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Bedford Institute
Of Oceanography

Biennial Review
1973/74

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GOVERNMENT OF CANADA

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FISHERIES AND MARINE SERVICE

ATLANTIC OCEANOGRAPHIC LABORATORY

MARINE ECOLOGY LABORATORY

DEPARTMENT OF ENERGY MINES, AND RESOURCES

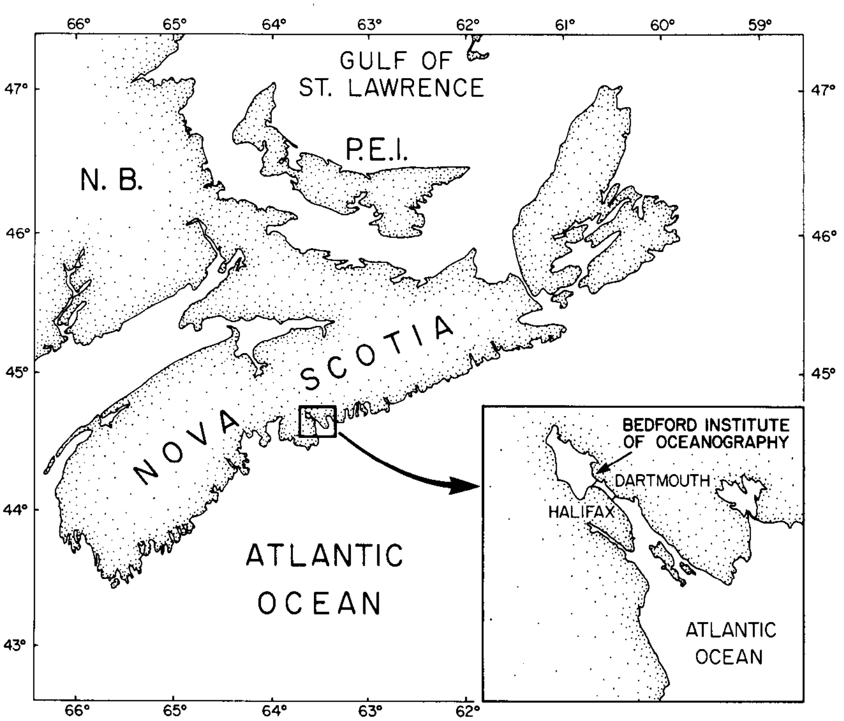
GEOLOGICAL SURVEY OF CANADA

ATLANTIC GECOESNCENTRE

BEDFORD INSTITUTE OF OCEANOGRAPHY

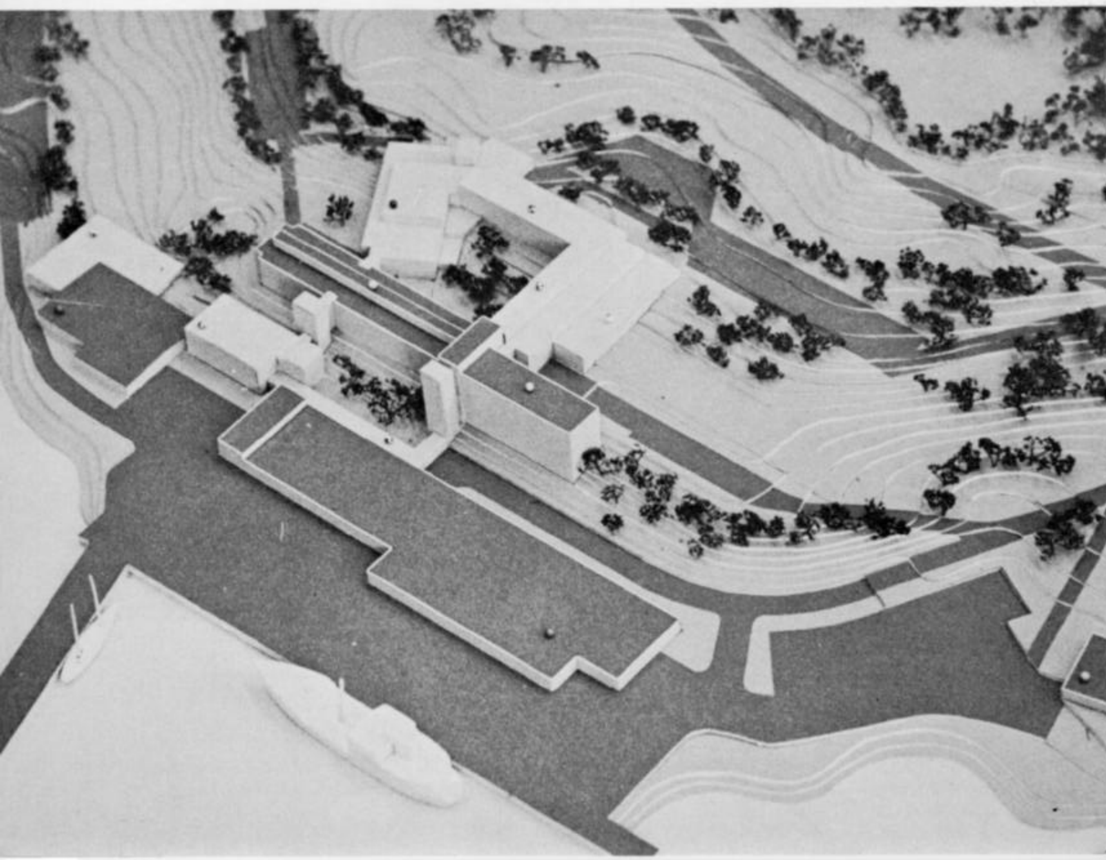
The Bedford Institute of Oceanography is a Government of Canada complex whose staff undertake scientific research and surveys in the marine environment. It consists of three main units:

THE ATLANTIC OCEANOGRAPHIC LABORATORY
THE MARINE ECOLOGY LABORATORY
THE ATLANTIC GEOSCIENCE CENTRE



The Bedford Institute of Oceanography today. (AOL 3395)

Architects' mode/ of the Bedford Institute of Oceanography in the future. See Foreword. *(AOL 3429.)*



Acknowledgements

As editor of this Biennial Review, I gratefully acknowledge the assistance of Roger Belanger, Norm Fenerty, Betty Gidney, and Heinz Wiele, who produced most of the photographs, Brian Baxter, Art Cosgrove, John Lord, and Bob Sibley, who prepared most of the diagrams and illustrations, Olive Ross and Judy Simms, who typed the final manuscripts, Brian Nicholls, who assisted with the editing, and Cheryl Dauphinee and Michael Strong who provided proofreading assistance.

M. P. Latremouille

Short Contents

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Foreword

This Biennial Review continues our practice, established in 1967, of issuing a single document to report upon the work of the Bedford Institute of Oceanography as a whole. Its aim is to convey an overview of our total activity to a broad national and international audience. The two-year cycle of publication has been generally well received. The mailing list *includes nearly 2000 addresses and in addition many copies are distributed to visiting scientists and delegates and in response to specific requests from individuals, agencies, firms, and libraries interested in marine science and technology.*

Again the Review features a section under the title of Ocean Science Reviews comprised of special essays covering subjects selected for their general interest from amongst the activities of the Institute. The titles are:

Navigation in Oceanography *by R. M. Eaton and R. F. Macnab*
Micropaleontology and the Search for Offshore Oil *by F. M. Gradstein*
Geophysical Fluid Dynamics *by C. Quon*
The Importance of Organic Compounds in Geological Oceanography *by M. A. Rashid*
Acoustic Fish Counting with a Computerized System *by R. Shotton and R. G. Dowd*
Sea Ice Research in Canada *by S. D. Smith and E. G. Banke*
Geological Evolution of the Labrador Sea *by W. J. M. van der Linden*

A limited number of copies of Ocean Science Reviews are available in separately bound format for additional distribution or sale.

During these two years accommodations in the Institute were becoming distinctly overcrowded; extensive temporary arrangements in trailers and in the Depot Building had to be installed. The design for new facilities to provide the needed permanent additions and modernize the existing laboratory is well advanced. Construction is expected to be under way in 1975. A view of the completed complex is seen in the architects' model on page V.

The proposal for the expansion of the Institutes facilities required an in-depth 'Make-or-Buy Analysis' of the total research program. As a result of this analysis, a number of projects with a potential for contracting out were identified. It is anticipated that a substantial portion of the expansion of the Institute's program will be achieved in close co-operation with Canadian industry provided that new resources are made available.

A very special project in this period was the commissioning of a portrait of the acknowledged father of the Institute, Dr. William E. van Steenburgh. It was painted by Leon Zwerling, noted Nova Scotian portrait artist. The portrait had been finished only a day or so when word was *received that Dr. van Steenburgh had passed away. The unveiling ceremony in honour of the man who had done so much for oceanography in Canada and for BIO in particular took place May 28, 1974 at the Institute. We were especially honoured and pleased to have with us his beloved wife, Lydia, and members of the family.*

Born Christmas Eve, 1899, in Havelock, Ontario, 'Dr. van' was a coal miner, biologist, soldier, military scientist, research administrator, Deputy Minister, Department of Mines and Technical Surveys, 1963-1966, and 1963 winner of the

Dr. W. E. van *Steenburgh, O.B.E., E. D., Ph.D., M.A., LL. D.: 1899 - 1974. (AOL 3441.)*

Professional Institute Gold Medal in recognition of his many contributions to the development of research in Canada. Under his leadership the scientific and support functions needed to carry out large-scale oceanographic programs were brought together to form the Bedford Institute of Oceanography, opened in 1962.

In July 1974, Dr. Lloyd M. Dickie, Director of the Marine Ecology Laboratory since its founding in 1965, left to take up appointments at Dalhousie University in Halifax as Director of the Institute of Oceanography and of the Institute of Environmental Studies. Dr. Dickie's vigorous and imaginative leadership played a key role in the development of the enviable reputation now enjoyed by MEL in scientific, environmental, and fishery circles. While his departure is felt within BIO, the oceanographic and environmental science communities as a whole in this region are benefactors. We wish him well in his new endeavours and look forward to even closer ties with our academic colleagues at Dalhousie University.

There were several thousand visitors to the Institute from business, government, universities, and the general public. Representative of the many distinguished guests we were privileged to host were:

- *Dr. Hans Walden,* Deutches Hydrographisches Institüt, *Hamburg, Germany*
- *Dr. J. R. Weir, Chairman, Fisheries Research Board of Canada*
- *Sir George Deacon, Director Emeritus, Institute of Ocean Sciences, Surrey, U.K.*

- *Rear Admiral D. S. Boyle, Maritime Command, N.S.*
- *Mme. Jeanne Sauvé, then Minister of State for Science and Technology*
- *Dr. S. S. Vogt, Institute of Oceanology, Academy of Sciences, USSR*
- *Mr. E. S. Bobrov, Counsellor of the USSR Embassy in Ottawa*
- *Dr. Boyd E. Olson, Naval Oceanographic Office, Suitland, Maryland*
- *Mr. Richard Gardner, Office of Coastal Environment, National Oceanic and Atmospheric Administration, U.S. Department of Commerce*
- *Dr. Charles C. Bates and party, U.S. Coast Guard, Research and Development, Washington*
- *Dr. Harold E. Edgerton, Massachusetts Institute of Technology, Cambridge, Massachusetts*
- *Admiral V. D. Shandabilov, Hydrographic Office, USSR*
- *Dr. N. R. Pannikar, National Oceanographic Institute, Panaji, Goa, India*
- *Dr. David F. Downing, British High Commission to Canada, Ottawa*
- *Members of APICS (Atlantic Provinces Inter-University Committee on the Sciences)*

The fundamental roles of the Laboratories of the Institute have continued essentially unchanged in keeping with the long term nature and extraordinary variety of the challenging questions presented by the marine environment and the resources within and beneath it. Major organizational developments in the Department of the Environment were in progress, projects have come and gone, priorities have changed, but the common mission to contribute to the growth of sound scientific knowledge about the marine environment and its resources goes on.

Wm. L. Ford
Director
Atlantic Oceanographic Laboratory

B. S. Muir
Acting Director
Marine Ecology Laboratory

Bosko D. Loncarevic
Director
Atlantic Geoscience Centre

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A

Atlantic Oceanographic Laboratory
Ocean and Aquatic Affairs
Department of the Environment
1973/74

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Atlantic Oceanographic Laboratory[1]

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Wm L. Ford

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- **Chemical Oceanography**
  A. Walton

- Coastal Oceanography
  R. W. Trites

- **Metrology**
  C. S. Mason

- **Ocean Circulation**
  C. R. Mann

- **Program Analysis and Project Co-ordination**
  C. D. Maunsell

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- **Hydrography**
  R. C. Melanson

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[1]Organization of Laboratory as of December 1974.

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[1] Joined AOL.
[2] Left AOL.
[3] Away on educational leave.
[4] Postdoctoral Fellow.
[5] MEL staff.
[6] AGC staff.
[7] Seconded to Maritime Command, CFB Halifax.

Director's Remarks

National science policy formulation in Canada has received much attention in latter years and oceanography is no exception. A new control apparatus in government, the Ministry of State for Science and Technology, was created thus bringing science into the Cabinet under its own flag, so to speak. One of the first major policies announced by the new Ministry on behalf of the Government was on Ocean Science and Technology, in July 1973. Briefly it requires that:

a. Canada stimulate the development and effective participation of Canadian industry in the plan to see that Canada controls the essential industrial and technological ingredients to exploit offshore resources

b. Special emphasis be given to a wide range of marine science and technology programs relating to the management of the marine environment, renewable and non-renewable resources, development and maintenance of ocean engineering at universities and in government laboratories, and better forecasting of weather, currents, ice, and similar atmospheric and oceanic factors

c. Canada, within five years, achieve world-recognized excellence in operating on and below ice-covered waters

d. Canada stand equal or superior to foreign governments or large multi-national corporations in developing and maintaining a current information base about its renewable and non-renewable offshore resources

In November 1974, the policy was followed up by Cabinet approval in principle of the Ocean Resource Management Program. Thus was put in place a policy for integrated 'big science' investigations of two major marine systems – the Strait of Georgia on the west coast and the estuary and Gulf of St. Lawrence on the east coast. The Gulf Project was described at length in our previous Biennial Review; it is now being reexamined in the light of work accomplished in the interim by various groups and a firm new funding proposal will be going forward in 1975.

The national science policy debate also produced the 'Make or Buy' policy, which sets out the objective that the performance of research and development for the Federal Government will be done by industry to the maximum extent possible. A widely accepted target is 50 per cent in 8 years. In 1974, implementation of the policy moved firmly ahead in AOL and jointly with the Atlantic Geoscience Centre and Marine Ecology Laboratory as a BIO-wide undertaking. Through the Department of Supply and Services, we entered into a dialogue with individual firms to establish their interest and capability in carrying out components of or entire projects. All aspects of the program were so studied. The process is continuing; it leads on to tender calls and bids in the usual contracting process. What is new is the on-going exploratory dialogues.

Aside from our basic role of producing scientific results and hydrographic surveys for the public, we have regarded spin-offs and technology transfer to industry as of importance in contributing to the further development of an ocean-oriented research and development industry. The 'Make or Buy' policy, as it comes to play its intended role, should prove a major catalyst in this development, if new funding is realized. Absolute growth in program will be largely represented in increased 'Buy'.

The involvement of our oceanographers in international negotiations increased markedly. It would appear to be a sign of the times. Not only has there been a burst of inter-governmental activity leading to regulation of mankind's uses of the seas, but oceanographers, it would seem, are being directly involved in the negotiations to a gratifyingly increased degree. A particular example, Dr. Alan Walton, Head of Chemical Oceanography, devoted several months in all as a member of the Canadian delegation to the International Maritime Consultative Organization's preparatory meetings, the plenary session, and the follow-up on the regulation of marine pollution from ships.

Dr. Cedric R. Mann, Head of Ocean Circulation Division, was on a sabbatical at Professor Lacombe's Laboratoire d'Océanographie Physique du Musée Nationale d'Histoire Naturelle in 1973. Shortly after his return he undertook a special 9-month assignment with the Fisheries Research Board of Canada to prepare an assessment of present status and new directions of oceanography in Canada. This report forms part of a broad study by the Board covering the fishery, fishery biology, marine ecology, and chemical and physical oceanography.

The Director, AOL, was appointed, in 1973, as the second Canadian delegate to the International Council for the Exploration of the Sea.

As the world addresses itself to the law of the sea, it is becomingly increasingly evident oceanographers will be having to conduct their field work under new regimes, national and international. These will be markedly more restrictive than the traditional freedom of the high seas, but they will also encourage co-operative programs between countries, in particular between developing and developed nations. Bilateral and multilateral marine research agreements are likely to burgeon forth to provide the framework within which continuing international programs could be conducted with a minimum of procedural complexity. Oceanographers should have many opportunities ahead to exercise their negotiating talents.

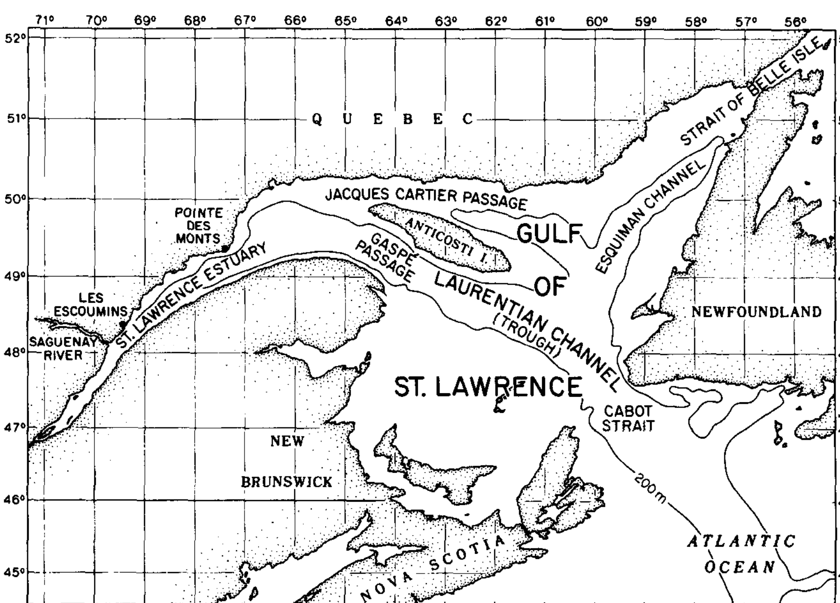
Wm. L. Ford

Chemical Oceanography

The principal research activities of Chemical Oceanography include studies of:

- The processes and mechanisms controlling the inorganic constituents of sea water
- The fluxes of gasses through air-sea exchange
- The fluxes and origins of organic material in the oceans
- Hydrocarbons in the marine environment
- Nutrients and biological/physical processes
- Stable isotope variations and transport mechanisms

A major overall objective has been, and remains, the development of our understanding of the chemical features of the Gulf of St. Lawrence and the North Atlantic. In the past two years many of the marine chemical features of the Gulf of St. Lawrence have been investigated and a broad understanding of the region has evolved. For the most part the Gulf can be considered, not as a unique inland sea as was once the generally-held view, but, rather, as an extension of North Atlantic coastal waters.



The Gulf and estuary of the St. Lawrence. (AOL *3597.)*

Although marine chemistry does not recognize within itself any broad divisions, it has been found administratively useful to group our projects into five major categories: Inorganic, Organic, Physical, Nutrient, and Stable Isotope Chemistry. Our major programs and activities are highlighted under these headings.

A. Walton

Inorganic Chemistry

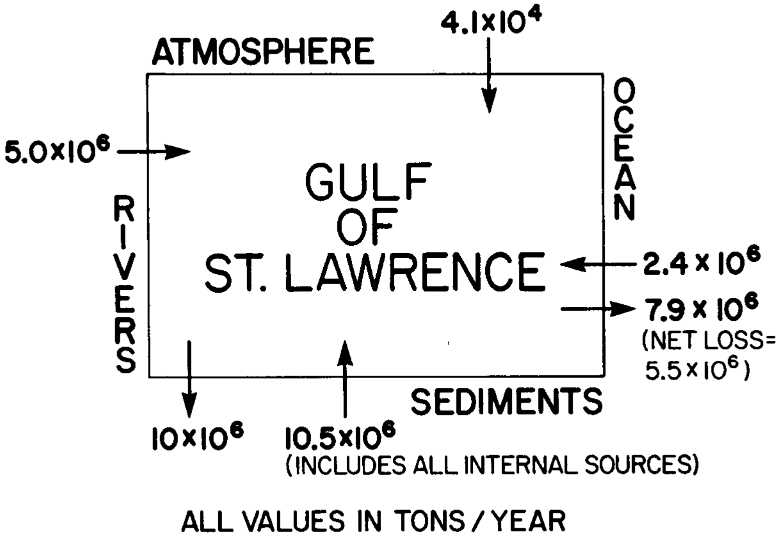
Trace Element Geochemistry. The behaviour of transition and other heavy metals is being studied in two regions: the St. Lawrence estuary, and the Scotian Shelf off Nova Scotia. For the latter, a long-term baseline section was established in January of 1974. Chemical and physical measurements are being made throughout the water column at half-yearly intervals. The work is a contribution to national and international efforts to evaluate both the natural levels of chemicals in sea water and the extent to which man’s activities have modified them. The data obtained thus far suggests that the concentrations of trace metals in coastal waters are very similar to those in the open ocean. Only in areas adjacent to the coast that receive significant surface run-off are the levels modified to any detectable degree.

It appears that previous estimates of the concentrations of heavy metals in sea water have been exaggerated and, in many cases, the metals occur at levels still below improved analytical detection limits.

Farther north, the waters of the St. Lawrence River, Gulf, and estuary are being studied with a view to understanding the geochemistry of these areas. The St. Lawrence River discharges about 1 per cent of the global river run-off and it drains both the St. Lawrence lowlands and a large part of the Canadian Shield. Although the physical characteristics of water circulation in the Gulf and estuary are relatively well understood, until recently little was known of the chemical characteristics of the water. This work relates closely to the River input to Ocean Systems (RIOS) programs of SCOR (Scientific Committee on Ocean Research) and UNEP (United Nations Environmental Program). An initial survey of the Gulf of St. Lawrence showed that only the concentration of iron varies markedly. This variability appears to be controlled by the transition of iron from the dissolved to particulate phase as the River water mixes with sea water and is transported seaward.

The behaviour of metals is being examined via model studies of element geochemistry on global and local scales. This work includes modelling of watersheds and element cycles on large scales in the hydrologic cycle. The aim is to understand the degree to which the composition of river water is controlled by precipitation, weathering, dust fallout, and air-sea transfers of material.

Suspended Particulate Matter. A major project was carried out in the St. Lawrence River, Gulf, and estuary to study the quantitative distribution of suspended particulate matter (SPM). A three-layer distribution (surface, intermediate, and bottom layers), each layer having its own characteristic concentration of SPM, was found. Budget calculations indicate that 5 million tons/year of suspended matter enter the Gulf from the rivers and that coastline erosion and reworking of sediments contribute 10.5 million tons/year of SPM. SPM is probably the primary agent of material transfer of chemicals between the water column and sediments. The SPM work relates very closely to the trace element studies, and an examination of the major partition of trace metals between dissolved and particulate phases has been commenced. It is hoped to further examine partition in the particulate phase such that differentiation between elements of detrital and non-detrital origin can be made.



The budget for suspended particulate matter in the Gulf of St. Lawrence. (AOL 3598.)

Halogen Transfer Across the Air-Sea Interface. The major anions, chloride and bromide, exist in approximately the same ratios in both precipitation and sea water while the anions, fluoride and iodide, are enriched in precipitation relative to sea water. A largely theoretical study was conducted to examine the extent to which atmospheric dust of continental origin could influence the halide composition of rain and snow. It was discovered that, contrary to what has been suggested, the dust has but a minor effect on the halides. However, there exists much evidence that methyl iodide gas can excape from the sea surface as a result of biological processes. Fluoride behaves altogether differently from iodide in biological processes and it seems unlikely that it would be volatilized to any extent by this method. The study subsequently investigated the possibility that hydrogen fluoride gas excapes from the sea surface. Though it was possible to calculate theoretically that hydrogen fluoride transport accross the air/sea interface is large compared to other sources of fluoride in the atmosphere, the results have still to be substantiated experimentally.

Fluoride Marine Chemistry. Continued investigations into the distribution of fluoride in the oceans have settled, we believe, the long-standing dispute concerning the existence of deep-ocean fluoride anomalies. Work carried out jointly at Bedford Institute of Oceanography, University of Rhode Island, and the U.S. Naval Research Laboratory, Washington, D.C., has established that deep-ocean fluoride anomalies do not presently exist at stations previously reported as anomalous. Since large variability in composition of deep water over periods as short as a decade seem improbable, it is likely that the original anomalies were not real but an artifact of sampling or analysis. In any event, no satisfactory mechanism has been found to explain the existence of the anomalies since the magnitudes of known fluoride sources are inadequate to provide the large quantities of this halide that are required.

J. M. Bewers, I. D. Macaulay, B. Sundby, P. A. Yeats

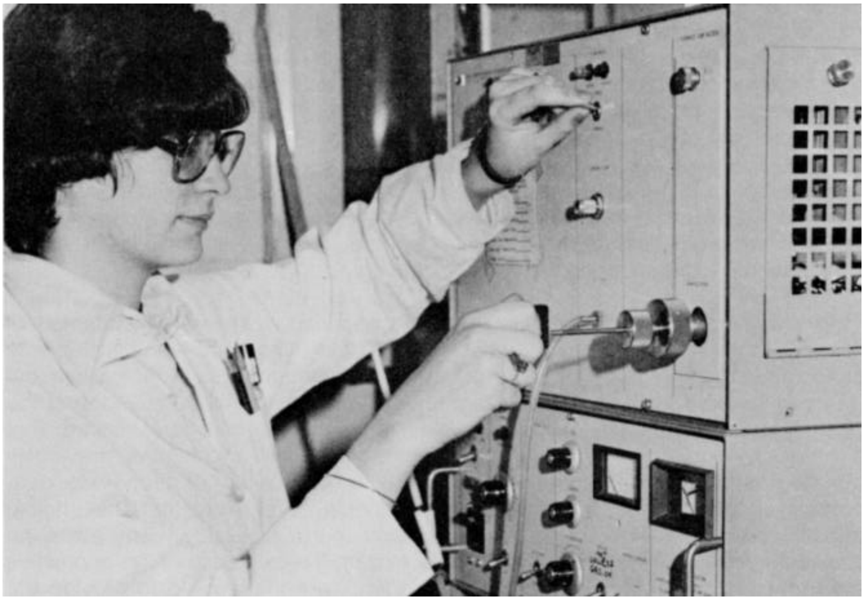
Organic Chemistry

Gulf of St. Lawrence Survey. The Gulf of St. Lawrence is an important area of interaction between land and sea because organic matter of both marine and terrestrial origin can be expected to be found there. In determining the quantities of land-derived organic matter to the marine environment, C/N ratios are measured. The C/N ratio for land-derived plant material, which consists mainly of cellulose and lignin, usually far exceeds 10 whereas for marine plant and animal remains the ratio is 6 to 12.

We are currently attempting to determine in the field whether terrestrial organic matter is quantitatively significant in the coastal zone. Initial results from our cruises to the Gulf of St. Lawrence indicate it is not. Incoming sea water, rather than incoming fresh water, is the source of organic matter in the coastal zone. However, land-derived organic compounds are abundant in environments close to pulp and paper mills.

A study is underway to determine the concentration and distribution of various halogenated hydrocarbons including PCBs (polychlorinated biphenyls), DDT, and metabolites and dieldrin. The method used to determine concentration is a liquid-liquid extraction of whole sea water with hexane, followed by concentration of this organic solvent, column chromatographic clean-up, and, finally, gas-liquid chromatographic analysis.

Development of Analysis Methods. A method for the immediate quantitative analysis of dried sedimentary and particulate organic samples has been developed. It uses a commercial carbon, hydrogen, and nitrogen analyzer and a calculator system aboard ship. The Hewlett Packard 185B Carbon, Hydrogen, Nitrogen Analyzer provides a reproducible dry combustion method for the rapid



The concentration of organic matter in sediments and on filters is determined in the organic chemistry laboratory using a Hewlett-Packard 185B Analyzer and accessories. (AOL 3631-6.)

oxidation of the carbon, hydrogen, and nitrogen present in organic matter to gaseous products, which are subsequently determined by gas chromatography.

An analytical system is being developed to measure dissolved organic carbon at sea. In this system organic carbon in sea water is ‘instantaneously’ volatized by a direct injection-combustion technique that converts it to CO_2. The CO_2 is converted to CH_4 and the carbon therein is analyzed by a flame-ionization detector.

R. Pocklington, R. D. Smillie

Physical Chemistry

Physical Chemistry and Marine Pollution Studies. During 1973 and 1974, studies of the distribution of temperature, salinity, dissolved oxygen, total dissolved CO_2, carbonate, and total alkalinity and dissolved/dispersed petroleum products in the Gulf of St. Lawrence and St. Lawrence estuary were continued. In addition, exploratory studies were carried out in the fjord systems of Bonne Bay and Hermitage Bay in Newfoundland to determine whether the deep waters in these fjords were undergoing eutrophication. In neither area were anoxic conditions found in the deep waters.

The concentration levels of petroleum residues in the Gulf of St. Lawrence have been monitored on an annual (or more frequent) basis since 1970. Concentrations of 0 -10 parts per billion are encountered in most regions and depths in the Gulf of St. Lawrence and the Atlantic Ocean south of Newfoundland. The concentrations appear to be closely related to the flow of water into and out of the region if local inputs from shipping and other human activities are considered. During July 1973, the spill resulting from the collision between the bulk carrier *Florence* and the tanker *St. Spyridon* in the St. Lawrence estuary near Les Escoumins was studied in some detail. While the oil moved upstream and downstream with the tide, there was a net movement downstream of approximately 24 kilometres per day.

Among the incidents for which an identification of the source of beached oil was required was one that occurred in the summer of 1974 when oil appeared on several of the recreational beaches on the north shore of Prince Edward Island. Chemical analyses demonstrated conclusively that this particular incident was not a result of leakage from the barge *Irving Whale* that sank north of the Island 4 years earlier.

