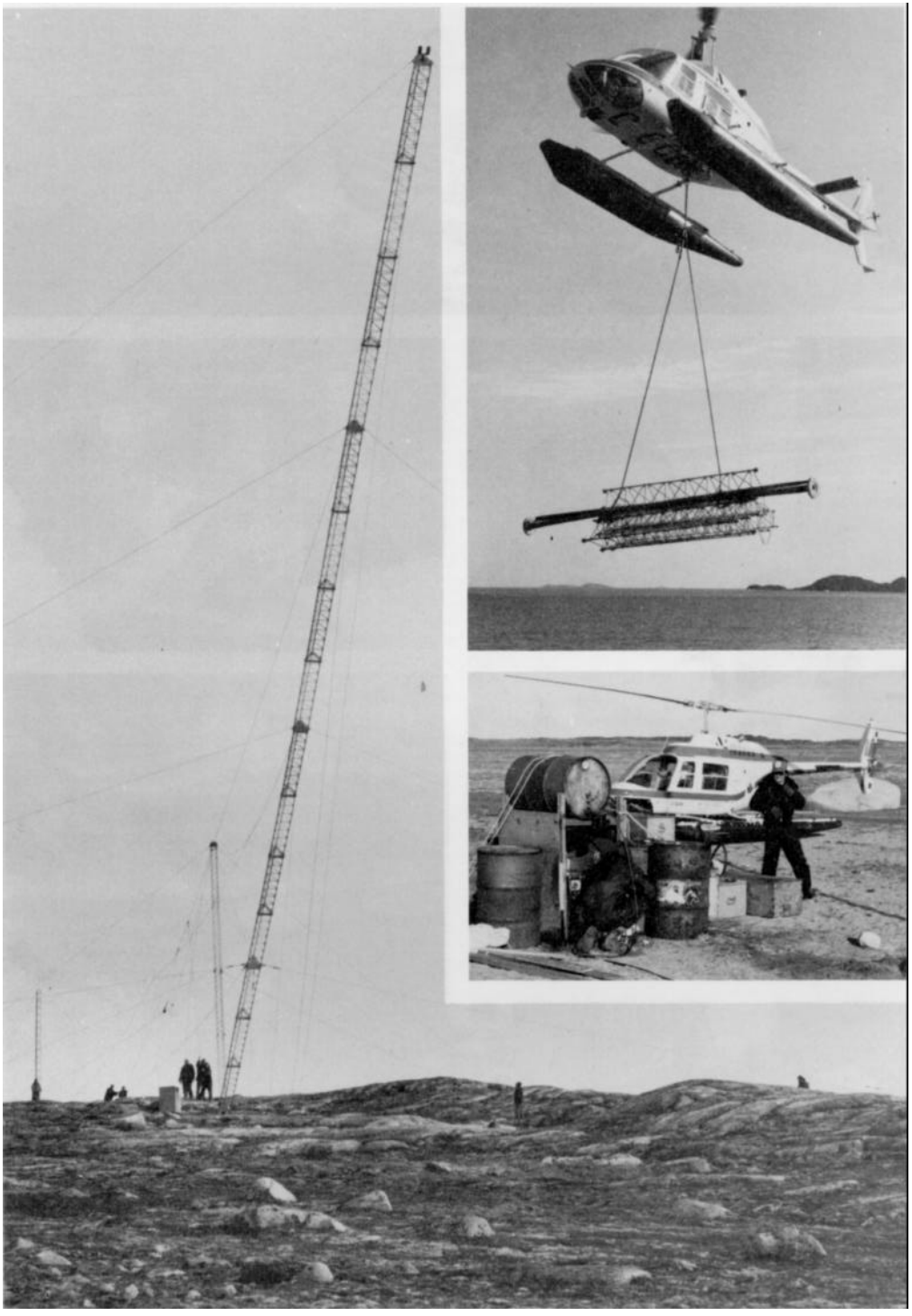

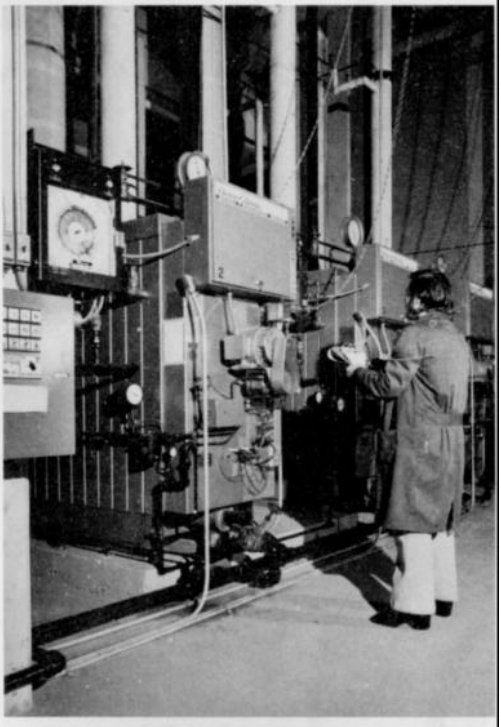

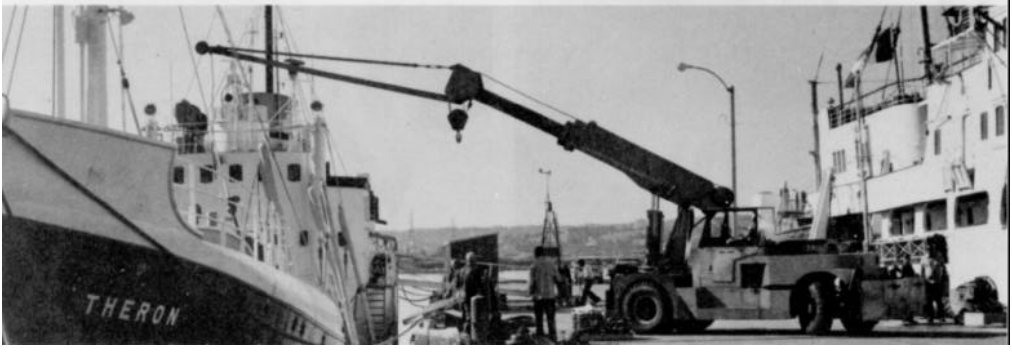
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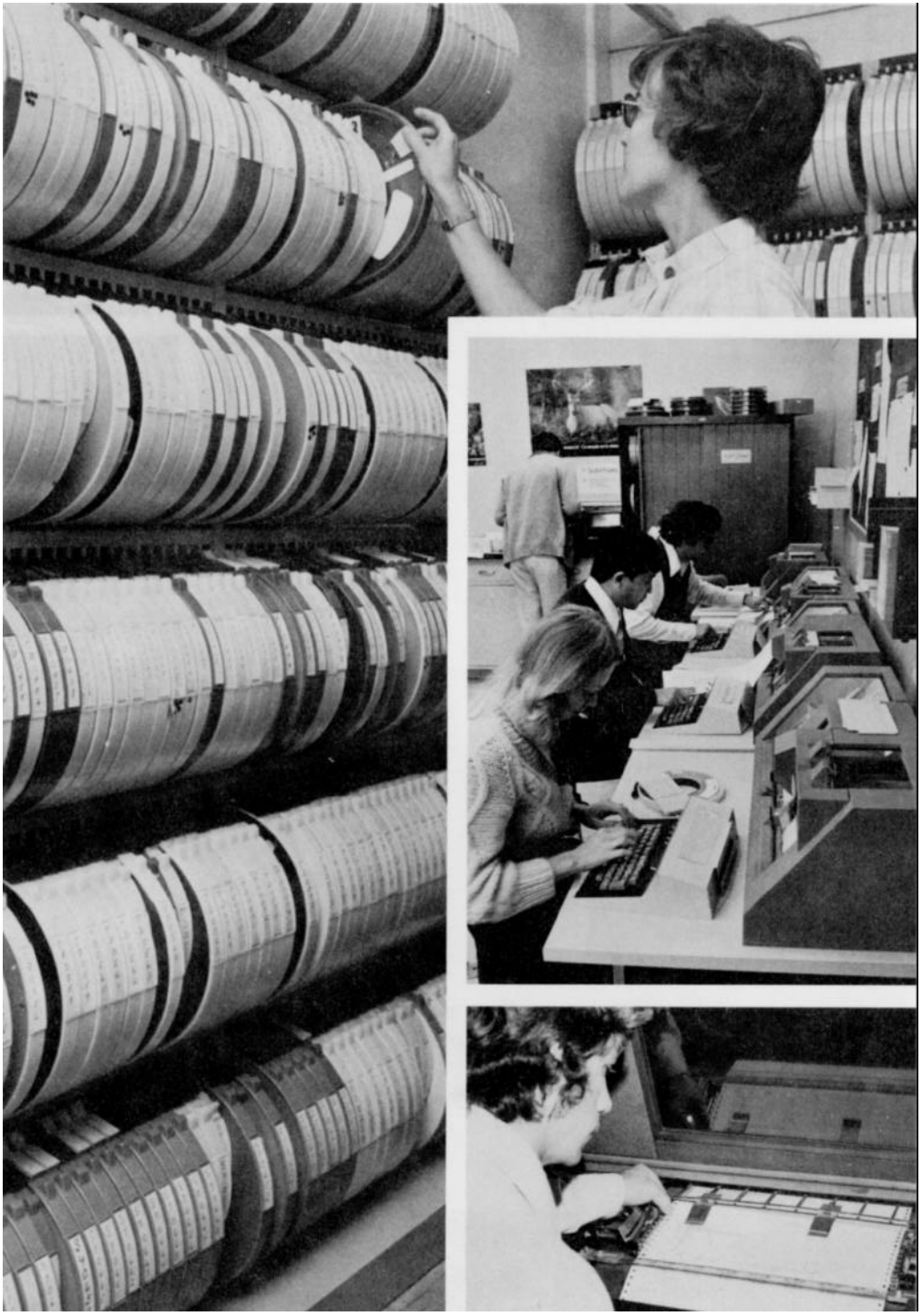
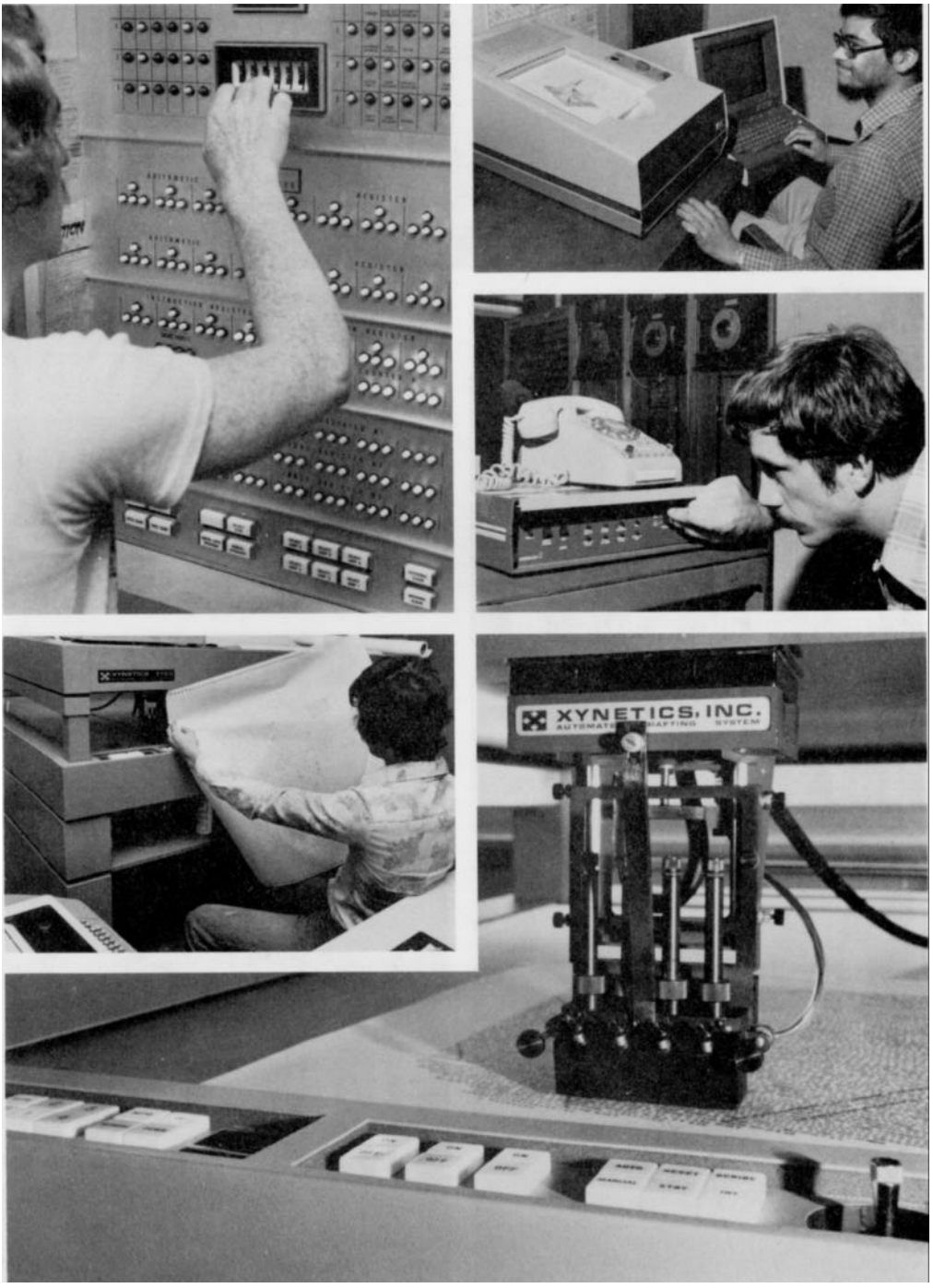
# Computing Services




XYNETICS, INC.