The distribution of petroleum residues in the form of ‘tar balls’ floating on the surface of the North Atlantic has been studied since 1971. Samples have been collected over a broad expanse of the Atlantic Ocean from the Equator to the limits of marine navigation in the Arctic and from Canada to the Azores, as well as in the Mediterranean Sea. The distribution of tar on the North Atlantic seems to follow a log-normal distribution with a geometric mean of about 0.15 milligrams/square metre. In some areas repetitive sampling has been carried out but the spatial variability of the tar is such that it has not been possible to determine temporal changes, if any, over the time-scale of the experiment. In the western North Atlantic, the regions dominated by the southward flowing Arctic waters are comparatively free of tar balls, but their abundance increases abruptly when the Gulf Stream system is entered. Similarly, tar ball concentrations are high over broad expanses of the Sargasso Sea.

A brief study was carried out of the possible relationship between the concentration of dissolved and/or dispersed forms of petroleum residues

Oil sample being taken from the ruptured forward tank of the bulk carrier Florence *in the St. Lawrence estuary in July 1973. (AOL 2910.)*

(determined by fluorescence spectrophotometry) and that of chlorophyll in the waters between Nova Scotia and Bermuda. Such a relationship should exist if the present concentration levels of 'petroleum residues' are the result of recent photosynthetic activity. However, there is no evidence that it does actually exist.

In conjunction with the foregoing studies of ocean oil pollution, a great deal of effort has been put into the various planning stages for the Pilot Project on Marine Pollution Monitoring (which is sponsored by the Intergovernmental Oceanographic Commission and the World Meteorological Organization) to commence January 1, 1975, and also into the GESAMP (Group of Experts on the Scientific Aspects of Marine Pollution) Working Group on the Impact of Oil in the Marine Environment.

Air-Sea Interaction Chemistry Studies. A program has been initiated to measure gas exchanges between the ocean and atmosphere using the Reynolds flux or eddy correlation method. It is proposed to study CO_2 first for two reasons. Firstly, it is perhaps the most important gas to study in view of speculations regarding what is happening to the COO produced by the combustion of fossil fuels. Secondly, CO_2 would seem to be one of the easier gasses to deal with because it is one of the more abundant in the atmosphere and estimates of its flux are as large as any. The proposed measurements will be made in collaboration with the Air-Sea Interaction group (see Metrology) and gas fluxes will be correlated with other fluxes (energy, momentum, and water vapour) as well as environmental variables such as wind speed, humidity, and the temperatures of both the air and sea.

E. M. Levy, E. P. Jones, A. Walton

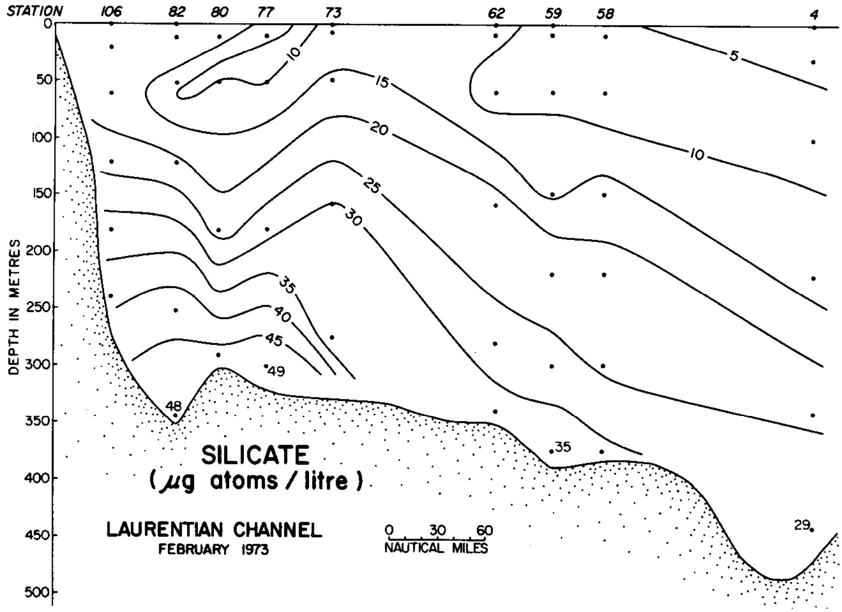
Nutrient Chemistry

Gulf of St. Lawrence. A general survey of the chemical characteristics of the Gulf of St. Lawrence has been carried out by Chemical Oceanography to provide baseline data and to obtain relationships between observed distributions and circulation features within the Gulf. The distribution of dissolved inorganic silicate, phosphate, and nitrate has been measured during the course of several cruises. The distribution of these substances is mainly determined by a combination of estuarine circulation and regeneration of the nutrients so that the deeper waters of the Gulf are enriched in nutrients. The concentrations of the nutrients increase with depth and with distance from Cabot Strait along the Laurentian Trough. The concentrations at the bottom of the Laurentian Trough just inside the Gulf are higher than at a similar depth outside the Gulf, and thus there exists a nutrient 'front' in the vicinity of Cabot Strait.

"Overflow '73". The nutrient section participated with Ocean Circulation, AOL, in the "Overflow '73" expedition aboard CSS *Hudson* in Denmark Strait during August and September 1973. This multi-ship, international expedition was organized by the Conseil International pour l'Exploration de la Mer to observe and measure the flow of water over the series of submarine ridges that extend from Greenland through Iceland and the Faroes to the Shetland Islands. It is in this region that a major component of North Atlantic bottom water is formed and where this important feature of the circulation of the Atlantic Ocean, which so far has eluded quantitative interpretation, can be measured. "Overflow '73" was the first extensive international survey of these waters using moored instruments, CTD (conductivity, temperature, depth) profilers, and conventional oceanographic bottle casts.

Silicate and phosphate data were obtained in Denmark Strait during the whole period of the survey. Nitrate data were obtained on about the first 30 stations. The nutrient data collected have been subjected to several preliminary treatments. Oceanographic Section plots as well as plots of the nutrient parameters against salinity, temperature, and plots of one with the other have been made. Phosphate and nitrate have also been combined with oxygen and plotted as the derived parameters "NO" and "PO". T-S (temperature-salinity) volume analysis indicates that the observed nutrient concentrations are related to water mass characteristics.

Digitizer. A multi-channel digital logging system consisting of a Techal digital voltmeter and Kennedy Mag-Tape Unit has been assembled and tested with the assistance of Engineering Services, AOL. This system is used to log the output from the AutoAnalyzer II colourimeters for later off-line processing by CDC 3150 or HP 2100 computers. The colourimeter output is digitized at 5-second intervals from voltages supplied by retransmitting potentiometers attached to the AutoAnalyzer chart-recorder drives. Peak heights are derived by a simple



Section of silicate along the middle of the Laurentian Channel from Station 106 near the Saguenay River to Station 4 in Cabot Strait. (AOL 3585.)

peak-picking routine. The peak values for calibration, baseline-blank, and unknown samples are then processed to provide an immediate computer printout of sample identification and concentration values as well as a record stored on magnetic tape. Under ideal circumstances a completed data report can be made available at the end of a cruise.

A. R. Coote, P. A. Yeats

Stable Isotope Chemistry

Studies of $^{18}O/^{16}O$ Ratios. The characteristics of the water masses in the Gulf of St. Lawrence and St. Lawrence estuary as revealed by their $^{18}O/^{16}O$ ratios are being examined. It was determined that the $^{18}O/^{16}O$ ratios of water masses at selected stations in the Gulf range from +1.8 to +0.3 parts per thousand SMOW (Standard Mean Ocean Water). The ratios increase progressively with depth at all stations. The deep, warm water (4 to 6°C) can be characterized by a narrow $^{18}O/^{16}O$ range of +0.2 to -0.3 parts per thousand SMOW; it can be traced to the mouth of the Saguenay River. Meteoric water in the Gulf is estimated on the basis of an $^{18}O/^{16}O$ versus salinity relationship to have an $^{18}O/^{16}O$ ratio of -18.0 parts per thousand SMOW. Water samples, collected in 1974 in the St. Lawrence estuary for $^{18}O/^{16}O$ studies, will be used to study mixing and to characterize the water masses in the St. Lawrence estuary.

Ice core samples were collected from selected stations in the Gulf of St. Lawrence during April 1974 in a joint venture with the Marine Sciences Centre, McGill University, Montreal, Quebec. The results from four cores reveal an $^{18}O/^{16}O$ fractionation between sea ice and sea water of 0.9, 1.4, 2.0, and 2.5 parts per thousand SMOW, respectively. With the exception of the low value of 0.9 parts per thousand, which is believed to be due to contamination of the sample with light snow (-18.1 parts per thousand SMOW), the mean value (2.0 parts per thousand) is in good agreement with theoretical expectations and consistent with previous analyses by other workers.

Studies of $^{13}C/^{12}C$ Ratios. Water samples from selected stations and depths in the Gulf of St. Lawrence and estuary were collected and analyzed during a cruise in May 1973. The $^{13}C/^{12}C$ ratios of the total dissolved CO_2 will be used to characterize the water masses, study their mixing, and examine the depletion of dissolved oxygen from the deep, warm water. The $8^{13}C$ values of the surface water vary from +1.8 to +2.7 parts per thousand PDB (PDB is a carbonate standard prepared from a belemnite rostrum collected from the Cretaceous Peedee Formation of South Carolina.) The $8^{13}C$ values of the deep, warm water decrease from 0.0 parts per thousand PDB in Cabot Strait to - 1.5 parts per thousand PDB near the Saguenay River. Another set of samples was collected in August 1974 and will be used to check the results obtained in 1973.

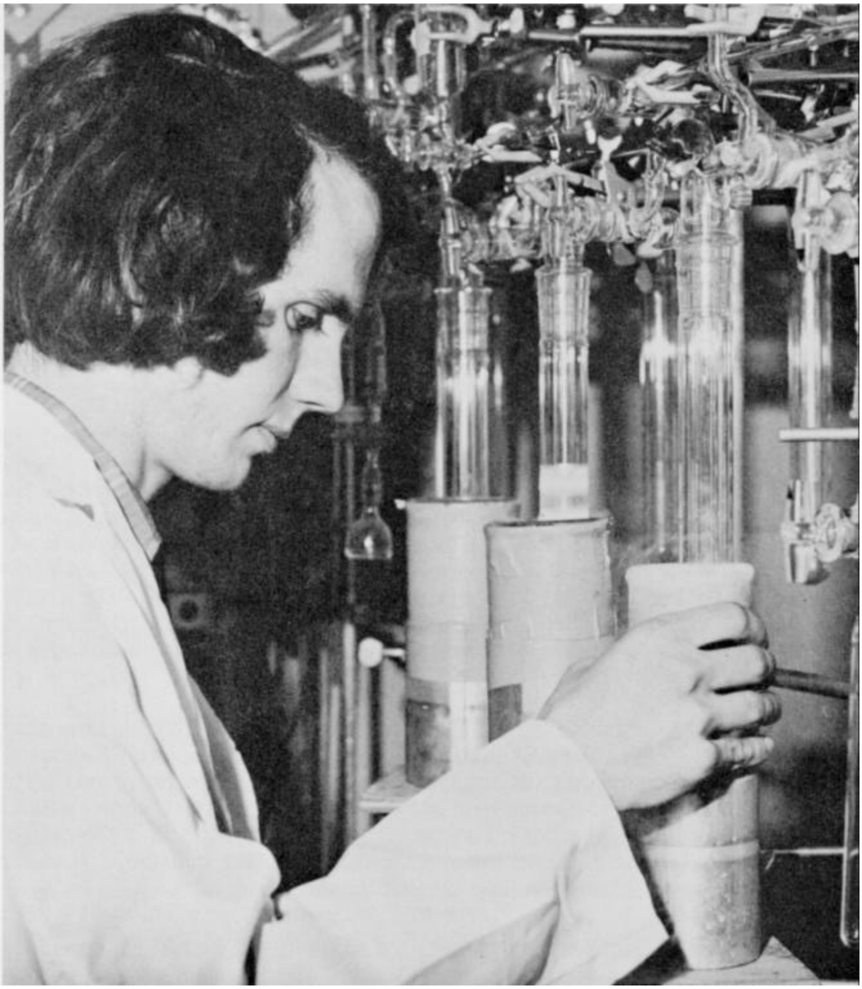
We have determined the $\delta^{13}C$ values of total dissolved CO_2 at stations in Bedford Basin, Nova Scotia, an area currently receiving considerable domestic sewage effluents, and have compared our results with relatively pollution-free St. Margaret's Bay, Nova Scotia. The results show that the untreated sewage effluent has a $\delta^{13}C$ value of -17.3 parts per thousand PDB, which is significantly lower than the CO_2 in the marine environment. The mean $\delta^{13}C$ values of Bedford Basin are lower than those of St. Margaret's Bay by 0.7 parts per thousand PDB. This is attributed to the contribution of domestic sewage to the Bedford Basin. A comprehensive program using a carbon isotope technique to study the changes in environmental quality is envisaged.

Sediment samples obtained from the Gulf of St. Lawrence and St. Lawrence estuary, Saguenay River, and Scotian Shelf will be analyzed for $^{13}C/^{12}C$ ratios to obtain information on the origin of organic matter in recent sediments of the Gulf of St. Lawrence, i.e., of land-derived or in situ origin, and to provide baseline data to study future man-induced organic pollution. The analytical aspects of the project are underway. The data will be interpreted in conjunction with the C/N ratios obtained by organic chemistry (see Organic Chemistry).

Approximately 100 samples from selected stations in the Gulf of St. Lawrence have been collected to study the $^{13}C/^{12}C$ ratios of particulate organic carbon (POC) during a cruise in July-August 1974. The purpose of this study is to investigate the origin and biodegradational aspects of POC and to provide a baseline level for pollution studies in the Gulf of St. Lawrence. The analytical aspects of this program are currently underway.

Stable Isotope Studies on Sediment Cores. The differentiation of depositional environments becomes difficult when fossil remains are lacking or sparsely distributed. Stable carbon and oxygen-isotope ratio techniques have been used successfully to study the environment of deposition in the absence of fossil or lithological evidence. In co-operation with the Marine Ecology Laboratory, the environment of deposition of sediment cores obtained from the Saguenay River during 1973 is being investigated. Work in progress includes $^{13}C/^{12}C$ and $^{18}O/^{16}O$ analyses of whole rock carbonates.

Mass Spectrometry Laboratory and Related Facilities. In-house and inter-laboratory calibration studies with stable isotope laboratories throughout the world were carried out to check the precision and accuracy of the Nuclide isotope ratio



Technician preparing Gulf of St. Lawrence water samples for oxygen isotope analysis. (AOL 3454-A-8.)

mass spectrometer and for various analytical and sampling procedures. The studies indicate that the spectrometer has a precision of ±0.05 parts per thousand for $^{13}C/^{12}C$ ratios and ±0.07 parts per thousand for $^{18}O/^{16}O$ ratios. The procedures for analyzing $^{18}O/^{16}O$ ratios of water samples were evaluated by analyzing International Reference Standard waters that were distributed by the International Atomic Energy Agency (IAEA) of Vienna, Austria. The results are in good agreement with the values reported by the IAEA.

A technique for precise sampling, extraction, and $^{13}C/^{12}C$ analysis of dissolved CO_2 in the marine environment has been developed. The technique is applicable both in the laboratory and at sea.

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

Data Processing

Chemical Oceanography has improved its facilities for the automated handling and interpretation of data in all areas, from experimental outputs and cruise location data to statistical interpretation of results.

A system of sample identifiers has improved the labelling procedure for samples collected on a cruise, and allows all parameters obtained from a sample to be related via one common identifier. The shipboard minicomputers on CSS Dawson and CSS Hudson have been used to create cruise-location files based on the common identifier scheme.

Shipboard systems have been developed that allow salinity/temperature data from the Guildline CTD (see Metrology, AOL), and nutrient data from the Technicon AutoAnalyzer to be made available as tables and graphs shortly after they are collected. The output of these devices is 7-track magnetic tape that can be processed by the shipboard computers.

Shore-based computer programs for reducing the outputs from salinity, oxygen, alkalinity, nutrient AutoAnalyzer, CHN analyzer, gas chromatograph, atomic absorption spectrophotometer, and isotope ratio mass spectrometer measurements have been run on a regular basis for some time. Data files and data reports are available for all Chemical Oceanography cruises in a standardized format.

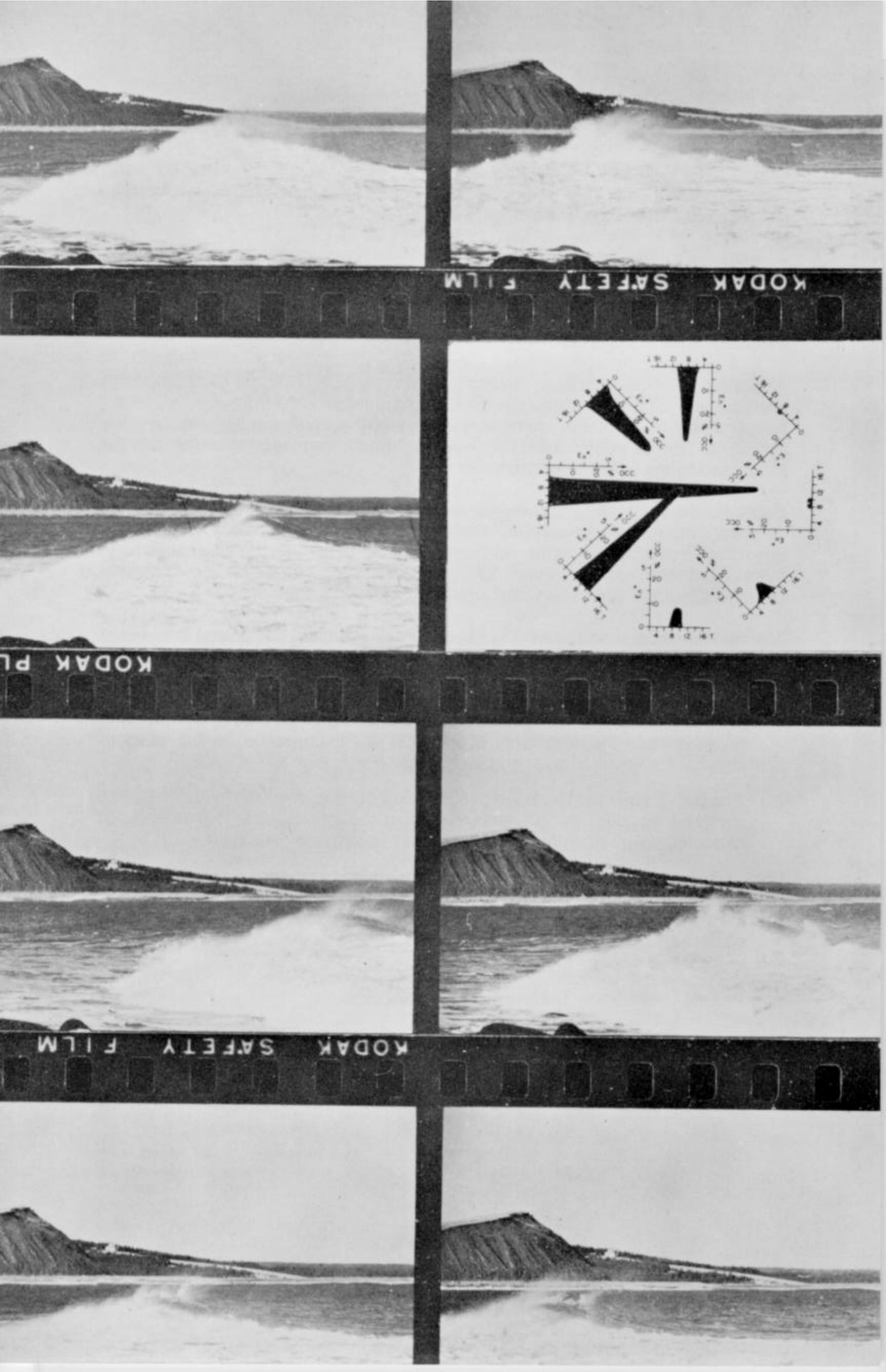
The mathematical procedures described below have been developed to assist in the interpretation of final results.

(1) Statistical tests for the significance of differences between population means are being used to help in understanding the differences between geochemical parameters in the sediments of the Gulf of St. Lawrence on the basis of physical composition and geographical area.

(2) Analysis of variance has been used to separate the variability in data sets into components due to differences between samples, differences due to experimental treatments, and differences due to experimental error.

(3) Factor analysis has been applied to data sets containing a large number of parameters measured on a large number of samples. This technique isolates a small number of linearly independent factors, related to the measured variables, which can be identified as underlying causes of geochemical processes.

J. L. Barron, G. J. Pearson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Coastal Oceanography

The main research activities of Coastal Oceanography include:

- Studies of the role played by hydrological and meteorological parameters in driving coastal circulation regimes
- Studies of waves, swells, and tides in the coastal region
- Numerical and analytical modelling of coastal regions to aid in the prediction of physical behaviour
- Studies (often interdisciplinary) of the inter-relationships between physical and biological production in the coastal region

Coastal oceanography, which is jointly supported and staffed by AOL and MEL, concentrates its research activities principally on the coastal regions with the objective of understanding the various physical factors that influence the circulation, dynamics, and exchange processes operative in these areas. Many of the projects involve an interdisciplinary team effort with researchers in other divisions of BIO. In the light of the mounting pressures on the coastal region from man's activities, increasing emphasis is being placed on simulation and systems modelling to provide a more comprehensive view of the characteristics and behaviour of such systems.

Effort within the Division is divided between the estuarine, coastal embayment, and nearshore regions on the one hand and the larger areas of the continental shelf and marginal seas on the other. Unfortunately, the extent of the shelf is such that only a relatively small part of it can be studied at any given time.

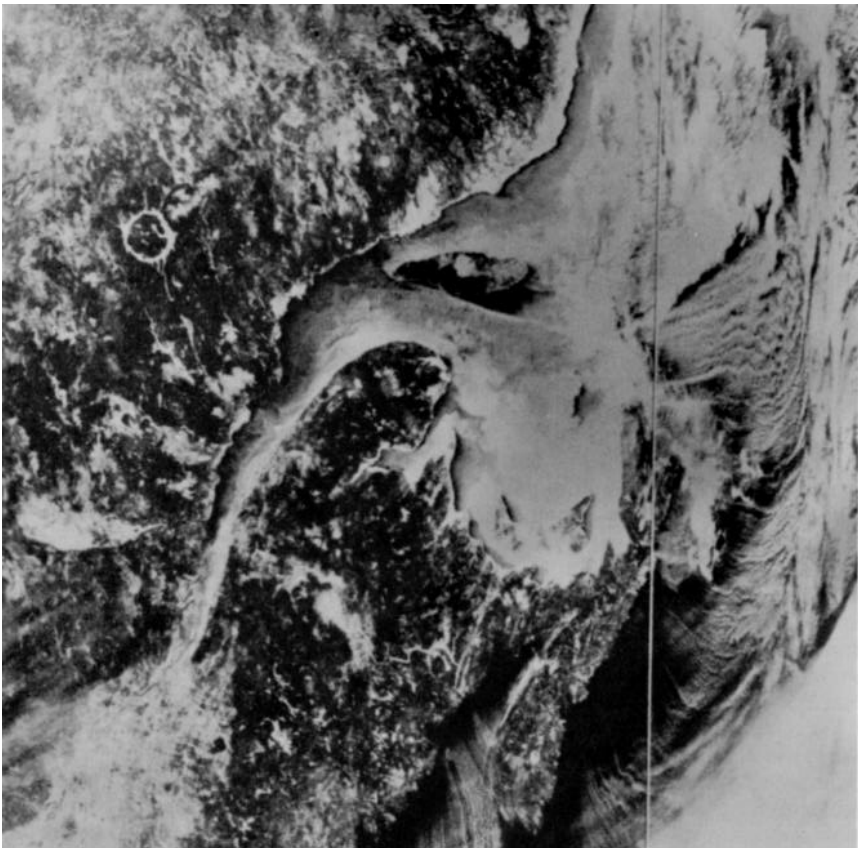
While the aim of the Division is to study coastal oceanographic processes to help in answering specific problems arising outside the Institute, the ever increasing pressure for quick responses makes it difficult to maintain the core programs at a high enough level to ensure that our research advice will continue to be of the highest calibre. In the inshore area, the problems have been principally involved with port, industrial, and urban development, where questions of navigation, coastal engineering, and environmental impact require oceanographic information. In the offshore area, they have been primarily related to fisheries management, pollution, and the offshore petroleum exploration industry.

The following sections highlight the Division's activities during the Review period. Aspects of the work that are particularly relevant to the Marine Ecology Laboratory are reported in that section of this review (see Environmental Oceanography).

R. W. Trites

Gulf of St. Lawrence Studies

A significant proportion of the Division's effort is directed towards the Gulf of St. Lawrence. One must be fairly selective, however, in the problems that are to be tackled, since resources have not been available to mount major field programs on a Gulf-wide scale. Accordingly, over the past two years the major effort was focussed on the St. Lawrence estuary in the vicinity of the Saguenay River where a major field program was carried out in the May-July period of 1973.



Sample photograph of the Gulf of St. Lawrence taken from the NOAA (National Oceanic and Atmospheric Administration, United States Department of Commerce) II weather satellite on 3 March 1973. For a map of the Gulf, see Chemical Oceanography, AOL

Temperature and Salinity in the Gulf. Winter temperature-salinity conditions in the Gulf continued to be investigated. A CSS *Hudson* cruise in the winter of 1972/73 covered most of the Gufl at the peak of the ice cover, with the exception of the Belle Isle Strait area and its vicinity. In the winter of 1973/74, two cruises were undertaken, one at the beginning and one at the end of the ice cover period. During the first cruise, current meters were moored in the estuary near the mouth of the Saguenay River but the planned coverage of the northeastern part of the Gulf including Belle Isle Strait could not be completed due to heavy ice conditions. During the second cruise, at the end of the ice-covered season, the current meters were retrieved and a comprehensive salinity, temperature, and depth survey of the Gulf including Belle Isle Strait was carried out. The data collected are currently being processed and analyzed.

E. M. Hassan

Internal Tides. A study of internal tides in the St. Lawrence estuary between Les Escoumins and Pointe des Monts has produced interesting and practical results. Because internal waves do not produce any vertical motion of the water surface, they are not detected by water level gauges and their presence is often overlooked or treated as of purely academic interest. Internal tides, however, may produce significant horizontal tidal streams at and near the water surface, and these must be considered to be of more than academic interest to mariners. In the St. Lawrence estuary, below the Saguenay River entrance, it appears that the character and magnitude of the surface tidal streams is determined much more by the internal than by the surface tide. Preliminary analysis of 1973 current meter observations from near Les Escoumins indicates that there is a very strong vertical shear in the tidal streams near the surface and that the streams at the surface may be about twice those at the shallowest normal measuring depth of 10 metres. This finding is in agreement with predictions from internal tide theory.

The very short wavelength of the internal tides, about 60 kilometres for the semidiurnal constituents, means that observed tidal stream conditions can change considerably over a short horizontal distance as well as over a short vertical distance; this makes tabulations of predictions for a large region difficult. Because of the short wavelengths, there must also be regions of relatively strong convergence and divergence between the crests and troughs of the progressive internal tides. This may partially account for hitherto unexplained build-up and relaxation of ice pressure frequently reported by ships operating in heavy ice in the estuary. The sensitivity of the internal tides to the density stratification must cause seasonal changes in the character of the tidal streams related to seasonal changes in stratification, which adds a further difficulty to tabulation of predictions.

The late Dr. D. M. Steven of McGill University reported at the Second Gulf of St. Lawrence Workshop at the Bedford Institute of Oceanography in 1970 that International Biological Program (Canada) studies indicate the region of the St. Lawrence estuary off the mouth of the Saguenay River can be regarded as a major 'nutrient pump' in which nutrients from the deep water of the Laurentian Channel are brought up into the seaward flowing surface water thus enhancing the biological productivity of the Gulf of St. Lawrence. The region of this so-called nutrient pump is also the region in which the internal tide is believed to be generated. It is possible that the mechanism involved in the generation of the internal tide contributes to mixing of the deep water, with its nutrients, up into the shallower water of the euphotic zone. Further studies of the generation of the internal tides and their possible effect on mixing are being conducted.

W. D. Forrester

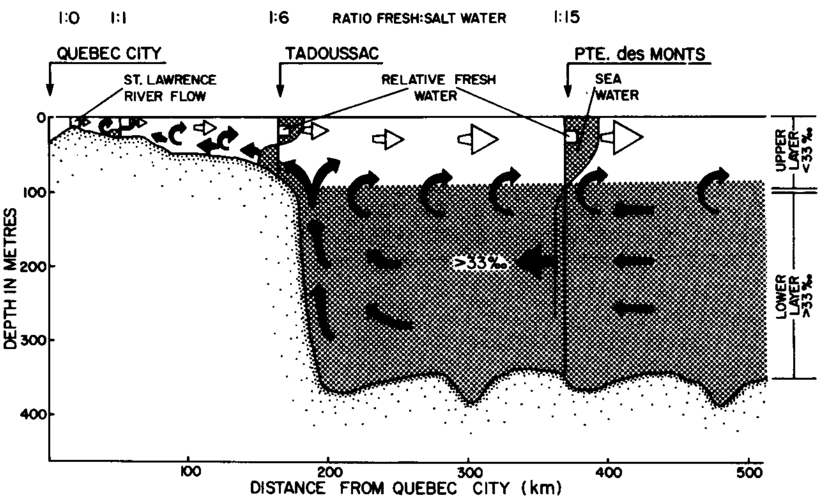
Impact of River Regulation

The importance of freshwater discharge in determining the physical oceanographic characteristics of estuaries is widely recognized, although less well understood in quantitative terms that one might expect. In turn, the physical regime is an important cornerstone of biological productive processes. Changes in the fresh water discharging into the sea through river regulations or diversions may subsequently produce significant alterations in marine ecosystems.

Since 1971, this problem has been studied and continued efforts have been aimed at identifying and quantifying the scope of the marine area that may be affected. One study has been focussed principally on the St. Lawrence River system. Large quantities of water from the spring run-off are retained in storage lakes and returned to the River during the low discharge period of autumn and winter in order to optimize power production. It has since been estimated that under present conditions the spring and summer peak run-off at the entrance to the Gulf of St. Lawrence has been reduced by between one-third and one-half (up to 10,000 cubic metres/second).

The general character of estuarine circulation in the St. Lawrence is represented schematically in the diagram below. The vertical-longitudinal circulation pattern shows a seaward-moving brackish upper layer (with salinity increasing seaward) and an inward-moving deep saline layer. Under steady-state conditions, velocities and transports increase seaward in the upper layer and transport values in excess of an order of magnitude greater than the freshwater discharge are attained. While the mixing and exchange processes are incompletely understood, it appears that under most conditions, the volume transports of salt water are positively correlated with increases in freshwater discharge. Preliminary indications are that a decrease in freshwater inflow of 10,000 cubic metres/second can produce surface salinity variations in excess of one part per thousand as far seaward as Cabot Strait. The maximum alteration in freshwater discharge occurs during the spring and early summer, coincident with the time of maximum primary productivity. This, together with the results of work by Marine Ecology ‘Laboratory, which indicated good correlations between St. Lawrence River discharge and subsequent commercial fish catches, emphasizes the need for continuing close study of this problem.

H. J. A. Neu



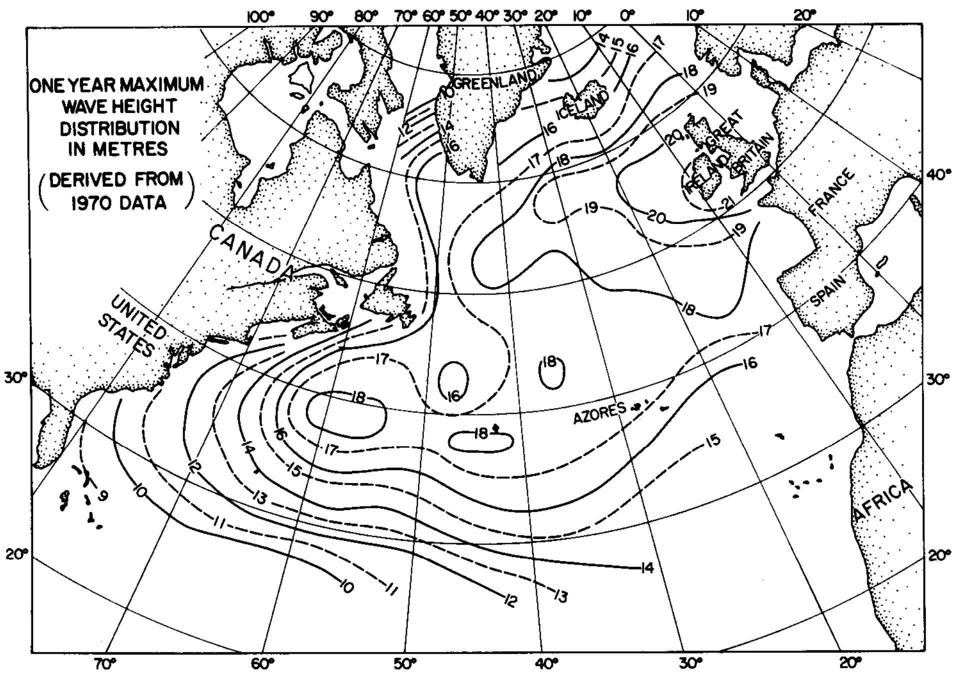
General character of estuarine circulation in the St. Lawrence River. (AOL 3518.)

Wave Climate of the North Atlantic

The increasing demand for energy has forced the petroleum industry to explore farther north and farther offshore along the Canadian coastline. This trend to explore in deeper and more exposed waters of the North Atlantic means more severe sea conditions can be expected, and close scrutiny of environmental conditions will be necessary. For this reason and to aid marine transportation in general, a wave climate of the North Atlantic Ocean is being developed based on data taken from synoptic wave charts supplied by the Maritime Forces Weather Centre, Halifax.

The 1972 maximum wave-height distribution is presented in the diagram below. It shows that the wave heights increase from south to north above latitude 30°N and from west to east above this latitude. These increases are in agreement with the predominant wind pattern over the North Atlantic. South of latitude 30°N, in the subtropical high pressure belt, winds are usually light and variable, and there are periods of calm. Between 30 and 60°N is the zone of prevailing westerly winds, which produces the rough conditions typical of the North Atlantic. In addition, these conditions are intensified by frequent passage of severe storms primarily during the winter months when cold Canadian continental air encounters moist warm air over the Atlantic. The track of these cyclones generally runs parallel to the coast of North America and then shifts out toward Iceland where they usually reach their greatest intensity. Because the longest open water fetches occur to the right of the storm paths, the largest storm waves are encountered on the east side of the storm route, or well off the coasts of North America, Greenland, and Iceland. There appear to be two ridges of extremes, one stretching from a region halfway between Newfoundland and Bermuda to the Azores and the other from off the coast of Newfoundland to Ireland. The largest waves of the North Atlantic, which occurred off the west coast of Ireland, exceeded a height of 21 metres.

H. J. A. Neu



Maximum wave-height distribution for 1972 of the North Atlantic Ocean. (AOL 3513.)

Hudson Bay System

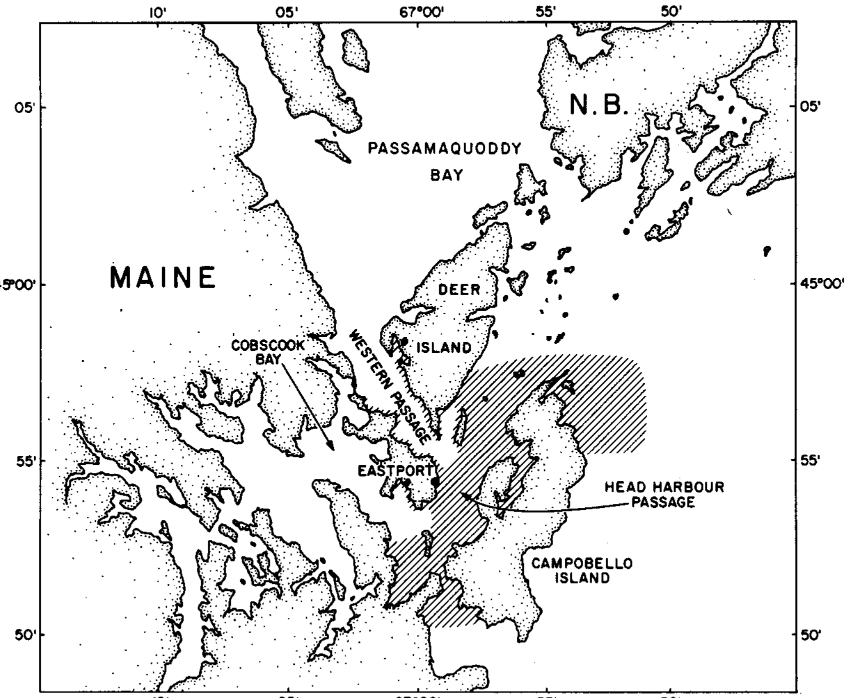
Perhaps the most pressing question to be answered in this region is, what will be the environmental impact of the James Bay hydroelectric power project? This project will eventually divert some rivers from their present course and lead to the regulation of others and to net annual changes of freshwater inflow to both James

Bay and Ungava Bay. Most people would agree that there will be changes to the marine environment as a result of the project. The debate centres on the actual magnitude and geographic extent of these changes. Primary operational responsibility for field programs in James Bay rests with Central Region, Fisheries and Marine Service, augmented with research input from the Institute. Physical oceanographic data collected in the summer of 1972, although limited in time and space, have been analyzed to provide some initial insights into the character of the system. Subsequent efforts have been directed to improving both the seasonal and geographic coverage.

E. M. Hassan

Estuarine, Coastal Embayment, and Nearshore Studies

Eastport Oil Study. Early in 1973, an oil refinery was proposed for Eastport, Maine, which would require tankers to travel through Canadian waters to reach its terminal. In response to a request from the New Brunswick government, a team of Department of the Environment personnel was formed to study some of the physical, chemical, biological, and socio-economic factors relating to potential oil spills in the Passamaquoddy Bay region of New Brunswick. Three separate studies by several members of the Division resulted. A current meter study was conducted during the summer of 1973 in the Head Harbour Passage and together



The estimated spread of a 50,000 ton oil spill after 17 hours is depicted. The spill is imagined to occur in Head Harbour Passage at low water. The figure shows that all the waters and shores of the Passage as well as those of Cobscook Bay and Western Passage would be vulnerable within one tide cycle (12 hours). (AOL 3603.)

with earlier studies provided the basis for a general description of the tidal and nontidal circulation of the proposed navigational channel for tankers. Large currents with a high degree of variability were found and these pose navigation problems. The literature on the general surface circulation in Passamaquoddy Bay and the Quoddy Region was reviewed to provide information on the areas that may become contaminated as a result of an oil spill. A second study of diffusion based on the current meter data predicted that a spill in Head Harbour Passage could cause contamination of all waters and shorelines in the passage within 12 hours of the spill. The waters and shorelines of inner Passamaquoddy Bay and Campobello and Grand Manan Islands would be vulnerable within a week. In the third study, a simulation model was constructed to explore the influence of environmental criteria on oil terminal operations. Prohibiting navigation during darkness was shown to be as influential with respect to performance as fleet size or diversion criteria whereas varying the number of oil storage tanks from 3 to 10 had no effect under the various other conditions chosen.

R. H. Loucks, K. Drinkwater, D. J. Lawrence, R. W. *Trites*

Fingerprinting of Water Masses. The particle spectrum of a given water mass is a function of the organic productivity, sediments in transport, and pollutants. To study the nature, distribution, and generation of particulate matter and to obtain a measure of the normal natural particulate levels for baseline information, a continuing program of measuring particle spectra for representative coastal environments is in progress. Other particulate variables such as total carbon, living carbon, and optical characteristics are also measured to help identify features of the size spectra.

During 1973 and 1974, the concentration, grain size, and general nature of the suspended particulate matter in Northumberland Strait and Minas Basin, two high energy, open, coastal environments, Petpeswick Inlet, a small, tidal inlet with pronounced seasonal differences, the large St. Lawrence estuary, and the medium-sized Miramichi estuary have been studied. These studies are being carried out in co-operation with the Marine Ecology Laboratory. The work in the St. Lawrence estuary was done in co-operation with McGill University of Montreal.

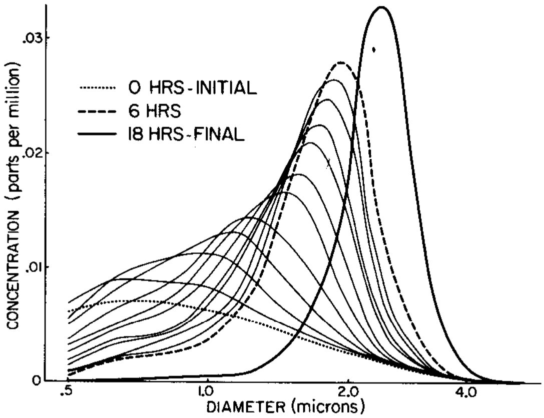
K. Kranck

Flocculated Particulate Matter. Sediment particles suspended in the sea are unstable as single grains and adhere on contact to each other. In areas where inorganic suspended sediment is abundant, this causes the particulate matter to form large fluffy flocs, the floc size of which is a function of the individual grain size. Flocculated particulate matter has a characteristic normal size distribution and forms the most common particle spectra recorded from coastal water. This is the mode in which sediment is transported and deposited and the physical properties of flocs are of primary importance in predicting the transport dynamics of suspended matter.

The distribution and circulation of particulate matter in Miramichi Bay, New Brunswick, have been studied. In this area the gradual transformation of relatively unflocculated river sediment into thoroughly flocculated marine sediment on contact with sea water was observed. Particulate pollutants from pulp and paper industries in the area also flocculate with the natural sediment and as a result these particles, initially very fine, settle out with the coarse particulate matter inside the Bay rather than flushing out to the open ocean.

In order to calculate the settling rate of suspended sediment from Stoke's Law, the size and density of the particles must be known. The size can be conveniently measured with a Coulter Counter but no method exists for the rapid determination of particle density. Attempts to develop in the laboratory a density index that approximates the density of particulate matter suspended in water are continuing.

K. Kranck



Fine glacial clay was dispersed in a solution and stirred continuously to test the sequence of flocculation in a sediment suspension. The graph shows how flocculation proceeds as a front along the distribution forming progressively larger flocs. After 18 hours the suspension stabilized in a broad normal distribution similar to that formed by natural flocculated sediment. (AOL 3457.)

Saglek, Labrador, Oil Spill. On August 3, 1974, about 500,000 gallons of Arctic diesel oil leaked from a filling pipe at the U.S.-operated radar station at Saglek, Labrador. Much of this oil flowed down a hill and into the ocean. The Environmental Protection Service of the Department of the Environment requested that Coastal Oceanography provide physical oceanographic advice pertinent to the clean-up operation. Under Captain Vondette a team of personnel from the Federal Departments of National Defence and Environment, Ministry of Transport, and Newfoundland Department of Revenue and Environment installed a boom around the stream of oil that flowed into the sea but due to the wind and wave conditions and the low viscosity of the oil the booms proved very ineffective. AH other efforts were then confined to attempting to control the fuel on the land. This was done by pumping the open reservoirs of oil into a spare storage tank and by burning as much of the oil that was flowing to the sea as possible. These tactics proved fairly successful and after completion of the project, it was determined that approximately half of the spilled fuel was either burned or contained (in the soil or storage tanks) and only 250,000 gallons had flowed into the sea.

P. E. Vandall

Strait of Canso, Nova Scotia. Both the present and planned industrial development in the Strait of Canso area serve to focus on the need for more detailed and more comprehensive knowledge about the nature and behaviour of the oceanographic system. Members of the Division continue to devote efforts to particular aspects such as water quality modelling as it relates to effluent dispersion on the one hand and swell propagation into Chedabucto Bay as it relates to navigation and unloading facilities on the other. The Ministry of

Fire was one of the successful tactlcs used to control the spread of oil spilledd at Saglek, Labrador, in August 1974. (AOL 3231.)

Transport, with responsibilities for development of port facilities and navigational aids, has required that a study be done to delineate the environmental conditions existing at various potential dock sites and approach areas, and to implement real-time monitoring of these conditions to assist in navigation and port traffic control. The Division has been actively involved in advising and assisting with specifications for the measurement program, which was initiated in 1974.

D. J. Lawrence, H. J. A. Neu

Development of Techniques

Statistical Analysis. The traditional method of simulating the spread of pollutants is to use Lagrangian tracers such as dye or drogues. While these give good spatial coverage, their temporal coverage is generally limited because they sometimes move out of the area of interest and/or are diluted below the threshold level of detection. It is expensive and logistically difficult to extend the temporal coverage by repetition. On the other hand, Eulerian data are relatively easy to collect from moored self-recording current meters. To facilitate the use of these data, methods were devised to get Lagrangian estimates for Eulerian data. Specifically, these methods operate on the velocity signal with the ‘variance time function’. The analyses are interpreted as portraying the envelope of an ensemble of plumes and are therefore due more to fluctuations of the plume than to the spreading of its elements. Dye patch data, which overlapped the current meter data temporally and spatially, were chosen from St. Margaret’s Bay and Lake Ontario.

A technique judged more applicable to patch scales is that of range analysis. Whereas variance-time-function analysis can be interpreted as plume envelope scale due to wafting, range analysis can be interpreted as patch ensemble scale due to diffusion (provided wave motions are discriminated against). Variance time-function analysis can be described as follows: a given series of Cartesian components of velocity is subjected to a running sum technique over an appropriate time interval to generate a series of ‘distances made good’. The standard deviation of the distribution of these distances is then interpreted as the plume envelope width. Range analysis, on the other hand, determines within each ‘distance made good’ the maximum deviation from the trend line. The mean of this deviation over all ‘distances made good’ is then interpreted as patch ensemble scale.

The agreement between dye observations and range estimates was good for the Lake Ontario data and this was especially satisfying as this was the one location where dye and current observations were at similar depths rather than being separated by a sheared layer.

As an extension of the technique, the slope of the range characteristics is used to give an estimate for the Hurst Coefficient (it has been noted by others that many geophysical signals exhibit long-term dependence exponentially proportional to the Hurst Coefficient, *H,* where $0.5 \leqq H \leqq 1.0$). The Hurst Coefficient can be used to model and thereby extend the spectrum to enable estimates to be made of extreme ocean currents.

The above techniques have been applied to current meter data from the Strait of Canso, Nova Scotia, and Come By Chance, Newfoundland, in connection with industrial development and in Head Harbour Passage in connection with a proposed marine terminal and oil refinery at Eastport, Maine. It is planned to utilize them in an experiment in St. Margaret’s Bay, N.S., that will investigate the causes for spatial heterogeneity of phytoplankton.

D. J. Lawrence, R. H. Loucks, D. V. Ingraham

Water Quality Modelling. A multi-stage water quality assessment scheme has been developed specifically for the recently industrialized Strait of Canso but it is judged to have general applications to coastal embayments. It consists of an interlocking combination of field measurements and computer modelling. The field program gives critical insight into the dynamic processes and scales present and can guide the choice of models. It enables an embayment to be realistically segmented for modelling purposes. Within each segment, an expanded field program of synoptic measurements can give meaningful averages and ‘within-sample’ statistics. Due to a lack of reliable sensors, particularly in the water quality field, continuous, self-recording, moorable instruments are not usually available. Thus, field measurements tend to be point sampling done from ships from which one can form quasi-synoptic spatial averages at infrequent intervals, say, once per 3-10 days. Thus, in a given segment of an embayment, only poor estimates can be made of the ‘between-sample’ variance. Modelling based on the field measurements can complete and extend the temporal coverage as outputs can be generated at closely spaced time intervals over the duration of the field measurements and beyond. Then the combination of within-sample variance from the field program and between-sample variance from modelling together yield an estimate of the total variance, which in turn forms the basis for predicting concentration maxima and their frequency of occurrence and duration. Finally, as reliability is improved, the extensive field program can be reduced and a combination of modelling and spot checking will suffice.

In the Strait of Canso, field measurements were carried out in 1973 by a team from the Atlantic Geoscience Centre. The modelling effort began with a steady-state, one-dimensional box model. This was followed by a time-dependent wind- and tide-driven one-dimensional box model. Although insufficient data were available to fully calibrate and validate the model it was nevertheless sufficient to demonstrate the usefulness of a time-dependent model in providing such important statistical outputs as the distribution of residence times, distribution of concentrations, and the duration and frequency of occurrence of concentration maxima.

D. V. Ingraham, R. H. Loucks, D. J. Lawrence

Numerical Modelling. The past decade has seen an almost explosive growth in the use of computers to solve, using numerical methods, equations describing the hydrodynamics of inland seas. Part of this growth can be attributed to an increased understanding of the basic physics involved and the development of powerful finite-difference techniques. However, the greater part has been due simply to an advance in computer technology. Staff of the Division have been intimately involved for several years with the development and application of numerical techniques.

The equations commonly used are based on laws of conservation of mass, heat, and momentum. These equations, in their general form, possess an infinite number of degrees of freedom and, hence, in order to get meaningful results compatible with measurement and computational errors, it is usual to filter the equations by some sort of scale averaging. The resulting equations are then transformed into difference equations and solved by a variety of techniques. The most powerful feature of these models is that various physical processes can be included or excluded at will by suitable modifications of the equations. In fact, such numerical experiments have provided a major feedback in advancing knowledge of circulation dynamics.

There are, however, severe limitations to be resolved. The inability to establish the parameters that describe the motions on the small scale, the use of ‘eddy’ coefficients, the inadequate treatment of the stability effect of free convection, and the unrealistic treatment of physical boundaries constitute important problems that have yet to be resolved.

In summary, numerical models permit experiments that simulate the dynamics of natural water bodies to be set up and, thus, they fill a vital gap. If one progresses from the simple to the more complex, an understanding of the effects of the free parameters implicit in the model can be made. In this fashion, some organization emerges from the complex interaction of variable topography, stratification, and simple atmospheric forcing. Long-term forecasts cannot as yet be made. In fact, due to the nature of the equations, a pure deterministic solution probably will never emerge and we will have to be content with statistical averages.

G. H. Seibert

Remote Sensing. To date, remote sensing tools have been used only to a limited extent by physical oceanographers. In large measure, this has come about because they have seldom been sufficient by themselves but serve, at best, to augment *in situ* measuring devices. Moreover, they have been limited in providing surface or near surface data, which while useful or potentially useful for studies of waves, tides, and air-sea transfer processes, are inadequate for studies of the interior of the water body. Nevertheless the development of a host of both active and passive scanning devices in recent years has been remarkable, and it is important to keep abreast of these developments. Part of our efforts are in this direction. Studies in the St. Lawrence estuary have been augmented with remote sensing data gathered from aircraft both in 1972 and 1973.

In August 1974, the Canada Centre for Remote Sensing at the urging of several remote sensing users undertook an evaluation experiment on the Bendix multi-spectral line scanner (10 visible and near infra-red bands and one thermal infra-red band). They chose the Port Mouton area, near Liverpool, Nova Scotia, as the test site and requested assistance for 'ground truthing' from all interested parties in Nova Scotia through Dr. G. Beanlands of the Department of the Environment (DOE) Lands Directorate. AOL and MEL together with Dalhousie University in Halifax made the appropriate measurements in the harbour area on August 19, 1974. From a chartered boat and a DOE Fisheries Service boat, sea surface temperature, salinity, chlorophyll concentration, and sediment concentration were measured and surface wave parameters and variation in the Secchi disc depth were monitored. Some idea of local diffusion was gained by releasing rhodamine B dye in two locations. The results of this test will not be known for a few months but it is hoped that this system will be as useful over water as aerial photography is over land.

P. E. Vandall

Support Activities

Although Coastal Oceanography is dependent on others for fulfilling some of its needs, it does give support to other groups especially in the area of providing and maintaining current meters (including reduction of the data collected by the meters), moorings, and other physical oceanographic equipment. The Division is responsible for monitoring the Halifax and Cabot Strait sections as part of the Canadian commitment to ICNAF (International Commission for the Northwest Atlantic Fisheries) and for undertaking an 'ice forecast cruise' each November in the Gulf of St. Lawrence to collect the oceanographic data needed by Sea Ice Central of the Atmospheric Environment Service who issue the ice forecasts.

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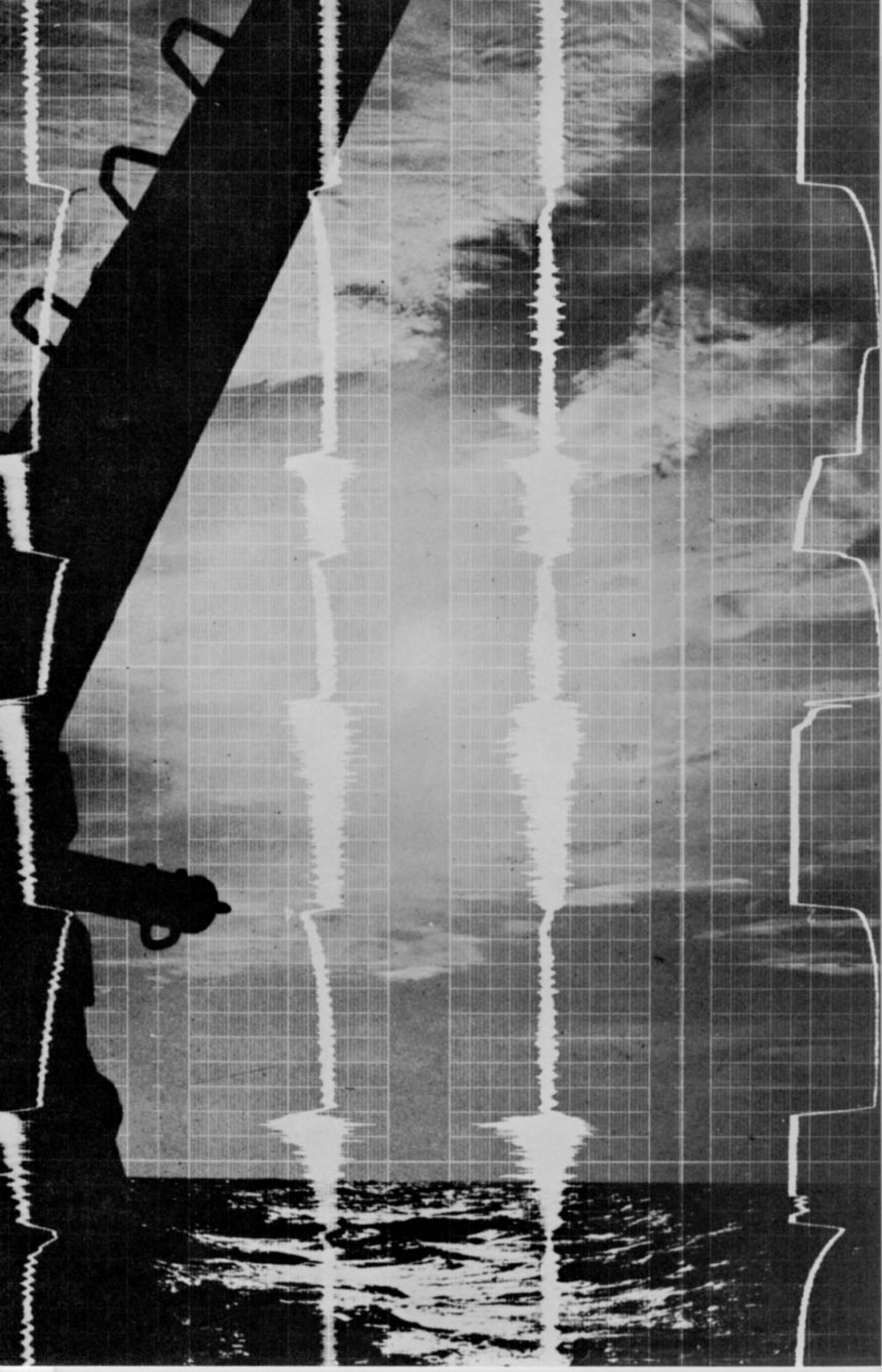


Metrology

Metrology directs its main efforts towards:

- Developing, modifying, and testing new methods, standards, and equipment to meet the needs of the Bedford Institute of Oceanography for collecting data
- Experimental studies of the physical interactions at the air-sea interface with particular emphasis on measuring strong wind stress generated over very large fetches and the mechanisms of wave generation

The work is carried out in close collaboration with other marine scientists and technologists at the Institute and within the local industry and university communities. As a contribution to the Canadian Government policy to stimulate the growth of new industry in Canada, some of our new technology (e.g., Batfish, Electric Rock Core Drill) and many of our hardware requirements have been transferred to industry.

The installation of a large, stable, offshore tower for collecting wind data is one of our current major goals. The tower has been designed by a local firm, which has also undertaken the project management work of overseeing the modification, construction, and installation. It is hoped the tower will be installed and operational by 1976.

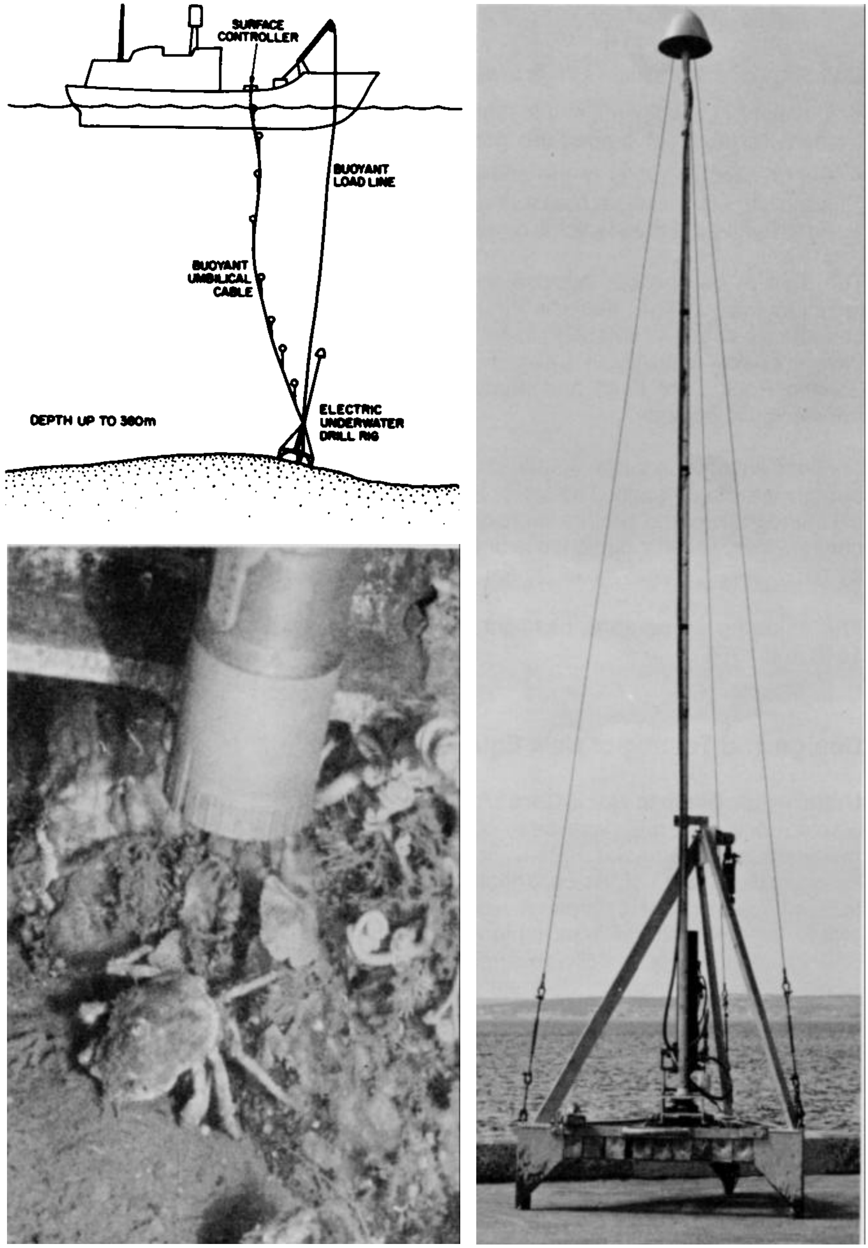
The following paragraphs highlight Metrology's programs and activities during 1973 and 1974.