# Library Services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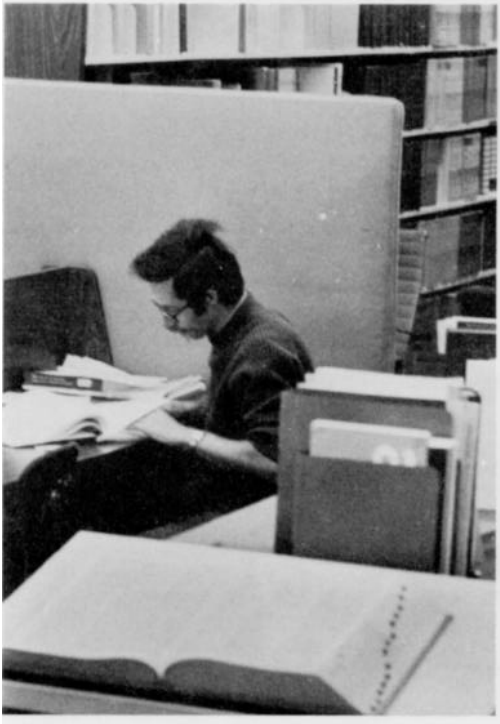
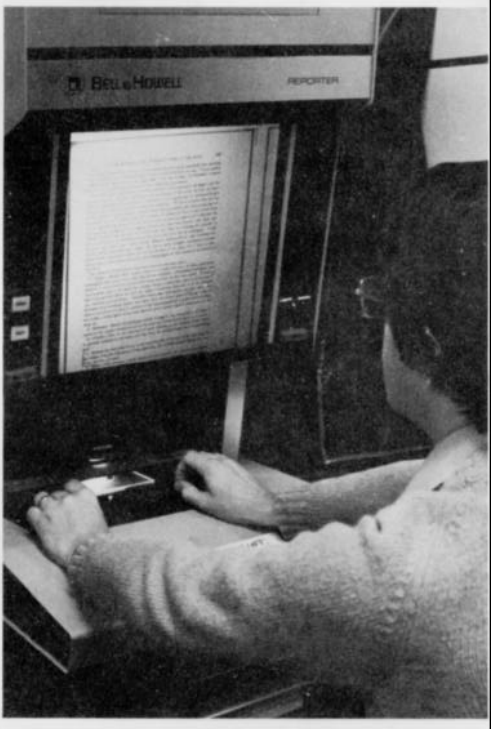
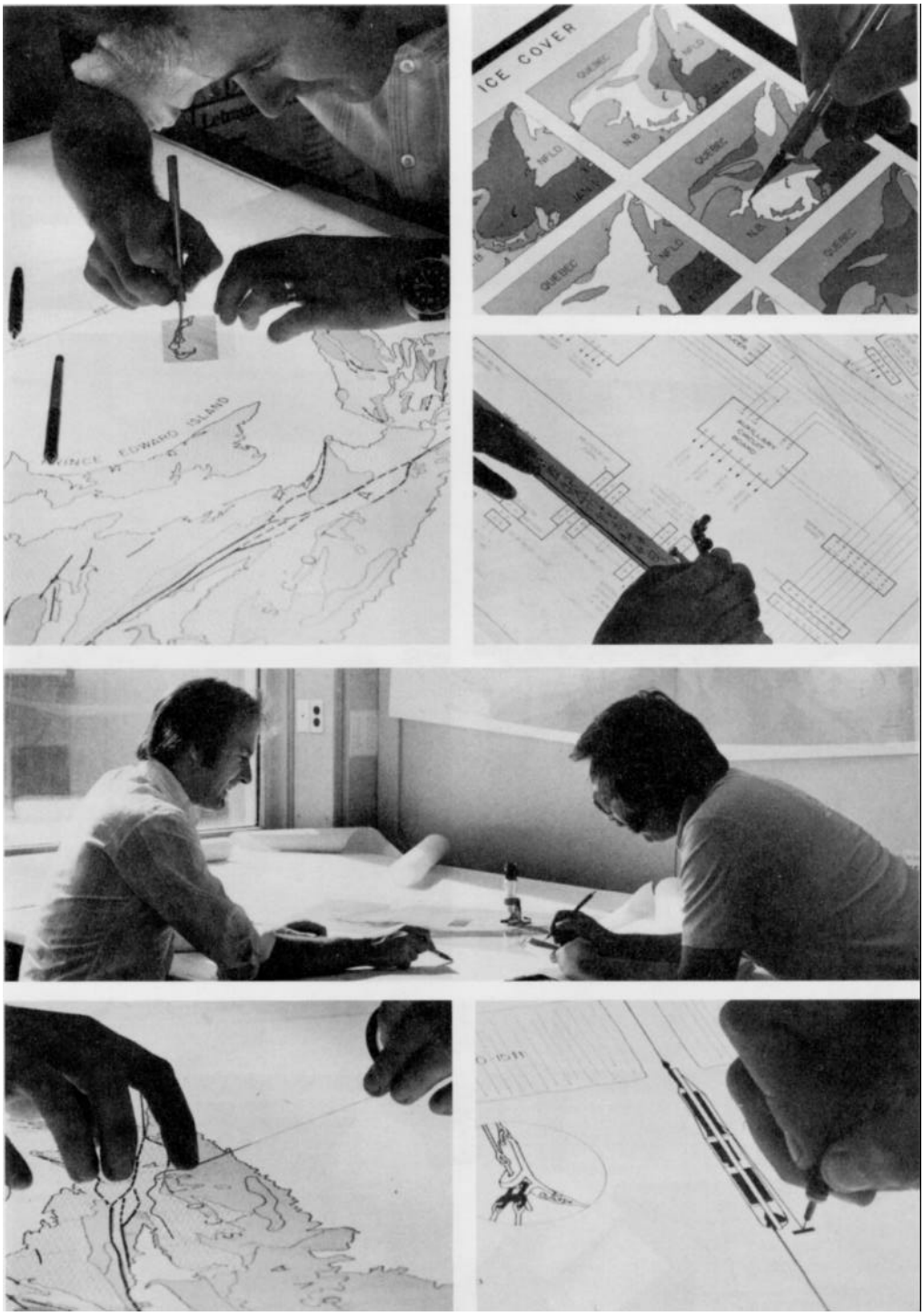
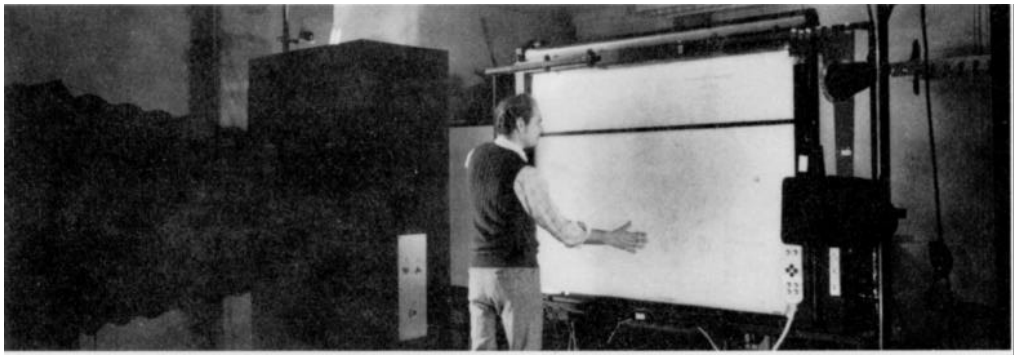
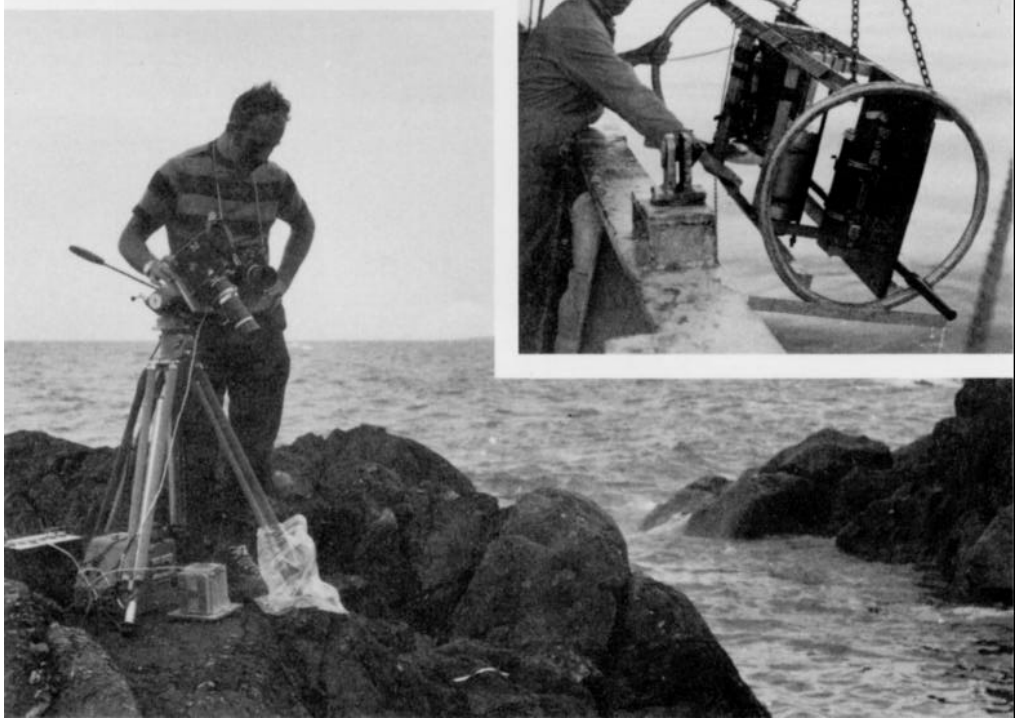



BELL & HOWELL
REPORTER

# Drafting and Illustrations







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# Ocean Science Reviews
1975/76

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# Ocean Waves

**F. W. Dobson,** *Atlantic Oceanographic Laboratory*

## Why study waves?

Ever since the launching of his first boat man has been engaged in the study of waves, and it may seem surprising that he has not yet fully studied such a widespread phenomenon. The fact is that although the seaman's understanding of the effects of waves on ships and the shore, and of the prediction of waves from the local meteorology is profound and rests on long tradition, the science of hydrodynamics is relatively young, having had to wait for Newton to start it in the 1600s. Still, 300 years is a long time even for scientists to come up with answers, and some explanation is called for. The physics of oscillations on the water surface was worked out in some detail by Green, Airy, Thomson (Lord Kelvin), Stokes, Helmholtz, etc., in the 1800s and by the time these great men had finished the job everyone naturally assumed it was done - there remained but to work out the details. The details, unfortunately, turned out to be more difficult than was imagined, and today theoreticians and experimentalists alike are devising and using new tools they hope will elucidate some of the pressing problems that remain unsolved.

The tremendous destructiveness of storm waves has long been recognized, and the ability to predict their occurrence even a few days ahead (one cannot hope to do so now) would be of great service. Shipbuilding, for instance, has been evolving for centuries, and yet ships still sink. The accompanying photograph shows why. At the top of the photograph is the 205 metre-long, 33,400 ton liner *Leonardo da Vinci,* standing by the stricken freighter *Ambassador* in an Atlantic storm in February 1964. The two ships are separated by about the length of the *Leonardo,* and lie on successive crests of one wave. It is hard to gauge the height of the wave, but from my experience I would say it is 10-15 metres high, which is not at all uncommon in an Atlantic Ocean storm. There were 35 men on the *Ambassador,* of which only 16 were rescued. The *Leonardo* watched helplessly - she could not get a boat into the water - while two loaded life rafts drifted down her side; they disappeared into the gathering darkness and were never seen again. The *Ambassador's* captain was the last man to leave his ship, but he was dead when he arrived at the rescuing vessel, the USCGS *Coos Bay.*

*The foundering of the* Ambassador, *February 1964. The Italian liner* Leonardo da Vinci *stands by. (Courtesy of the Department of National Defence, photo by R. Be/anger)*

By understanding and being able to predict the occurrence of waves we would be able to forestall disaster by providing optimum routes for ships at sea; to predict the dispersal of marine pollutants; and to schedule diving operations, the movements of large marine structures such as oil drilling rigs, and loading/unloading operations in harbours. Designers of marine vehicles, harbours, and coastal protection systems would benefit enormously from improved knowledge of wave forces on structures and from better long-term statistics.

There are many more subtle reasons for studying waves. As understanding of the processes involved in the generation, growth, propagation, and dissipation of ocean waves grows, so grows the realization of the important role they play in meteorological and oceanographic processes. Meteorologists need to know, for instance, how much drag the sea surface exerts on the wind above it; otherwise weather prediction models do not predict winds correctly at their lower boundaries. The interaction of the waves and the air modifies the manner in which heat and wave vapour are transferred from water to air and back again. Waves also play a large but as yet little-investigated part in the mixing of the upper layer of the ocean, which acts as a large reservoir of heat for the atmosphere.

Breaking waves send salt spray upwards and air bubbles downwards. The spray evaporates and becomes a source of both water vapour and condensation nuclei for clouds: the bubbles dissolve and saturate the surface waters with life-giving oxygen. Waves greatly increase the sea surface area available for the air-water exchange of heat, water vapour, and various atmospheric gases - especially oxygen and carbon dioxide.

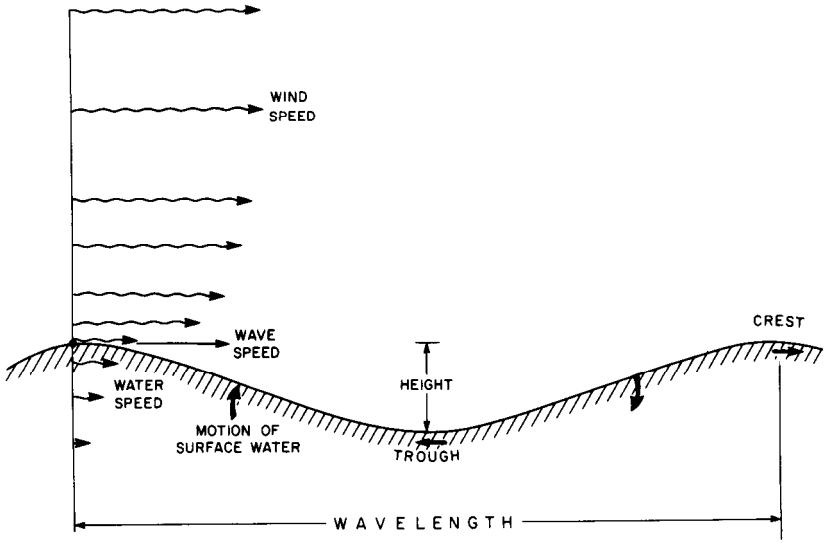
Wave problems are not easy to investigate: few environments put instruments and investigators to more severe tests than the surface of the ocean. The waves themselves are the principal difficulty. To study the air flow near the water, sensors must be mounted there, but no one has yet successfully made measurements at a fixed height (a few have tried) of the character of the air flow below the height of the highest expected wave. Nevertheless, a knowledge of the structure of the near-surface air flow is necessary to understand the generation and growth of wind waves. The water most oceanographers work in is salty, and salt water is the bane of electronics. As a consequence a whole technology has had to be developed to isolate electronics from the environment while keeping sensing heads free to measure.

Under water, the waves cause large oscillatory currents that so completely mask many of the transfers processes (that is, vertical transfers of heat, gases, horizontally-directed momentum, etc.) that in spite of their importance no one has been able to make satisfactory transfer measurements in the presence of waves. The wave-induced currents and the waves themselves hinder the oceanographer trying to measure currents in the deep ocean. Surface buoys for tethering strings of current meters between the surface and the bottom of the sea have only recently been supplanted by a system of underwater near-surface floats and acoustically-triggered anchor releases. Until this system had been developed, the motions of the surface buoys caused the current meters to move and generate a background noise of self-induced 'currents' on their records, which often made interpretations impossible.

## About Waves

For practical purposes water is incompressible. In reality it will give a little - about as much as does high-strength steel. It may seem unnecessary to talk about how little a fluid that flows around objects so well can be compressed, but it is water's incompressibility and high density - a cubic metre weighs one metric ton - that make it so destructive. I remember sitting in the oceanographic laboratory of CNAV *Whitethroat* when she was hove to in an 80-knot gale, and the forward bulkhead, which is the first forward-facing vertical object aft of the bows, was struck by 'a green one'. It was as if some giant outside had struck the bulkhead with an immense sledge hammer. There was no roar of water - only a deafening CLANG! All those somnolent or seasick on the deck of the lab rose and hastily went below. I climbed the companionway to the bridge above, and saw that the wave had smashed everything not made of solid steel and bolted down. There is nothing as effective as the real thing to convince one of the validity of theoretical assumptions!

In a real sea many wave trains - ripples, sea, and swell - are present all at once and they travel in many different directions. The air and the water near the surface are normally fully turbulent; that is, they are gusty or highly variable in speed and direction. In the air there is a strong average flow in one direction on which the gusts are superimposed: in the water there is only a very small average flow. The accompanying diagram shows a highly simplified wave with realistic average variations of the nearby air and water flows with height and depth; air and wave are both moving to the right. The average speed of both air and water varies with height, roughly in the manner shown in the diagram. It is plain to see that most




An *idealized sea wave. (AOL 4114)*

of the variation with height occurs very close to the water surface. The air flow follows the water surface and hency is 'wavy' there; the waviness, however, dies out quickly with height, and cannot be found in the turbulent zone at heights of more than one-quarter wavelength. The water has wavy motions superimposed on its random turbulent motion. It moves in near-circles as the waves go by, and advances only very slowly relative to the speed of the waves themselves. The circular motion disappears at a depth of about a wavelength. This circular water motion under the large, long, swell waves is a major hazard to divers. I cannot think of a more unpleasant way to get seasick than to SCUBA dive in a strong ground swell! In the diagram the small arrows just below the surface show how the water moves as a wave goes by; with the wave at the crests, against the wave in the troughs, upwards ahead of the crests, and downwards ahead of the troughs. The wave speed given is the speed the disturbance moves through the water, which is in general much faster than the speed of the water itself. Note that there is a layer of air close to the water where the wave is travelling faster than the wind; thus, an observer moving with the wave would encounter a wind blowing against the waves in that region!

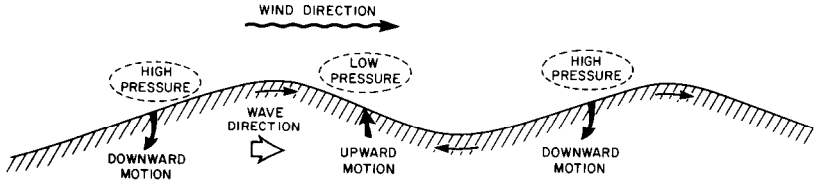
Waves obey a strict relationship between their speed and their wavelength. Long waves travel quickly - those with periods of 15 seconds have a wavelength of 351 metres and travel at 23.4 metres per second (45.5 knots). As the wavelength becomes shorter, so does wave speed, which reaches a minimum of 0.23 metres per second (0.5 knots) at a wavelength of 1.7 centimetres. At smaller wavelengths, speed increases again but more gradually so that the so-called 'capillary' waves seen in 'catspaws', with wavelengths of about 1 millimetre, travel at speeds of about 0.7 metres per second (1.25 knots). The small-wavelength waves are called 'capillary' waves because the force that returns the water to equilibrium after it is perturbed is surface tension. Larger-wavelength waves are known, for a similar reason, as 'gravity' waves. The longest, largest waves take the longest time to grow to their full size because they travel faster relative to the wind. A storm sea is not said to be 'fully-developed' until its dominant waves are travelling at the wind speed. The shorter, slower waves grow quickly to the height where they begin to break, and thereafter they remain at an

'equilibrium height'. If one had an instrument that could 'watch' the size of waves of a given length as they travelled away from a beach in an offshore wind (the experiment has actually been done), one would see that the waves grow slowly at first, roughly in proportion to their distance from shore. At some stage they reach a size where they begin to interact with the air flow above them. At that point their growth rate becomes dependent on their size and they grow exponentially. When they begin to break their growth slows down, and the waves finally reach an equilibrium height about 10 per cent less than the maximum height achieved. Why the waves overshoot their equilibrium height is not entirely clear, but the overshooting accounts for the presence of very steep waves in any sea, and these can be very troublesome to fishermen and yachtsmen alike. The phenomenon is very important to the growth of waves because the 'overshot' waves, which are too big, are unstable and lose some of their surplus energy to waves of slightly different, usually longer, wavelength. The longer waves then interact with their progenitors, and an interesting phenomenon results. As two tones of almost the same frequency 'beat' to produce a rhythmic variation in sound level, so waves of nearly the same wavelength interact to form 'groups' of high waves interspersed with periods of relative calm. The groups are plainly visible in most recordings of waves, and form the basis of the seaman's belief that the seventh wave is the big one. It may sometimes be the fifth or the ninth wave, but on the average every seventh wave is not a bad guess. The seaman's comment would of course be that he could have told you that without going into all the research necessary to predict the effect theoretically, and, in a way, he would be quite correct, but now at least the explanation is on paper for anyone to understand and build on.

## What Makes Sea Waves Grow?

The answer is self-evident to the seaman: the wind. To go one step further and ask how? broadens the question to include most areas of basic research in air/sea interaction. The 'solution' has been found three times now: by H. Helmholtz and Lord Kelvin in 1868-71, by Sir Harold Jeffreys in 1925, and by O. M. Phillips and John Miles in 1957. The Helmholtz-Kelvin and Jeffreys theories have been proven incorrect except in special circumstances well outside the ranges of wind and wave speeds normal at sea. The Phillips-Miles theory has since 1957 been proven, disproven, and reproven a number of times. To see what the latest beliefs are, it is necessary to appreciate some of the physical mechanisms that *can* form waves and make them grow.