C. S. Mason

Design and Testing of New Equipment

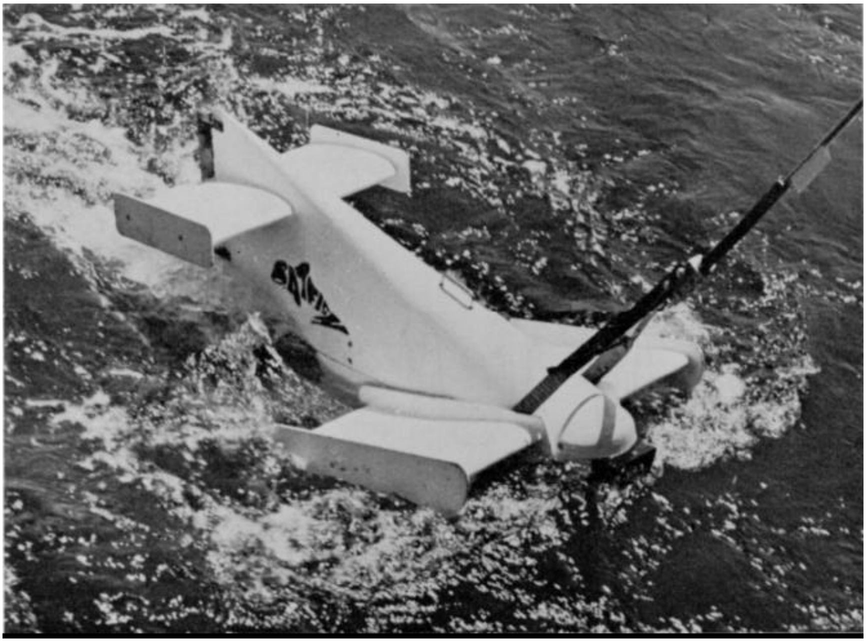
Underwater Electric Rock Core Drill. The design and testing of the underwater electric rock core drill have been completed and the drill has been licensed for manufacture by Canadian Patents and Developments Ltd. The drill is ideally suited for scientific studies of the continental shelf and has been designed for operation from an oceanographic research vessel. It can penetrate up to 5.75 metres of rock (core diameter is 25 millimetres) in water depths up to 360 metres. The complete drilling operation can usually be completed in under an hour. The drive mechanism of the drill is mounted on the base of a lead ballasted tetrahedral frame and the total rig weighs 650 kilograms. The 6-metre long drill barrel is housed in a close fitting aluminum mast that minimizes barrel vibration. An umbilical cable, which is played out by hand from the ship, supplies the electrical power to the drill and transmits signals from drill to ship. The neutral buoyancy of the load line and umbilical cable that connect the drill to the ship helps keep the drill upright on the ocean bottom. A surface controller monitors and controls the drill's operation and displays drill-bit penetration. The drill's penetration is limited by core jamming in the bit and core catcher, a common problem in fractured rock. Successful core recovery is also dependent on good navigational and seismic control to locate outcrop close enough to the sea floor surface. In the future, the drill rig itself will be used as a platform for mounting instruments that will measure the geotechnical properties of the rocks and sediments and recover difficult materials such as glacial till.

J. Brooke, G. A. Fowler, P. F. Kingston



The underwater electric rock core drill is used for continental shelf exploration and can be operated from an oceanographic research vessel.

Bottom Avoidance System for Batfish. The Batfish is a vehicle designed to be towed underwater at varying depths while carrying a range of oceanographic sensors. The license for its manufacture has been transferred from Hermes Electronics of Dartmouth, Nova Scotia, to Guildline Instruments Ltd. of Smith's Falls, Ontario.



Batfish. (Courtesy of the Halifax Herald Ltd., Halifax, N.S.)

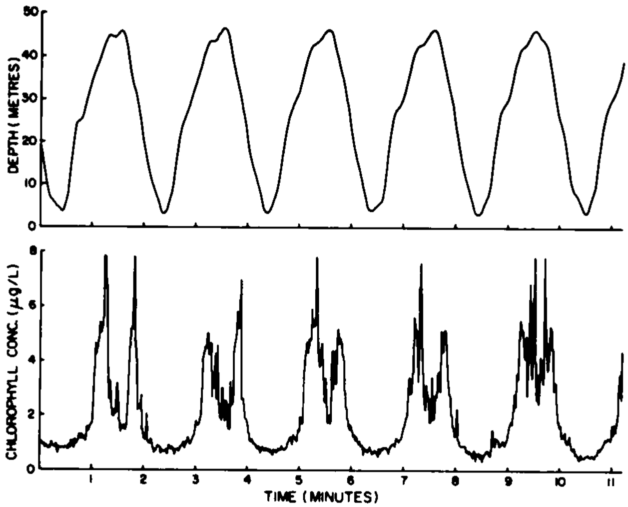
A totally automatic bottom avoidance system for Batfish has been designed and tested: it permits the Batfish to be towed in shallow water (less than 100 metres) with minimal risk. If the porpoising, towed Batfish dives to an 'alarm height' of 15 metres above bottom, it is automatically commanded to return to the surface at a rate of 1 metre per second.

J.-G. Dessureault, A. W. Herman

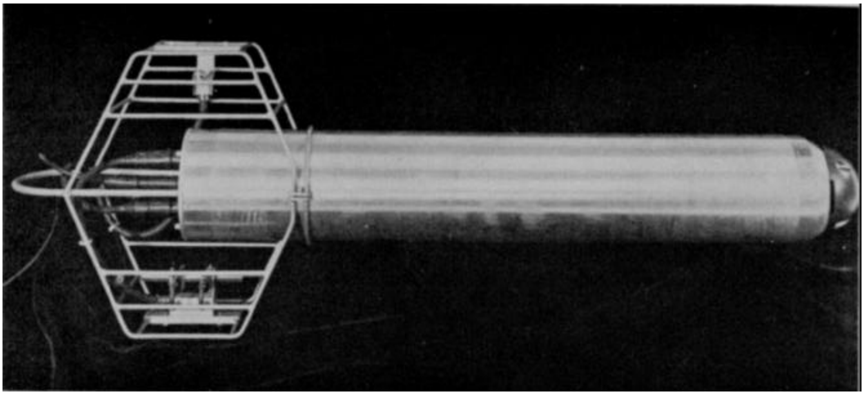
Variosens Fluorometer. An *in* situ Variosens fluorometer (Impulsphysik, West Germany) mounted on Batfish was tested during sea trials for chlorophyll (which is related to phytoplankton distributions) and rhodamine dye detection in a co-operative research effort with MEL. The fluorometer can detect a lower limit of 0.1 milligrams of chlorophyll/cubic metre of sea water and as little as 0.02 milligrams/cubic metre of dye. Chlorophyll data from the Variosens have shown high correlation with data from the more conventional Turner Ill fluorometer and the absolute concentrations measured agree to within 20 per cent.

A. W. Herman

New CTD. A modified CTD, an instrument that electronically measures the conductivity, temperature, and depth of sea water as a function of increased pressure with depth, was designed by the National Research Council of Canada (NRCC) and tested by Metrology. This new CTD is a solid state version of the previous model. A few modifications to the design were incorporated after the first trials and the final model is now being manufactured by Guildline Instruments Ltd. The calibration of the modified CTD is more stable and has reduced the scatter of



Chlorophyll layer detected by the Variosens fluorometer mounted on a porpoising Batfish towed at 3.5 metres per second. (AOL 3411.)



The hard-anodized aluminum pressure case of the new digital CTD (conductivity, temperature, depth) profiler. (Courtesy of Guidline Instruments Ltd., Smifh's Falls, Ont.)

readings experienced with the previous model by a factor of 2.5. Salinity measurements as referred to simultaneous bottle measurements were within 0.012 parts per thousand of the expected values with the new CTD. The main improvements are in the electronics, which have reduced noise interferences, and in the new single-piece cell design, which has improved the instrument's stability. The data from the CTD are recorded, processed, and displayed by a Hewlett-Packard 2100A computer. Mounted on a Batfish the new CTD was used on GATE (the GARP Atlantic Tropical Experiment, see Ocean Circulation) on 22 tows and a second CTD was used as a vertical cast instrument in over 300 casts at depths of 500-1500 metres.

A. S. Bennett, J. J. Betlem

Prototype Laboratory Salinometer. A prototype laboratory salinometer from Guildline Instruments Ltd. was evaluated in field trials. The unit is now successfully in operation and the one purchased by AOL was used on GATE. The new salinometer is an improvement over previous models because it requires a less skilled operator and a smaller sample, and it is more accurate.

A. S. Bennett, J. J. Betlem

Digital System for CTD. A prototype digital system for the Guildline CTD was designed and built at NRCC in a joint project between NRCC and Metrology. The new system simplifies the problems of transmitting data between the ship and Batfish when the Batfish is equipped to carry a wider range of oceanographic sensors than normal. A digital system is useful for oceanographic casts in excess of 2000 metres and it is hoped that this system will facilitate development of a single-wire towing cable system for vertical casts. In field trials aboard CFAV *Sackville* in July of 1974, the prototype model gave good results. Guildline Instruments Ltd. plan to manufacture the digital CTD.

J. P. Thorburn

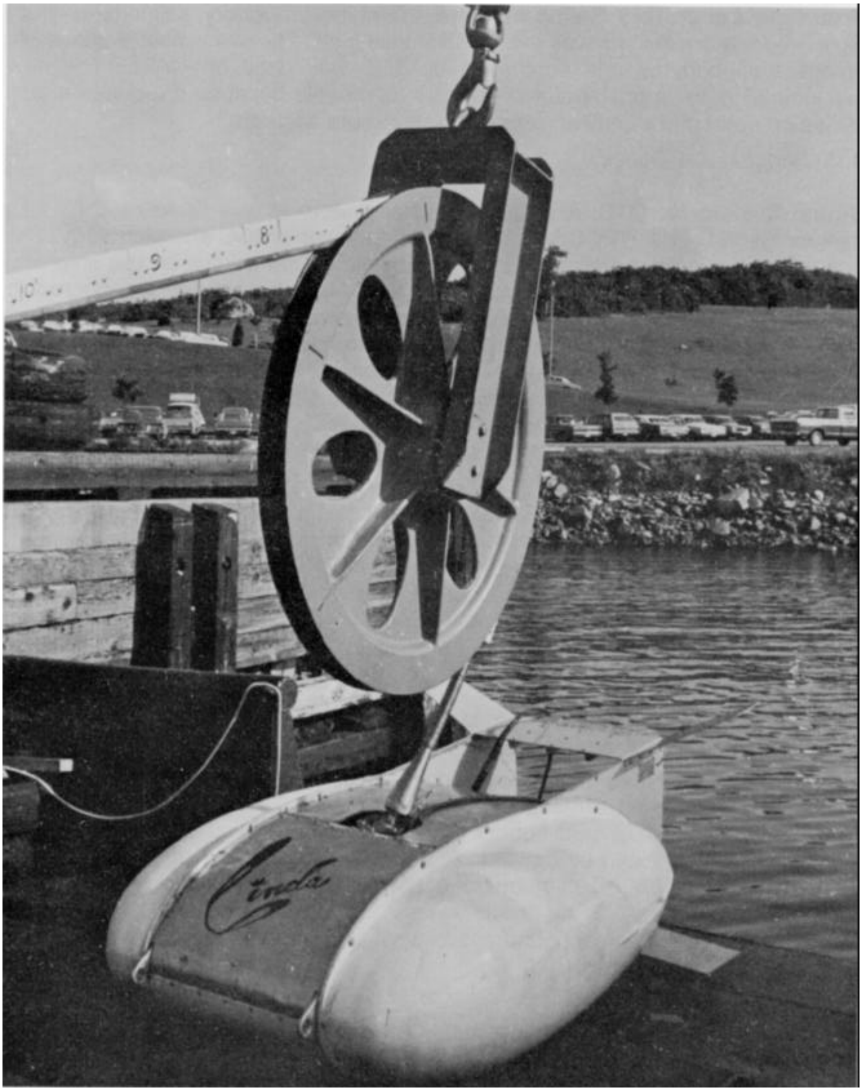
Deep-Towed, High-Resolution, Seismic System. In the latter part of 1974, AOL and AGC formulated and supervised a program to evaluate the deep-towed, high-resolution, seismic system designed and built by Huntec ('70) Ltd. of Toronto, Ontario. The Huntec system consists of a boomer-type source mounted in a body that can be towed near the ocean floor to depths of 300 metres. The boomer is an acoustic-electrodynamic source that produces a high-energy pressure pulse signature of closely controlled and repeatable shape. The field trials were intended to determine the characteristics of the towed body and acoustic source and the system's performance in areas of well-defined geology. Trials were conducted in Bedford Basin, Nova Scotia, and along the Offshore Acoustic Test Range, established by the Nova Scotia Research Foundation over an area of variable but well-known geology off Canada's East Coast. On the whole, the Huntec system penetrated acoustically hard bottom and resolved geological events better than any other system tested by us to date. Its main advantage is that it permits the geology of the first 50 to 100 metres of ocean bottom to be defined with resolution better than 0.3 metres. Some problems need to be overcome but in broad terms the system meets the manufacturer's claims and fills a gap that has existed in seismic profiling equipment.

D. L. McKeown

Acoustic Positioning Systems

Many oceanographic studies demand precise underwater navigation and positioning and the most practical means of achieving this is with acoustic positioning systems. In these systems, acoustic markers are placed on the ocean bottom. The bottom markers may be beacon pingers, which emit acoustic energy at predetermined times controlled by an internal clock, or acoustic transponders, which respond to external acoustic interrogations. Acoustic positioning systems are classified as short baseline systems (SBS) or long baseline systems (LBS). SBS use a single acoustic source on the bottom and a hydrophone array on the ship and LBS use several bottom markers and a single hydrophone on the ship. Some of our recent work with acoustic systems is described below.

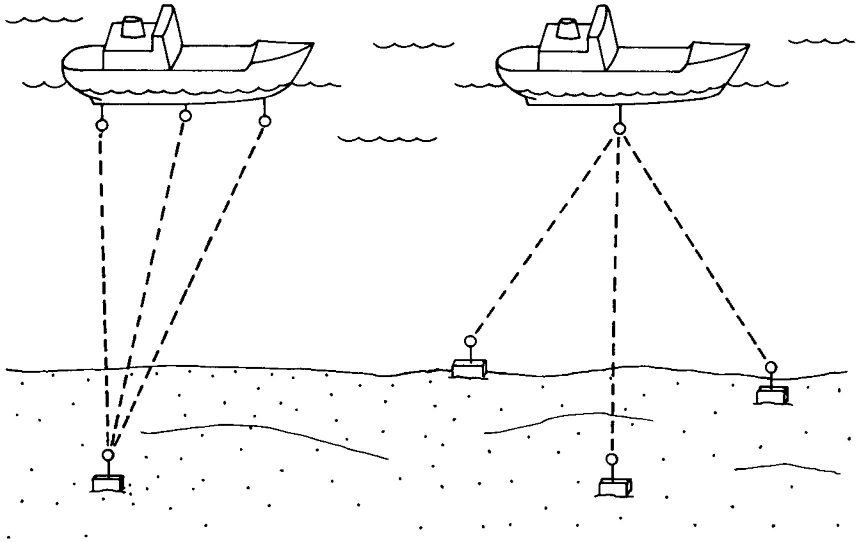
Accuracy and Repeatability of an LBS Positioning System. An experiment was conducted off Cannouan Island at the northern end of the Grenadines to test the repeatability of a long-baseline range-range acoustic positioning system.



The Huntec, deep-towed, high-resolution, seismic system's towed body. (AOL 3304-7A.)

Seven acoustic transponders were placed on the Caribbean Sea bottom at depths of 356-2461 metres and 12-20 kilometres offshore. Precise-ranging radar transponders were located at elevated geodetic stations on two nearby islands. About 9500 acoustic and radar fixes of the ship's position were obtained and differences between 2900 of these were computed. The results show that the LBS can position the ship with an accuracy and repeatability comparable to the radar transponders and that bottom marker survey techniques, which establish the relative positions of the transponders, are valid.

D. L. McKeown, R. M. Eaton (Hydrography)



Acoustic positioning systems: the short baseline system (left) versus the long baseline system (right). (AOL 3602.)

Tracking Current Drogues Under Ice. Oceanographers traditionally track current drogues visually or with radio-direction finders to study the movements of surface waters. To study these movements without wind effects, the oceanographer must wait for calm weather or, preferably, track the drogues beneath sea ice during winter. We have equipped drogues with acoustic pingers that will permit the drogues to be tracked under ice. The drogues with pingers are slightly negatively buoyant but are supported by a positively buoyant synthetic rope tail so they will not snag on the irregular under-surface of the ice. The modified drogues were visually and acoustically tracked under open water conditions and plans are underway to field test them beneath the winter ice cover of Bedford Basin, Nova Scotia.

D. L. McKeown

Identifying Radio Navigation Lanes. An economical and accurate method has been devised to resolve radio navigation system lane ambiguities during hydrographic surveys over deep and ice-covered water. An expendable beacon pinger is lowered to the sea floor at a known geographic position and a pair of hydrophones on the ship receive the pinger signal. Since the pinger position is known, the geographic position of the ship can be determined to resolve possible lane count ambiguities that occur during offshore survey operations. This new method will be field tested early in 1975.

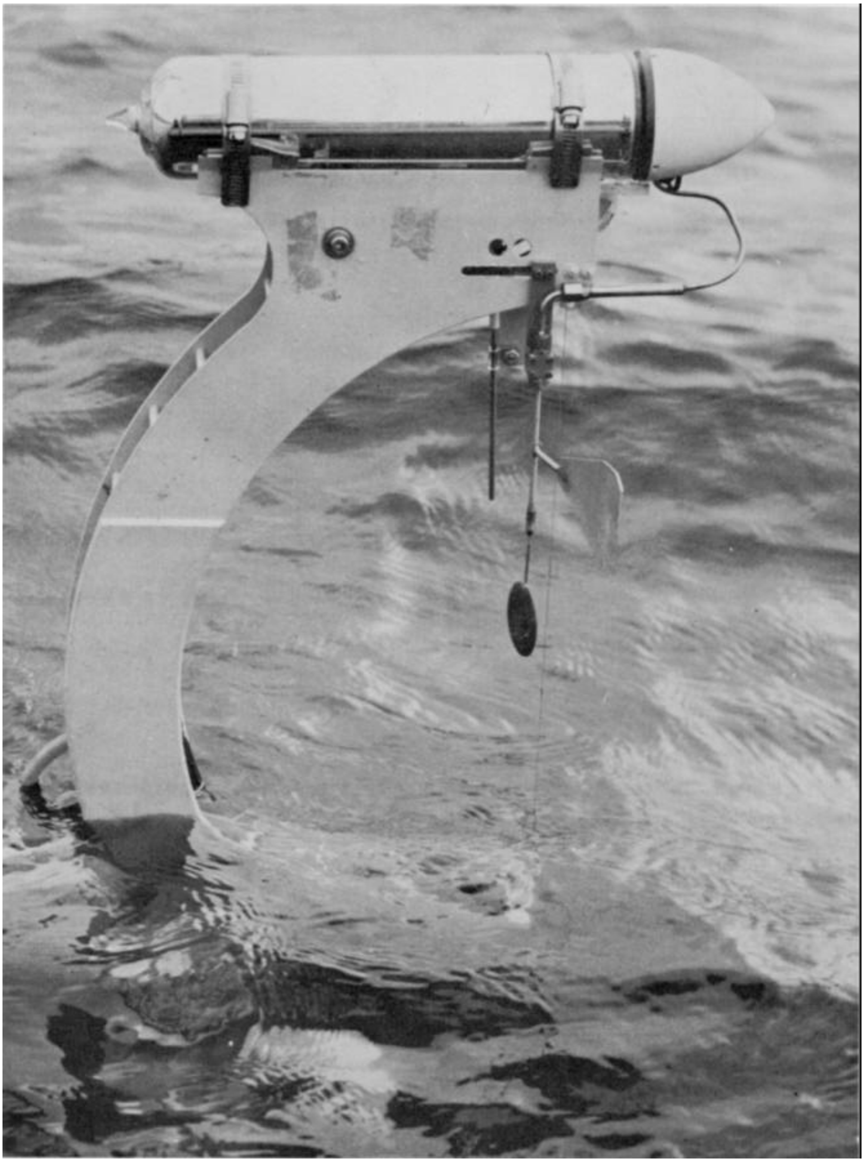
D. L. McKeown

Positioning Towed Bodies. A method has been devised that permits the position of a towed body such as the Batfish to be defined relative to the ship at any point in the water column. A beacon pinger equipped with a precise internal clock emits periodic signals that are picked up by an array of hydrophones on the ship. These signals can be used to specify both the bearing angle and range of the towed body relative to the ship.

D. L. McKeown

Air-Sea Interaction Studies

Wave Follower Program. The BIO wave follower program is one of experimental basic research into the mechanics of the air flow over growing wind waves. It is based on the realization that an understanding of the mechanism by which the wind generates ocean waves and causes them to grow can only be understood by investigating the air flow very close to the water surface.



Wave follower sensor package. (AOL 2905-11)

To this end a servo-controlled wave-following device has been developed. The design is based on one originally built by the Chesapeake Bay Institute (CBI) of Johns Hopkins University; the BIO version was designed with the shortcomings of the CBI instrument in mind. A hydraulically actuated piston maintains a streamlined sensor package at a constant height above the water surface. Water level is sensed with a fine-wire capacitance wave gauge on the sensor package. The signal from the wave gauge is compared with a fixed, remotely-controlled voltage; the resulting 'error' signal is amplified and sent to an electro-hydraulic servo-valve, which channels hydraulic flow from a 2-horsepower pump to drive the piston in the direction that reduces the observed 'error'. At the moment the wave-follower sensor package is equipped to measure (besides wave height) fluctuations in pressure and horizontal wind speed. The wave follower has been in use for two years, and during the period covered by this Review, it was used on two international expeditions.

JONSWAP II (Joint North Sea Wave Project) was a major international project held in the German Bight in the fall of 1973 to study how waves dissipate themselves, and the extent of the wind energy into the wave field. Five AOL scientists participated in this six-country, NATO-funded project. An undersea tower, designed and built at BIO, was placed in the North Sea and a small radio mast was mounted on it. Signals from the instruments on the mast were sent via underwater cables to the nearby VWS *Atair* of the German Hydrographic Survey where they were recorded on magnetic tape for subsequent analysis. Storms limited the amount of data collected and, although the aims of the project were not fully realized, initial results show that substantial progress has been made.

Another joint experiment was held in the Bight of Abaco, Bahamas, with Nova University of Fort Lauderdale, Florida. The equipment used was similar to that used in JONSWAP II but included, in addition, an horizontal array of four fixed-height pressure sensors from Nova University. The objective was to inter-compare techniques for measuring near-water pressure fluctuations. The importance of measuring pressure fluctuations near the sea surface is that it permits a direct estimate of the rate of work of wind on waves, an estimate that has become possible only recently. At present, the data sets from both experiments are being analyzed; the future course of the program will depend on the outcome of the analyses.

F. W. Dobson, D. Harvey, D. Knox

Stable Tower Project. An offshore stable tower is being constructed that will provide a fixed and stable point on the surface of the ocean and thereby permit undisturbed measurements of stress, heat flux, and evaporation over the sea as functions of wind, temperature, humidity, and sea state. The tower has been designed by Whitman Benn and Associates Ltd. of Halifax and its construction is now underway. It is anticipated that the 12-metre high tower will be installed and operational over a 55-metre deep section of water outside Halifax Harbour by 1976. The tower offers minimum wind resistance and can withstand waves of 18 metres height (a previous model was designed to withstand 9-metre waves). Instruments that will be mounted on the stable tower include a fast-response anemometer, thermometer, humidiometer, and telemetry wave gauge.

J. Brooke, S. D. Smith

Wind Turbulence Studies. Wind turbulence over the west spit of Sable Island, Nova Scotia, was measured to obtain air-sea interaction parameters such as will be obtained from the stable tower in 1976. The low-lying spit is a stable measuring

View of Sable Island. N.S.

surface with relatively low wind resistance; however, shoaling near the spit affects waves. Our measurements indicate that wind drag near Sable Island is greater by about 10 per cent than over the open ocean.

During 1973, wind velocity fluctuations over sea ice that had been recorded with a sonic anemometer at a number of locations in the Arctic Ocean and Robeson Channel were used to compute surface stresses and drag coefficients. It was shown that wind drag is related to an elevation characteristic of the surface that can be calculated from profiles of ice surface elevation. In addition, it was found that in measuring wind change over an area of pack ice, allowances must be made for greater wind drag on ice pressure ridges. These ridges are rugged walls of broken ice formed when wind or currents squeeze ice floes together. A new method of measuring wind drag over ridges was tested with Defence Research Establishment Ottawa in Robeson Channel in 1974. In this method, pressure sensors embedded on the slopes of a ridge measure the form drag of the wind on the ridge.

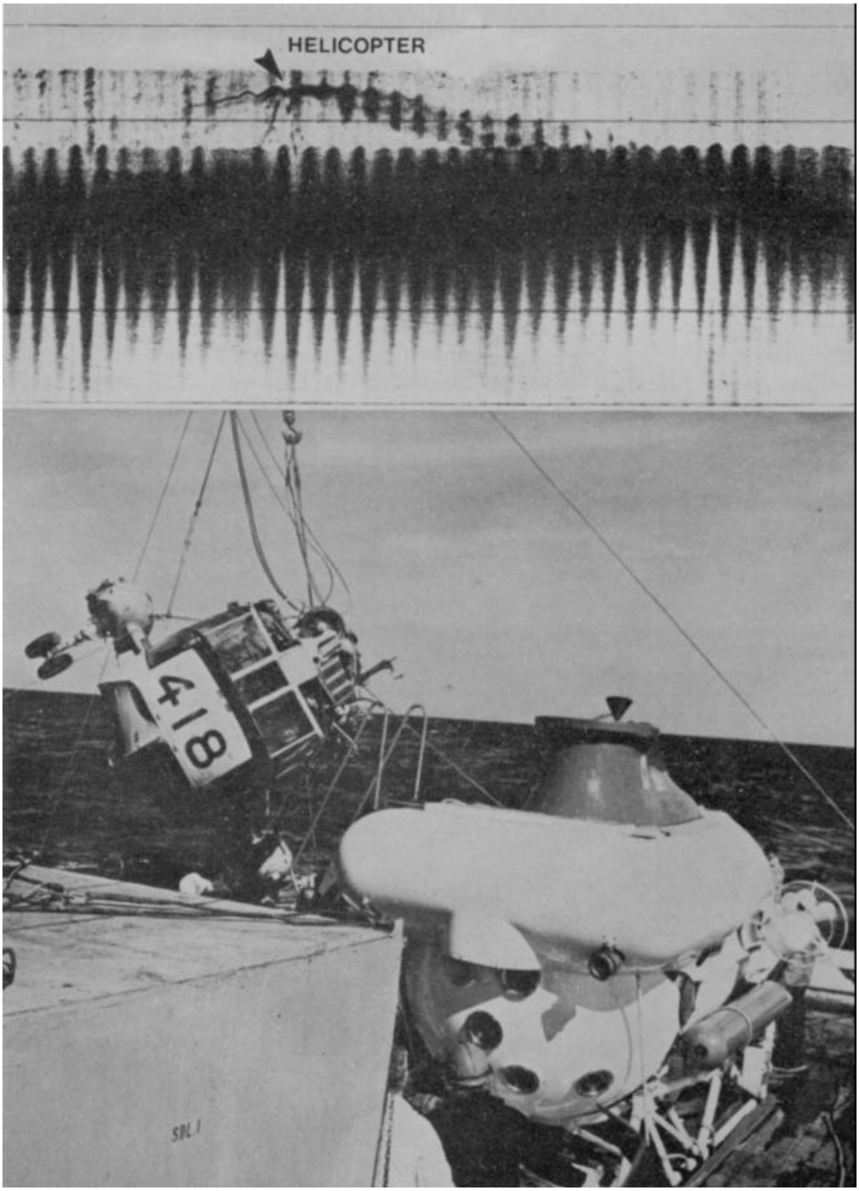
S. D. Smith, E. G. Banke

(See also the essay “Sea Ice Research in Canada” by S. D. Smith and E. G. Banke in Ocean Science Reviews, Part D of this Biennial Review.)

Other Projects

Recovery of SEA KING Helicopter. On 29 April 1973, a Canadian Armed Forces SEA KING helicopter crashed and sank into the Atlantic Ocean some 50 kilometres from Halifax. The crew escaped unhurt but the helicopter sank in 166 metres of water. Metrology assisted Maritime Command in the search and recovery effort. The CSS *Sackville* collected side-scan sonar records of the 60 square kilometre search area that had been delineated. From the records, 60-70 possibilities were identified and further acoustic surveying pinpointed the most probable target (see photo). With the help of the DOE submersible *Pisces IV* from Victoria, B.C., and the navy *SDL-7* (Submersible Diver Lockout), and after some difficulties with high seas, the position of the helicopter was corroborated and it was recovered.

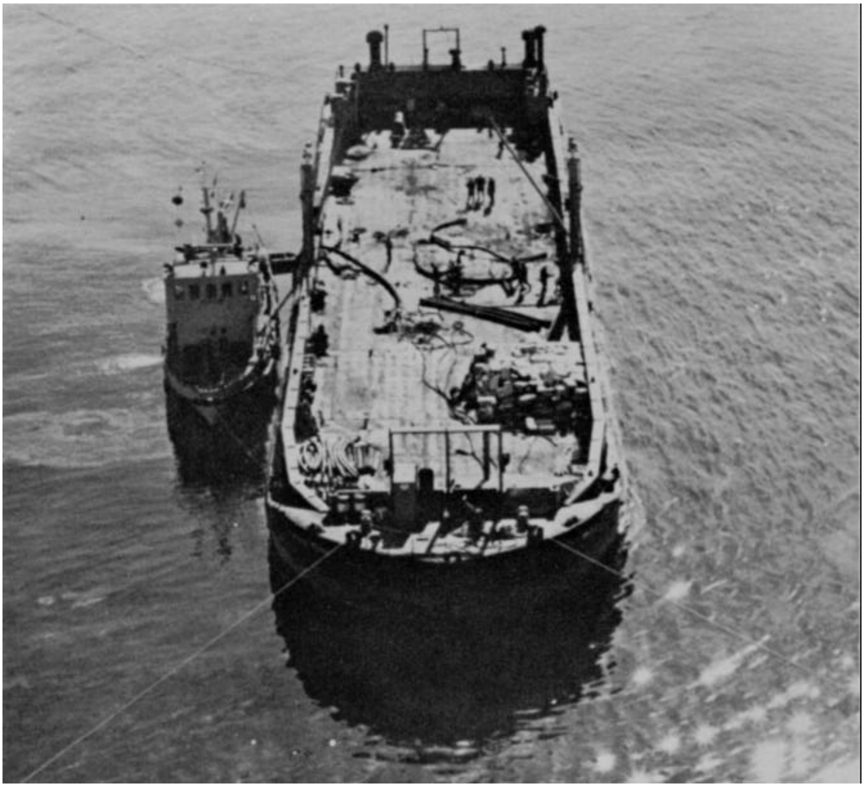
D. L. McKeown, P. G. Jollymore, P. L. D’Entremont



Sea King helicopter search and recovery effort. The acoustic record shows the helicopter on the sea floor. (AOL 3487.) In the lower photograph, the helicopter is being winched aboard a barge after its recovery by the SDL-I (foreground) submersible. (Courtesy Canadian Forces.)