Aerodynamic pressures associated with the air flow over the water surface have been for many years the causative mechanism uppermost in the minds of the theoreticians. If the air flowing over the waves causes a pressure distribution that travels with the waves (see the accompanying diagram),




*The working of air pressure on a water wave. (AOL 4114)*

and produces regions of low pressure ahead of the crests and high pressure ahead of the troughs (that is the pressure is low as the water rises ahead of the wave crests, and high as the water falls ahead of the troughs), then the pressures do work on the waves and make them grow. The rate at which work is done is simply the product of pressure and vertical water velocity, averaged over a wavelength.

The first idea, suggested by Sir Harold Jeffreys in 1925, was that, as the air flowed over a field of sharp-crested waves, it would actually 'separate' from the downwind faces of the waves, in much the same way that the wind does when blowing over the top of a sand dune. A region of turbulent air in which the pressure was below-average would thus exist downwind from the wave crests, and there would be a corresponding region of high air pressure on the upwind side of the wave crests. The forewarned reader has of course already spotted the difficulty. For large waves at sea the wave speed is very nearly equal to the wind speed some distance above them; wind speed decreases rapidly toward the sea surface so the air encountered by the large, fast waves is travelling slower than they are, and separation is not possible. It is thought now that separation is only likely to occur over very short, sharp, slow waves or over waves travelling against the wind. It certainly occurs, for instance, over surf during an offshore wind.

The ripples on the water that begin to form immediately when the wind blows are caused by an instability very close to the water. The dynamics of the air flow above the water are dominated by turbulence everywhere except for a 1-2 millimetre-thick layer of air near the water surface. In this region there is no vertical room for large turbulent eddies to exist, and smaller eddies are quickly slowed down and damped out by the air's viscosity. Relative to the water surface, the air speed in this 2 millimetre thick layer reaches about one-third of the mean wind speed by the top of the layer. This large variation in air speed within a very small vertical distance is unstable by nature. In the air and the water, perturbations with wavelengths of 2 to 5 centimetres will grow, causing the air to do work on the waves by producing pressure fluctuations low downwind of the crests and high upwind of the crests. Recent experimental work using radar to examine the growth of selected wavelengths in wind-water tunnels has confirmed the predictions of the theory, first suggested by M. S. Longuet-Higgins in 1952 and later refined by B. Benjamin and John Miles.

The theory with the largest tradition in modern work is that put forward by John Miles in 1957. Its mechanism depends on the initial presence of a field of waves large enough to perturb the air flow immediately above them into wavelike motion. Miles demonstrated theoretically that the air flow reacts to this disturbance by shifting the wavelike air motions along the wave, which results in a pressure distribution that moves with the waves and has less than average pressure on the downwind slopes and greater than average pressure on the upwind slopes of the waves. The predicted growth rates are strongly dependent on the size of the waves, on the difference between wind and wave speeds, and on the way the wind speed varies with height.

The experimental challenge has been to make sufficiently accurate growth rate measurements to prove or disprove the theoretical predictions. The problem is not simplified by the fact that the ranges of validity of many of the theoretically likely mechanisms overlap, and some experimentalists

have erroneously attributed observed wave growth by one mechanism to another. Also, waves can grow in ways not directly related to the wind - they interact with each other and with the water around them. One example of such growth is the increase in wave height seen when waves run against a tidal current - the infamous 'tide rip'. Waves also interact with other waves, exchanging energy and momentum, and one particular wave component can grow at the expense of other components with no help at all from the wind. Theoreticians and experimentalists are presently discovering and investigating a number of exciting 'wave-wave interactions'.

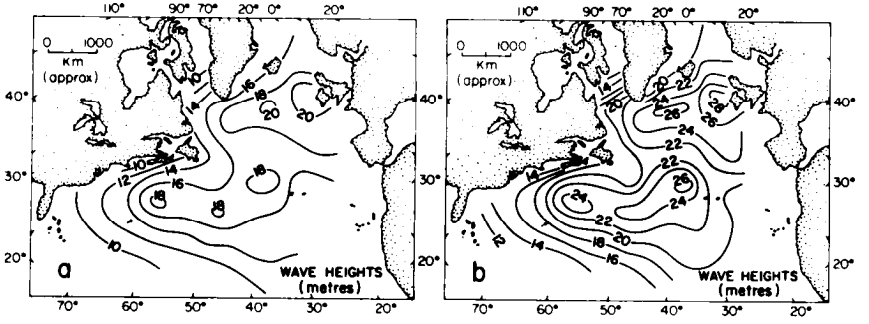
Experiments performed over the last 6 years at a site in the North Sea off north Germany called the JONSWAP (Joint North Sea Wave Project) series have produced an excellent set of wave data on which to base theories of the growth of an entire wave field in space and time. So far the most important results of the series have been the recognition that interactions among the waves themselves can cause significant wave growth independent of the wind, and the development of a wave prediction scheme that uses a minimum of input information (wind speed and direction, length of time and distance over which the wind has been blowing) to make predictions not only of the height and period of the dominant waves, but also of the makeup of the entire wave field including the variation of both direction and height with wavelength.

## Research at the Bedford Institute of Oceanography

At the Bedford Institute of Oceanography (BIO) research on waves is being carried on with two rather different approaches, and there exists between the two research groups a constant, healthy controversy about the relevance of the methods used. A group led by H. J. A. Neu of Coastal Oceanography Division [Atlantic Oceanographic Laboratory (AOL)] has for some years now been making measurements and compiling statistics to provide engineers with the statistical wave information they need to design structures for the marine environment. The group has had a choice of data sources, which is rare in the game; two organizations have been collecting locally-relevant wave data. The Canadian Armed Forces Weather Centre at Halifax, Nova Scotia, issues twice-daily charts of wave and weather information in the North Atlantic Ocean, and the Canadian Department of Public Works has been collecting wave data at specific locations, mostly at existing or planned harbour sites, from telemetering accelerometer buoys. The approach taken has been to use the Armed Forces wave charts with their wide and continuous coverage as the main data base, and then at specific locations to compare the results of the study with the results from the Canadian Department of Public Works' buoys. The method of analysis chosen was that favoured by the engineer and wave statistician: process many 'crude' observations to produce statistics related to directly observable quantities, such as wave height, wave period, probability of the wave height exceeding a given height in a given time, etc. The observations are crude in the sense that they are normally visual estimates of wave height, period, and direction reported by watch-keeping officers at sea; hence they are to some extent subjective (the height a trained observer will give as his estimate of the wave heights at sea corresponds closely to the average of the largest one-third of the waves). Since there are many different observers, each observation is checked by the mapping personnel against nearby observations and against forecasts from older maps. On the long-term average such careful crosschecking has led to the production of a

time series of maps that are an excellent source of data for the statistical approach.

Two studies have been done, both on wave climates for the year 1970: one for the Canadian Atlantic Coast and one for the entire North Atlantic Ocean. Two of the most interesting results of the work are shown in the accompanying figure: the figure shows charts of the North Atlantic Ocean with contours of calculated maximum wave height for one year, 1970, and predicted maximum wave height to be expected in any lo-year period. The values are based on well-known statistical relations for sea waves. The results are new and still somewhat tentative, but where and when comparisons have been possible they have been favourable. Also given in the same report - Wave Climate of the North Atlantic, by H. J. A. Neu - are predictions for 100-year maximum wave heights, numbers used extensively by engineers interested in long-term design. The practical use of such information to the designer of offshore structures cannot be overstressed.



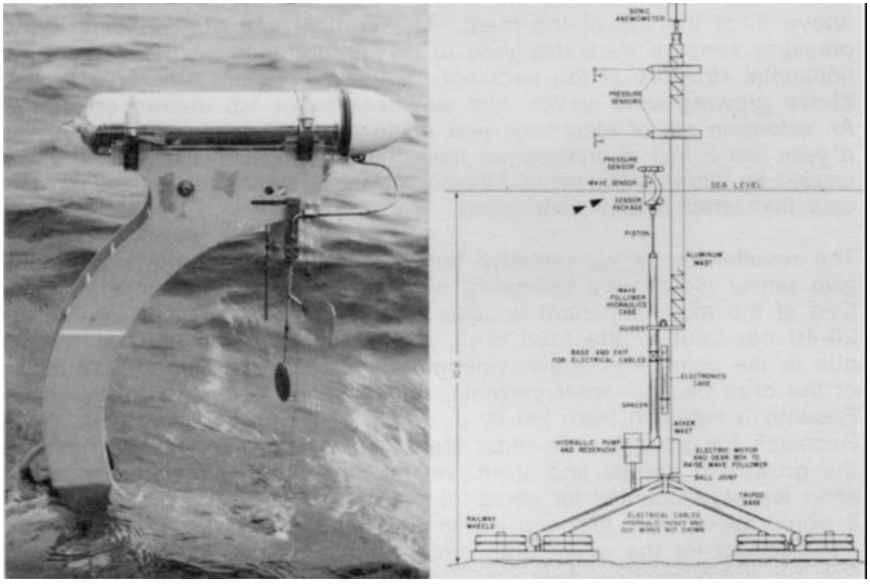

*Results from wave cllmate studies of the North Atlantic by H. J. A. Neu: (a) one year maxlmum wave heghts from 1970 data and (b) predicted 10 year maximum wave heights. (AOL 4135)*

The second approach to wave research has longer-term goals. The Air-Sea Interaction group of the Ocean Circulation Division of AOL is looking into the physical processes that govern the generation and growth of ocean waves, with emphasis on field experiments. Results from the work will be useful in solving many of the unanswered riddles brought up earlier concerning how waves indirectly affect us via their modification of meteorological and oceanographic processes. Our effort over the last 7 years has centred on the measurement, in the field, of wave-coherent pressure fluctuations. Simultaneous measurement at the same location of the vertical velocity of the water surface allows us to compute the rate of working of the measured pressure fluctuations on the waves. Further, by assuming or measuring the distribution of wave travel directions, we can estimate the drag exerted by the waves on the air and compare that with direct measurements of the total drag of the water on the air.

The measurement of pressure fluctuations in the midst of a turbulent flow has only been possible in the last 7 years, though measurements have been made on the boundaries of the flow for a much longer time. The measurement was pioneered by J. A. Elliott, now at BIO, who did the work at the University of British Columbia. The problem had been begging for a solution for years: how could one measure the very small pressures asso-

ciated with turbulent flow (typically 0.01-10 pascals, or $10^{-7}$ to $10^{-4}$ atmospheres - the pressure exerted by a column of air 1 millimetre to 10 centimetres in height) when the sensing head itself, by distorting the flow and causing Bernoulli-effect pressures, can be a source of spurious pressures as large as those being measured? The answer has been to cancel the Bernoulli pressures by using a carefully shaped sensing head, and now three different types of sensing head exist. At BIO we use the Elliott type, which has characteristics that are still as good as any.

Over the last 6 years a wave following device has been developed for making pressure measurements close to the water surface. The design of the device closely follows that of one originally conceived by Blair Kinsman of the Chesapeake Bay Institute (CBI), The Johns Hopkins University. It is the direct result of a two-year collaboration between BIO and CBI and the resulting instrument, although considerably more flexible than its progenitor, still resembles it closely. By hydraulically actuating a piston carrying the sensors to follow the vertical motion of the sea surface, the wave follower allows measurement of the air pressure and flow field at heights not possible with fixed instruments, which if placed too low would be struck by the waves. The business end is shown in the accompanying figure. The shiny cylinder contains a pressure sensor; the Elliott sensing head is the disc mounted below the small wind vane, which keeps the disc aligned with the wind (normally the entire device is pointed into the wind, but it was calm when this picture was taken). The tube leading into the shiny cylinder carries the fluctuating pressure signals from the sensing head to the sensor. Two other sensors are visible. The vertical rod behind the wind vane holds a tiny anemometer, a sensor used to measure wind speed by recording the electrical current required to keep its temperature constant at about 250°C when being cooled by the wind. The thin vertical

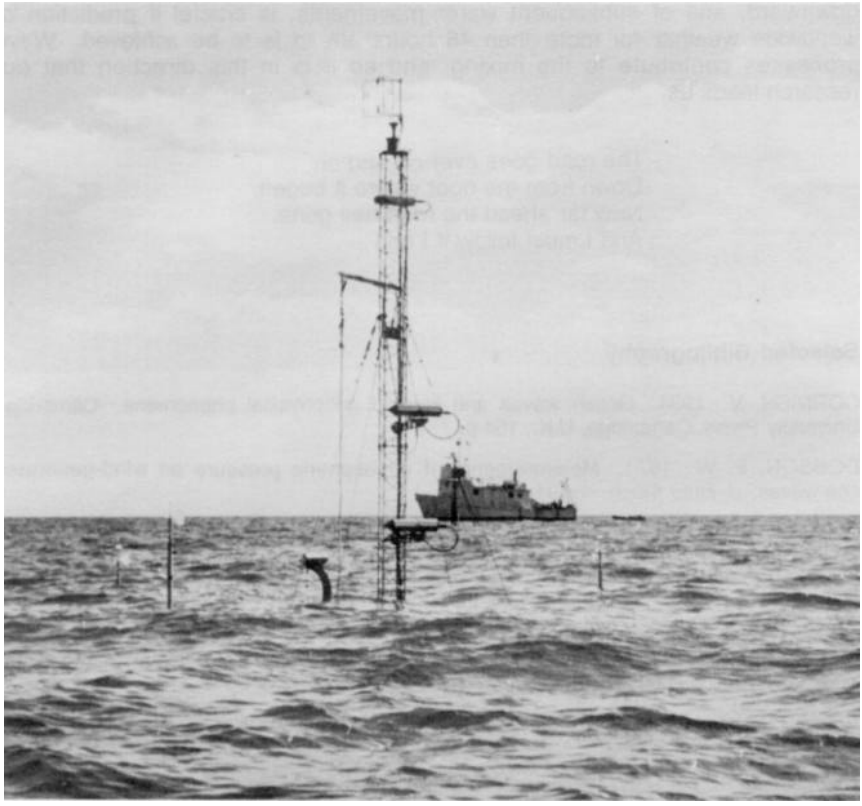



*The air flow sensing instruments of the BIO wave follower and a diagram of the entire wave follower. (AOL 2905)*

wire, which appears ahead of the pressure-sensing disc in the photograph, measures water level, and its electrical output signal is used to vertically position the hydraulically-driven piston on which the sensing instruments are mounted. The hydraulics and electronic servo system that move the piston are mounted entirely underwater to avoid unnecessary interference with the air flow being measured.

The BIO wave follower system has now been used in two co-operative field experiments, one in September 1973 in the North Sea (JONSWAP 2), and one in December 1974 in the Bight of Abaco, Bahamas. The data accumulated from the two experiments are still being processed. The pressure-wave correlations from JONSWAP 2 yielded no useful information on wave growth, but the anemometer measurements may yet tell us something about the structure of the air flow above the water surface. The Abaco experiment produced a large volume of useful data. The experiment was designed to bring together the three people who have so far made field measurements of the rate of working of pressure fluctuations on sea waves: the author and J. A. Elliott from BIO, and R. L. Snyder from Nova University in Fort Lauderdale, Florida. All instruments were carefully intercalibrated before and during the experiment, in laboratory and field conditions, and most of the data were recorded and analyzed separately by both the BIO and Nova parties. All this was felt necessary because the earlier-published results of the three gave wave growth rates that were respectively ten times, three times, and the same as those predicted by the Miles wave generation theory, in the same wind and wave conditions! A photograph of the experimental setup is shown in the accompanying figure. The Snyder instruments, one of which is barely visible to the left of the mast, were arranged in a carefully designed horizontal array with the BIO wave follower at the centre; the mast, also near the centre of the array, held a separate wave sensor, two Elliott-type pressure sensors, one above the other, and a turbulence anemometer for measuring the total drag exerted by the water on the air above it, at the top of the mast. The vertical and horizontal arrays of pressure sensors were designed to give information on the vertical and horizontal structure of the turbulent and wave-coherent pressures existing above growing wind waves with wavelengths of 1.5 metres or greater. An extensive set of recordings was made over a 3-week period, and after a year and a half of analysis we have removed most of the inconsistencies caused by known instrumental failures, leaving a substantial residue of ‘good data’ from which to draw conclusions.

The results are as yet tentative but encouraging. All three experiments give similar growth rate estimates, within expected scatter and error limits. One of the more important findings from a practical point of view is that 20-40 per cent of the total drag of the water on the wind is directly due to the dominant, long-wavelength waves. Presumably the remainder of the drag causes water currents, ripples, and short-wavelength waves. Recently a research team led by J. Wright of the Washington, D.C., Naval Research Laboratory made radar measurements in a wind-water tunnel of the growth of ripples and short waves, and found that the ripples and short waves accounted for about 75 per cent of the observed drag. Thus it would appear that the long waves and the short waves, taken together, can account for the entire drag force exerted by the water on the wind. But that being so, how does one account for the presence of other, highly obvious evidence of direct momentum transfer to the water, such as wind-induced currents, and large storm-induced oscillations of the entire upper



*The Abaco expenment in operation. (AOL 4195)*

layer of the ocean? Partly it must be that the waves, having gained momentum from the wind, quickly lose it to water currents by breaking or other dissipative processes. Some of the wind drag, perhaps up to 10 per cent, is caused by direct frictional contact of the wind with the water surface, but because of the extreme difficulty in making measurements of small average currents in the presence of large oscillatory ones, it is impossible to do more than guess at whether the mean currents are what would be predicted. The interactions of the waves with other waves and with the water beneath them are little-understood, and yet it is by studying the interactions that the processes of upper oceanic mixing will finally be understood.

## The Future

The most pressing problem now facing meteorologists and oceanographers is solving the huge riddle of accurate weather prediction, and a large international effort, the Global Atmospheric Research Program (GARP), has been organized to make a serious effort toward that end. A high priority has been set on the study of the mixing of the oceanic upper layer, which acts as a highly effective 'storage unit' for the heat of the atmosphere. A knowledge of the time it takes for heat to be absorbed and mixed

downward, and of subsequent water movements, is crucial if prediction of worldwide weather for more than 48 hours ahead is to be achieved. Wave processes contribute to the mixing, and so it is in this direction that our research leads us.

The road goes ever on and on
Down from the door where it began,
Now far ahead the road has gone,
And I must follow if I can . .

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# Project MAREX: Detailed Exploration of the Mid-Atlantic Ridge

B. D. Loncarevic, *Atlantic Geoscience Centre*

In a lecture before the Royal Institution of London, Sir Francis Younghusband, the leader of the 1922 Mount Everest Expedition, said:

> The expedition is being sent to climb Mount Everest because it is the highest mountain in the world, and we consider that there is no part of the earth's surface, and most certainly not the highest point, to which we should not at least try to penetrate.

This same spirit of exploration, this need to know what was hitherto unknown, has urged man to sail the oceans. The development of scientific instruments after World War II made it possible to explore and describe the longest mountain chain on Earth, the mid-ocean ridge system that extends over 75,000 kilometres. When the scientific program of the newly established Bedford Institute of Oceanography was formulated in the early 1960s it was decided that a detailed study of a segment of the Mid-Atlantic Ridge system would be undertaken. The spirit of exploration felt by the project participants was depicted by the celebrated Halifax cartoonist, Chambers, following the return of the second BIO Mid-Atlantic expedition (see next page). In this essay an overview of the first decade of Project MAREX (Mid-Atlantic Ridge Exploration) is presented.

The Mid-Atlantic Ridge (MAR) is a broad swell of rocky jagged mountains bisecting the Atlantic Ocean. It was discovered shortly after the middle of the last century when the plotting of the routes for the first trans-Atlantic cable demanded some knowledge of the depth and nature of the ocean floor. The intimate connection between the cable-laying project and the Ridge is seen from the first names given to these undersea features: Faraday Hills (British) and Telegrapher's Plateau (American).

As happens so often, the initial description was quite accurate and sufficiently detailed to suffice for three-quarters of a century. Speaking before the Royal Geographical Society in 1870, Sherard Osborn, who had previously distinguished himself in the Canadian Arctic during the Franklin Search expeditions, stated (Osborn 1870):

> I propose to confine myself in this paper, to placing on record one section of the harvest of knowledge regarding the sea-bed which we are now garnering, viz.: that which tells of the depth of the ocean, and the character


*(Courtesy of the Halifax-Herald Ltd.)*

> and form of the earth's crust on which it rests: a knowledge still far from perfect, but which has made such important progress, that within the last few years we have been enabled to lay nearly 17.000 miles of submarine telegraph cable (worth more than six millions sterling) across the silent depths with perfect safety.

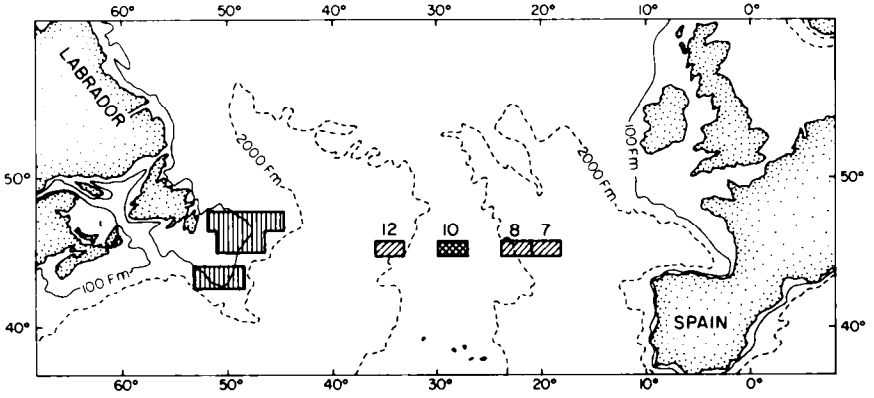
He described next the three tracks of soundings across the North Atlantic and concluded:

> The contour, therefore, of the North Atlantic basin may, I think, be safely considered as accurately delineated by these sections, and represents two great valleys, separated by an intervening range, which we can trace from latitude 40 N as far as Iceland. . .

and further on

> The submarine ridge which divides these two valleys in about 30°W longitude appears to be of singular uniformity of height, or rather of depth, from the surface; having only 1600 fathoms, or 9600 feet of water on its crest between the Azores and the latitude of Hebrides, where it rises gradually, and culminates above water in Iceland with the volcano of Mount Hecla and its geysers.

During the 1960s a profound change in the style of deep ocean exploration occurred. Up to that time, because of the vastness of the oceans, far ranging expeditions sailing single tracks through uncharted areas contributed the most significant scientific discoveries. After about a dozen years of this type of reconnaissance exploration, all major regions of the oceans were criss-crossed by single tracks. The second track through an area usually adds little new information and, when this was realized, a concept of systematic, detailed investigations of carefully selected areas evolved. The BIO study of the Mid-Atlantic Ridge (MAR) at 45°N was the first major investigation in the new style of marine research. As such, it had a profound effect on the sea floor research of the 1970s including the French-American Project 'FAMOUS' (Mid-Atlantic Ridge at 37°N) and the many site-survey studies of the Deep Sea Drilling Project.




*Location of the Institute's geophysical surveys in the Mid-Atlantic. Area 10 is discussed in the essay.*

We selected a one-degree wide strip of the MAR centred on 45°30'N as our study area. So little was known about the mid-ocean ridges in the early 1960s that selecting an area for a detailed study could be done equally well by throwing a dart at a map on a wall or by bibliomancy. We selected 45°N because some data existed from two previous British expeditions. We believed that this area would be representative of a 'typical' ridge segment, since the selected area was about midway between the two major tectonic disturbances of the ridge: the Charlie-Gibbs Fracture Zone (at 52°N) and the Azores (at 37°N). There were no major fracture zones displacing the crest so the linearity of the morphology and of the geophysical anomalies would likely be preserved. The Median Valley (Hill, 1960) in the region was clearly identified and easily found. Analysis of dredged rock samples showed that the ridge was composed of fresh young basaltic rocks (Muir and Tilley, 1964). Seismic activity along the crest of the Ridge and a high heat flow value recorded in the Median Valley to the north further testified to the volcanic activity of the region. From Halifax, the area was the nearest segment of the MAR where the weather, due to the influence of the summer high pressure area ('The Azores High'), was favourable.

Between 1960 and 1975, five ships spent over 250 working days in the area on nine expeditions (see table). As a result of investigations by over 65 scientists, some 72 reports and papers were published up to the end of 1975 (Loncarevic, 1976).

*Summary of survey expenditures on the Crest Mountains and High Fractured Plateau of the Mid-Atlantic Ridge near 45°N.*

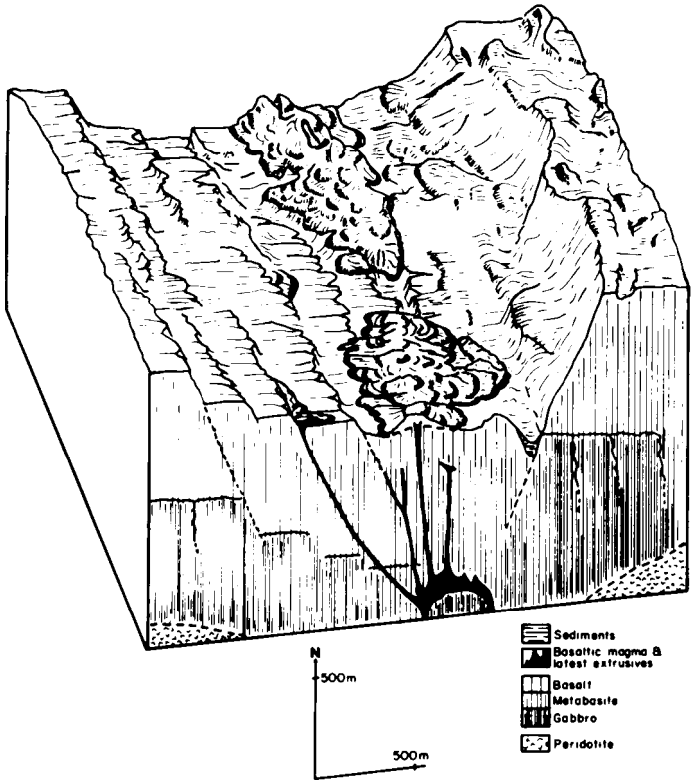
| Year | Ship | Survey (kilometres) | Stations |
|---|---|---|---|
| 1960 | *Dscovery ii* | 430 | 5 |
| 1965 | *Hudson* | 1950 | |
| 1966 | *Hudson* | 6960 | 62 |
| 1966 | *Hudson* | 13,940 | 67 |
| 1966 | *Theta* | | 3 |

| | | | |
|---|---|---|---|
| 1969 | *Hudson* | | 28 |
| 1971 | *Hudson* | 1000 | 88 |
| 1972 | *Shackleton* | 1400 | 2 |
| 1975 | *Discovery* | 2250 | 3 |

## Ocean Floor Spreading and the Median Valley

Portions of the Earth's crust have been moving relative to each other for at least the last 200 million years. Three types of relative motions of the 'plates' on the Earth's surface are possible: plates can slide past each other, collide, or separate from each other. The first case results in transform faults such as the San Andreas Fault system in California. In the second case, large mountain systems will be formed if the colliding plates have continental edges. This is happening in the Himalayas today. If the colliding zone is between a continental and an oceanic edge, or between two oceanic edges, a deep sea trench will be formed as is happening along the rim of the Pacific Ocean. In the case of plates drifting apart, new material must upwell from the underlying mantle to close the gap in the crust.

The study of accretion edges is important for three reasons. Firstly, new material is added to the crust here. This is the beginning of the process




*Perspective view of the Median Valley at 45°N looking northeasterly approximately from the upper slopes of Confederation Peak. Brock Seamount is the farthest peak. (Courtesy of F. Aumento and K D Sullivan)*

that through uplift, erosion, sedimentation, and metamorphism eventually produces all the rich variety of the geological fabric. Secondly, the gap between the accretion edges represents a window through which we may catch a glimpse of the structure and nature of the lower layers of the crust and the upper mantle. Thirdly, it is in the vicinity of the accretion edges that the forces responsible for the movements of the plates are evident. The mechanism responsible for continental drift is unknown and the study of the ridge system may provide new evidence that will enable us to work out the mechanism of crustal drift.

The Median Valley is the centre of spreading, and for that reason has been the centre of our attention throughout the project. Between 45°N and 46°N the Valley is a linear feature, delineated by the 2560-metre (1400-fathom) contour (Loncarevic et al., 1966). The mean width of the Valley, taken as the distance between these contours on opposite walls, is 9.5 kilometres. At the southern and northern extremities of the area, the Valley narrows considerably, where it is blocked by outpourings from pairs of flank volcanoes. In the north-central region, at 45°40'N, the Valley broadens to 18.6 kilometres, but narrows rather abruptly immediately northwards. The westernmost part of the widest section of the Valley is bounded by a steep cliff running east-west for about 6 kilometres. This may be a surficial expression of a small transverse fault.

The floor of the Valley cradles five basins, whose depths exceed 2900 metres, separated by small ridges and rises. In general, the depressions become deeper northwards, so that the greatest depth (3520 metres) is found at 45°41.4'N, 27°47.7'W. There is no correlation between the depth and the width. The Valley floor is almost devoid of sediments, and several attempts to recover a sediment core failed.

The rocks exposed on the bottom are the latest additions to the sea floor. The rounded basaltic lava pillows solidified quickly when the hot molten rock came in contact with sea water. The outer layer of these samples 'froze' first. Several of these pillows were recovered by dredging. The chilled margins were covered by volcanic glass, which peeled off and shattered on deck when the gradual warming up of the rocks increased the internal strain in the glass. Aumento (1969) analyzed these glass shards using the fission track method. His results established the youngest age at about 12,000 years. On a geological time scale, this indicates that the Valley is very young, and that the geological processes there are still active today.

A strong positive magnetic anomaly associated with the Median Valley is its most prominent characteristic. The amplitude of this anomaly is much larger (by a factor or two or more) than the anomalies over the adjoining crestal mountains. Its cause has been the subject of many speculations and for that reason we were interested in the magnetic properties of the crustal rocks recovered from the ocean floor.

Irving (1970) and others have analyzed representative samples from our collection. The rocks from the floor of the Median Valley had a surprisingly high intensity of magnetization, due to a rapid quenching of lavas that produced dispersed titanomagnetite of very small grain size. The measured values were ten times larger than those previously assumed in the modelling experiments. Because of secondary oxidization of magnetic minerals, the intensity of magnetization falls off rapidly with the distance from the

*Underwater photograph of the Median Valley fjoor shows fresh pillows (camera station 8-66, photograph 90c, depth 2930 metres).*

accretion edge: by a factor of ten within 10 kilometres and by a factor of 200 on the crestal mountains. The thickness of the layer of rocks assumed in the modelling of magnetic anomalies depends on the values of magnetization. The high initial values of magnetization suggest that the volcanic layer may be only 200 metres thick. As this is within the penetration depth of the Deep Sea Drilling Project (DSDP), the above inferences could be checked by a few deep holes. That at least, was the expectation when the magnetic results were first obtained. The actual drilling produced less conclusive results as we will see later.

Irving attributed the decrease of magnetization and other changes in magnetic properties to a mild hydrothermal activity in the axial zone of accretion. On cooling, the lavas contract and fracture forming pathways through which sea water can circulate. This circulation encourages oxidation and other chemical changes. In addition to its effect upon the magnetic anomally, this process could be an important mechanism for the formation of mineralization zones within the volcanic rocks. The study of rock magnetism has thus led us to a practical problem of considerable economic importance.

In addition to recovering rock samples by dredging, several expeditions were successful in obtaining a number of rock cores using the BIO hydrostatic drill (Ade-Hall *et al.,* 1973a). The big advantage of the rock cores is that their orientation is known (we can tell which way is 'up') and so we can measure the direction of magnetization in the rocks relative to the present day inclination of the Earth's magnetic field. Analysis of these samples showed departures from the expected direction of magnetization. All the samples were young, and were located within the area of the strong central magnetic anomaly of 400 to 700 nanoteslas, and must have been extruded during the current normal magnetic epoch (Brunhes). The measured directions of magnetization in four of six samples depart significantly from the expected direction of +64° two are of normal polarity with significantly shallow inclinations (+37° and +47°) and the remaining two are reversely magnetized (-12° and -45°). A small number (5 per cent) of reversely magnetized samples is to be expected within the Bruhnes epoch because of the two short events of the reversal of the magnetic field. Two of six samples do not represent a statistically significant sample but other measurements on samples from the area of Project FAMOUS and from 22°N all show about 30 per cent of reversely magnetized rocks. Similar variability has been encountered on Bermuda (Ade-Hall *et al.,* 1973b) and in DSDP deep crustal holes 332 to 335 on Leg 37. This unexpected variability shows again how complex the real geology is! The Vine-Matthews-Morley hypothesis made possible enormous advances in our understanding of global geology by assuming simple uniformly magnetized blocks in the oceanic crust, carrying away from the spreading axis the record of the reversals sequence of the Earth's magnetic field. The sampling to date indicates that the magnetic anomalies observed with the shipboard magnetometers are not due to a uniformly and strongly magnetized sequence of lava flows but to a sum effect of numerous basaltic lavas (and perhaps intrusions) whose magnetic inclinations and directions vary widely. It is perhaps fortunate that the elegant simplification of the Vine-Matthews-Morley hypothesis was made before the rock samples were available or that great generalization might not have been accepted by most geoscientists.

The tectonic mechanism responsible for the formation of the Median Valley

is still an enigma. Detailed studies of the petrology of rocks made it possible to construct a plausible model and limit the range of alternatives. The study of the seismic characteristics of the region and of the gravity anomaly helped us delimit the model further, though a number of important questions remain unanswered.

Careful petrological analysis established the framework for the geological evolution of the oceanic crust at the ridge crest (Aumento and Loubat, 1971; Aumento and Sullivan, 1974). According to these authors, large discontinuous lopoliths of mafic magma were emplaced beneath the axis of the ridge following a phase of major lateral fracturing due to forces responsible for ocean floor spreading. These pools of magma are within 1 to 2 kilometres of the Median Valley floor; the bottoms of the pools are less than 24 kilometres below sea level. Most of the time, the pools are quiescent and thus allow slow crystallization and magmatic differentiation to take place. Occasional collapse of the roof of the cupola of the lopoliths leads to extrusion of lavas on the valley floor. Subsequent tectonic uplift exposes the solidified sides of the pools and allows us to sample a sequence of deeper emplaced rocks. At the bottom are ultramafic rocks (dunite and peridotite), which may represent the uppermost layers of the upper mantle. Above them are the gabbros; the boundary between them and the ultramafics may represent the Mohorovicic discontinuity (the boundary between oceanic layers 3 and 4). With time, metamorphism due to burial, subsequent intrusions and extrusions, percolating sea water, and generally high heat flow, affects these rocks in a manner approaching that of continental regional metamorphism. Gabbros and diabases are transformed into greenschists and amphibolites. At the same time, it is possible that the dispersed sulphides found in these rocks are concentrated into ores.