Irving Whale. In September 1970, the oil barge *Irving Whale* sank in 60 metres of water between Prince Edward Island and the Magdalen Islands, Gulf of St. Lawrence, with 4500 tons of Bunker C crude oil aboard. Since that time, the Ministry of Transport (MOT) has periodically checked the *Whale.* In the latter part of 1973, Metrology assisted MOT and the Department of National Defence (DND) in examining the sunken barge. Metrology provided an acoustic tracking system for the *SDL-1* and an underwater television system belonging to AGC. An electric rock core drill was modified so that it could drill through the steel deck. The intention was to withdraw a vertical sample of the oil from the Whale's fuel tank via a plastic tube lowered through the drill hole, then re-seal the tank. When the drill was lowered to the barge it became entangled in cables and the lifting cable broke. Plans are underway to retrieve the lost equipment. Also, a new technique that may allow the amount of oil to be determined without drilling will be tested. Because oil attenuates sound faster than sea water, it may be possible to define the oil-water interface within the fuel tanks by sounding the fuel tank horizontally while traversing the side of the tank vertically with a transducer. The interface would be defined by a shift in the distance axis of the sounding record. A 'bottom crawler' is being designed that will position and move the transducer up the side of the tank.

D. L. McKeown, J. Brooke, P. F. Kingston



The oil barge Irving Whale alongside a diving tender in Chedabucto Bay, N.S., prior to its loss in a storm (see text) on September 7. 1970. The Whale is situated over Cerberus Rock where the Liberian tanker ARROW ran aground on February 4, 1970. (AOL 3486.)

Events of 1973/74

Some of the more significant events of the past few years not described in preceding paragraphs are summarized below.

Ocean '74. The fifth IEEE International Conference on Engineering in the Ocean Environment (Ocean '74) was held in Halifax, Nova Scotia, 21 to 23 August 1974. Metrology and other BIO staff played a major role in organizing this large conference that attracted 529 people from many different countries. The major portion of the work presented was electrical and electronic but the Technical Program Committee, which was composed of BIO staff, did seek papers from other disciplines to exemplify the multi-disciplinary nature of oceanography. Two of the major sessions dealt with "Engineering and Physics of Sea Ice" and "Sensing in the Ocean Environment". An unusual feature was the concluding "Overview of the Conference and Future Trends of Ocean Technology" that was presented by several invited speakers.

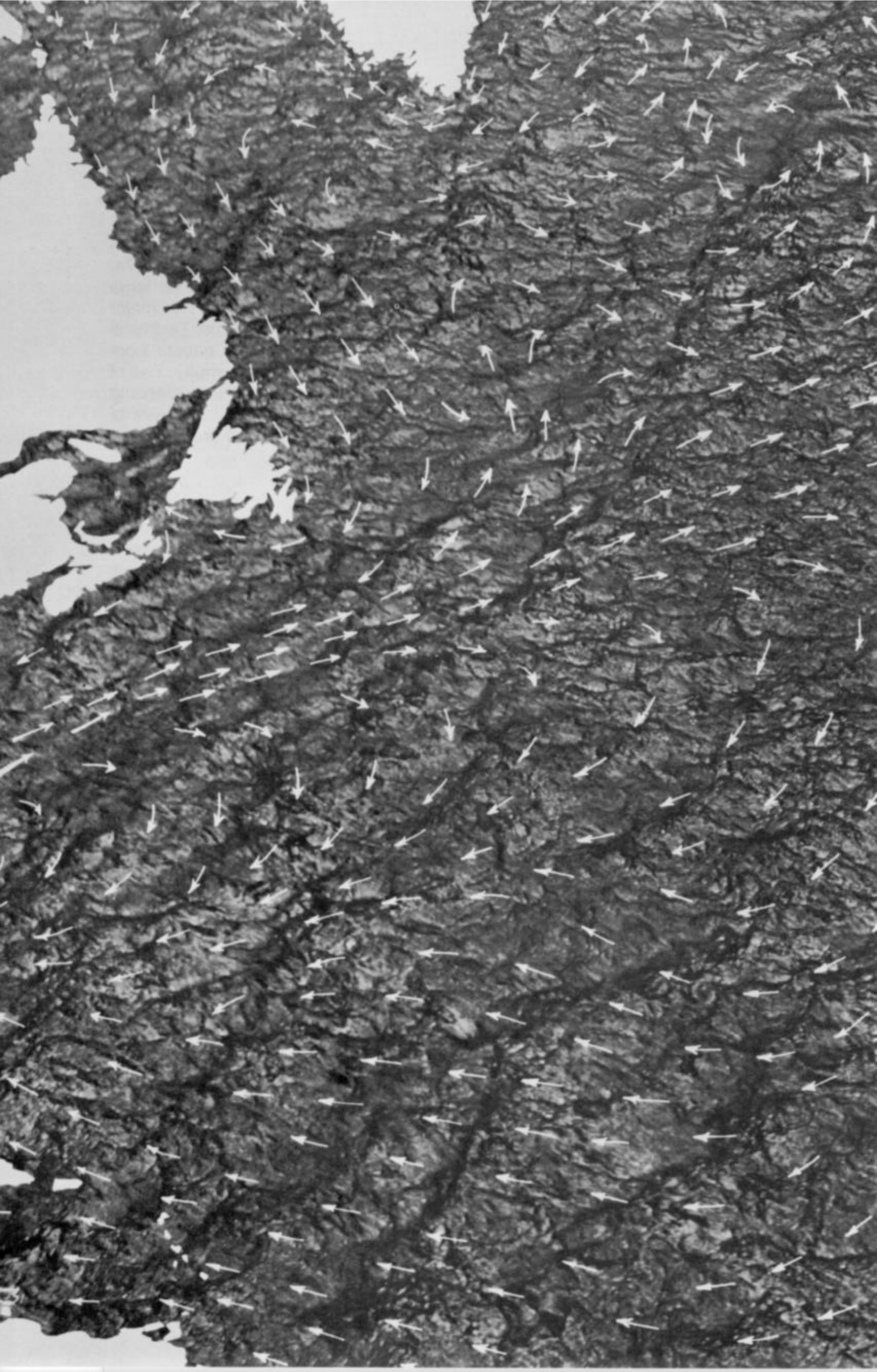
J. Brooke, C. T. Schafer (AGC)

Demonstration of Oceanographic Equipment. Participants from nine countries took part in a mission organized by the Department of Industry, Trade, and Commerce to demonstrate Canadian oceanographic equipment. The equipment tested included a Batfish and the CTD and laboratory salinometer described earlier. The program included a demonstration cruise, seminars and discussions, and tours of the Institute and local industry. The event was successful and consideration is being given to having more of this type of mission.

C. S. Mason

Workshop on Sensors in the Ocean Environment. A three-day joint Canadian-German workshop was held at the Institute in April of 1973. Representatives from industry, government, universities, BIO, and the Institut für Meereskunde, Kiel, attended. The participants discussed their work, stressing recent developments, problem areas, and future plans. The workshop was most successful and recommendations and conclusions included proposals for laboratory studies and intercalibration, joint participation in field programs, and exchange of staff for extended periods.

C. S. Mason



Ocean Circulation

The main activities of Ocean Circulation include:

- Field and theoretical studies of the large-scale circulation patterns of the oceans and their related distributions of heat, salt, oxygen, etc.
- Theoretical laboratory and experimental studies of small-scale oceanic features and processes such as internal waves and microstructure
- Development of mooring technology and of instruments capable of measuring the microstructure of the oceans

Our program of research is aimed at understanding the physical processes operating in the interior of the ocean. As the science of oceanography has developed, the Division's efforts have shifted somewhat from experiments designed to describe the large-scale distribution of oceanic properties such as heat, salt, and momentum to experiments that examine the details of the exchanges of such properties. In most instances this shift has involved the study of time-dependent processes that, in some average sense, lead to the large-scale distribution of properties with which oceanographers have become familiar. Today's physical oceanographer studies, at one end of the spectrum, 'eddies' on the scale of a few tens of kilometres, which are probably basically responsible for the transfer of heat, salt, and vorticity in the oceans, and, at the other end of the spectrum, microstructure on the scale of a centimetre, which also influences the distribution of heat and salt and is important in the dissipation of kinetic energy in the ocean. Ocean Circulation is involved in many aspects of such problems and most of these will be described in more detail below.

Our larger programs include a continuation of work on the Gulf Stream - Slope Water System and a major expedition to measure the outflow of bottom water through the Denmark Strait. This past summer (1974), a significant contribution was made to the GARP Atlantic Tropical Experiment (GATE) (described further on). These large-scale experiments involved international co-operative efforts with institutions such as Woods Hole Oceanographic Institution and international co-operative efforts with organizations such as the International Council for the Exploration of the Sea and the World Meteorological Organization. The need to mount more comprehensive experiments will continue and the Division can look forward to even more co-operation on the international level. Indeed, as oceanography advances, the need to exchange ideas and results on all aspects of the science in international forums becomes more and more evident.

G. T. Needler

The Gulf Stream-Slope Water System

Since its opening in 1962, the Bedford Institute of Oceanography has been conducting studies of the Gulf Stream System. The last and most ambitious experiment was carried out in 1972 and made use of large numbers of moored instruments and three ships: the C.S.S. *Hudson* of BIO, the R.V. *Chain* of Woods Hole Oceanographic Institution, USA, and the R.S. *Cirolana* of Fisheries Laboratory, Lowestoff, U.K.

The main objective of this experiment was to determine the circulation pattern to the south and east of the Tail of the Newfoundland Banks where, after encountering the shallowing bottom at the southeast Newfoundland Ridge, the

Gulf Stream appears to split into a northern branch and a somewhat diffuse southern branch. The northern branch is believed to be joined by Slope Water (described in more detail below) and to form the North Atlantic Current that flows northward along the eastern edge of the Grand Banks. The experiment was also designed to determine whether a deep boundary current carrying bottom water arising from the Denmark Strait Overflow existed in this region and to obtain some measure of the Labrador Current in the region of Flemish Cap.

During the past two years, the data from all three institutes have been analyzed and combined. Estimates of the transports of the various currents in the region were made and it was found that the circulation pattern generally supports the picture outlined from previous less comprehensive work. Although bottom water arising from the Denmark Strait Overflow was found, there was little suggestion of a southward flowing boundary current in the area. In addition to the overall current patterns obtained, the balances of dissolved oxygen and nutrient concentrations in this region are being investigated in order to determine the relative importance of mixing along and across isopycnal surfaces, and the advection of properties in this region of strong current shears and sharp concentration gradients.

In the vicinity of Cape Hatteras, the Gulf Stream turns east to flow approximately along the fortieth parallel of latitude across the Sohm Abyssal Plain to the Newfoundland Banks. In this region, north of the Gulf Stream and south of the Continental Shelf off Nova Scotia, lies a large area where warm water from the Gulf Stream mixes with the cold southerly flowing water of the Labrador Current to form a body of water known as Slope Water. The interweaving and mixing processes are complicated and have so far defied detailed understanding. At present, we have only a coarse description of the temperature and salinity fields and a few records from current meters located near the Scotian Shelf.

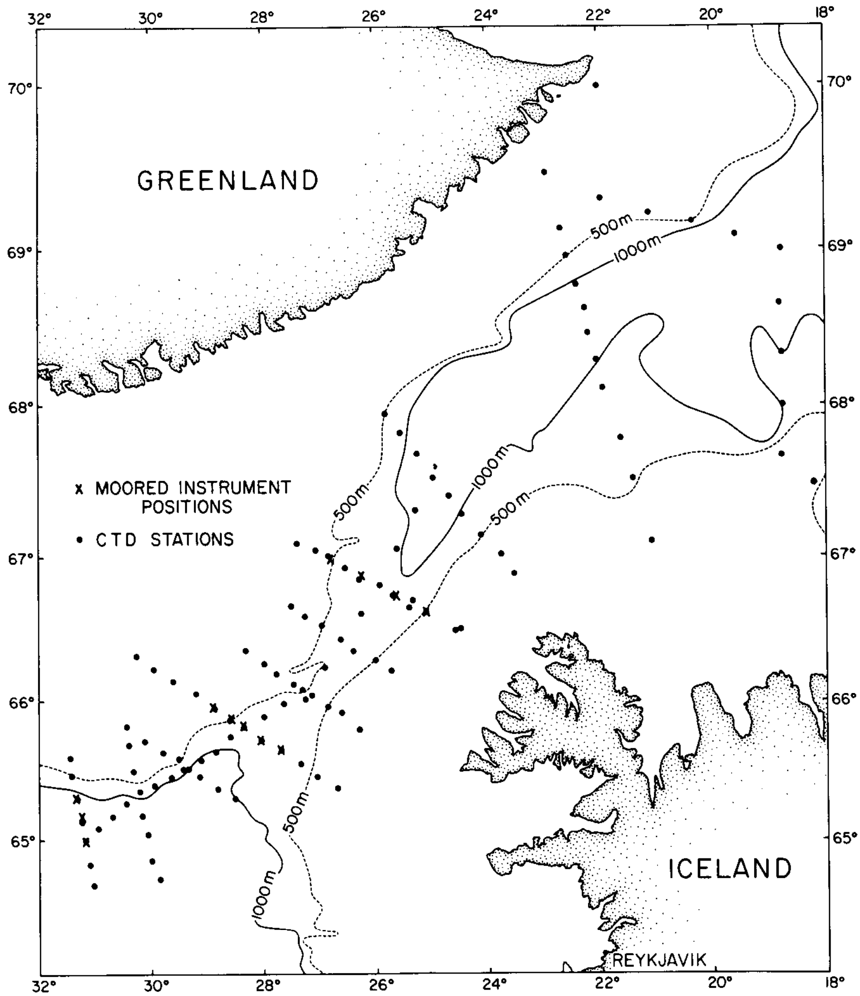
In collaboration with the Department of Oceanography, Dalhousie University, Halifax, a new attempt has been initiated to understand the physical oceanography of the area. A start has been made at maintaining long-term current meter moorings off the entrance to the Laurentian Channel and at approaching the problem on a theoretical basis. From the data obtained locally and further to the west, it is known that one to two years of frequent sampling are necessary to obtain statistically stable estimates of physical parameters in the area. In 1974, an attempt to keep moorings in place in the Slope Water for longer than two months failed because the moorings corroded. It is hoped that in 1975 the problems will be overcome and records will be obtained from a few selected sites for long enough periods to obtain the desired averages.

R. A. Clarke, C. R. Mann, R. F. Reiniger

Denmark Strait Overflow

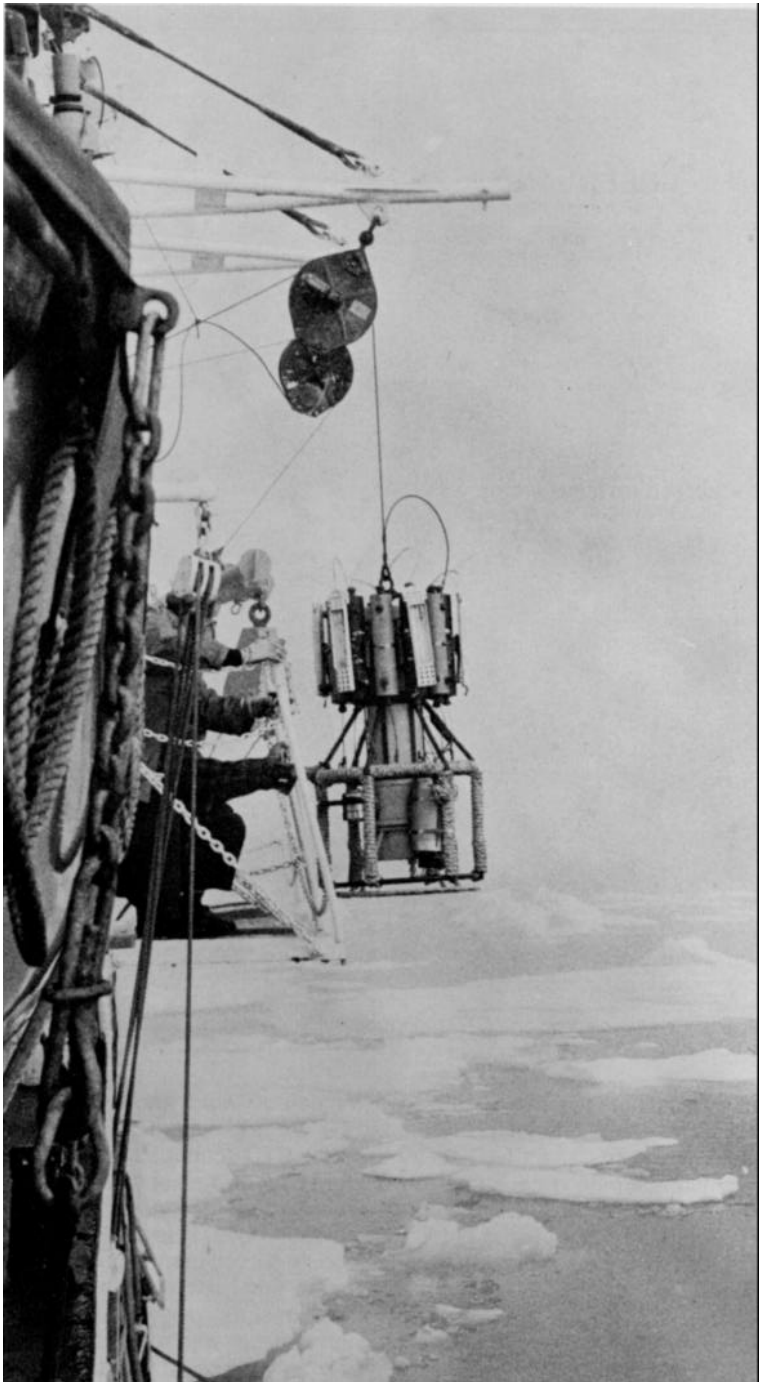
The Greenland-Scotland Ridge inhibits the cold, dense water of the Norwegian Sea from flowing freely into the deep basins of the North Atlantic. Some Norwegian Sea water ‘overflows’ in a near-bottom layer at several locations along the ridge to become a major component of the deep and bottom water in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

To study the overflow, the International Council for the Exploration of the Sea sponsored “Overflow ‘73”, an expedition involving seven countries and 13 ships. The Atlantic Oceanographic Laboratory participated with C.S.S. *Hudson* in the Denmark Strait. In spite of unusually heavy ice coverage in much of the working area, 12 current meter moorings were placed and all but one were recovered after



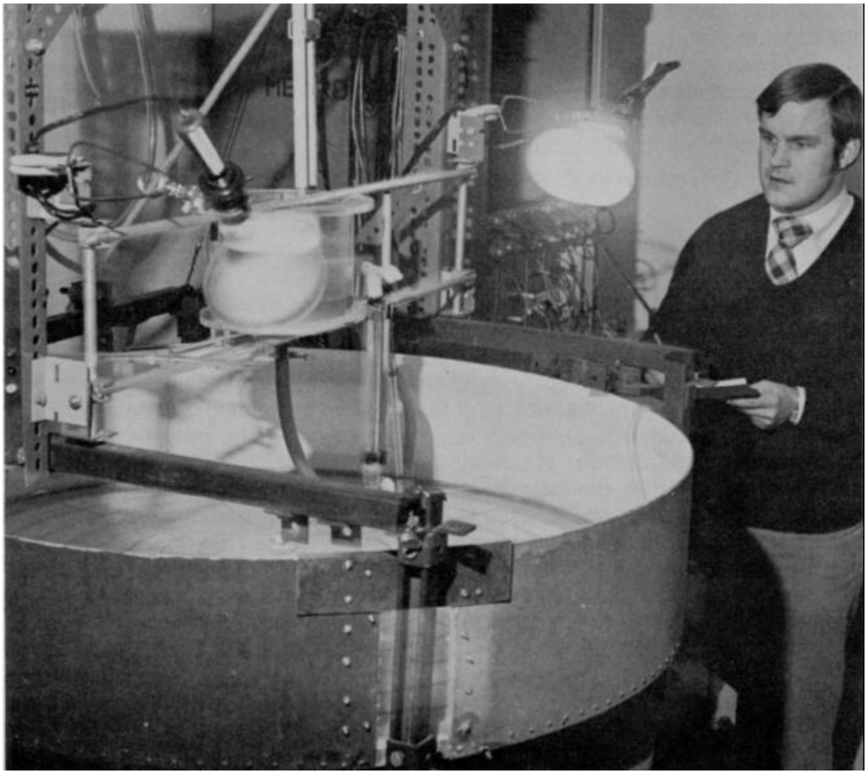
Moored instrument positions and CTD (conductivity, temperature, depth) stations occupied during "Overflow '73". (AOL 3538.)

5 weeks. Excellent data on the circulation immediately north and south of the sill in Denmark Strait have been provided by 26 current meters and 6 Digibridge temperature recorders, as well as by the 203 CTD (conductivity, temperature, depth) stations, where water samples were taken for oxygen and nutrient analysis. A program of OCTUPROBE lowerings investigated the microstructure in the region. The use of this instrument is discussed in detail below. Bottom samples were collected in support of a manganese nodule survey carried out by Dalhousie University. The moored instrument records show that north of the sill the currents are strong (maximum average velocity 0.6 metres per second; maximum measured speed 1.6 metres per second) and variable with most of the power at periods longer than one day. Although it has been reported that the overflow is intermittent, our observations from four moorings across the western slope of the channel indicate that near-bottom, cold water was almost never completely absent but that its location and intensity were highly variable.



Preparing to sample water properties in Denmark Strait using a continuously recording CTD (conductivity, temperature, depth) sonde with attached water bottles. (AOL 2966.)

To gain deeper insight into the dynamics of the overflow, several theoretical models and laboratory experiments have been carried out to isolate and study certain physical processes at work in the region. The starting point was a mathematical model whose solutions resemble the pattern of overflow measurements. Using dimensional analysis, a laboratory experiment on the rotating table at BIO (shown below) was then designed to reproduce certain aspects of the model on a laboratory scale. For the experiment, the density stratification was created with two fluids of slightly different densities while the continental slope was produced by using a basin with a sloping bottom. The entire apparatus was mounted on the rotating table at BIO in order to model the Earth's rotation. The laboratory flow fields showed strong similarities to the ocean currents and expanded our understanding of the phenomenon.



The rotating table is used for laboratory modelling of general ocean circulation. (AOL 3431.)

The first experiments were designed to study the effects of bottom friction on the overflow. A theoretical model of a steady source flow in a rotating system has demonstrated a mechanism by which the momentum and energy of the density current can be dissipated by turbulent bottom stresses. The experiment to test this theory was partially successful; it confirmed certain qualitative aspects of the solution but a steady state was never attained in any experiment even though the source strength was held constant. The laboratory flow fields always contained large-scale waves with a period of several inertial periods. Since low-frequency variability is a distinct feature of the Denmark Strait data, an attempt was made to relate the laboratory measurements with those observations. For mean conditions typical of both flows, a stability analysis showed that the wavelengths and frequency of the observed motions correspond closely to those of the most unstable baroclinic wave. Furthermore, eddy heat flux computations made using current meter and temperature records from the overflow indicate the release of available potential energy necessary for an amplifying baroclinic wave. Thus, the process primarily responsible for the strong variability in the Denmark Strait current measurements may be hydrodynamic instability of the outflow current itself rather than fluctuations within the Norwegian Sea as was previously proposed.

Additional experiments dealing with the problem of turbulent entrainment by density currents in a rotating system are underway. Entrainment is the process by which the characteristics of the Norwegian Sea water are modified by mixing with adjacent Atlantic Ocean water downstream from the sill. It is widely believed that the amount of turbulent entrainment at a density interface depends solely on the density contrast and the velocity shear; however, for geophysical scales of motion the Earth's rotation may be expected to play a role. The experiment is designed to assess the influence of rotation on entrainment in a turbulent stratified shear flow as a function of velocity and density profiles at various rotation rates.

C. K. Ross, C. R. Mann, P. C. Smith

The Mediterranean Salinity Anomaly

In recent years, theoretical models have been constructed that can, to a large extent, describe the distribution of water masses in the anticyclonic gyres below the surface frictional layer. In general, these models fit the main features of the density field in the anticyclonic gyres just as well by neglecting diffusion of mass as by including it. The nonlinear nature of the problem has defied a general solution. Even though non-diffusive models appear to describe the density field in the anticyclonic gyres, changes in temperature and salinity fields along streamlines show that strong diffusive effects are present. One of the most striking examples of such an effect is the disappearance of high salinity water from the Mediterranean in one crossing of the North Atlantic. A detailed analysis of the diffusive effects in this water mass has been performed to determine whether they are large enough to be important in the mass balance of the area. It was found that the salt anomaly relative to a linear temperature-salinity relationship largely behaved as a three-dimensional "tongue". The change of vertical and horizontal scales along the tongue allowed the computation of the vertical and horizontal mixing coefficients. In spite of the fact that this anomaly is indeed diffusively controlled it was shown that diffusion of mass is not of first-order importance to the mass balance in the main pycnocline of the region.

G. T. Needier

Numerical Models for Oceanic Processes

A semi-implicit mixed spectral and finite-difference numerical algorithm on variable grids has been set up to solve a system of 3-dimensional partial differential equations that describe the behaviour of a rotating stratified fluid in an enclosed domain. The specific objective of this algorithm is to study the temporal development and the quasi-steady structure of baroclinic waves in a differentially heated rotating annulus.

Preliminary results from this algorithm are comparable to the results from a 3-dimensional finite difference algorithm. The advantage is that the new algorithm leads to a phenomenal reduction in the computer storage needed and the computer time required for computation is about one-twentieth of that required by a 3-dimensional finite difference algorithm. By way of illustration, the computation of a simple case, done by using a 3-dimensional finite difference scheme, consumed 150 hours of computer time on a Univac 1108. A similar computation with the new algorithm took 7 hours on a CDC 6500, which has a speed comparable to the Univac 1108. Currently the program is being run on a CDC 7600 at NCAR (National Center for Atmospheric Research) to study dispersion and amplitude vascillation of baroclinic waves. Other studies such as those on geostrophic turbulence are now within our capacity.

A project to develop a numerical, multi-layered baroclinic model of the Labrador Sea has begun. At present, a 2-dimensional numerical model of a stratified ocean that incorporates some characteristics of the Labrador Sea is being used to make a preliminary study of the Sea's response to various types of forcing. It is hoped that this study will facilitate the development of an appropriate 3-dimensional model of the interesting and prominent features of the Labrador Sea, one of the important water masses in the North Atlantic. With the installation of a CDC 7600 computer at the Atmospheric Environment Service in Dorval, Quebec, we hope to be able to broaden our numerical studies and eventually produce some realistic models of the world oceans.

C. Quon

(See also the essay "Geophysical Fluid Dynamics" by Charles Quon in Ocean Science Reviews, Part D of this Biennial Review.)

The Internal Structure of Lakes

In 1970 and 1971, time series of vertical profiles of temperature through a fresh-water thermocline indicated that the step-like temperature structure sometimes observed migrates through the thermocline rather than remaining at a fixed depth or temperature. The study has been continued with the aim of obtaining a basic understanding of the cause of this structure, which is typical of naturally stratified fluids such as the oceans and atmospheres.

The major investigation to date was undertaken in Lake William near Waverley, Nova Scotia, in the summer of 1973. Two rafts, equipped with automatic instruments capable of measuring temperature profiles, were moored at the one-quarter and three-quarter points along the centre line of the lake. Alongside these rafts, Aanderaa thermistor chains were moored to record the temperature at eleven depths every 5 minutes. The data from both instruments confirm the presence of a migrating step-like structure. Analysis of the thermistor chain data reveal that two large-scale internal oscillations are responsible for creating the migrating structure. Firstly, there exists an internal adjustment of the stratified lake to the surface set-up caused by the wind stress. This roughly diurnal adjustment exhibits a phase difference through the water column such that the oscillations at depth occur in advance of the oscillations near the top of the thermocline. Secondly, an oscillation exists, with an approximately 6-hour period, due to the internal seiche of the lake. It is believed that the thermal structure is created by interaction between the motion of the internal seiche and the motion associated with the internal set-up. The details of the process are not clear and further investigation with laboratory apparatus is planned.

J. R. N. Lazier

Internal Waves

In observations of ocean currents, the semi-diurnal tides often contribute a large, if not dominant, part of the total signal. A significant portion of this tidal current is usually in the baroclinic (or internal) mode and hence outside the realm of prediction by ordinary tidal analysis. Within the spectral band of internal gravity waves in the ocean, the semi-diurnal internal tides are therefore a particularly important subject of study. Questions concerning their geographical distribution, their role in ocean mixing, and their predictability await better theoretical and experimental answers. The problem of generation of internal tides by interaction of the surface tide with topography has now been solved to the extent that over essentially two-dimensional topographic features, such as continental slopes, knowledge of density structure allows one to construct models of internal tides, the essential features of which can be checked in the field.

With the knowledge gained from an earlier study (1967-69) of currents and temperature over the continental shelf and slope off Nova Scotia, an experiment to study the structure of the semi-diurnal tide was carried out in March 1973 using an array of current meters and Digibridges (BIO designed temperature recorders). Using the data from the two experiments, a picture of the semi-diurnal tides emerged that is consistent, in general, with theoretical predictions and confirms that internal tides dominate the tidal streams particularly on the slope. Enough energy may be pumped into the baroclinic tide to make it behave locally as a shallow-water tide, an indication that the internal wave height is a substantial fraction of the total depth.

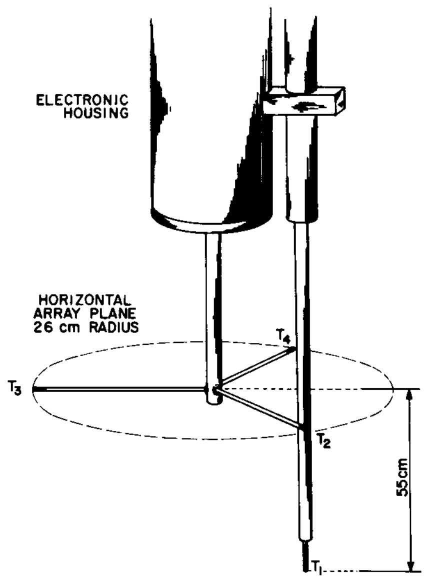
Another field experiment was begun in co-operation with Coastal Oceanography in the estuary of the St. Lawrence River with the aim of making a detailed comparison of predicted and measured tidal streams. The data are being processed.

H. Sandstrom, B. Petrie (Dalhousie U.)

Microstructure Studies

The oceans are continuously mixing through a sequence of processes that tend to reduce the large-scale, vertical and horizontal gradients of temperature and salinity. These processes are complex and may include many steps, such as stirring by advective or intrusive currents, vertical convection induced by buoyant forces, and turbulent mixing. All tend to increase the local gradients until they are sufficiently sharp to make molecular diffusion effective. This final, molecular stage of mixing takes place for gradients over distances of less than 10 centimetres; the largest gradients occur in regions approximately 1 centimetre thick. The smallest scale features are called oceanic microstructure. Examples of microstructure gradients can be found in almost any vertical profile of temperature or salinity; the intensity is higher at the boundaries of different water types.

During the past two years (1973-74) an instrument package called OCTUPROBE has been used to observe microstructure in the oceans. The instrument measures a detailed vertical profile of the temperature, conductivity, and velocity of water at selected stations. Two studies were undertaken to correlate the occurrence of microstructure with large-scale oceanographic features, one across the Gulf Stream south of Halifax and the other in the vicinity of Denmark Strait. In both studies, numerous microstructure profiles were obtained along boundaries that transected the various water types. OCTUPROBE was also used to obtain data during the GATE program (discussed in more detail below). Profiles, taken over one month, sampled the level of microstructure in the main thermocline of the equatorial Atlantic. Important to the interpretation of the rates of local mixing, as indicated by a level microstructure, is the mechanism of generation. The most



OCTUPROBE (Oceanic TUrbulence PROBE). The thin-film thermometer array (T_1 to T_4) shown has been used to study the horizontal and vertical changes in temperature microstructure as the instrument drops through the water at 1 metre par second. (AOL 3459.)

prevalent mechanism is thought to be shear instability, a condition that occurs when the ratio of the vertical gradient of density to the horizontal velocity reaches a critical value. During the GATE program some observations were made to evaluate this ratio as well as the level of microstructure and to correlate these observations with local winds, internal waves, and oceanographic fronts. In the Denmark Strait, we have also studied the detail of the structure at these small scales by employing an array of four thermometers. Spaced on a horizontal and vertical 50-centimetre grid, the simultaneous profiles were examined for the three dimensional structure of the small-scale features. Temperature features were found to have slopes and vertical velocities (or curvatures) with statistical distributions similar to that expected from an internal wave field superimposed on horizontally layered microstructure.

J. A. Elliott, N. S. Oakey

GARP Atlantic Tropical Experiment (GATE)

The Global Atmospheric Research Program (GARP) is a long-term international program organized to study the behaviour of the Earth's atmosphere. Within the framework of this program, a large experiment, known as GATE, was carried out in the tropical Atlantic Ocean from June to September, 1974. Its objective was to study atmospheric convection over tropical waters. To this end, 30 ships from

CCGS Quadra was used on GATE (see text). (Courtasy of Simpson SIudio, Victoria. B.C.)

various countries occupied fixed station positions across the Atlantic Ocean between 5°S and 15°N to provide a grid of synoptic meteorological stations that would not otherwise be available. Many vessels acted merely as weather observing stations but near 8°N, 23.5°W a number of vessels were equipped to look at atmospheric processes in greater detail. The Canadian weather ship, CCGS Quadra, from Victoria, B.C., formed part of this denser array and occupied a station at 9°N, 22.2°W. Scientists from the Atmospheric Environment Service, University of British Columbia, and McGill University studied the atmosphere while a group of AOL scientists conducted a series of oceanographic observations and experiments from *Quadra.*

All ships working on GATE collected CTD profiles of the upper layers of the ocean 6 or 8 times a day to depths of 500 metres. Once a day these profiles were collected to a depth of 1500 metres. From these data, it was hoped to monitor the changes of the upper layers of the ocean to the extent that they could be related to meteorological changes. Changes in ocean water with time can be due to an actual change in the water locally as a result of heating or mixing or to the advection of a new water mass into the area. It is therefore important to determine the degree of spatial inhomogeneity of the upper layers of the ocean to be able to estimate the contribution of advected water masses from day to day. To this end, Quadra and other GATE vessels recorded temperatures to depths of a few hundred metres along their track lines to Dakar, Senegal, and to and from station. The data were collected with XBTs (expendable bathythermographs) every 5 kilometres. *Quadra* also used a towed CTD system mounted on Batfish (see Metrology) to record conductivity data.

During the final phase of GATE, the oceanographic program was expanded to include a number of experiments to study the physical processes in the upper ocean directly. Measurements of currents and temperature at the surface, and at 15 and 30 metres, were made from a moored surface buoy. The objectives are to measure the amount of kinetic energy in the mixed layer of the ocean as a function of time and to monitor the behaviour of the main thermocline. The Batfish was used to map the upper layers in order to permit estimates of the scales of local spatial inhomogeneities and to learn more about internal wave fields. In addition, the oceanic turbulence probe was used to examine small vertical scale response to changes in atmospheric forcing and the internal wave field.

R. A. Clarke, A. S. Bennett (Metrology), J. A. Elliott, N. S. Oakey


Ice
235'
Cairn
BAC
226'
Point

Hydrography

Hydrography Division of the Atlantic Oceanographic Laboratory (AOL) is part of the Canadian Hydrographic Service. Its prime responsibilities include:

- Charting of all navigable waters within the Atlantic region to satisfy the requirements of the mariner
- Surveying of the continental margin in close co-operation with the Atlantic Geoscience Centre (AGC) to produce the Natural Resource Series maps (see also Regional Reconnaissance, AGC)
- Directing the tidal, tidal current, and water levels work carried out by the Canadian Hydrographic Service in the Atlantic region
- Investigating and implementing instrumentation and techniques designed to increase the efficiency and accuracy with which a hydrographic survey can be conducted
- Providing specialized positioning techniques to meet the needs of marine scientists and surveyors at BIO

Two new departures in the Atlantic region program evolved in 1974. The first is the conduct of surveys of the Labrador Sea to secure data for a regional outlook of the entire area that will allow the efficient execution of detailed surveys. The second is the management of contract surveys and the operational responsibility of a production-training survey in Guyana, South America.

In 1973, a third charter vessel was obtained to conduct surveys on the Labrador coast. This charter was secured as a replacement for the *CSS Kapuskasing,* which was returned to the Department of National Defence in late 1972.

In order to fulfill regional and national responsibilities the Division is composed of four sections: Charting, Development, Navigation, and Tidal. The activities of the Division are discussed under these general headings.

R. C. Melanson

Charting

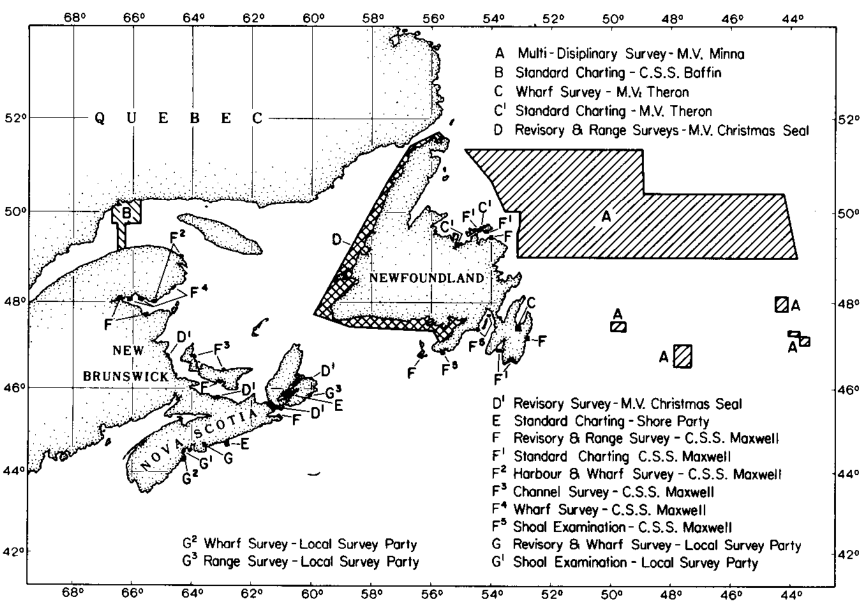
The Charting Section has the responsibility of planning and conducting field surveys of navigable water within the Atlantic region for the production of navigational charts and related publications. In both 1973 and 1974, seven survey establishments were placed in the field. The field seasons began in early May and terminated in late October. The main charting areas were concentrated in the eastern Arctic, sub-Arctic, St. Lawrence estuary, Labrador Sea, and northeast Newfoundland Shelf. As well, many smaller projects were carried out in the Atlantic provinces. In addition to the normal 1974 survey program, the Atlantic region had the operational responsibility for a production training cruise in Guyana, South America, operating under the auspices of the Canadian International Development Agency. A further responsibility in 1974 was the management of a contract survey for engineering and navigational purposes in the Miramichi River, New Brunswick.

The accompanying tables give a brief outline of the projects carried out by the various establishments in each of the 1973 and 1974 field seasons.

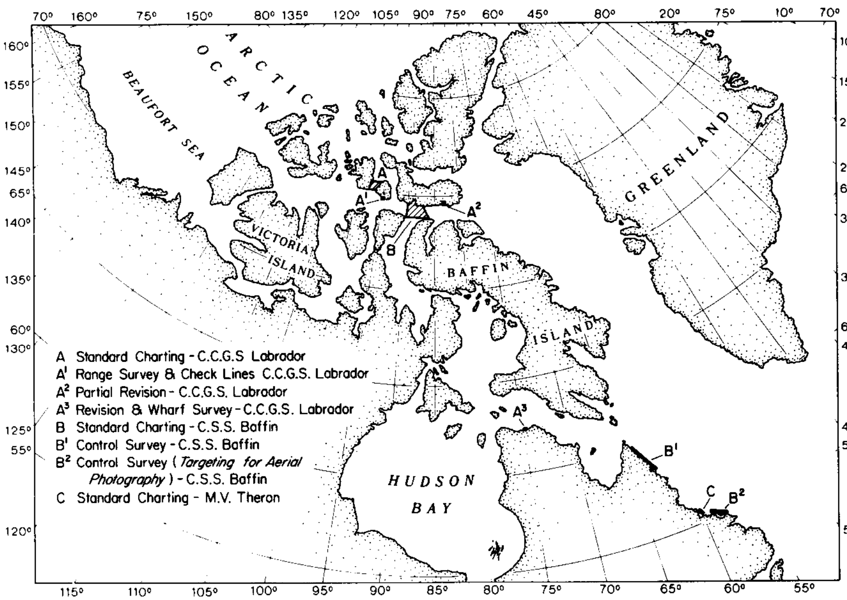
1973 Field Program

Establishment	Area	Type of Survey
CSS Baffin	St. Lawrence estuary	Navigational charting, gravity, magnetics
	Lancaster Sound. N.W.T.	Navigational charting, gravity, magnetics, and seismics
Charter Vessel I	Northeast Newfoundland Shelf	Multidisciplinary surveys including bathymetry, gravity, magnetics, and seismics
Charter Vessel II	Labrador coast	Route surveys
CSS *Maxwell*	Chaleur Bay Prince Edward Island East coast of Newfoundland St. Mary's Bay, Newfoundland St. Pierre, France	Chart revisions Harbour surveys Standard charting Standard charting Chart revision
Shore Party	Eastern Shore, N.S. Bras d'Or Lake, N.S.	Standard charting Standard charting
Charter Vessel III	South and west coast of Newfoundland	Chart revisions
Eastern Arctic Surveys	Little Cornwallis Island Eastern Arctic Islands	Reconnaissance charting Track sounding

Many projects of a minor nature were completed as shown in the figures below.



Hydrographic survey operations in the Atlantic provinces in 1973. (AOL 3014.)



Hydrographic survey operations in the Arctic in 1973. (AOL 3014.)

1974 Field Program

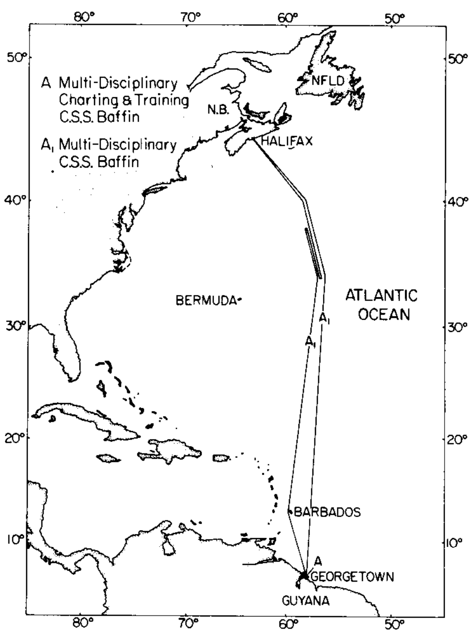
Establishment	Area	Type of Survey
CSS Baffin	Guyana, South America	Navigational charting, engineering studies, and training
	St. Lawrence estuary, Lancaster Sound	Navigational charting, gravity and magnetics. Standard charting, and magnetics
Charter Vessel I	Labrador Sea	Regional multidisciplinary survey. Bathymetry, gravity, and magnetics 32 kilometre line spacing, seismic 64 kilometre line spacing
Charter Vessel II	St. Mary's Bay, Newfoundland Davis Inlet to Nain, Labrador	Standard charting Route surveys
CSS Maxwell	Yarmouth Harbour, Nova Scotia Saint John Harbour, New Brunswick Dalhousie, New Brunswick Grand Bay, Newfoundland Placentia Bay, Newfoundland	Chart revision Chart revision Channel survey Standard charting Anchorage and engineering surveys

Shore Party	Eastern Shore, Nova Scotia	Nichol Island to Duck Island
	Bras d'Or Lake, Nova Scotia	Standard charting
Charter Vessel III	Pistolet Bay to St. John's, Newfoundland	Revisory and range surveys
Eastern Arctic surveys	Eastern Arctic	Track soundings from *CCGS Louis S. St. Laurent, CCGS John A. MacDonald, CCGS Labrador,* and *CCGS Norman McLeod Rogers*

Many projects of a minor nature were undertaken and completed as shown in the figures below. A large number of these projects were conducted by our local surveys establishment.

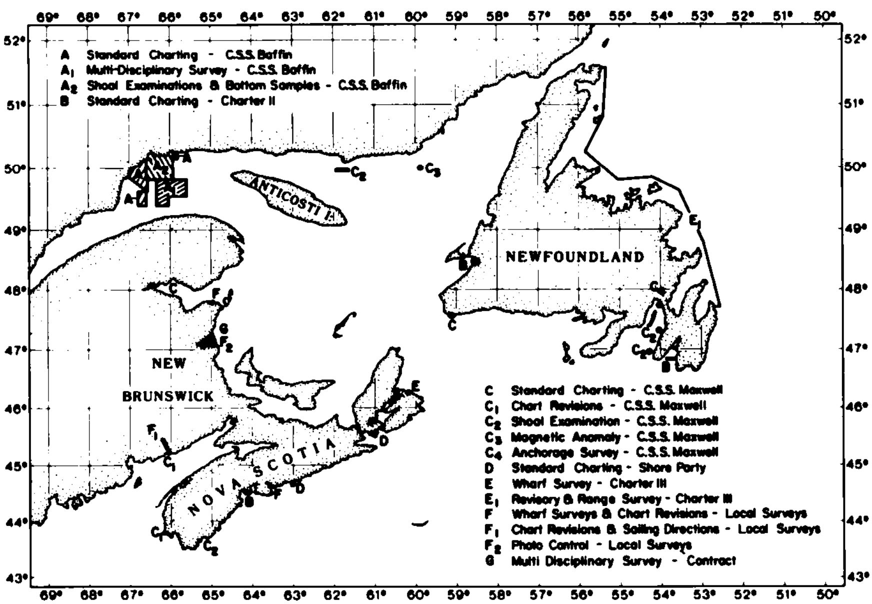
The field season was very successful as evidenced by the large number of completed projects. The only mar on this successful program was the unfortunate grounding of Charter I (MV *Minna)* and its subsequent loss at Resolution Island, N.W.T.

G. *R Douglas*

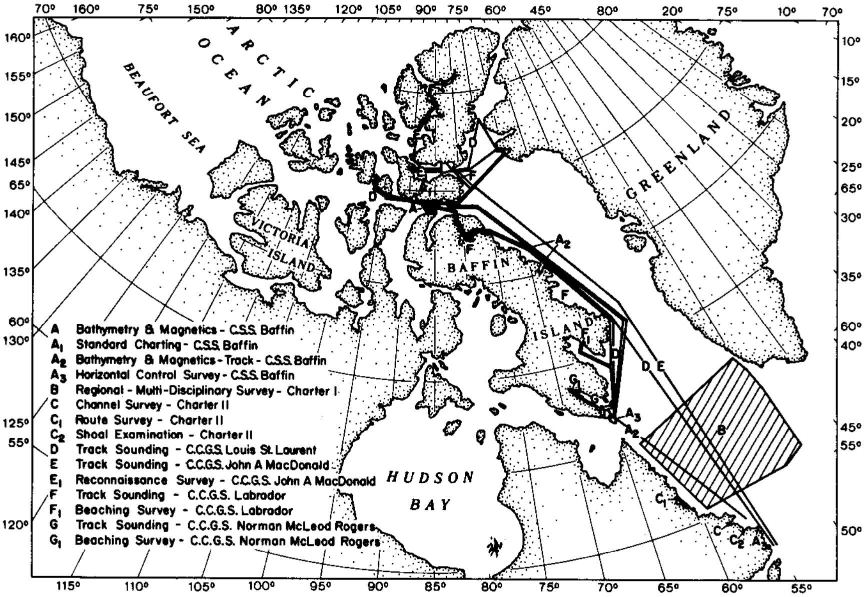


Guyana, South America, survey in 1974: (AOL 3475.)

CSS Baffin *arriving in Georgetown, Guyana. (AOL 3093-4)*



Hydrographic survey operations in the Atlantic provvinces in 1974. (AOL 3321.)



Hydrographic survey operations in the Arctic in 1974. (AOL 3321.)

Hydrographic Development

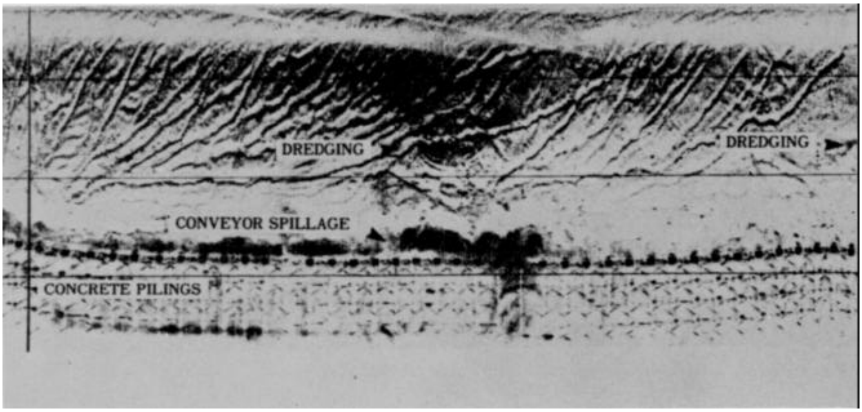
The Hydrographic Development Section at AOL, together with other groups of the Fisheries and Marine Service located at the Canada Centre for Inland Waters (Burlington, Ontario), Pacific Region (British Columbia), and Headquarters (Ottawa), forms part of an overall technical support and development program within the Canadian Hydrographic Service. Close co-operation is maintained with the sister groups in order to avoid duplication of effort and to gain maximum benefit from the program.

The primary role of the Section is to investigate and implement instrumentation and techniques designed to increase the efficiency and accuracy with which a hydrographic survey can be conducted.

An EG&G Mark II Side-Scan Sonar has been acquired. Projects carried out over the past two years have demonstrated its usefulness as a search and reconnaisance tool. It has proved a valuable aid in supplementing conventional detailed surveys of dock sites, channels, and ranges. To date the system has been used to locate two missing current meters and a SEA KING helicopter (see Metrology).

A Bo’sun Multibeam Sonar evaluation has been completed. Side-scan sonar can be thought of as a search tool while the Bo’sun system is a measurement sonar. Twenty-one slant range measurements along with navigation and time data are recorded on magnetic tape for subsequent computer processing. The end product is a contoured bathymetric chart. Results from a survey carried out with the system have demonstrated the potential of this technique; however, before a system is acquired two problems require further study. Firstly, the transducer mounting for arctic operation may present some difficulties; secondly, the system collects a vast amount of data in comparison with conventional techniques. Software will have to be developed in order to process that data in a manner that meets the stringent requirements of the Canadian Hydrographic Service.

With the Hydrographic Acquisition and Processing System (HAAPS) in field use, efforts have been directed towards developing software and techniques for effectively handling data from semi-automated surveys. Routines have been written to manipulate bathymetric sounding data, to plot these soundings on a high



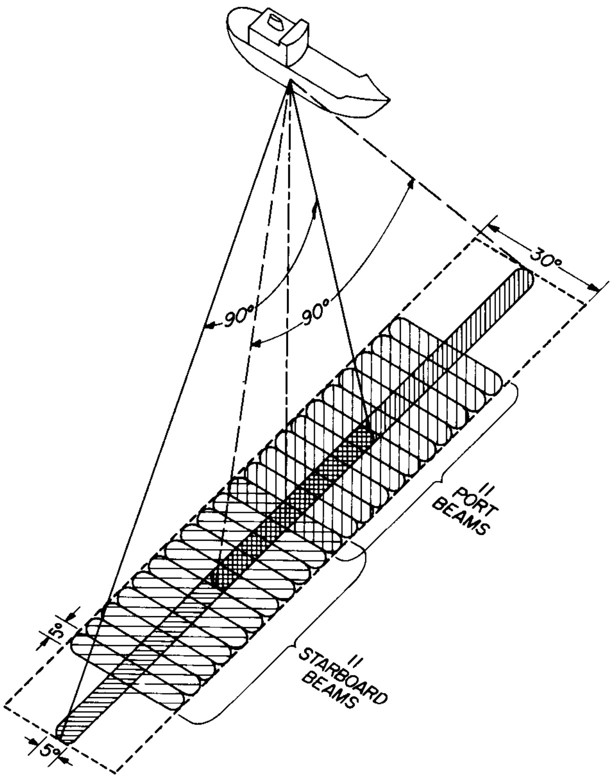
An EG&G Mark II Side-Scan Sonar record at the Pointe Noir iron ore loading dock, Sept-iles, Quebec. (AOL 2290.)

precision flat-bed plotter, and to employ the computer and plotter for the composition and production of title blocks. A Gradicon Digitizer table has been acquired and programs have been written to plot digitized shoreline. Ultimately, it is hoped that the results from a field survey can be supplied in computer-compatible format on magnetic tape.

Over the past two years a number of circuit design projects have been undertaken. A semi-automatic fixing device, now in the final testing stage, is designed to generate fix commands on the basis of selectable time intervals or predetermined pattern readings. The position readings at each fix are retained in a display unit until the next fix is generated. An interface that permits a Motorola Mini-Ranger Ill positioning system to be used with HAAPS has been built and tested.

Part of Hydrographic Developments role is the training of hydrographers in the use of computers and new equipment. Several of the rotational hydrographic staff have been given projects involving side-scan sonar, computer graphic applications, and software development. This training program provides the participants with an insight into some of the aspects of modern technology that is affecting hydrography while providing fresh and imaginative input to the Development Section.

R. G. Burke



The Bo'Sun Multi-beam Sonar. The figure illustrates the formation of the 21 adjacent beams that permit a cross-track coverage of about 2.6 times depth. (AOL 3418.)

C.H.S. FIELD SHEET NO. 4546
(SHEET NO. 56)

PROJECT NO. 6600-47

ATLANTIC REGION
CANADIAN HYDROGRAPHIC SERVICE
OCEAN AND AQUATIC AFFAIRS
DEPARTMENT OF THE ENVIRONMENT

SURVEYED BY MR. G.M. YEATON,
ASSISTED BY MESSRS. R.C. AMERO, J.S. WARREN,
R.L. TRACEY, S.R. FORBES, B.W. RUBY AND R.F. MCCREADY

Portion of a computer-generated map title block.

Tidal Section

The Tidal Section has the responsibility of directing the tidal, tidal current, and water levels work carried out by the Canadian Hydrographic Service in the Atlantic region.

During the past two years, the section has been engaged in several projects, both short-term and continuing. Tide gauges have been supplied to hydrographic field parties, as well as other users both in the Institute and at Dalhousie University. The records from these gauges are digitized, analyzed, and forwarded to Marine Environmental Data Services for further processing and dissemination.

Work has been progressing favourably on the development of a telemetry system for the Tides and Water Levels (Department of the Environment, Ottawa) submersible tide gauge. The engineering and design of this system have been undertaken and a working model constructed. Further refinements to the tide gauge are necessary to complete the unit. The instrument has the capability of transmitting tidal data from the bottom-mounted gauge to a surface vessel at a maximum range of about 32 kilometres.

An Aanderaa TG-1A offshore tide gauge has been acquired. After preliminary testing, a program of measurement of the tides on the shelf areas was embarked upon. Due to the high loss factor involved with ocean moorings, arrangements were made with Mobil Oil and Shell Oil to allow AOL to use their drilling rigs as stable platforms. Mooring and recovery under this arrangement is a simple matter of lowering the instrument and subsequently pulling it back up again. This arrangement also has the advantage of giving a knowledge of the barometric pressure during the duration of the mooring.

Moorings have been made at three locations - Sable Bank, Cabot Strait, and LaHave Bank. To date we have been fortunate in retrieving all data. The data obtained from these moorings will give a better picture of the tides near the edge of the continental shelf, particularly as an input to the Bay of Fundy/Gulf of Maine system.

Considerable work has been done in the field of software development and, as a result, we have a reasonable facility at present for processing all types of tidal data to a finished form.

D. L. DeWolfe

Navigation Group

The Navigation Group exists primarily to serve the specialized positioning needs of marine scientists and surveyors at BIO. However, as the only group in the country working on precise navigation at sea, we also are asked to advise government departments and industry elsewhere in Canada and abroad.

There has been sharpening interest in Loran-C in 1973-74. The Institute’s two precise range-measuring Loran-C navigation systems, introduced and adapted to particular requirements, have come into routine use in hydrographic surveys and in geophysical and ocean circulation studies. In the U.S.A., the Department of

Transportation has announced that 12 new transmitters will be built by 1980 to make Loran-C the designated navaid for the coastal zone and harbour approaches. Developments in long-range navigation are particularly significant at a time when Canada is proposing to extend control to the edge of the continental shelf, much of which is beyond present navaid coverage. As perhaps the most experienced Loran-C user in this country, the Navigation Group is evaluating the advantages and problems of extending the Loran-C network into Canada; R. M. Eaton has presented a number of papers and seminars to acquaint users with the potential of Loran-C, and has joined in discussions on implementation.

The investigation of radio-wave propagation, particularly velocity, has continued; this propagation is fundamental to positioning accuracy since all measurements are in terms of time and must be converted to range by means of velocity. A calibration cruise in the CSS *Sackville* off the coast of Nova Scotia verified that predictions for Hi-Fix, at 2 megahertz, gave a ranging accuracy of about ± 150 metres in 1000 kilometres. A joint experiment with hydrographers from Ottawa and Burlington, Ontario, measured the change in distance measurement caused by the freezing of arctic waters in Amundsen Gulf; it amounted to 40 metres in a 180 kilometres line. This work will go on with emphasis on overland phase lag and pulse dispersion in Loran-C.

Utility work is continuous, much of it arising from specific requests within BIO. Computer programs have been written to convert radio-positioning readings of several types to geographic position, and to produce a variety of lattices at sea. Doppler sonar speed logs have been operated successfully in sea ice, and have been shown to give better than 1 per cent accuracy over the measured mile. Positioning methods varying from underwater acoustics to precise microwave ranging have been evaluated with other units of BIO and with industry. Satellite navigation has been interfaced to the ship's log and gyro on the CSS *Hudson* and a navigation centre has been set up onboard to contain all precise navigation equipment. Courses, seminars, papers, and technical contributions have been given at BIO and across the country.

(See also the essay "Navigation in Oceanography" by R. M. Eaton and R. F. Macnab in Ocean Science Reviews, Part D of this Biennial Review.)

R. M. Eaton

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TECHNICAL SERVICES

The majority of the services required to carry out the scientific research and surveys of the Bedford Institute of Oceanography (BIO) have been gathered into a central group known as Technical Services. Six units comprise Technical Services.

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

Technical Services is, administratively, a part of the Atlantic Oceanographic Laboratory (AOL) but provides services to all at the Bedford Institute of Oceanography. Technical Services is founded on the belief that common services can be operated more economically and efficiently when joined. Peak and/or fluctuating workloads are met by subcontracting some of the work to local industry in order to maintain cost effectiveness and in support of the Canadian government policy to encourage the growth of industry.

In the sections that follow, highlights of the activities and concerns of Technical Services during the period covered by this Review are given.

R. L. G. Gilbert

Ships

Ships Division is made up of the research and survey fleet, which includes a permanent fleet of four ships (CSS *Hudson,* CSS *Baffin,* CSS *Dawson,* and CSS *Maxwell)* as well as a number of launches and chartered vessels, and an administration section responsible for the day-to-day and long-term operation of the fleet in support of the research and survey activities carried out by BIO and other organizations.