## The Crestal Mountains and Other Seamounts

The highest relief on the Mid-Atlantic Ridge is within the central region: the crestal mountains flanking the Median Valley represent the highest elevations on any profile of the North Atlantic Basin. Within the survey area at 45°N there are three pairs of volcanic peaks flanking the valley (Loncarevic *et al.,* 1966). The northernmost pair at 45°51'N were named Gog and Magog by M. N. Hill. The shallowest depths of the western and eastern peaks are 928 fathoms (1967 metres) and 770 fathoms (1335 metres). The southeastern peak is a very impressive mountain. It rises from a depth of 1200 fathoms (2195 metres) in about 2700 metres, or at an average slope of 1:2. This peak is therefore approximately the same size as Mount Vesuvius. We named it Confederation Peak, in honour of Canada's Centennial in 1967. The eastern flank of the Valley and all three peaks on it are shallower than the corresponding features on the west side. The lines connecting the pairs of peaks are oriented east-west and thus make an angle of 71° with the strike of the valley. The volcanism responsible for these paired peaks might be concentrated along the zones of crustal weakness transverse to the strike of the ridge, although no important fracture zones or transform faults displace the axis of the structure.

Confederation Peak has been surveyed, dredged, and photographed in detail (Aumento, 1968). The data collected make it possible to visualize the growth of the volcano from its early stages at the bottom of the Median Valley, through its subsequent evolution, both compositionally and physi-

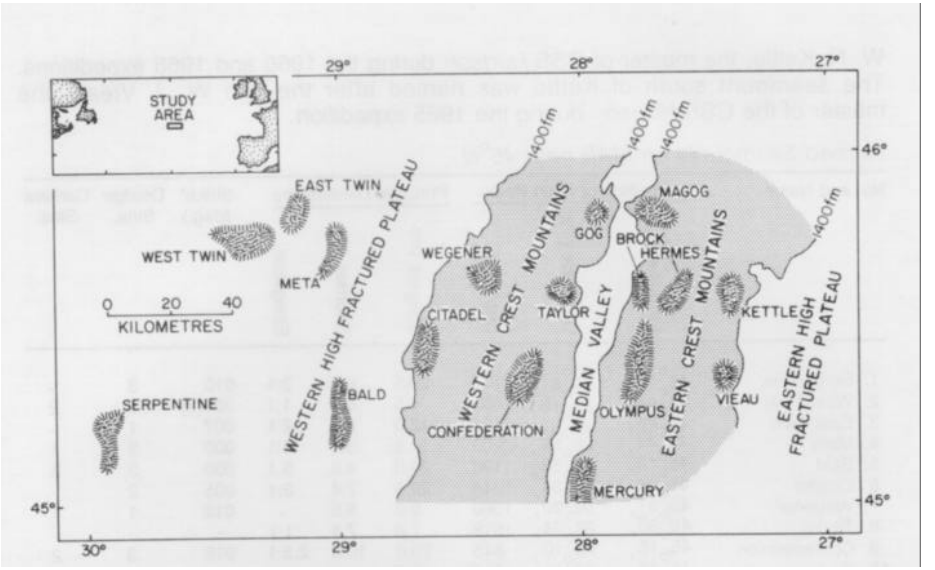



*Chart of the named seamounts In the surveyed areas.*

cally, to a large extinct volcano on the crest mountains, capped by altered lavas. Chemical and petrographic evidence has shown that although considerable crystal fractionation occurs beneath the volcanoes of the Mid-Atlantic Ridge, these processes are not responsible for the continuous tholeiitic-alkali sequence observed. Both magma types must be derived from a single source in such a way as to produce a continuous trend of alkali enrichment for each volcanic cycle.

The high rugged peaks of the Crestal Mountains extend about 40 kilometres either side of the Median Valley, apparently bounded by the 1400-fathom (2560-metre) contour. Beyond that distance the sedimentary basins become more extensive and mountain peaks appear as solitary features surrounded by sediment ponds. It is questionable whether the 1400-fathom boundary between the Crestal Mountains and the High Fractured plateau (as the area beyond was named by Heezen *et al.* (1959)) is a distinct break signifying a change in the tectonic development of the ridge. Some older measurements of sediment thickness indicated significant and sudden increases away from the ridge crest explained by a hiatus in sea-floor spreading up to 6 million years ago and/or a more rapid rate of spreading since. Better and more systematic seismic profiling surveys in recent years (Keen and Manchester, 1970) indicate that, if enough measurements are averaged, the thickness of sediments increases uniformly and that the break between the Crestal Mountains and the high fractured plateau is not clearly marked. There is no need to postulate major changes in the average rate of spreading or tectonic development. On a very short time scale or considering any specific locality, one would have to admit, however, that the development must be episodic.

Within the survey area there are at least 36 distinct seamounts. Sixteen of these have been named (see table). We named those seamounts around which substantial sampling or survey work was carried out and for which we needed a reference name. The second most impressive seamount after Confederation Peak (45°36'N, 27°19'W) is named after the late Captain

W. N. Kettle, the master of *CSS Hudson* during the 1966 and 1968 expeditions. The seamount south of Kettle was named after the late W. J. Vieau, the master of the *CSS Hudson* during the 1965 expedition.

*Named Seamounts on MAR near 45°N*

| No. and Name | Position of Main Peak | | | Principal Dimensions | | | Strike* (deg.) | Dredge Stns. | Camera Stns. |
|---|---|---|---|---|---|---|---|---|---|
| | Latitude (°N) | Longitude (°W) | Least Depth (m) | Longest (m) | Shortest (m) | Elongation | | | |
| 1. Serpentine | 45°15' | 29°51' | 2107 | 20.5 | 6.5 | 3:1 | 010 | 3 | - |
| 2. West Twin | 45°44' | 29°16' | 1865 | 6.5 | 6.5 | 1 1 | 350(?) | 3 | |
| 3. East Twin | 45°40' | 29°07' | 2107 | 12.0 | 6.5 | 2:1 | 007 | 1 | 2 |
| 4. Meta | 45°44' | 28°57' | 2209 | 14.8 | 3.7 | 4:1 | 000 | 3 | |
| 5. Bald | 45°12' | 28°56' | 1196 | 24.0 | 4.6 | 5.1 | 000 | 3 | 1 |
| 6. Citadel | 45°26' | 28°34' | 1244 | 20.5 | 7.4 | 3:1 | 005 | 2 | - |
| 7. Wegener | 45°31' | 28°20' | 1360 | 9.2 | 5.5 | - | 013 | 1 | 1 |
| 8. Taylor | 45,36' | 28°04' | 1518 | 7.4 | 7.4 | 1:1 | | | |
| 9. Confederation | 45°18' | 28°10' | 845 | 25.0 | 10.0 | 2.5:1 | 016 | 3 | - |
| 10. Gog | 45°50' | 27°53' | 1697 | 6.5 | 6.5 | 1:1 | | | |
| 11. Magog | 45°50' | 27°41' | 1408 | 11.0 | 5.5 | 2 :1 | 300 | 1 | 1 |
| 12. Olympus | 45°23' | 27°42' | 722 | 27.0 | 7.4 | 4:1 | 013 | 1 | - |
| 13. Brock | 45°38' | 27°42' | 1335 | 16.5 | 3.9 | 4:1 | 000 | 2 | - |
| 14. Mercury | 45°05' | 27°56' | 964 | I2+ | 7 | - | 012 | 1 | 1 |
| 15. Hermes | 45°34' | 27°34' | 1106 | 17.2 | 5.8 | 2:1 | 029 | - | - |
| 16. Kettle | 45°36' | 27°19' | 980 | 14.7 | 8.2 | 2:1 | 000 | 1 | - |
| 17. Vieau | 45°21' | 27°23' | 1675 | 11.0 | 5.6 | 2:1 | 000 | 1 | - |

*Refers to strike of longest dimension.

The seamounts closer to the Valley are shield volcanoes formed by more or less continuous outpourings of lava; the younger flows appear at higher elevations. The samples collected at different elevations thus reflect magmatic differentiation with age. The seamounts away from the centre show evidence of thrust and block faulting and subsequent undersea erosion. Careful dredging along the slopes of these seamounts enables us to make some inferences regarding the deeper layers of the crust, which are believed to be exposed near the bottom of the slopes.

Such an interpretation was carried out by Barrett and Aumento (1970) who used seismic compressional wave velocities to distinguish different crustal layers. The near vertical block faulting implies that at least 1.5 kilometres of the geological section is represented in the dredge samples. The consistency of rock types in the material dredged from a given depth below the tops of seamounts is indicative of a systematically layered crust prior to these major vertical movements. The uppermost vesicular pillow basalt layer thins with increasing distance from the axis. This is attributed to mechanical and chemical denudation from the tops of seamounts. The underlying massive basalt layer also thins with increasing distance from the axis. As a result of this, there is an apparent progressive shallowing of the metamorphosed basalt and gabbro layer away from the axis of the ridge. The average compressional wave velocity of basalt, metabasalt, and metagabbro increases for these rocks in the order given. It is suspected that the metamorphic rocks of higher grade when at greater depths than those observed here will exhibit velocities comparable to those of layer three. The rocks dredged near the base of block faulted seamounts thus might be representative of the deep seated layer three rocks.

The study of the gravity anomalies (Woodside, 1972) adds to the broader picture. The free air gravity anomalies, over a rugged terrain, reflect the topography. This effect must be eliminated in order to enhance the effect of underlying geological changes. Because of the ruggedness of the topography the shape of the anomaly contours is very sensitive to the choice of density for the material replacing the water column. As the optimum density value is approached, correlation between the Bouguer anomaly and topography decreases, but the anomaly profile does not become uniformly smooth. This means that a choice of one density cannot eliminate the residual anomaly, which in turn gives further evidence of geological inhomogeneity. The gravity anomaly is caused by deep density differences that, on the ridge crest, would reflect a distribution of rock types and/or temperature with depth. With time, the buoyancy forces will adjust the elevation of the crust so as to eliminate the gravity anomaly (isostatic adjustment). The lack of close correlation between the gravity field and the present day Median Valley suggests that the latter has been in existence in its present location for too short a time to allow for isostatic adjustment. Alternatively, it is possible that forces due to mantle convection are maintaining buoyancy imbalance. In either case, the inference is that the physical expression of the Median Valley has a short time constant compared to that of the ridge crest growth. It appears that the Median Valley is a short lived feature created rapidly through a sudden burst of tectonic activity and then obliterated by infilling from flank volcanoes prior to a new valley formation within some tens of kilometres of the old axis.

For the whole survey area, the calculated gradient of the gravity anomaly (Bouguer) versus depth relationship is about half of that calculated for the western Atlantic Basin. From this it is inferred that the Crestal Mountains are not compensated by undulations of the crust-mantle interface but require an upper mantle density deficiency and/or tectonic forces to maintain their elevation. As interpreted by Woodside (1972), gravity results support the contention that the direction and rate of sea floor spreading changed about 10 million years ago and that the rate of spreading eastwards and westwards may not be equal. On an ocean-wide basis, the direction and rate of spreading are most easily determined by the study of magnetic profiles and inferred magnetic lineations or stripes. At 45°N we had enough magnetic observations to construct a map. This map did not show clearly the complete sequence of magnetic lineations. The only clearly defined stripes were those corresponding to the present, or Bruhnes, epoch of normal magnetic polarity over the Median Valley, and those representing the so-called ‘anomaly 5’ or a 10 million year isochron. A sophisticated technique of directional averaging was used (Loncarevic and Parker, 1971) to extract the magnetic signal from the background noise caused by tectonic disturbances such as block faulting and the intrusion of serpentinite diapirs. It was possible to show that the magnetic pattern did conform to the worldwide model of seafloor spreading with a rate of spreading of 1.28 centimetres per year westward, and 1.10 centimetres per year eastward.

Further study of the magnetic data by Bhattacharyya *et al.* (1975) led to a somewhat different interpretation. These investigators suggested that the overall average geological trend of 017°E in the survey area is made up of nearly north-south segments offset every 10 to 15 kilometres. They further proposed that there was an old spreading centre near 45°20’N, 29°20’W, about 70 kilometres west of the present Median Valley. At least 20 kilometres of sea floor may have been produced here over a period of up to 5 million years.

## A New Look at MAR

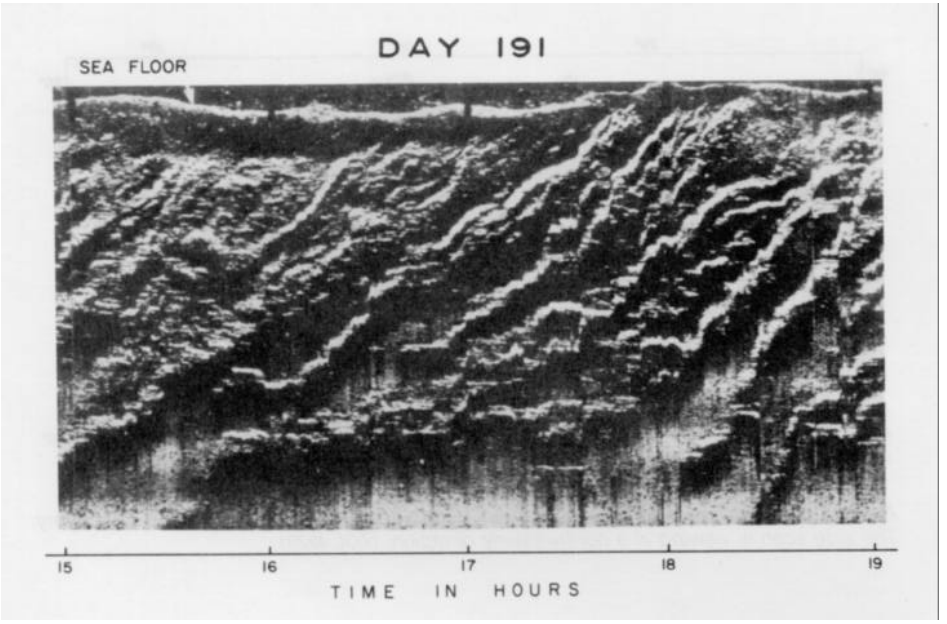
Since 1972, British oceanographers have been continuing research investigations near 45°N. Promising are their studies of earthquake seismicity, which should lead to a better hypothesis for the origin of the Median Valley. The seismic refraction experiments using ocean bottom seismometers will better define the structure of the crust and the upper mantle. Our immediate concern, however, is the investigations carried out by Dr. A. S. Laughton and others on board RRS *Discovery* in 1975 using a deep sea long range sonar called Gloria which gives us a new look at the area. The new data should resolve the questions raised by the magnetic and gravity data regarding the direction of geological trends, changes in these directions, and the character of faulting and rifting in the survey area (Whitmarsh and Laughton, 1976).

Gloria is a long range side-scan device developed at the Institute of Oceanographic Sciences, Wormley, England. In deep ocean and under ideal conditions (good weather that permits smooth towing: good signal-to-noise ratio; a minimum of sound wave refraction; etc.) a maximum range of up to 27 kilometres is possible. At that distance it takes the sound pulse 36 seconds for a round trip from ship to target and back. An array of transducers and control mechanisms is towed astern the ship at a depth of 100 metres. The towed vehicle weighs 6.7 tons in air (3.5 tons in water) and is one of the most cumbersome of oceanographic instruments. The superb pictures of the ocean floor justify the effort required to use Gloria. The information it provides is unique and we are fortunate that it has been used over the MAR near 45°N to complement other scientific data already available from this area.

On *Discovery* cruise 73 in July 1975, a survey of 2250 kilometres was carried out along tracks running in a 050° - 230° direction. The average track separation was 12.5 kilometres allowing for a 20 to 50 per cent overlap of the insonified areas.

A typical Gloria record is shown in the accompanying photograph. The ship was on course 230° and Gloria was looking to starboard, thus, in direction 320°. The record starts over the Median Valley (1500 to 1600 hours) where it is mottled due to a number of small features not insonified at normal incidence. The stronger echoes between 1630 and 1900 hours are the returns from the western flank of the Valley. The subparallel ridges are clearly defined, presumably because the beam incidence is closer to normal on the exposed scarps of the tilted blocks. The lower slopes of Confederation Peak are insonified between 1600 and 1700 at the maximum range but do not give a sharp echo and are not well defined, presumably because of the accumulation of scree and sediment debris. The record shows two clear cases of yaw. At 1730 to 1735 and 1800 to 1805, the Gloria gyro indicated heading departures greater than 5°. The corresponding straight segments parallel to the ship's track (top of the picture) and apparently displacing long linear targets are thus only artifacts of recording. If these artifacts are removed, we obtain a set of unbroken subparallel echoes throughout the range of recording.

Interpretation of *Gloria* records requires considerable expertise in addition to a detailed comparison of sonar pictures with bathymetric profiles taken at right angles to the sonar track. These comparisons are necessary to identify individual targets on sonar records and to eliminate artifacts due to

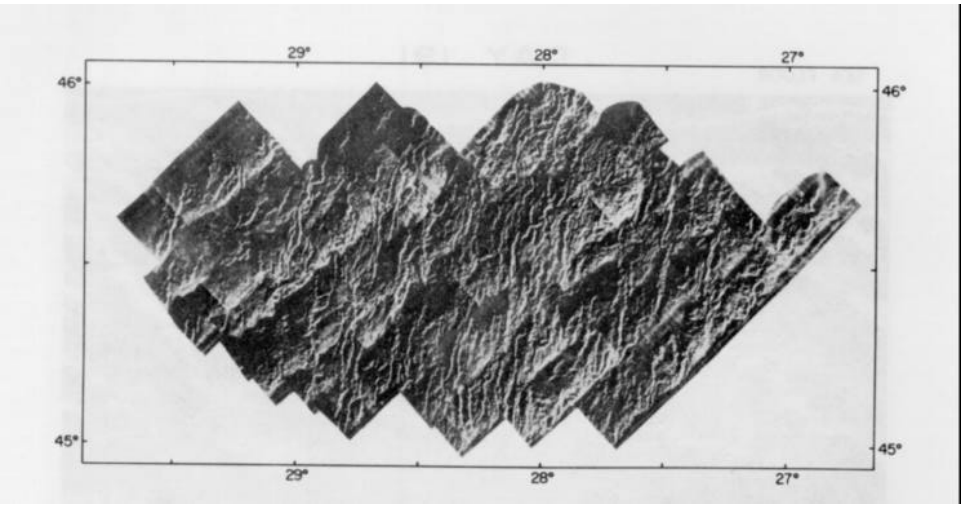



*A four hour* Gloria *record over the Median Valley: the sonar is 'looking' northwesterly while the ship is proceeding on course 230° at 1.25 kilometres per hour (AOL 4222)*

small navigational errors and course alterations, yaw of the towed vehicle, slant range distortion, and the effect of shadows and screening by elevated topography close to the ship's track.

The overall tectonic fabric of the Mid-Atlantic Ridge is illustrated in the figure. This figure is a composite mosaic of all sonograms from the Discovery survey. There is a clear overall trend from 015° to 020°E. If the yaw and navigational errors are taken out, remarkably straight and continuous targets appear. Some of the scarp faces or ridges extend for 30 to 50 kilometres across the survey area. There are no identifiable fracture zones in the area with the possible exception of an - 12 kilometre long east-west target near Twin Peaks (45°45'N, 29°16'W), which may mark a small displacement in line with the widest portion of the Median Valley. In examining the mosaic, it is interesting to note that first order features revealed by echo sounder surveys, such as the Median Valley or large seamounts, are not delineated by Gloria. The side-scan thus bridges the gap between a geomorphic map compiled from echo sounder profiles and bottom photography.

The main conclusion from the examination of the mosaic is that the overall tectonic pattern is consistent in direction, that the trend is about 15° east of north, and that there are no large or systematic displacements of this trend. At the same time, the wealth and strength of targets confirm that there are large numbers of long exposed faces, scarps, and ridges. Detailed studies of these should help us to describe the tectonic forces and events that accompany and follow the formation of accretion edges of tectonic plates.




*A* mosaic *of side scan records obtained during the 1975 survey by RRS* Discovery. *The side scan* IS *vIewing in a northwesterly direction. (*AOL *4223)*

## Outstanding Problems for Future Research

In many ways, the study of the Mid-Atlantic Ridge is just beginning. The International Program of Ocean Drilling (IPOD) completed the first deep drill hole at 45°N late in the summer of 1976 and the results are not yet available. Ocean bottom seismometry is revolutionizing seismic studies at sea and novel interpretation techniques will greatly improve the definition and the resolution of the crustal structure and will impose limits on plausible physical models. Future use of deep diving submersibles will refine undersea geological mapping, which will limit the range of geological models. This work should help solve four major problems recognized today:

-The cause of marine magnetic anomalies is unknown. Potential field interpretations have defined a range of models and their physical characteristics that could produce the observed magnetic field. These models require fairly uniform magnetizations (and directions) in the upper few hundred metres of the crust, within layer 2. This layer has now been drilled and measurements on samples recovered show that layer 2 could not be responsible for magnetic anomalies, at least not in the areas drilled. In addition, a considerable number of reversely magnetized rocks have been sampled where normal directions are expected. Since the magnetic stripe pattern was the first clue that led to the formulation of the Plate Tectonics Hypothesis it is important to pinpoint the source of the anomalies.

-The Median Valley is the most characteristic feature of slow spreading ridges, yet there is no satisfactory explanation of its origin. Detailed seismic work recently conducted in the Valley should prove useful. Nevertheless we are a long way from a satisfactory explanation that will encompass both the depth of the floor of the Valley and the heights of the flanking mountains.

-Research by a number of institutions was concentrated on the studies of the Ridge crest because there was a feeling that this area would give a clue to the nature of the driving force for continental drift. There is a consensus among geoscientists that large scale horizontal movements of the Earth's crust have taken place during the past 200 million years. It is thus embarrassing that we do not have an acceptable hypothesis for the driving force; the true understanding of Plate Tectonics is not possible without a description of the forces behind it. The study of the crest alone will not yield this explanation although it will be an important contribution toward defining the boundary conditions of the problem

-Some of the geological processes at accretion edges may be important in the formation of mineralization zones containing metallic ores. Magmatic and tectonic evolution accompanied by metamorphism of various degrees can produce metallic sulphides. In addition, hydrothermal circulation of sea water through cracks of rapidly cooled and fractured rocks could lead to leaching and subsequent redeposition of metalliferous sediments of the type found in the Red Sea 'hot brine' depressions. While direct 'hard-rock' mining of the Mid-Atlantic Ridge does not appear feasible in the near future, we must never underestimate the capabilities of as yet undiscovered technology. In any case, the knowledge of the mechanism of the origin of the metallic ore deposits will enhance our exploration methods on land and will lead us to new resources.

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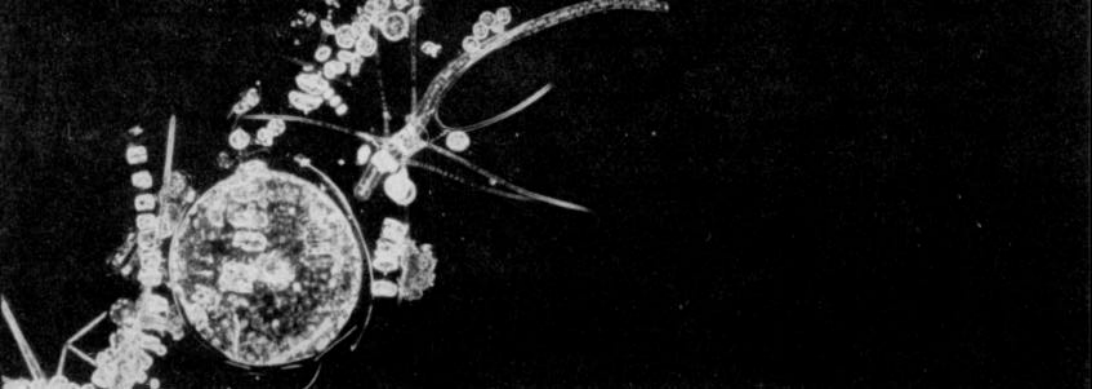


# Phytoplankton Patchiness

Trevor C. Platt and Kenneth L. Denman, *Marine Ecology Laboratory*

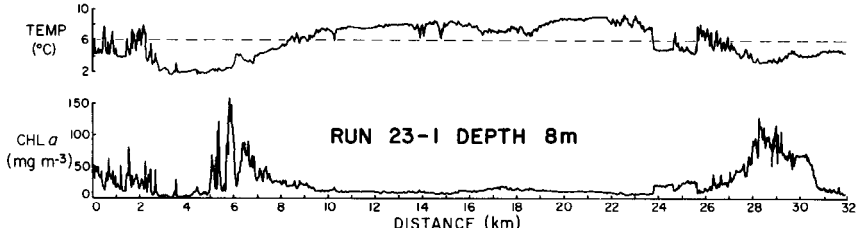
Spatial variability of the environment together with the resulting organization of organisms are crucial factors in the maintenance of stability in ecological systems (Huffaker, 1958; Smith, 1972; May, 1973). The Marine Ecology Laboratory's (MEL's) concern is, of course, the study of marine ecological systems. In particular, we study the phytoplankton, which are the microscopic free-floating plants that are responsible, in the ocean, for converting the sun's energy into energy capable of being used by the rest of the ecosystem.

The distribution of phytoplankton populations is intimately related to their environment (Steele, 1974a) because the generation time of the organisms (the time in which they double their concentration) is comparable to the time period of a tidal cycle, a storm, a daily heating and cooling cycle, etc., all of which can generate water motions that result in the passive dispersal of the phytoplankton organisms. Furthermore, both the spatial distribution of the phytoplankton and the intensity of the dispersion process can be measured. These considerations have recently stimulated interest in the study of spatial heterogeneity of phytoplankton in oceans and lakes.

In the sea, phytoplankton populations are structured in three dimensions. Vertical layering of the phytoplankton results from vertical density gradients of the water itself and from the exponential decrease of the available light with depth. These factors impose special constraints on the dynamics of phytoplankton populations that are altogether different from those that give rise to structure in the horizontal dimension. It is the inhomogeneity in the horizontal, the so-called patchiness (see figure), that we discuss here.

The principal aims of the study of spatial heterogeneity in plankton are: to be able to describe it, in particular to discover its characteristic scales in space and time under different conditions; to account for its origin and persistence; to determine the intensity of the coupling between the physical and biological components of the ecosystem; and to assess its significance for the behaviour and stability of the ecosystem.

One of the major goals of our laboratory is to improve our ability to predict biological production in natural ecological systems. In mathematical modelling of the production of phytoplankton, an understanding of patchiness is



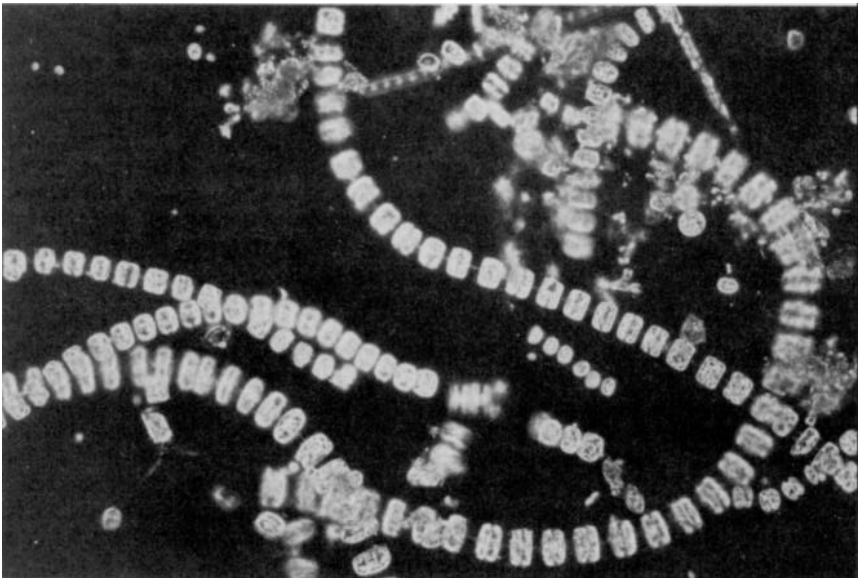

*The variability of phytoplankton distributions as indicated by chlorophyll a measurements in the lower St. Lawrence estuary. (AOL 3656)*

important for a number of reasons. It allows us to estimate the reliability of our sampling of the real world and therefore to estimate the probable magnitude of the observational error in the initial state of the system. Knowledge of this error is necessary for the numerical solution of differential equations that calculate the concentration of phytoplankton (biomass) at subsequent times at any point in the system. Also, the observational determination of the characteristic space scales helps in the parameterization of the patchiness for the construction of grid point models for biomass. This parameterization is necessary since the scales are usually smaller than a practical mesh size for the grid. The magnitude and distribution of fluctuations is important for the calculation of the effects of thresholds and nonlinearities in the system equations (Platt and Denman, 1975). And finally, the understanding of patchiness is important for constructing generalized food chain models of the marine ecosystem because, for many organisms (including commercial fish species) with a planktonic larval stage, it is thought that survival of the larvae is critically dependent on their finding a higher-than-average food concentration at some key phase in their life (Conover, 1968; Jones, 1973; Lasker, 1975).

## An Example from Fisheries

A compelling example of the implications to the fisheries of patchiness in phytoplankton has been provided by Lasker (1975). Working with larvae of the northern anchovy *Engraulis mordax,* spawned in the laboratory, he was able to study their feeding behaviour under controlled conditions. First-feeding larvae are able to eat phytoplankton but, among several conditions required for successful feeding, the number of food particles per unit volume in the anchovy larva's environment must be above a certain minimum. Furthermore, the greater the concentration of food particles, the more frequent are the feeding strikes, and the greater the success of the larvae in capturing food. Lasker was able to take laboratory-reared larvae into the field (California coast) and test directly whether the amount of food in the water was sufficient to sustain their successful feeding. He found that feeding by larvae in water from the surface was minimal but that extensive feeding occurred in water from deeper layers containing phytoplankters having minimum diameters of about 40 micrometres in densities of 20-40 particles per millilitre. In March and April 1974, he found a dense layer of phytoplankton roughly 100 kilometres long that was able to support successful feeding by the larvae. A storm mixed extensively the top 20 metres of the water column, obliterated the layer, and thus effectively destroyed the feeding ground of the larval anchovy. As the correct feeding conditions must be available within 2.5 days after the larvae are ready to feed, passage of this storm would ensure that anchovy larvae in the area simply

would not survive. Lasker emphasized the transient nature of good feeding conditions. By improving our understanding of the horizontal and vertical variability of phytoplankton abundance, we can learn more about the ways the environment influences the survival of the larvae of our commercial fish species.



*Phytoplankton are neutrally buoyant unicellular aquatic plants that are usually immotile but are transported passively by water.*

## Characteristic Scales

The investigation of spatial inhomogeneity in the phytoplankton is still in its infancy. From the work that has been done, however, we can begin to set some limitations on the scales of patchiness known to occur, but always with the realization that it is impossible to dissociate completely the results obtained from the sampling methods used.

We shall discuss only those studies, which treat fluctuations of the phytoplankton biomass as a whole, usually indexed by the concentration of chlorophyll a pigment that can be measured *in situ* automatically. A few investigations (e.g., Richerson *et al.,* 1975) have looked at individual species separately, but for predicting the production of the entire phytoplankton population, these studies are of lesser interest. Platt *et al.* (1970) examined the variance of chlorophyll measurements made at stations in clusters of different sizes in an exposed bay (St. Margaret's Bay, Nova Scotia). The dependence of the variance on the cluster size gave an estimated characteristic patch size of 0.5 to 1.6 kilometres. A similar study in a semi-enclosed bay (Bedford Basin, Nova Scotia), but concerned with actual growth rates of phytoplankton, gave a patch size of 0.6 to 1.9 kilometres (Platt and Filion, 1973). Primitive attempts at spectral analysis of

point-sampled data on chlorophyll concentration in the nearshore zone (Platt *et al.,* 1970) suggested a scale of 1-2 kilometres for the plankton patches. Statistical analyses of the chlorophyll and temperature fluctuations in the surface layer of the Gulf of St. Lawrence (Denman and Platt, 1975) indicate a characteristic scale size for the phytoplankton patches of less than about 5 kilometres. Similar measurements in Lake Tahoe (Powell *et al.,* 1975) suggest a scale of ~ 100 metres for the phytoplankton.

In addition to estimates of characteristic scales from field measurements, one can also attempt theoretical calculations, but progress here has been minimal also. The earliest approach was that of Kierstead and Slobodkin (1953) who identified the characteristic scale as that for which the opposing tendencies of turbulent diffusion and phytoplankton growth were just balanced. Allowing for the dependence of the turbulent diffusion coefficient on the length scale of the turbulent eddies (Okubo, 1971), it may be shown (Platt and Denman, 1975) that this treatment gives a characteristic length scale for phytoplankton patchiness of between 50 and 100 metres. Okubo (1974) calculates a range of 100-1000 metres using a somewhat different method.

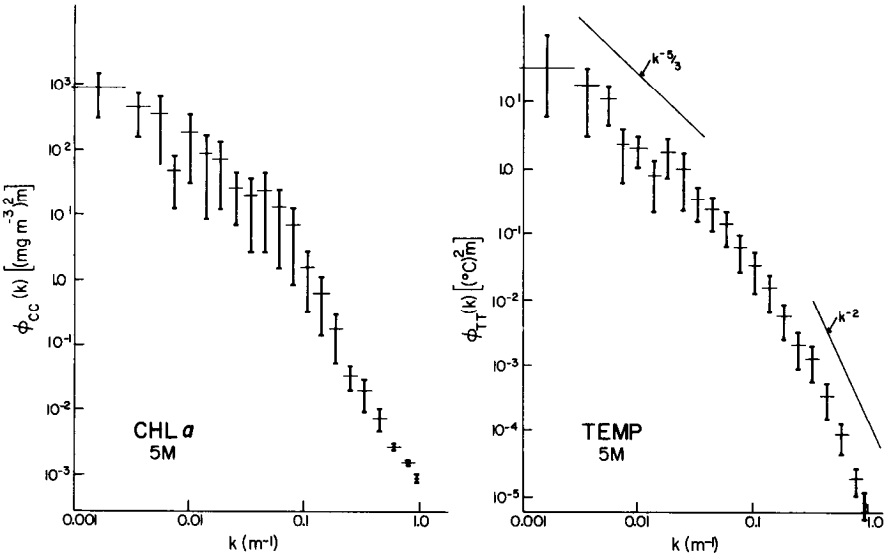
There are at least two reasons why such a simplistic treatment would tend to *underestimate* the length-scale for phytoplankton. First, the boundary conditions on the original Kierstead and Slobodkin formulation precluded the possibility of growth outside of the patch. It would be more realistic to allow growth outside the patch, but at a different rate than that inside. Second, the effect of *grazing by herbivorous zooplankton* has been neglected. If the grazing effect is introduced, the appropriate length scale is increased to about 1 kilometre, where phytoplankton growth and zooplankton grazing are almost equal (Platt and Denman, 1975).

The above studies indicate that the horizontal length scales relevant to the patchiness range from 100 metres to 10 kilometres. The corresponding range of time scales is about 3 hours (minimum generation time of phytoplankton) to 2 weeks (lifetime of the largest zooplankton patch ever studied systematically, Cushing (1963) ).