Research and Survey Fleet

In the table below, the 1973/74 activities of the AOL-operated research and survey fleet are indicated. Details of particular cruises are given in Section E of this Review under 'Major Cruises of 1973/74'.

Vessel	Number of Cruises		Days Away from Home Port		Nautical Miles Steamed	
	1973	1974	1973	1974	1973	1974
CSS Baffin	3	2	243	221	25,053	26,460
CSS Dawson	10	14	215	153	32,604	19,575
CSS Hudson	6	4	250*	207	34,314	34,451
CSS Maxwell	3	3	218*	243*	6252	7653
CFAV *Sackville*	9	12	138	131	20,444	16,961
MV *Minna*	1	1	109	60+	16,700	12,500
MV *Theron*	1	1	100	109	3500	4100
MV *Christmas Seal*	1	1	156	165	1900	2100

*Includes some refit and drydock time.

+On 18 August 1974, the MV *Minna* went aground on the east side of Resolution Island, N.W.T. Attempts to salvage the ship failed, and it was reported that she finally sank on September 30.

In addition to these operations, icebreakers were made available for hydrographic survey work in the eastern Arctic through the courtesy of the Ministry of Transport. Additional survey and research operations were carried out from launches and small charter boats.

Pertinent statistics on the research and survey fleet operated by AOL in 1974 are given in the table below.

Vessel	Year Built	Length		Tonnage (displacement)	Complement	
		feet	metres		Ships	Scientific
CSS Baffin	1956	285.50	87.02	4420	77	28
CSS Dawson	1967	211.75	64.54	1975	31	13
CSS Hudson	1963	296.60	90.40	4793	62	25
CSS Maxwell	1961	115.00	35.05	275	14	7
CFAV *Sackville**	1941	205.75	62.56	1250	33	11
MV *Christmas Seal*+	1943	104.00	31.70	149†	6	4

MV *Minna* +	1962	275.00	83.82	4280	21	18
MV *Theron* +	1950	198.84	60.60	820	23	9
CSS Acadia †	1913	182.00	55.47	1350	-	-

*Owned by Department National Defence.
+Time charter.
†Retired.
‡Gross tonnage.

Administration

The overall aim of Ships Division continues to be to improve the economical and efficient utilization of the AOL-operated fleet in support of research and survey activities carried out by BIO and by universities and other research organizations.

One of the problems has been to obtain and retain sufficient qualified seagoing personnel to man the fleet. Close co-operation is maintained with the Personnel Section at BIO, with agencies supplying personnel to government-owned vessels, and with marine training establishments in local and other areas. Continued support is given to personnel wishing to upgrade their certificates and qualifications. Shore staff as well as ships' officers have attended various courses designed to enable personnel to deal with the increasing complexities affecting the marine industry.

Several improvements to the AOL vessels have been completed and more are in progress. An experimental sewage system installed on the CSS *Hudson* is being redesigned to conform with proposed regulations. On CSS *Maxwell,* a vacuum sewage system with holding tank and shore pump-out arrangements has been fitted successfully. A complete equipment package of a similar type has been purchased for *CSS Dawson,* and a pollution control system designed for CSS *Baffin* that embodies both the holding-tank principle and an incineration plant.

This winter (1975), the CSS *Baffin* is undergoing an extensive self-maintenance program utilizing ships' personnel and various small firms. This will result in considerable savings in the annual refit costs. A similar program but on a somewhat smaller scale is being carried out on the *CSS Dawson* and also on the CSS *Hudson.* The major item on the CSS *Hudson* is the replacement of the Paxman Service Generators with new caterpillar machinery.

In 1974, the CSS *Baffin* was redesignated from a registered passenger vessel to a cargo vessel. This change should result in reduced maintenance costs and will also permit the vessel to carry explosives.

A study is underway to change the outdated launch davits on the CSS *Baffin.* A prototype set will be installed on the vessel on a trial basis. If successful, this new type should result in a considerable saving in manpower now required for the operations of the present installation.

Women are now being employed for the first time on an AOL vessel. A female deck officer and female catering personnel were engaged for the *CSS Hudson.*

Studies dealing with the cost and effectiveness of charter vessels versus ships owned by the Department of Environment have continued. Indications are that costs are less for charter vessels. However, the number of suitable vessels available for charter in Canada is very restricted.

The CSS Hudson *is a diesel-electric driven ship designed as a combined oceanographic research and hydrographic survey vessel. She is primarily utilized for multi-disciplinary offshore oceanographic surveys ranging from tropical to arctic waters. The vessel is ice-strengthened, has a cruising range of 24,000 kilometres with 60 days endurance, and is equipped with a bowthruster, scientific laboratory facilities, and recording instruments. (AOL 1727-51.)*

The CSS *Dawson is a diesel-driven ship designed and used for oceanographic work in offshore as well as coastal waters. She has a cruising range of 19,200 kilometres and 60 days endurance. The vessel is equipped with a bowthruster and controllable pitch propellers and is partcularly well suited for placing and retrieving moored buoys and instruments. (AOL 1727-51.)*

The CSS Baffin *is a diesel-driven ship designed primarily for hydrographic survey work in arctic waters. She is used for offshore hydrographic charting and geophysical studies and for survey work in coastal and arctic waters. The vessel is ice-strengthened, has a cruising range of 22,400 kilometres and 45 days endurance, and carries five hydrographic survey launches and geophysical recording instruments. (AOL 3093-2.)*

The CSS Maxwell *is a diesel-driven ship designed for hydrographic work in nearshore and coastal waters. She has a cruising range of 3200 kilometres and 14 days endurance, and carries two survey launches. The Maxwell is utilized mainly for hydrographic charting along the coasts of the Atlantic provinces. (AOL 2637-4.)*

As in the past the AOL fleet and vessels on charter have been utilized in support of numerous activities in areas ranging from the Gulf of St. Lawrence, St. Lawrence estuary, and the continental shelf of the Atlantic provinces to the north and mid-Atlantic, from Guyana (South America) and the Caribbean to the high Arctic. The users have been many and a breakdown based on operational days (Days at Sea) and the number of available berths onboard the various vessels shows the following distribution: AOL agencies, 62.9 per cent, of which Hydrography Division (AOL) used 50.6 per cent, the Atlantic Geoscience Centre, 17 per cent, and universities, 10.9 per cent, of which Dalhousie University, Halifax, used 6.9 per cent. The remaining 9.2 per cent included the Nova Scotia Research Foundation, St. Andrews Biological Station (New Brunswick), Defence Research Board Atlantic, National Museum Canada, Kenting Explorations (Alberta), Marine Ecology Laboratory, and others.

A. Holler

Engineering Services

Engineering Services Division is made up of four sections. The largest, Marine Electronics, is responsible for the repair, maintenance, modifications and design changes, and overhaul of electronic equipment on the ships and launches of BIO and in the engineering design and research laboratories. Systems Engineering develops new mechanical, electro-mechanical, and electronic equipment for use by the scientific and survey staff. It also provides engineering advice to staff at BIO and within the local university community. Depot Workshops (the main workshops at BIO) fabricate mechanical and electro-mechanical prototype equipment designed at the Institute. Tradesmen skilled in welding, machining, sheet-metal fabrication, engine repair, carpentry, and electrical work also overhaul survey launches and much of the heavy mechanical equipment used during oceanographic and hydrographic cruises. Buildings and Grounds is responsible for the physical plant and for the necessary changes to accommodations and fittings.

Marine Electronics

The five main groups comprising Marine Electronics - Communications, Sonar, Electronic Positioning, Computer Microwave, and Test Equipment - are responsible for the repair and calibration of most of the electronic equipment used within the Institute, on the ships, and in the field. They have considerable involvement in the design and maintenance of various computer interfaces and coupling devices for matching various input parameters to acquisition systems. Marine Electronics staff also serve as installation technicians for various electronic equipment on board departmental ships in preparation for oceanographic and hydrographic cruises.

C. R. Peck

The Communications Group maintains over 500 units of general and specialized communications equipment. The group has been responsible since the original acquisition of the equipment for the technical aspects of Loran-C. This has consisted of evaluating large rho-rho Loran-C systems together with some smaller hyperbolic Loran-C systems and training staff in the maintenance and operation of the equipment. At present, the Institute has two rho-rho Loran-C and a number of smaller hyperbolic installations. With the recent emphasis on operations in northern waters, the Communications Group has provided extended coverage by re-orienting the antenna installations at the Institute and by more appropriate selection of radio frequencies for long distance communications. As a result of these measures, AOL had direct communication with CSS *Hudson* and CSS *Baffin* in the high Arctic on a regular basis except during a polar cap absorption (PCA) event in August 1974.

The communication facility at AOL has been used on a number of occasions by various government departments operating in the local area. A typical example occurred following an oil spill at Saglek, Labrador, in 1974 when for 2 days the sole communication facility available was our system via MV *Theron,* which was dispatched to the area. The AOL communication facility handled hourly weather reports for the area provided by MV *Minna,* CSS *Dawson,* and the lambda slave station on Spotted Island, and transmitted these reports directly to Atlantic Weather Central in Halifax from which the information was retransmitted to Goose Bay. On the basis of these reports, flights into the spill area were made. The Communications group is now involved in the installation of a complete new W/T station of modern design on *CSS Baffin.*

W. F. Shearman

The Sonar Group provides and maintains echo sounding systems for the acquisition and display of bathymetric data in both analogue and digital form during hydrographic and oceanographic surveys. The group has spent considerable time evaluating commercially available deep-sea equipment and is now engaged in replacing the Alpine Gifft recorder transceiver combinations with new dry-paper programmable recorders and high power transceivers developed by Raytheon Corp. An evaluation has also been carried out on a correlation echo-sounding processor (CESP) and the unit was first used in a hydrographic survey in 1974. The next new undertaking for the group will be the installation of a narrow beam tri-frequency echo-sounding system on CSS *Hudson.* The stabilized transducer will be fitted through a gate valve so that it can be withdrawn during operation in ice. The equipment will be used for improved sea-bed delineation.

W. W. Goodwin

The Electronic Positioning Group provides the technical support for the operation of precise navigation and positioning equipment used by scientific and hydrographic ships, launches, and occasionally by helicopters in hydrographic surveys. Systems included are Decca 12f lambda, Hifix, MiniFix, hydrodist, and tellurometers. The systems are normally in use from mid-April to mid-November and are overhauled and refurbished each winter. The positioning-system technical staff also support the navigation group at BIO during evaluations of positioning system parameters such as phase lag and positioning accuracy.

H. B. Sutherland

The Computer Microwave Group provides technical support to 28 computer systems and their associated peripheral equipment such as teleprinters, tape transports, readers, punches, disc assemblies, line printers, and plotters. Microwave equipment, including ships' radar transponders, satellite navigation systems, and similar equipment, is also maintained by technicians in this group. Considerable time was spent in designing and constructing a microwave navigational positioning system using existing transponders together with a modified Decca 050 radar. This system was successfully evaluated in 1974.

A. D. Parsons

The Test Equipment Group calibrates or arranges contracts for the calibration of approximately 1200 pieces of test equipment each year. They also maintain up-to-date computer inventories of all electronic test equipment in the Institute and assign equipment to users.

R. E. Delong

Systems Engineering

The research and survey programs carried out at BIO receive support from Systems Engineering in the fields of electrical and mechanical engineering. The type of support varies, according to user needs, and includes feasibility studies, system specification, contract supervision, and equipment design, evaluation, and manufacture. To provide such support the group draws on the resources of its engineers and technologists in the two fields.

The group's work program is jointly reviewed annually by the Heads of Engineering Services and Metrology to minimize duplication of effort. Typical projects carried out by the group in the period of this Review are described below.

D. F. Dinn

Checking the frequency standard with a phase comparison receiver. (AOL 3448-1.)

Tebmetering Temperature Profiling Equipment. Two identical systems were designed and built for the Ocean Circulation Division (AOL) to enable vertical temperature profiles at two locations in a lake to be obtained automatically. The system consists of an automatically reversing winch carrying 39 metres of cable and a thermistor, signal conditioning circuits, and a VHF FM transmitter, all of which are battery powered and mounted on a small raft. The data-receiving site, some 3 kilometres distant, displayed the telemetered temperatures from both lake sites on a chart recorder in addition to recording them on an audio tape recorder for later analysis at the BIO computing system. Both systems were in use during the 1973 field season in Lake William, Halifax County, where an investigation into temporal changes of vertical temperature profiles was carried out (see Ocean Circulation, AOL).

P. F. Green

Tilt Current Meter. In an effort to evaluate and statistically describe the magnitude of surge currents in the ocean, an instrument was developed in conjunction with Coastal Oceanography (AOL) that responds directly to the current, i.e., without the integrating-averaging feature of conventional current meters. The device operates on the principle of an inverted pendulum in which the angular displacement of a positively buoyant cylinder is a function of the fluid flow rate past it.

A commercially available device was evaluated and found to be unacceptable because of limited recording capacity and lack of ruggedness. Model tests were used to determine a stable body shape (cylinder with V-fin) and a prototype unit was constructed. The initial unit utilized a chart recorder for internal data recording. Measurement of current direction was not included in the prototype. Limited testing revealed that the unit's performance was close to that predicted by theory but because of package size constraints the limited buoyancy resulted in too high a sensitivity.

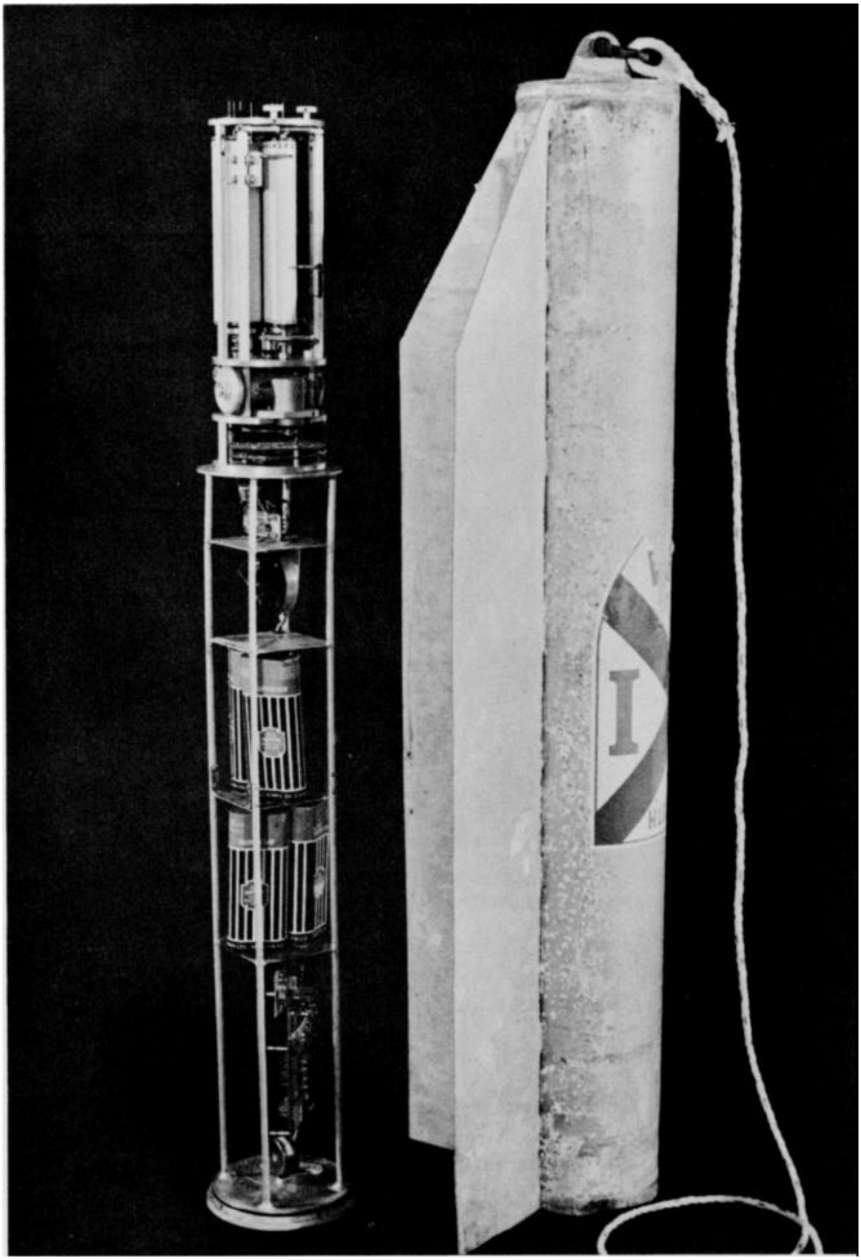
Technician wiring and assembling an e/ectronic chassis. (AOL 3446.)

Future work will include improvements to the data-recording system and a look at a negatively buoyant instrument package wherein the sensitivity could be changed at will by addition of internal or external weight.

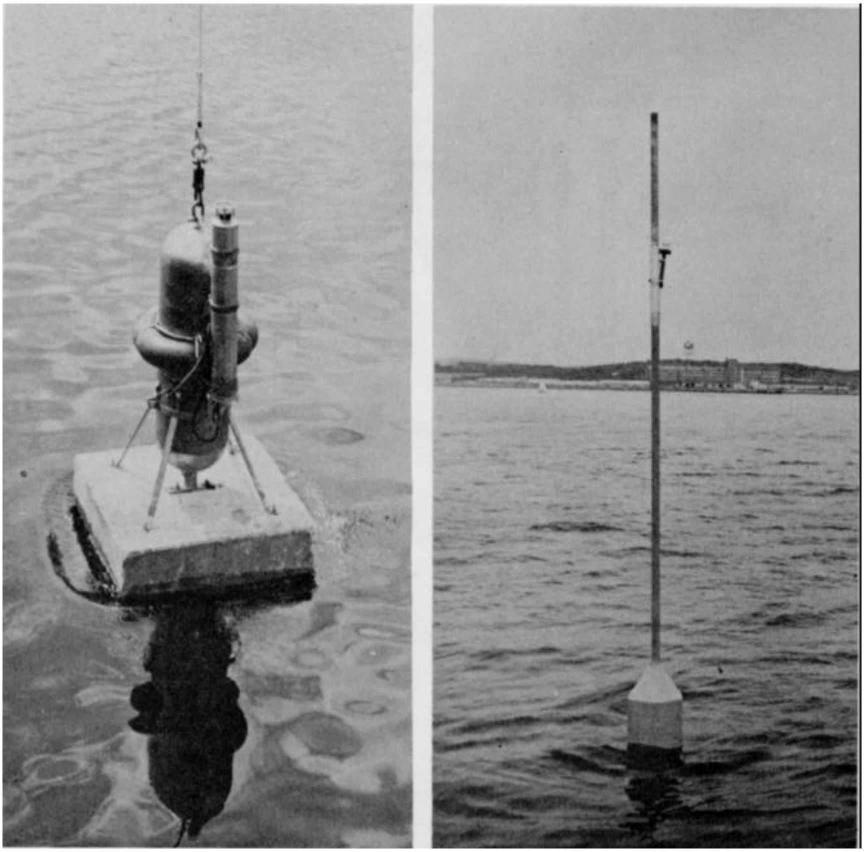
H. S. Scott

Incubator Lamp Controler. Primary productivity studies that were carried out by MEL required that the banding or focussing effect on light caused by waves be simulated in an incubator. This simulation was accomplished by modulating the intensity of the fluorescent lamps used in the incubator in such a manner that the average intensity, the modulation level, and the modulating period (3-30 seconds) could be independently set. The lamp modulation unit is used on a routine basis in special productivity investigations.

P. F. Green



Electronics and shell of prototype tilting current meter. (AOL 3635-12.)



To the left is the submersible tide gauge and automatic telemetering package and to the right is the acoustic /radio relay buoy used for telemetry of tidal data. (AOL 3204-3 and-12.)

Tidal Data Telemetry. In response to a request from Hydrography Division (AOL), a prototype system was developed that telemeters tidal data from a submersible tide gauge to a survey ship. The system, which is still being evaluated prior to actual use, operates in conjunction with the in situ gauge developed by the Tides and Water Levels (TWL) branch (Department of Environment, Ottawa). Information from the TWL gauge is converted to a digital format and telemetered acoustically to a surface buoy from which it is relayed via a VHF radio link to the survey ship operating in a 20-kilometre radius. On the ship, the readout equipment gives the hydrographer a tide height with an arbitrary reference that must be determined by levelling or by average water-level transfer methods. Corrections for barometric pressure must also be applied since the basic tide gauge responds to the total pressure above it (hydrostatic plus atmospheric pressure).

Further work on this project will likely be directed toward interfacing the system to the Aanderaa tide gauge, which overcomes many of the shortcomings of the TWL gauge, and toward possible elimination of the high-risk surface buoy, i.e., acoustic telemetry (range 1 kilometre) directly to the ship.

D. F. Dinn, G. E. Awalt, R. N. Vine

Data Acquisition System. Specifications for an off-line data acquisition system were drawn up for Chemical Oceanography (AOL) to enable the outputs of the AutoAnalyzer chemical analysis system to be digitized automatically. The system is capable of accepting inputs from up to 16 analogue sources and scans each channel at the same preset rate. Data are logged onto computer-compatible 0.5 inch magnetic tape. Close co-operation between Chemical Oceanography and Systems Engineering in sorting out initial hardware and software snags has resulted in a system that can be used readily, in the laboratory or at sea, with the AutoAnalyzer.

D. F. Dinn

Attenuance Meter. Ongoing assistance is being given to users of the optical beam attenuance meter developed by Systems Engineering. The work includes calibration checks, repairs, and instruction to users on proper operating procedure.

The demand at BIO for the device has grown to the point that Coastal Oceanography and Chemical Oceanography (AOL) have each decided to acquire their own instrument. To this end, Systems Engineering is supervising a contract with a local firm for construction of attenuance meters.

Plans for various applications of the units are being discussed with users; they include mooring an attenuance meter for a period of 30 days and recording the temporal variation of attenuance, placing a meter on a cast with a CTD and rosette bottle sampler, and using the device in conjunction with a small settling column to achieve, hopefully, a more rapid method of measuring particle concentration.

E. Larsen

Loran-C Navigation Interface to BIODAL. An interface has been developed to accept and format range data from the Loran-C navigation system and present it to the BIODAL system for logging. The quantity of data in the three ranges the Loran-C computer can provide precludes logging more frequently than once per minute on the relatively slow BIODAL system.

G. D. Steeves

Depot Workshops

In the past two years, many changes were brought about in the Depot Workshops and much new equipment was obtained. In addition to the normal duties of fabrication and launch maintenance, a number of new developments have been instituted. One of these was the installation of a gasoline power jet drive system in one of the Bertram launches, and another was to modify one Bertram launch from diesel propulsion to propulsion by two 115 horsepower Mercury outboard motors.

R. D. Wardrope

Building and Grounds

During the period covered by this Review and in addition to the normal building maintenance, heating plant maintenance, and watchkeeping duties, a considerable effort was expended in the development of approximately 3000 square metres of new lab space and in renovating and improving the older lab spaces in the main building.

J. F. Greig

Computing Services

Computing Services was formed in 1965 and in the same year a medium scale, general purpose, digital computer, a Control Data Corporation 3100, was installed. This machine has constituted the main in-house computing facility since that time. A number of hardware and software upgrades and enhancements over the years have helped to expand its performance and ‘through-put’ capabilities to cope with the increasing work load. (The most recent hardware upgrade was in January 1974 and involved the installation of two more disc drives, three faster magnetic tape drives, and a more cost-effective line printer.) During the Review period the work load on the 3100 has not changed appreciably because a significant and growing proportion of the total computing requirements are being met by the Institute’s minicomputers on the one hand, and by external installations (service bureaus) on the other.

Data Processing

Electronic data processing at the Bedford Institute of Oceanography formerly involved almost exclusively the scientific and technical activities of the Institute. More recently, however, more of the support and administrative groups within the Institute have begun to take advantage of the benefits of automatic data processing. Since the benefits and cost effectiveness of computer-based systems are greater when the operational procedures and algorithms involved do not change frequently, it is to be expected that administrative and support systems should lend themselves to effective computerization. This trend, therefore, should be encouraged. In-house data processing arising from the programs of the three laboratories generally involves the creation and maintenance of conventionally organized files upon which various types of analyses are done usually accompanied or followed by report generation. A significant amount of numerical modelling and other types of computationally bound jobs have been done also. Analogue-to-digital conversion is another capability provided by the CDC 3100, which has been programmed and utilized in both batch mode and priority mode. The amount of off-line plotting using magnetic tapes written by jobs executed on the CDC 3100 has been very substantial during the Review period. (The plotting facilities were also upgraded by the installation of an EAI 430/100 flat bed plotter.)

Improved Services

The consultative and monitoring roles of Computing Services have increased as more users employ computing facilities external to the BIO Computing Centre. In response to the need for full and accurate accounting of EDP project costs and the desirability of identifying the most cost-effective computing resources for each type of job, benchmarks have been selected and written to be run at a number of service bureaus as well as on our CDC 3100. Partly to facilitate benchmark selection, the job accounting information derived and recorded by the operating system of the 3100 was expanded considerably to show more completely the resource utilization of each job step and to identify the programs being executed. It is hoped that these benchmarks will permit us to establish more realistic rates for CDC 3100 services. The more extensive accounting is also facilitating a comprehensive analysis of the 3100 job stream. This, in conjunction with the results of the BIO computing requirements survey, should help in drawing specifications for any contemplated replacement of the in-house machine.

Minicomputers

During the Review period more minicomputers were acquired by the Institute bringing the total number to 24 including spare units and representing a total investment of approximately one million dollars. Most of the minicomputers are used to provide ship-board computing facilities. Some of these units are dedicated to specialized functions such as navigation, plotting, etc., while others are used for general purpose computing. Most of the recent acquisitions have been Hewlett Packard 2100 series computers. These machines offer considerable sophistication in their capabilities considering their small size and low price. The potential of these computers has not always been fully realized, particularly their multiprogramming and real-time capabilities. However, an important step in this direction, taken during the Review period, was the initiation of a project to implement an on-line CTD (conductivity, temperature, depth) data logging and monitoring system. Also a proposal is being considered to utilize the Real Time Executive (multi-programming) Operating System.

The Institute possesses a considerable amount of distributed computing power in these minicomputers. However, to date there has been little motivation to study the feasibility of linking these dispersed units to form an information network. It would appear that utilization of the facilities of a synchronous communications satellite would be required to obtain reliable ship-to-ship and ship-to-shore data links in such a network.

External Computing Usage and Time-sharing

Growth in use of external computing facilities has accompanied the growth in the number of numerical modelling and similar type jobs, which require large memory allocations and powerful central processing units. Improvements in the remote batch terminal simulation capabilities of the CDC 3100 have helped to facilitate remote job entry and print output recovery for these jobs. Towards the end of the Review period, this facility was used for remote batch job submission to the CDC Cyber 70, Model 76 computer at the Atmospheric Environment Service in Dorval, Quebec. This is currently one of the most powerful computers in the world.

The use of ‘time-sharing’ services in the local area experienced considerable growth during the previous Review period but seems to have stabilized during the current Review period. However, time-sharing users continue to account for a large proportion of the use of external facilities in the local area. (Long distance time-sharing is still generally too expensive.) Convenience, quick access, and rapid program development are some of the features of interactive computing that attract users.

V. N. Beck

Scientific Information Services and Library

New Directions and Collections Development

During the Review period, a major revision of library services took place. An open meeting was held with institute scientific and technical staff to discuss a 'work plan and review', which had been prepared covering proposed library and scientific information services for 1973/74. The users emphasized their wish for a good basic library; other services, such as literature searching, were said to be of secondary importance. Following the meeting, SISL was invited to present the next version of their plans to the Directors of the Institute. These plans attempted to take into account the long-term needs of the Institute. The Directors approved the majority of proposals including, notably, a new position of Collections Development Officer, which has been filled, and a substantially increased budget for 1974/75. A major decision from this revision was that the Library's collection of books, journals, and reports be expanded. In the past, the Library has serviced the specific interests of the Institute only and has not attempted to collect an extensive oceanographic collection as a matter of policy. All new marine science titles, with the exception of elementary texts and some foreign language items, are to be acquired. Gaps in journal holdings will be filled and holdings of back issues are to be expanded.

In April 1974, the Institute hosted a meeting of local librarians to consider interlibrary co-operation in the Halifax-Dartmouth area. At this meeting two topics were selected for further action: an interlibrary truck service for the transfer of loan material from one library to another and the rationalization of library collections within the area. Subsequent progress in both areas has been encouraging. Within the Institute the library introduced an informal newsletter designed to keep users better informed of library and other scientific information matters.

New Services

A scientific editor/reviewer was appointed to the staff of SISL in 1973. Authors are encouraged to submit their manuscripts to the editor prior to submission to scientific journals. The aim of the service is to help authors write more effectively.

During 1974, the Institute made use of an on-line, interactive, reference retrieval system known as WATDOC (Water Resources Document Reference Centre), which is operated by Environment Canada, Ottawa. Data bases such as Environment (containing literature on water and water-related topics relevant to Canada) and Oceanic Abstracts are available for retrospective searching under this system. They can be queried directly from the Institute using a computer terminal. Another on-line system is CAN/OLE (Canadian On-Line Enquiry) developed by the Canada Institute for Scientific and Technical Information. Data bases such as Chemical Abstracts, Biological Abstracts, INSPEC, and Engineering Index can be accessed through this system. Here the Institute has combined with five other local libraries to sponsor a 6-month trial of CAN/OLE during the first half of 1975.

New Publications

The publications of the Bedford Institute of Oceanography include: the *Biennial Review* and *Ocean Science Reviews,* the annual volume of *Collected Contributions,* which brings together the major scientific research papers written by Institute staff and published in primary research journals, and technical reports, which are known as the *Report Series, Data Series,* and *Computer Note Series.* Volume *5,* 1972, of the *Collected Contributions* was produced in a new, compact format. The technical reports issued during the Review period are referred to in Section E of this Review under 'Major Publications of 1973/74'. One of these reports (see Section E, Bedford Institute of Oceanography Technical Reports, Nicholls and Sabowitz, 1974) is an index of technical reports written by staff of the Institute from 1962 to 1973. A similar index covering journal articles and other publications is nearing completion and an index of cruise reports is planned.

Founding Librarian Retires

Miss C. S. Allan, who had been with the Institute as Librarian since shortly after it was founded in 1962, retired from federal public service in July 1974. Nearly one hundred people attended a farewell gathering for Miss Allan on her last working day at BIO.