One difficulty that probably invalidates the whole concept of the calculation of a characteristic scale is that it considers effects on only a single patch. Actual patches occur over a whole range of space scales, as can be seen from variance spectra (such as those in the figure) that separate the variance of a data series into the contributing spatial scales.

## Theoretical Variance Spectra

One of the most powerful ways to describe the spatial heterogeneity of phytoplankton is to measure the chlorophyll concentration in the ocean continuously and to represent the results in a variance spectrum in either wavenumber or frequency space. Recent field work analyzed in this way has been published by Powell *et al.* (1975), Denman and Platt (1975) Fasham and Pugh (1976), and Denman (1976). These spectra have been interpreted previously under the hypothesis that the phytoplankters are carried passively and dispersed by the turbulent motions of the water, and they have been compared with the spectra of purely passive scalars, such as temperature. Because phytoplankton cells are reproducing continuously, chlorophyll *a* concentration is a non-conservative quantity, and it is not




*Variance spectra for chlorophyll a* and *temperature at a depth of 5 metres in the lower St. Lawrence estuary. (AOL 3099)*

immediately obvious how this affects the spectral shape one might expect to observe in the ocean. Using dimensional arguments, we have recently proposed a theoretical representation of the variance spectrum of phytoplankton in wavenumber space (Denman and Platt, 1976), and this is outlined below.

Suppose that the turbulent eddies in the water can be characterized by a length scale *d*, or in the usual spectral notation a wavenumber $d^{-1}$. One can also define a time scale $\tau$, the time taken for an eddy of size *d* to break down and transfer its kinetic energy (velocity variance) to eddies of diameter *d/2*. We compare this time scale $\tau$ with a characteristic time scale for the phytoplankton reproduction, given by the reciprocal of its exponential growth-rate $r$. The general equation for chlorophyll variance as a function of wave number, $E_\beta(k)$, then has the form

$$E_\beta(k) = A\chi_\beta r^{-1}k^{-1}F(k/k_c) \qquad (1)$$

where the subscript $\beta$ denotes chlorophyll biomass; *k* is the wavenumber; A is a dimensionless constant; $\chi_\beta$ is the rate of destruction of p-variance at high wavenumber (see for example Batchelor, 1959); and *F* is an unspecified function of the dimensionless variable $k/k_c$ where $k_c$ is a characteristic wavenumber, $k_c = (r^3/\varepsilon)^{1/2}$, depending on $r$ and on $\varepsilon$ (the dissipation rate of turbulent energy). Three ranges are recognized for $E_\beta(k)$, according to the relative magnitudes of the time scale $\tau$ for the decay of turbulent eddies in the flow field and the characteristic time scale $r^{-1}$ for phytoplankton reproduction. For large size scales in the region $\tau >> r^{-1}$ (or equivalently $k << k_c$) our hypothesis is that $\varepsilon$ is an unimportant parameter of $E_\beta(k)$ compared to the parameter $r$, i.e., that biological processes dominate over turbulent processes for this region. In this case, (1) takes the form

$$E_\beta(k) = A' \chi_\beta r^{-1} k^{-1} \qquad (2)$$

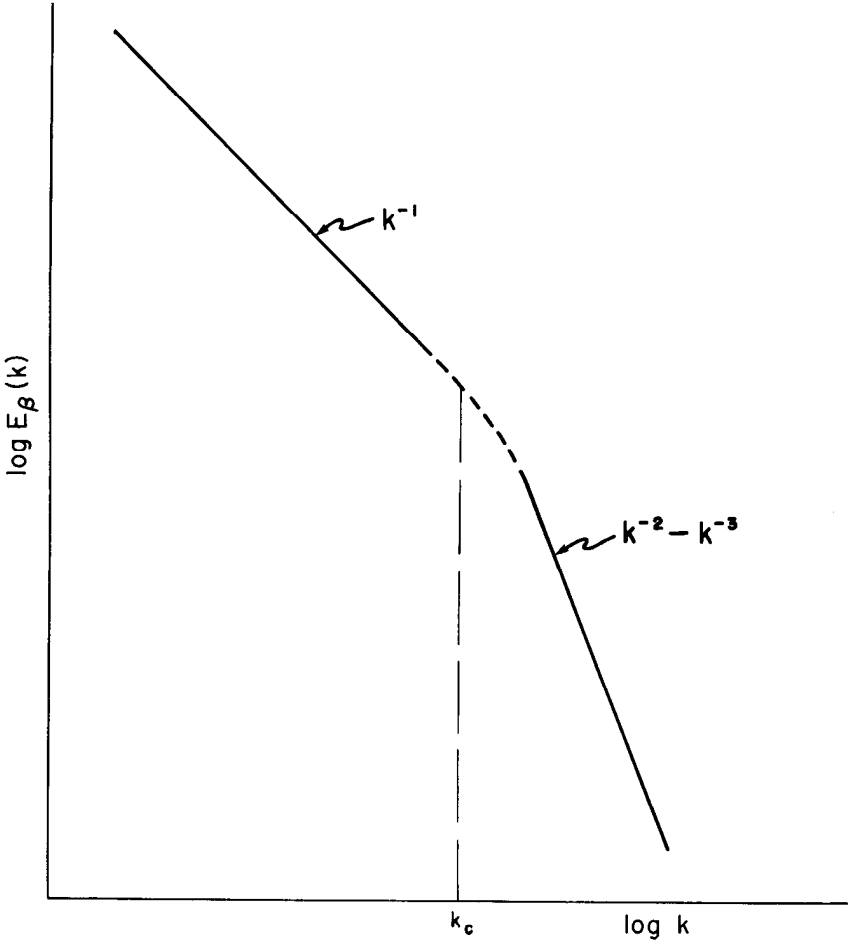
where A' is another dimensionless constant. This result implies that individual phytoplankton species with different growth rates will share a common spectral slope $k^{-1}$ in this region, $k << k_c$ (the magnitude of $k_c^{-1}$ is 1 kilometre). Also, the chlorophyll spectrum will be flatter than the spectrum of a conservative passive scalar contaminant of the flow field, such as temperature. The other two ranges are: $k >> k_c$ ($\tau << r^{-1}$), where the spectrum is similar to that of a passive scalar like temperature with a wavenumber dependence $E_\beta(k) \propto k^{-5/3}$ (Kolmogoroff, 1941) and $k \approx k_c$, which is a transition zone between the above ranges.

The above arguments assume a simplified picture of the water motions since observations of the variance spectra of sea-surface temperature at these scales (Saunders, 1972; Holladay and O'Brien, 1975) have a wavenumber dependence from $k^{-2.2}$ to $k^{-3}$ rather than $k^{-5/3}$. A $k^{-2}$ wavenumber dependence suggests that the turbulent transfers occur primarily at fronts or discontinuities; a $k^{-3}$ wavenumber dependence suggests a two-dimensional turbulent field (Kraichnan, 1967) bounded by the thermocline below rather than the assumed three-dimensional turbulent field unbounded in all directions. But these are minor considerations for the region of primary biological interest, $k << k_c$, where the rate of physical turbulent transfer should not be an important parameter, and, we believe, the $k^{-1}$ dependence should still apply to the variance spectrum of chlorophyll. In the high wavenumber region $k >> k_c$ we expect $E_\beta(k)$ to follow the temperature spectrum $E_\theta(k)$ with a slope from $k^{-2}$ to $k^{-3}$. A schematic plot of this theoretical phytoplankton spectrum is given in the figure.

## Significance of Patchiness

Since the horizontal variability in phytoplankton biomass and reproduction rate is a function of time and space, its effects tend to be diminished when measurements at a fixed station are averaged over time. Platt (1975) illustrates this in his analysis of the importance of spatial and temporal variability in the estimation of annual production by phytoplankton in the Bedford Basin.

The significance of spatial heterogeneity has only just begun to be explored in theoretical models. One of the earliest ecological examples was provided by Segel and Jackson (1972) who showed that, in the presence of diffusion, nonlinear interactions between populations in adjacent levels of the marine food chain could bring about the breakdown of a steady state condition and the development of spatial inhomogeneities in a certain band of wavelengths. Steele (1974b) made a similar study for plankton and found equivalent results, showing also how the variance could be transferred between length scales. Okubo (1974) has also calculated the effects of diffusion-induced instability on populations of interacting species. Richerson *et al.* (1970), extending the work of Margalef (1967), developed the concept of the pelagic environment as a mosaic of diverse microhabitats, each inhabited by different species of phytoplankton with different growth characteristics. The structure of the mosaic is considered to be sufficiently stable in time to maintain spatial variability among the phytoplankton but not stable to the point that the population of each microhabitat reduces to a single species. This concept of 'contemporaneous disequilibrium' was found to

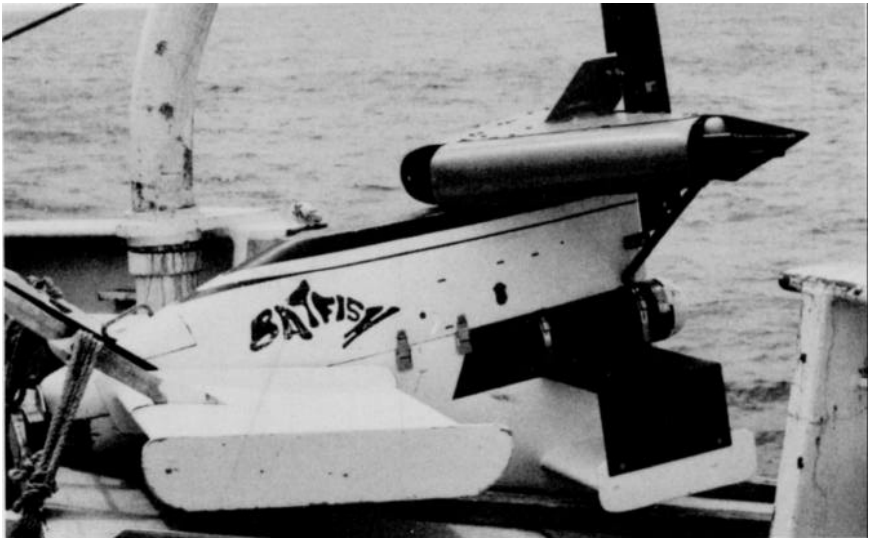



*Theoretical variance spectrum of phytoplankton patchiness. See text for details. (AOL 3831)*

be a satisfying explanation for the results of Platt and Filion's (1973) study of spatial variations in the rate of reproduction of phytoplankton. Levin and Paine (1974) in an investigation of the importance of spatial heterogeneity in general ecological models, arrived at an essentially similar concept of the natural community "as a spatial and temporal mosaic of small-scale systems, recognizing that the individual component islands or patches cannot be considered closed. Rather they are part of an integrated patchwork, with individual patches constantly exchanging materials". Environmental perturbations disturb natural sequences of species composition within the patches and prevent these communities from ever reaching equilibrium; it is appropriate then to disregard the properties of the individual patch in favour of the macroscopic properties of a number of patches. Levin and Paine consider the spatial heterogeneity of such profound importance for community dynamics that they postulate the patch as the fundamental unit of community structure. The full implications of such an hypothesis are still being explored.

## The Future

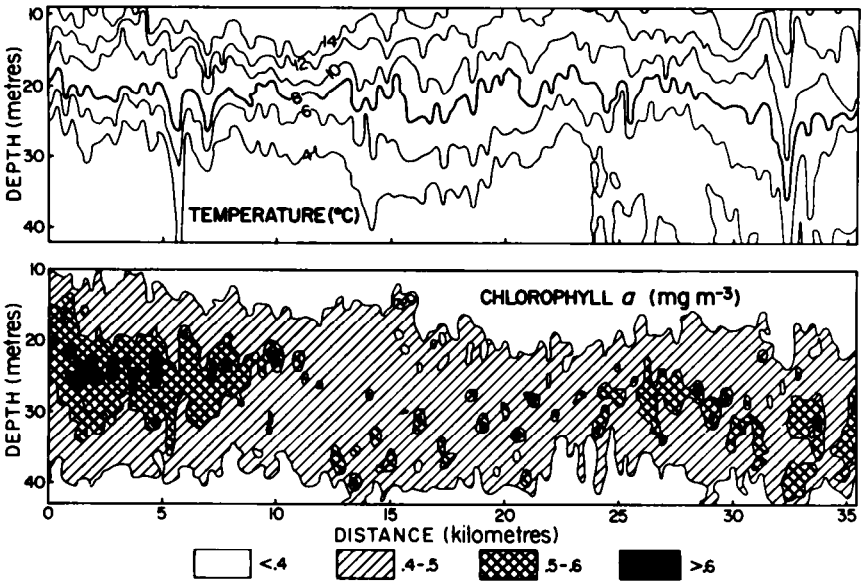
Research at MEL, and other research such as that of Lasker described earlier, underscore the necessity of obtaining a *three-dimensional* picture of the biological patchiness in the ocean. To achieve this goal, we in the Marine Ecology Laboratory have been working with Dr. Alex Herman of the Atlantic Oceanographic Laboratory to incorporate a Variosens (Impulsphysik) *in situ* fluorometer on Batfish, a towed porpoising body.




*The* Batfish *wrth* a *fluoromeler mounted on its back. (AOL 3520)*

With such instrumentation we are now able to observe both the horizontal and vertical structure of phytoplankton patchiness simultaneously and unambiguously. An example of the very exciting data that this system is capable of providing is shown in the figure for the Scotian Shelf southwest of Halifax. This 35-kilometre section is constructed from 114 cycles of a Batfish transect in waters averaging 150 metres depth. We can see a very distinct zone of high relative chlorophyll concentration between 20 and 30 metres extending over the first 10 kilometres of the section.

At present we are using the Batfish to study the spatial structure and phytoplankton dynamics in the frontal systems that exist in the ocean at the edge of the continental shelf south of Halifax (Herman and Denman, in press). The Atlantic Oceanographic Laboratory is, at the same time, mounting a study of the physical dynamics that initiate and control the extreme variability displayed by this frontal system. The profound significance of the interplay between physics and biology for the dynamics of phytoplankton growth in frontal regions has been demonstrated by some refined measurements of Pingree *et al.* (1975) along the tidal fronts in the English Channel. They found that rapid growth of phytoplankton occurred in nutrient-rich water recently mixed into the surface layer along the tidal front. Prolonged periods




*Scotian Shelf data from the Batfish system. (AOL 3562)*

of slackening neap tides, low winds, and sunshine could create 'quiescent' conditions favourable for phytoplankton blooms to culminate in red tides.

The theoretical and experimental expertise that we have acquired in the Marine Ecology Laboratory, coupled with the physical oceanographic and technical capability that exists in the Atlantic Oceanographic Laboratory, put us in a strong position to make unique, exciting discoveries in the field of plankton patchiness for some years to come.

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# Appendices

Research, Survey, and Senior Support Staff

Major Publications of **1975/76**

Major Cruises of 1975/76

BIO Building Expansion

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# Research, Survey, and Senior Support Staff

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C. J. Ritcey
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Photography: N. E. Fenerty - Head

Scientific Editor: M. P. Latremouille

[1]New staff member
[2]Left BIO
[3]Away on educational leave
[4]Postdoctoral Fellow
[5]Seconded to Maritime Command, CFB Hafifax
[6]Ocean and Aquatic Sciences, Atlantic, staff member reporting to Director-General
[7]Acting Director to August 1976
[8]Acting Director to July 1975
[9]Transferred to office of Director-General with responsibility for program analysis and project co-ordination

# Major Publications of 1975/76

## Bedford Institute of Oceanography Contributions

A few papers earlier than 1975 that were not available when the 1973/74 Biennial Review went to press are included here. Bedford Institute of Oceanography Contribution Numbers are listed within brackets on the last line of each reference. The abbreviations used in the list follow the Chemical Abstracts Service *Source Index: 1907- 1974 Cumulative.*


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# Major Cruises of 1975/76

**1975 Cruises**

| Cruise No. & Vessel | Cruise Dates | Officer in Charge | Area | Objectives |
|---|---|---|---|---|
| 75-001 *Dawson* | January 3-16 | W. D. Forrester, AOL | NE Gulf of St. Lawrence; Northumberland Strait | Equipment placement; temperature, salinity, and particulate matter measurements |
| 75-002 *Sackville* | January 20-23 | S. B. MacPhee, AOL | Northern Atlantic | Equipment evaluation |
| 75-003 *Dawson* | January 27-February 1 | A. R. Coote, AOL | Halifax-Bermuda | Studies of organic matter, pollution, and marine geology |
| 75-004 *Dawson* | February 1-16 | R. W. Sheldon, MEL | Bermuda | Surface and deep-water fish and plankton investigations |
| 75-005 *Dawson* | February 24-28 | R. Reiniger, AOL | Laurentian Fan | Equipment testing and placement |
| 75-006 *Hudson* | March 22-April 4 | C. S. Mason, AOL | South of Bermuda | Equipment development and evaluation |
| 75-007 *Hudson* | April 11-24 | D. L. McKeown, AOL | Emerald Basin Bank; St. Margaret's Bay | "Pockmark" study; seismic data collection; equipment evaluation |
| 75-008 *Dawson* | April 14-May 2 | R. Reiniger, AOL | Laurentian Fan | Recovery and replacement of moorings and tide gauges; mapping and following of small-scale front |

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|---|---|---|---|---|
| 75-009<br>*Hudson* | | | | |
| Phase I | April 25-<br>May 29 | G. B. Fader,<br>AGC | East of Avalon Peninsula to Flemish Cap and the Arctic | Geological investigations of the Grand Banks; development of an integrated survey mapping concept |
| Phase II | June 2-<br>July 3 | C. E. Keen,<br>AGC | Newfoundland Basin; Grand Banks | Geophysical investigations |
| Phase Ill | July 21-<br>August 20 | R. T. Haworth,<br>AGC | NE Gulf of St. Lawrence; northeast of Newfoundland | Geological and geophysical investigations |
| Phase IV | August 24-<br>September 13 | Ft. Fillon,<br>AGC | Labrador Sea; Davis Strait | Geological investigations |
| Phase V | September 14-<br>October 12 | S. P. Srivastava,<br>AGC | Baffin Island; Davis Strait; Labrador Sea; Greenland | Geophysical data collection and surveying; geological coring; etc. |
| 75-010<br>*Dawson* | March 3-<br>6 | R. O. Fournier,<br>Dalhousie Univ. | Halifax Section | Miscellaneous projects |
| 75-011<br>*Baffin* | April 30-<br>October 17 | J. M. R. Pilote, | St. Lawrence estuary; Labrador coast; Foxe Basin | Hydrographic charting |
| 75-012<br>*Maxwell* | April 30<br>October 31 | M. G. Swim,<br>AOL | Atlantic Provinces | Hydrographic charting |
| 75-013<br>*Dawson* | May 6-<br>May 14 | E. M. Hassan,<br>AOL | Strait of Belle Isle; Esquiman Channel; Cabot Strait | Temperature and salinity structure investigations; occupy Cabot Strait section |
| 75-014<br>*Christmas* Seal | May 26-<br>October 29 | V. J. Gaudet,<br>AOL | NS coast; PEI | Chart revisory and navigational range surveys |
| 75-015<br>*Dawson* | May 27-<br>June 6 | R. Pocklington,<br>AOL | Gulf of St. Lawrence; Cabot Strait; Strait of Belle Isle; Northumberland Strait | Studies of oxygen, petroleum residues, organic matter, nutrients, and carbon and oxygen isotope ratios |

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|---|---|---|---|---|
| 75-016<br>*Dawson* | | | | |
| Phase I | June 20-<br>July 6 | K. Kranck,<br>AOL | Strait of Belle Isle;<br>St. Lawrence estuary | Recovery of current meter moorings; studies of particulate matter characteristics |
| Phase II | July 8-<br>26 | G. H. Seibert, | St. Lawrence River | Estuarine circulation studies; current meter mooring and recovery |
| 75-017<br>*Theron* | June 27-<br>October 12 | A. L. Adams,<br>AOL | Newfoundland and Labrador coasts | Standard charting and route surveys |
| 75-016<br>*Martin Karlsen* | July 4-<br>October 14 | G. M. Yeaton;<br>R. K. Williams, AOL | Northern Newfoundland coast; Labrador coast and Sea | Hydrographic-Geophysical survey; check errors in Cape Race Loran-C transmitter |
| 75-019<br>*Dawson* | July 29-<br>August 4 | E. M. El-Sabh,<br>UQAR | St. Lawrence estuary | Multidisciplinary studies |
| 75-020<br>*Dawson* | August 11-<br>15 | R. Reiniger,<br>AOL | Laurentian Fan | Equipment recovery; CTD profiling |
| 75-021<br>*Dawson* | August 25-<br>29 | R. O. Fournier,<br>Dalhousie Univ. | Halifax Section | Nutrient recycling study |
| *75-022*<br>*Maxwell* | August 19-<br>31 | A. W. Herman,<br>AOL | Halifax Harbour approaches; Yarmouth coast, NS | Chlorophyll detection; equipment testing |
| *75-023*<br>*Dawson* | August 16-<br>22 | D. R. Bignell,<br>ICNAF | Sable Bank | ICNAF inspection patrol |
| *75-024*<br>*Dawson* | September 2-<br>19 | W. F. Gidney,<br>Fisheries Offfcer | Grand Banks; Flemish Cap | Fisheries patrol |
| *75-025*<br>*Dawson* | September 23-<br>October 1 | D. L. McKeown,<br>AOL | Gulf of St. Lawrence | Measure oil content of sunken *Irving Whale;* equipment testing |

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| 75-026<br>*Dawson* | October 6-10 | J. M. Bewers, AOL | Halifax Section | Baseline chemical oceanographic data collection |
| 75-027<br>*Dawson* | October 20. 30 | C. S. Mason, AOL | South from Halifax along 62°W from 43°N to 37°N and return | Instrument intercomparisons with Kiel University; instrument evaluations; OCTUPROBE measurements |
| 75-028<br>*Dawson* | November 3-14 | G. Vilks, AGC | Coastal NS; Bay of Fundy | Geological and biological studies |
| *75-029*<br>*Maxwell* | November 4-5 | D. D. Lelievre, AOL | Halifax Harbour entrance | Equipment placement |
| 75-030<br>*Maxwell* | | | | |
| Phase I | Ndvember 10-20 | J.-G. Dessureault, AOL | Bedford Basin | Equipment testing |
| Phase II | November 20-December 5 | P. G. Simpkin, Huntec ('70) Ltd. | St. Margaret's Bay; Emerald Basin; Bedford Basin | Shallow seismic profiling; pockmark examination; bottom sampling; equipment appraisal |
| 75-031<br>*Dawson* | November 17-28 | T. Ft. Foote, AOL | Gulf of St. Lawrence | Temperature and salinity sampling for the Ice Forecast Central Office, DOE |
| 75-032<br>*Baffin* | October 20-November 3 | D. R. Bignell, W. Higgins, ICNAF | NE Newfoundland | Fisheries patrol |
| 75-033<br>*Dawson* | December 2-5, 8-14 | R. Reiniger, AOL | Gulf Stream | Gulf Stream studies, including current meter moorings |
| 75-050<br>*Sigma-T* | Periodically | M. Hodgson, MEL | Bedford Basin | Light saturation study |
| 75-051<br>*Navicula*<br>*Sigma-T* | Periodically | J. Therriault, MEL | St. Margaret's Bay | Study of spatial variability of primary production |

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| 75-052<br>*Whip-the-Wing* | May 15-<br>July | B. Tessier,<br>MEL | Bedford Basin | Study of short term variability of light saturation parameters |
| 75-053<br>*Margaret Robert Navicula* | Periodically | K. F. Drinkwater,<br>AOL | St. Georges Bay, NS | Physical oceanographic survey |
| 75-054<br>*Prince* | June 12-20 | R Shotton,<br>MEL | Gulf of St. Lawrence | Acoustic fish survey |
| 75-055<br>*Sigma-T Navicula* | Periodically | Various MEL scientists | St. Margaret's Bay | Biological studies; hydrographic surveys |
| 75-056<br>*Rigolet* | September 2-<br>October 6 | A. Cardinale,<br>GIROQ | St. Lawrence estuary | Miscellaneous projects |
| 75-057<br>*Bayfield* | July 4-19 | S. Carignan,<br>UQAR | St. Lawrence estuary | Temperature and salinity measurements |



**1976 Cruises**

| Cruise No.<br>& Vessel | Cruise<br>Dates | Officer<br>in Charge | Area | Objectives |
|---|---|---|---|---|
| 76-001<br>*Baffin* | January 26-<br>April 15 | R. Marshall,<br>CIDA | Continental margin of Senegal and The Gambia | Multiparameter surveys |
| 76-002<br>*Hudson* | February 23-<br>April 7 | R. A. Clarke,<br>AOL | Labrador Sea | Study of winter circulation of western Labrador Sea and formation of Labrador Sea water |

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| 76-003<br>*Dawson* | March 1-7 | R. O. Fournier,<br>Dalhousie Univ. | NS continental shelf and slope; Halifax section | Plankton and nutrient measurements; nutrient generation experiment |
| 76-004<br>*Dawson* | March 15-26 | D. E. T. Bidgood,<br>NSRF | NS continental shelf; Mahone Bay | Equipment evaluation; inshore geological studies |
| 76-005<br>*Dawson* | April 5-15 | P. C. Smith,<br>AOL | Scotian Shelf and Slope | Hydrographic and biological surveys; recovery and deployment of moored current meter array |
| 76-006<br>*Hudson* | April 29-26 | J. M. Bewers,<br>AOL | St. Lawrence estuary; Saguenay fjord | Study of trace metal behaviour |
| 76-007<br>*Dawson* | April 28-May 4 | B. Sunby,<br>N. Silverberg, UQAR | St. Lawrence estuary | Biogeochemical studies of the solid phase |
| 76-006<br>*Hudson* | April 29-May 7 | M. Dunbar,<br>McGill Univ. | St. Lawrence estuary | Biological sampling |
| 76-009<br>*Maxwell* | May 3-October 29 | R. M. Cameron,<br>AOL | Atlantic Provinces | Hydrographic charting |
| 76-010<br>*Dawson* | May 5-13 | R. J. Conover,<br>MEL | Gulf of St. Lawrence (Gaspe Current) | Euphausiid studies; studies of physiology and scattering layers; plankton tows |
| 76-011<br>*Northern Seal* | June 3-October 27 | E. J. Comeau,<br>AOL | Atlantic Provinces | Chart revisions and range surveys |
| 76-012<br>*Baffin* | | | | |
| Phase I | May 17-July 16 | D. D. Lelievre, | St. Lawrence estuary | Hydrographic charting |
| Phase II | July 26-September 30 | D. D. Lelievre,<br>AOL | Labrador coast; Foxe Basin | Hydrographic charting |

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| 76-013<br>*Hudson* | May 17-27 | D. L. McKeown,<br>AOL | Emerald Basin; Shelf break (NS) | Instrument development |
| 76-014 | | | | |
| Phase I | May 17-21 | D. DeWolfe,<br>AOL | Gulf of Maine | Tidal survey |
| Phase II | May 21-26 | C. T. Schafer,<br>AGC | Minas Basin and vicinity | Sediment sampling; placement of current meter moorings |
| 76-015<br>*Dawson* | June *2-6* | R. Reiniger,<br>AOL | Gulf Stream | Mooring placement and recovery;<br>CTD profiling; water sampling |
| 76-016<br>*Hudson* | June 14-16 | R. O. Fournier,<br>Dalhousie Univ. | NS coast off Halifax;<br>Halifax Section | Miscellaneous studies |
| 76-018<br>*Theron* | June 21-<br>October 6 | A. L. Adams,<br>AOL | Labrador coast | Hydrographic charting |
| 76-019<br>*Martin Karlsen* | June 28-<br>September 30 | J. M. R. Pilote,<br>AOL | Labrador Sea | Integrated hydrographic/geophysical survey |
| *76-020*<br>*Hudson* | June 28-<br>July 14 | P. C. Smith,<br>AOL | Scotian Shelf and Slope | Hydrographic and biological surveys; recovery and deployment of moored current meter array |
| 76-021<br>*Dawson* | June 22-<br>July 2 | A. R. Coote,<br>AOL | Slope Water - Cabot Strait | Nutrient studies in Strait and Slope Water distribution |
| *76-022*<br>*Dawson* | July 19-27 | M. I. El-Sabh,<br>UQAR | West of Anticosti Island | Study of conditions in and around the Anticosti gyre |
| *76-023*<br>*Hudson* | July 26-<br>August 19 | R. K. H. Falconer,<br>AGC | Labrador Shelf; Baffin Bay; Lancaster Sound | Geophysical studies of shelf and margins |

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| 76-024<br>*Dawson*<br><br>Phase I | August 9-12 | D. DeWolfe, AOL | South of Georges Bank and Scotian Shelf | Mooring of tide gauges |
| Phase II | August 12-17 | R. O. Fournier, Dalhousie Univ. | Gulf of Maine; Halifax Section | Miscellaneous studies |
| *76-025*<br>*Hudson* | August 19-September 13 | C. F. M. Lewis, Terrain Sciences Division, GSC | Lancaster Sound | Multidiscipline geological and geophysical studies |
| 76-026<br>*Dawson* | August 27-September 2 | A. W. Herman, AOL | LaHave Basin; Emerald Basin; Shelf Break (NS) | Equipment testing; zooplankton biomass study |
| 76-027<br>*Dawson* | September 7-17 | D. L. McKeown, AOL | Gulf of St. Lawrence | Measure oil content of sunken *Irving Whale;* test equipment |
| 76-029<br>*Hudson* | September 21-October 23 | R. K. H. Falconer, AGC | Baffin Bay; northern Labrador Sea | Geophysical studies; bedrock sampling |
| 76-030<br>*Dawson* | September 27-October 7 | N. S. Oakey, AOL | Shelf east of Emerald Basin | Examine variability in microstructure and turbulence at fixed site |
| 76-031<br>*Martin Karlsen* | October 2-16 | M. J. Keen, Dalhousie Univ. | Newfoundland Basin | Geophysical studies |
| 76-032<br>*Theron* | October 6-12 | D. DeWolfe, AOL | Shelf of Emerald Basin to south of Nantucket | Recover moored tide gauges |
| 76-033<br>*Dawson* | October 13-*22* | P. C. Smith, AOL | Scotian Shelf and Slope | Hydrographic surveying |
| 76-034<br>*Dawson* | November 1-10 | R. Reiniger, AOL | Gulf Stream | Physical oceanographic studies and current meter moorings |
| 76-035<br>*Labrador* | July 19-October 3 | V. J. Gaudet, AOL | Eastern Arctic | Hydrographic charting |

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| 76-036<br>*Dawson* | November 16-<br>*22* | T. Ft. Foote,<br>AOL | Gulf of St. Lawrence | Temperature and salinity sampling for the Ice Forecast Central Office, DOE |
| 76-037<br>*Dawson* | November 23-<br>December 3 | N. Silverberg,<br>UQAR | St. Lawrence estuary;<br>Rimouski shelf | Miscellaneous projects |
| 76-038<br>*Dawson* | December 9-<br>21 | P. C. Smith,<br>AOL | Scotian Shelf and Slope | Hydrographic surveying |
| 76-050<br>Various vessels | Periodically | T. C. Platt,<br>MEL | Bedford Basin | Biological studies |
| 76-051<br>Various vessels | Periodically | J. C. Smith,<br>MEL | St. Margaret's Bay | Biological studies |
| 76-053<br>*Queenie* | Periodically | D. E. Buckley,<br>AGC | Miramichi estuary and inner bay | Multidisciplinary environmental studies |
| 76-054<br>*Navicula* | Spring-<br>Summer | T. C. Lambert,<br>MEL | St. Georges Bay, NS | Biological studies |
| 76-055<br>*Hillsborough* | July 19-<br>24 | D. DeWolfe,<br>AOL | Scotian Shelf; Georges Bank; Gulf of Maine | Tidal surveys and gauge placement |
| 76-056<br>*J. L. Hart* | October 15-<br>November 29 | P. Lehman,<br>MEL | St. Margaret's Bay | Biological studies |

NOTES:

(1) Abbreviations used in both tables include: AOL - Atlantic Oceanographic Laboratory; AGC - Atlantic Geoscience Centre; MEL - Marine Ecology Laboratory; GIROQ - Groupe Interuniversitaire de Recherches Océanographiques du Québec; GSC - Geological Survey of Canada; NSRF - Nova Scotia Research Foundation; UQAR - Unwersité de Québec à Rimouski: Univ. - Unwersity

(2) For further Information on particular cruises, contact the Officer-in-Charge; Ships Division, lnstitute Facilities; or the Library. Bedford Institute of Oceanography, Dartmouth, NS B2Y 4A2.

(3) No cruises correspondlng to the following numbers were undertaken: 75-034 to 75-049; 76-028, 76-039 to 76-049, and 76-052.

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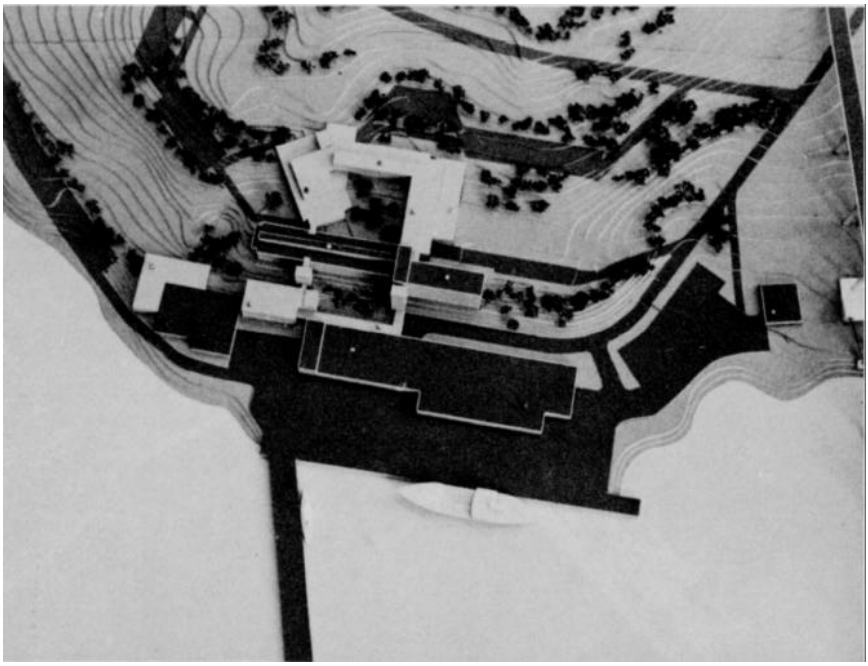
# BIO Building Expansion

In February 1975, the Bedford Institute of Oceanography received approval to upgrade its existing facilities and to construct additional facilities at a cost of 18,363,000 dollars. The expansion is to be carried out over 5 years and will double the existing space. New facilities will include laboratories, offices, a library and computing centre, a solar control system to reduce heat build-up in offices, a new access road, and extensions to our current fish holding tanks and geological core storage facilities. A substantial portion of the new facilities will be used to house industrial representatives whose companies have been awarded government research and development contracts. Construction of the new facilities is proceeding on schedule and a view of the partially completed complex is shown in the two-page photograph that follows.



*Architect's model of BIO's building expansion shows the new buildings (lighter coloured buildings). (AOL 3429)*

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