H. B. Nicholls

Drafting and Illustrations

The main function of the Drafting and Illustrations unit is to translate scientific data to a graphic form suitable for publication or viewing as transparencies or displays. As an aid to our basic production, we maintain facilities for certain specialized techniques including silk-screen printing, photo-typesetting, diazo whiteprinting (the Ozalid process), image projection for matching map scales, and a process for making aluminium instrument panels and plastic meter-faces for prototype equipment built at BIO.

A master system of sketches begun several years ago has now developed sufficiently to save many hours of labour. The master sketches contain basic information that is repeatedly used on illustrations. By preparing a diazo plastic print of the appropriate master and plotting the new data on that print, the basic data need not be redrawn each time they are needed.

A large portion of our work is done on outside contract with private firms. Contracting began as a method of helping meet overload periods but has since developed into a feature that permits us to handle urgent projects more readily and to provide a closer liaison with the scientists.

J. R. Lord

Photography

The Photography unit provides the Institute's central photographic service and its functions include field assignments for deep ocean-bottom, surface and aerial observations, cartographic reproduction, provision of studio facilities, processing of all sizes of film, colour slide production, and audio-visual services. The provision of photographic services to the various groups of BIO is normally a routine procedure but, periodically, this routine is broken by a different or special request and it is these requests that provide topics of interest.

As the last (1971-72) Biennial Review neared completion, our first motion picture, 'HUDSON 70', which dealt with aspects of the major oceanographic expedition around North and South America of the CSS Hudson in 1970, was about to be released by the National Film Board (NFB) of Canada. Now, two years later, we have a very favourable indication of its success. We repeatedly get compliments on it from many unexpected and distant places. The film is stocked in all NFB libraries. We are presently producing a film on the activities of Hydrography Division (AOL). This film will cover many aspects of their work over the past 5 years including work done in the Arctic, along Canada's east coast, and in equatorial Guyana. Again, it will be produced by NFB from our film.

Our biggest picture: a 6 by 9 foot map reproduction of the Atlantic provinces is laid out for Spiking. (AOL 2739.)

Field work during the Review Period has been varied. In the spring and summer of 1973, we participated in the operations of the Environmental Marine Geology Subdivision of AGC in the Strait of Canso and Chedabucto Bay, Nova Scotia. During the summer of 1973, coverage was also provided of CSS *Baffin* operations in the River and Gulf of St. Lawrence. In September 1973, an extensive program of ocean bottom photography was provided from CSS *Dawson* for the Regional Reconnaissance Subdivision of AGC. Our largest field operation of 1974 was a beach survey of the Magdalen Islands, Quebec. During the term of this operation, progressive photos were taken of beach configuration from many observation points. The work was supplemented with periodic aerial photographic work. We carried out a considerable amount of aerial photography during the summer and fall of 1974 as we provided coverage on several locations at the Magdalen Islands and also at Kouchibouguac and Chaleur Bay, New Brunswick. Aerial coverage was completed in one day of the Saint John River from Saint John to Woodstock, New Brunswick. Our one 'rush aerial job' was the photo-coverage of the oil spill at Saglek, Labrador, in August 1974 (see Coastal Oceanography, AOL). We went to the Arctic aboard *CSS Hudson* in August 1974 to photograph the sea floor in Barrow Strait and Peel Sound. It was the first time we used our new UMEL underwater camera system and the results proved the system very satisfactory.

As a change from our day-to-day technical work, we have one assignment that is considered special by all our photo staff. It is the photo-recording of the antiquity of the Institute's retired ship, CSS *Acadia. Acadia's* future is not known but her features are being photographed for recall when required.

N. E. Fenerty

Marine Ecology Laboratory
Ocean and Aquatic Affairs
Department of the Environment
1973/74

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Marine Ecology Laboratory[1]

Acting Director
B. S. Muir

Research

- **Biological Oceanography**
  T. C. Platt

- **Environmental Oceanography**
  R W. Trites

- **Environmental Quality**
  D. C. Gordon

- **Fisheries Oceanography**
  B. S. Muir

- **Social Science**
  R. D. S. Macdonald

Support

- **Administration**
  M. F. Blaxland

[1]Organization of Laboratory as of December 1974.

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B. S. Muir-Acting Director

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T. C. Platt - Program Head

P. C. Beamish
R J. Conover
K. L. Denman
S. R. Durvasula
M. Hodgson
T. G. Hughes[1,4]
B. D. Irwin
A. D. Jassby[1]
R. A. Laycock[2]
J.-L. Martin[2,4]
P. Mayzaud[4]
M. A. Paranjape
D. L. Peer
S. Poulet[2,4]
A. Prakash[2]
D. D. Sameoto
R. W. Sheldon
J. C. Smith
W. H. Sutcliffe
S. Taguchi[1,4]

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E. M. Hassan
D. P. Krauel[2]
D. H. Loring
R. T. T. Rantala
G. B. Taylor
P. E. Vandall

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D. C. Gordon - Program Head

R. F. Addison
D. C. Darrow
G. C. H. Harding
B. T. Hargrave
P. D. Keizer
G. Phillips
N. J. Prouse
W. P. Vass
T.J. M. Webster
D. E. Willis
J. H. Vandermeulen
M. E. Zinck

Fisheries Oceanography

B. S. Muir - Program Head

D. M. Ware - Acting Program Head

P. F. Brodie
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R. G. Dowd
R. E. Drinnan
K. R. Freeman
T. C. Lambert
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Social Science Research

R. D. S. Macdonald[1]

Administration and Support Staff

M. F. Blaxland - Program Head

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R. E. Duggan[1]	H. S. Glover	K. A. Overton[2]

[1]Joined MEL.
[2]Left MEL.
[4]Postdoctoral Fellow.

Director's Remarks

The Marine Ecology Laboratory (MEL) is approaching the end of its first decade at the Bedford Institute of Oceanography. It has been an interesting decade in terms of the development of national and international public awareness in a number of areas such as environmental matters and limits to natural biological production. In 1965, for example, 'ecology' was scarcely a household word, 'pollution' had mainly aesthetic connotations, and the major fisheries of the Northwest Atlantic were undergoing optimistic expansion by fishing a succession of stocks and species. Then public interest in the scientific warnings caught fire and these matters became the rallying point of citizens' groups and urgent concerns in the national and international political arenas. Appreciation of the need for environmental impact assessments has since become commonplace. History may reveal there has been over-reaction in some matters but the number and scale of events, and the often irreversible potential consequences, justified the concerns and actions. Chemical pollutants like mercury, DDT, and lead not only damage ecosystems but often render the end products unfit for human food. Marine disasters with resultant oil spills have a fundamental and at times lasting effect on the ecology. Industrial developments such as electrical generating installations, pipelines, causeways, and activities in the Arctic add large-scale climatic changes to the list of concerns as do river diversions and supersonic transports. The public is aware of the issues and reasonably well informed of the social implications. The irony, however, is that many of the concerns contribute to a general undercurrent of technological backlash, which has roots going back to World War II, at the same time that they create ever increasing demands for scientific information upon which to base decisions. The urgent need for scientific research in a moderately anti-science period of scientific re-appraisal and questioning by society as a whole faintly resembles the recession-inflation situation for which economists have coined new descriptive words.

Such was the setting in which the Laboratory was established and the period during which its philosophies and programs were developing. From the outset there has been considerable interaction with marine-science oriented laboratories in the Halifax-Dartmouth area. The number of these has grown and includes a developing private-sector capability as well as government and university; the interaction has also grown geographically in Atlantic Canada and, occasionally, farther afield.

The 'founding mandate' of the Laboratory was to encourage the development of knowledge of the dependence of fishery resources and their food chains on the physical environment and its man-made and natural changes. The elaboration and pursuit of this mandate represented a thrust away from the more descriptive aspects of fisheries research into a concentration on the physical and biological processes underlying marine production. A great deal of effort was required to develop methodology and experimental design for studying large scale ecosystems and for elucidating spatial and temporal variability.

Many of the studies in the early years focussed on the dynamics of a series of embayments: St. Margaret's Bay, Bedford Basin-Halifax Harbour, and Petpeswick Inlet. While a number of specific experiments continue in St. Margaret's Bay and

Bedford Basin, much field work is carried out in the Gulf of St. Lawrence and on the Scotian Shelf. St. Georges Bay, Nova Scotia, was selected for studies relating larval fish ecology to physical and biological variables. Physical studies were conducted in Bras d'Or Lake, in conjunction with the aquaculture program of the Cape Breton Development Corporation, and in the Miramichi estuary, in relation to salmon migration.

The embayment studies emphasized exchange with coastal water and the effects of large-scale oceanographic and climatic perturbations. One direction in which this work has been extended is toward the examination of the effects of variability in the St. Lawrence River discharge on the variability of oceanographic characteristics not only in the Gulf of St. Lawrence but also along the Scotian Shelf and as far as the Gulf of Maine. Such characteristics appear to affect fish productivity and are under active investigation. This work, plus the Laboratory's general interest in production processes, has led logically to detailed studies of areas of upwelling including the St. Lawrence estuary, southwestern shore of the Gulf (especially St. Georges Bay), and the southwestern extremity of Nova Scotia. Extensions into similar studies of the associated areas of the high seas will follow.

Patchiness in the distribution of plants and animals has received considerable attention not only because it affects sampling variability but because it appears to be an extremely important factor in productivity. Whales, for example, have been shown to remain closely associated with single schools of herring; plankton grazers such as larval fish and zooplankton exhibit threshold responses to food concentration; and filter feeding fish such as mackerel evidently consume more food daily than would be physically possible from uniform 'average' concentrations of prey. Euphausiids (krill) occur in dense layers that may be significant to their feeding habits and to those of their predators (cod, herring, whales).

Investigation of the behaviour and dynamics of pollutants in natural ecosystems has provided useful information concerning the short-term and long-term effects and fate of the pollutants as well as their origin and distribution. Some pollutants act as 'labels' and studying their transportation and concentration through food chains yields considerable insight into ecosystem processes, which complement our other studies. Physical, geochemical, and biological dynamics of sediments are totally inter-related and important examples of the pollutant-food chain similarity of study.

Details of the Laboratory's programs are given in the following pages. The enormous range in time and space scales of phenomena under investigation is noteworthy. Whilst 24 hours may be a significant time scale for phytoplankton and tides, the generation time for commercial fish species is several years and large scale climatic trends span several decades. Similarly, unique important experiments can sometimes be carried out at one discrete location while others require collection of data over thousands of square miles. The report of activities for a 2-year period misses some of the interaction that exists among these studies on a longer time basis.

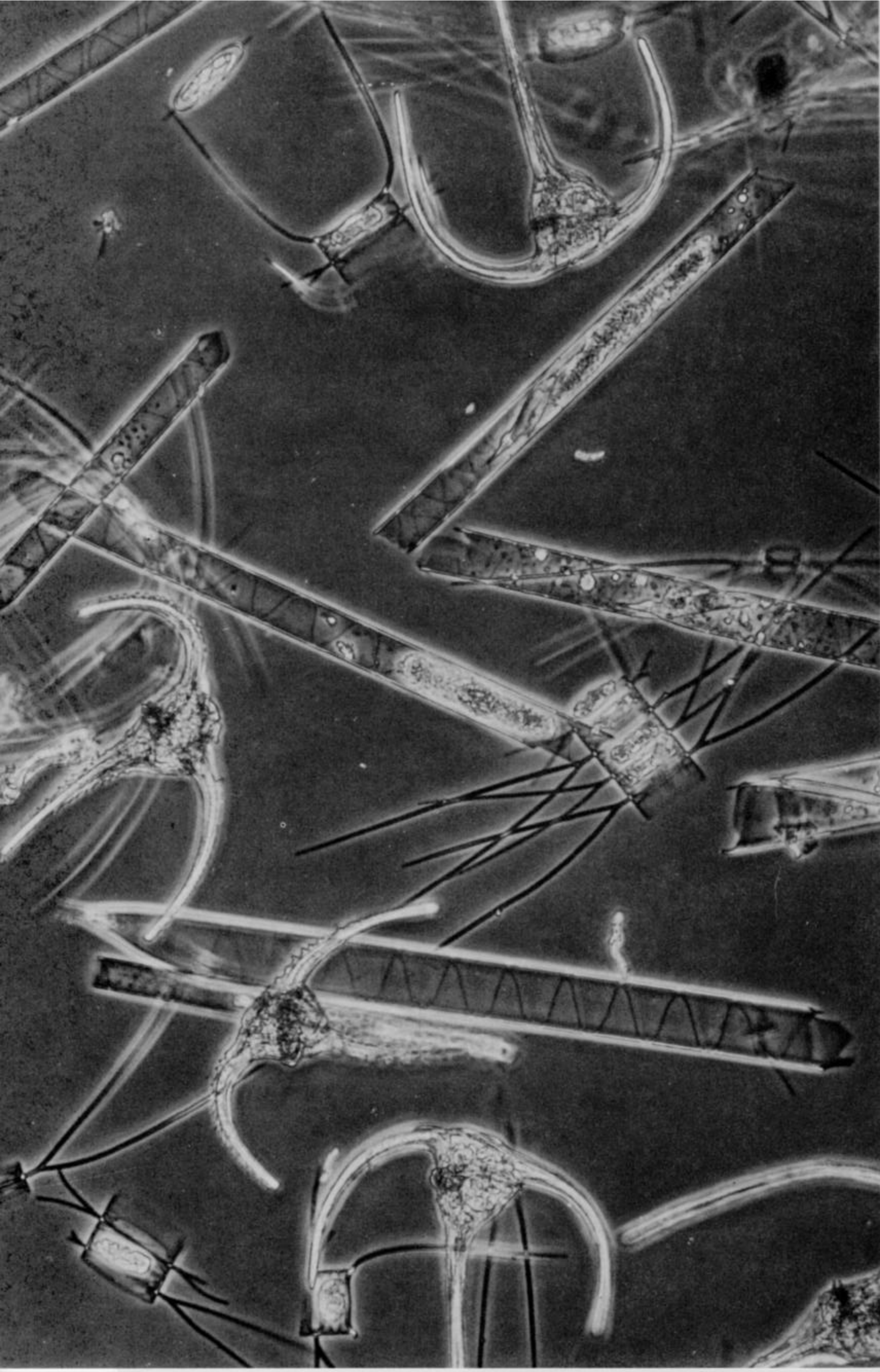
Administrative Review

A gradual expansion of resources and facilities has continued during the period under report and the total financial budget in 1974 exceeded 2 million dollars with a total staff of 84. We have continued during the two years to accommodate and support a number of visiting research workers such as postdoctoral fellows and various research colleagues and students. Likewise, our own research staff has enjoyed participating in research programs and activities in other universities, laboratories, industries, etc., in Canada and Europe. During 1973 and 1974 our scientists have undertaken sabbatical assignments in marine research laboratories in Scotland, England, and France and have participated in research assignments and exchanges in Canadian universities and also as consultants to Canadian industry and Crown corporations.

The laboratory has for the first time negotiated and administered moderately large research support contracts with Canadian industry through the Federal Department of Supply and Services to provide acoustic fish surveys of the continental shelf. There are two contracts of $400,000 and $300,000, which included the provision and equipping of fishing trawlers to carry out research and survey cruises.

Some updating and improvements have continued to our laboratory facilities, field stations, vessels, and equipment generally, and planning commenced in 1974 for general expansion of the total Institute, which will include added facilities for the Marine Ecology Laboratory, modernization of the Fish Studies and Salt Water Laboratory, and replacement of the large trailer laboratory and office complex. Construction will commence in 1975.

B. S. Muir



Biological Oceanography

The main activities of Biological Oceanography include studies of:

- Ecology and physiology of phytoplankton and zooplankton
- Particulate organic material
- Environmental fluctuations and marine production
- Cetacean bio-acoustics
- Fish metabolism

The general program of Biological Oceanography concerns the ecological dynamics of the plankton ecosystems. The ultimate objective is the development of a capability to predict biological productivity, first in the plankton community and then in the fishery itself. The following paragraphs highlight our research activities during 1973 and 1974.

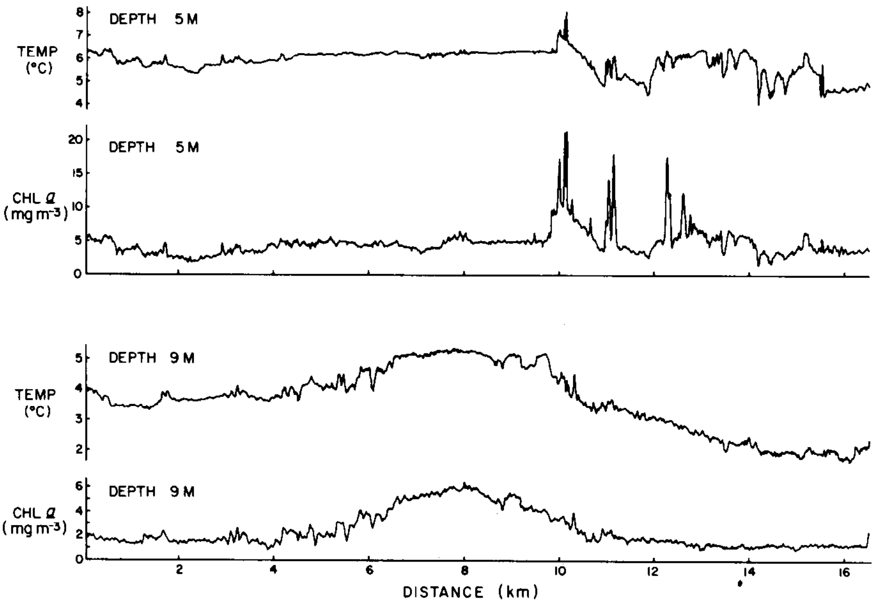
T. C. Watt

Phytoplankton Ecology and Physiology

Spatial Variability of Phytoplankton Distributions. Organisms at all levels of the marine ecosystem, from phytoplankton to whales, are not distributed in a uniform or random manner but, rather, in clumps or ‘patches’. Theoretical considerations indicate that such ‘clumping’ is ecologically advantageous: the oceans can support higher mean concentrations of organisms than would be possible if all organisms were uniformly distributed. However, at the present time, predictive models of ecosystem production cannot account for spatial variability in any acceptable manner. 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.

During the summer of 1973, a study of spatial variability of phytoplankton in the lower St. Lawrence River estuary was carried out on board the CFAV *Sackville.* Two pumps, each connected to a continuous flow fluorometer system, were towed simultaneously at about 3 metres per second with one pump at about 5 metres depth and the other at 10 metres.

Chlorophyll fluorescence of the phytoplankton, *in situ* temperature, and depth for each instrument were digitized and recorded on computer-compatible magnetic tape once each second. The traces for one such transect of 16.5 kilometres are shown on the next page. The power spectra of chlorophyll are similar to those measured previously. Like the spectra for temperature, they are consistent with the spectra one would expect to find in a stratified medium where turbulence and internal waves are present. As can be seen from the figure, the coherence or correlation between chlorophyll and temperature at the same depth is high but any two of the signals from different depths are incoherent. Under the conditions encountered during this cruise, the horizontal phytoplankton distribution appears to be controlled by the physical transport processes of advection and diffusion. In addition, the total lack of correlation between signals at different depths, and several vertical profiles of temperature and chlorophyll obtained during the cruise, indicate that there were intense vertical gradients and layering. Thus, much of the variation observed in both chlorophyll and temperature resulted from thevertical displacement of the horizontal layers by internal waves.



Measurements of chlorophyll a concentration and temperature along a 16.5 kilometre transect in the lower St. Lawrence River estuary during June 1973. The ship was travelling at about 3 metres per second. (AOL 3414.)

In 1974, two cruises were carried out on the Scotian Shelf southwest of Halifax aboard CFAV *Sackville.* Two new instruments were employed in an effort to separate pure horizontal variability of phytoplankton concentration from effects produced by internal waves. Firstly, a Batfish equipped with a CTD (see Metrology, Atlantic Oceanographic Laboratory) was used to get a two-dimensional picture of temperature and conductivity between depths of 5 and 50 metres. Secondly, an in *situ* Variosens fluorometer was used mounted on a Batfish to get a two-dimensional picture of chlorophyll concentrations. Repeated passes through the chlorophyll maximum layer revealed marked changes in the shape of that layer over scales of several kilometres. It is believed that such data will resolve for the first time the spatial distribution of phytoplankton in both the vertical and horizontal directions simultaneously and unambiguously.

In addition to this field program, theoretical investigations were undertaken to establish the critical length-scales for phytoplankton patchiness under a variety of physical and biological conditions. A typical scale-size for the variability is ~50 metres; this can increase to one or several kilometres if phytoplankton growth and zooplankton grazing are nearly balanced. The effect of wind on these patchiness scales is being examined.

An analysis was made of the effect of spatial and temporal heterogeneity on estimates of the annual production by phytoplankton in the Bedford Basin, Nova Scotia. It involved a study of the spatial variability of productivity to biomass (P/B) for scales of ~500 metres. Following periods of calm weather, pronounced differences in P/B can be observed between stations with this separation. For the scales considered, the relative contribution of temporal and spatial effects to the variability of P/B was ~1.50. Estimates of annual production at four different stations in the Basin agreed to within 5 per cent. These results are useful in planning sampling programs to measure the relative productivity of different environments around the coast. A more detailed program will attempt to account completely for the spatial variability in P/B. This work will be done mainly in St. Margaret's Bay, Nova Scotia.

T. C. Platt, K. L. Denman, J.-C. Therriault

Aspects of the Carbon Balance of Phytoplankton. A major obstacle in determining net particulate primary production of a body of water is the difficulty of correctly converting carbon-14 uptake over a 4-hour period into daily organic carbon production rates. The relationship between these two quantities is being studied with axenic cultures of marine phytoplankton growing in exponential phase. Carbon-14 uptake is monitored by the usual methods and compared with the actual changes in particulate organic carbon over a 24-hour period. The relationship between 4-hour carbon-14 uptake and 24-hour carbon changes cannot be predicted solely on the basis of the relative light received during the two periods. The influence on this relation of light intensity, day length, temperature, culture age, and species is now being investigated.

Photorespiration may lead to high losses of photosynthetically-fixed carbon in certain groups of phytoplankton, but no method has been developed to make estimates of this loss in undisturbed samples. The use of an oxygen electrode with a response time of a few seconds has revealed an oxygen influx in certain marine phytoplankton immediately after darkening that is several times the value for dark respiration. The effects of temperature, oxygen concentration, light duration, and light intensity on this influx are similar to the known effects of photorespiration. It appears that this "postillumination O_2 insurge" may reflect oxidation of the photorespiratory substrate and thus provide a convenient and rapid method of detecting photorespiration in concentrated phytoplankton samples. Experiments are underway to test this explanation of the insurge and to interpret its magnitude in terms of a corresponding carbon loss.

A. D. Jassby

Experimental Ecology of Phytoplankton. Experiments have been conducted on the possibility of stimulating primary production in the local coastal inlets by artificial upwelling. Controlled additions of bottom water to surface water *in vitro* have been made to measure the quantitative response of the surface phytoplankton community. The optimal enrichment addition of bottom water to surface water to stimulate primary production is 0.75 per cent.

Experiments using phytoplankton cultures have been carried out on the relative energy efficiency of primary production under light of different wavelengths. Using batch culture, little change in energy efficiency was detected. This work is being extended using continuous culture methods.

The response of the local phytoplankton populations to light of different intensities is being studied in detail and seasonally. The different ways of characterizing these light-saturation curves are being studied to establish the optimal method for making comparisons between different places and different times. Systematic seasonal changes have been found in the light response. The implication is that winter populations are more efficient at light utilization than summer ones.

Empirical equations for predicting the calorific value of plankton from carbon content have been refined: they now incorporate a great deal of information on zooplankton and should be useful in food chain calculations.

Detailed measurements made during the spring bloom of phytoplankton in Bedford Basin, Nova Scotia, show that the multiple regression equations that best describe the productivity observed during the study have almost exactly the same form as those that best describe the bloom in St. Margaret's Bay, Nova Scotia, previously studied in a similar way.

Phytoplankton productivity is being measured in Bedford Basin with the objective of making a predictive mathematical model. Every two weeks the following parameters are measured at a station in the centre of the Basin: in *situ* production, incident radiation, water transparency, temperature, salinity, turbidity, nitrate, nitrite, ammonia, phosphate, silicate, chlorophyll, particulate carbon and nitrogen, ATP, size spectrum, and species composition of phytoplankton. Three points are given particular emphasis: light adaptation, the relationship between primary production and cell size, and the contribution of phytoplankton to the total particle volume.

T. C. Platt, R. J. Conover, S. R. Durvasula, B. D. Irwin, L. Maranda, S. Taguchi

Zooplankton Ecology and Physiology

Study of Euphausiids (Krill) in the Gulf of St. Lawrence. High-frequency sonar has been used to locate concentrations of euphausiids in the Gulf of St. Lawrence, between Rimouski and the tip of Gaspe, Quebec. The aim was to determine if the animals were present in large enough concentrations to warrant commercial fishing. In addition, data were gathered on the behaviour, feeding habits, age structure, and species distribution to determine the annual productivity of these animals and their importance to the ecosystem of the Gulf. Data on the distribution of chlorophyll-a were obtained at the same time using a towed submersible pump and fluorometer. A high correlation was found between the presence of large concentrations of euphausiids and high chlorophyll concentrations. It is not known if the large numbers of animals were present because the chlorophyll was high or if the high chlorophyll readings were the result of increased nutrients from animal excretions.

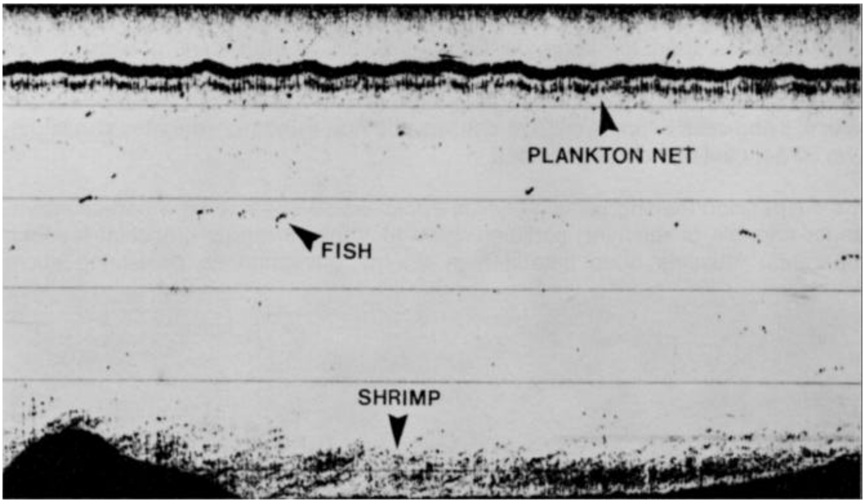
The high-frequency sounder has proved to be a very powerful tool in zooplankton sampling. It allows the researcher to locate areas of animal concentration and thereby design sampling schemes that are much more efficient and economical than blind random station sampling. In addition it permits more accurate abundance estimates of the animals to be made.

Concentrations of euphausiids up to about 4 grams wet weight per cubic metre have been found. It is believed that with a better understanding of animal behaviour much higher densities could be detected. The results suggest that a krill fishery may be possible in this region of the Gulf.

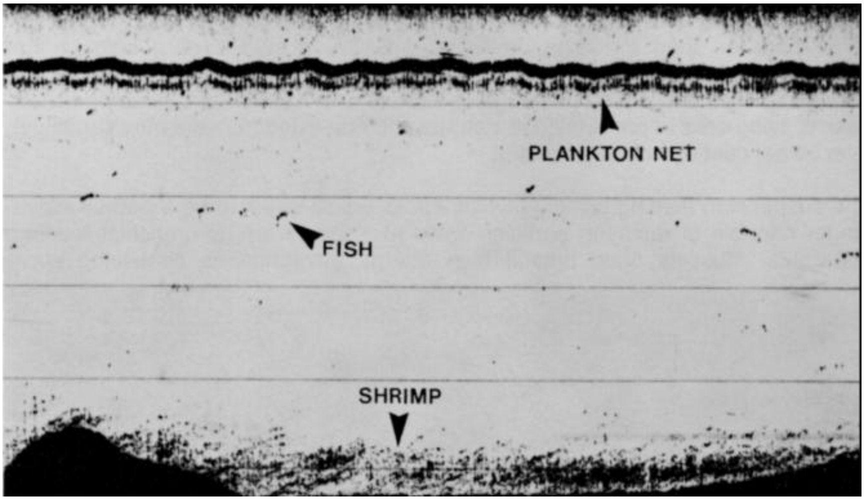
D. D. Sameoto

The Study of Zooplankton Sample Variability. Four experiments were conducted to measure the variability of zooplankton samples in the inshore waters and on the Scotian Shelf off Nova Scotia. The aim of the work is to understand the nature and range of variation found on a fixed station in order to determine what the confidence limits of samples taken on routine surveys are. At present this type of variance is not well understood. The knowledge is vital if prediction about future zooplankton production or fish larval populations are to have any validity.

D. D. Sameoto



Sonar echograms of the euphausiid (krill) in the Gulf of St Lawrence. (AOL 3502.)



Utilization of Organic matter by Herbivorous Copepods. In order to measure aspects of the transfer of organic matter through the first step of the food chain precisely, an attempt was made to set up an instantaneous measurement of the assimilation of organic matter using digestive-enzyme assays. Activittes of carbohydratases, proteases, and lipases of herbivorous copepods were measured during the summer and part of the fall in the Bedford Basin. Specific activities (per milligram of zooplankton protein) will be related to the biochemical composition (proteins, lipids, carbohydrates) of the particulate matter to estimate the grazing pressure on the standing stock as well as the productivity of the phytoplankton. Utilization of the organic matter by the zooplankton was also estimated by measuring respiration and nitrogen excretion (ammonia and organic nitrogen). No attempts were made to estimate the amount of particulate organic matter recycled by the zooplankton.

Though the analysis of the various samples is still in progress, several trends are evident in the results already obtained. Herbivorous copepods assimilate all three biochemical fractions and carbohydrate is the one most actively assimilated. The activity of amylase increased with the phytoplankton biomass throughout the summer despite the fact that this enzyme seems to function on substrate-limiting kinetics. It is expected that when the study of the two other groups of enzymes is completed it will be possible to suggest some of the regulatory mechanisms involved in the digestion of food by tooplankton.

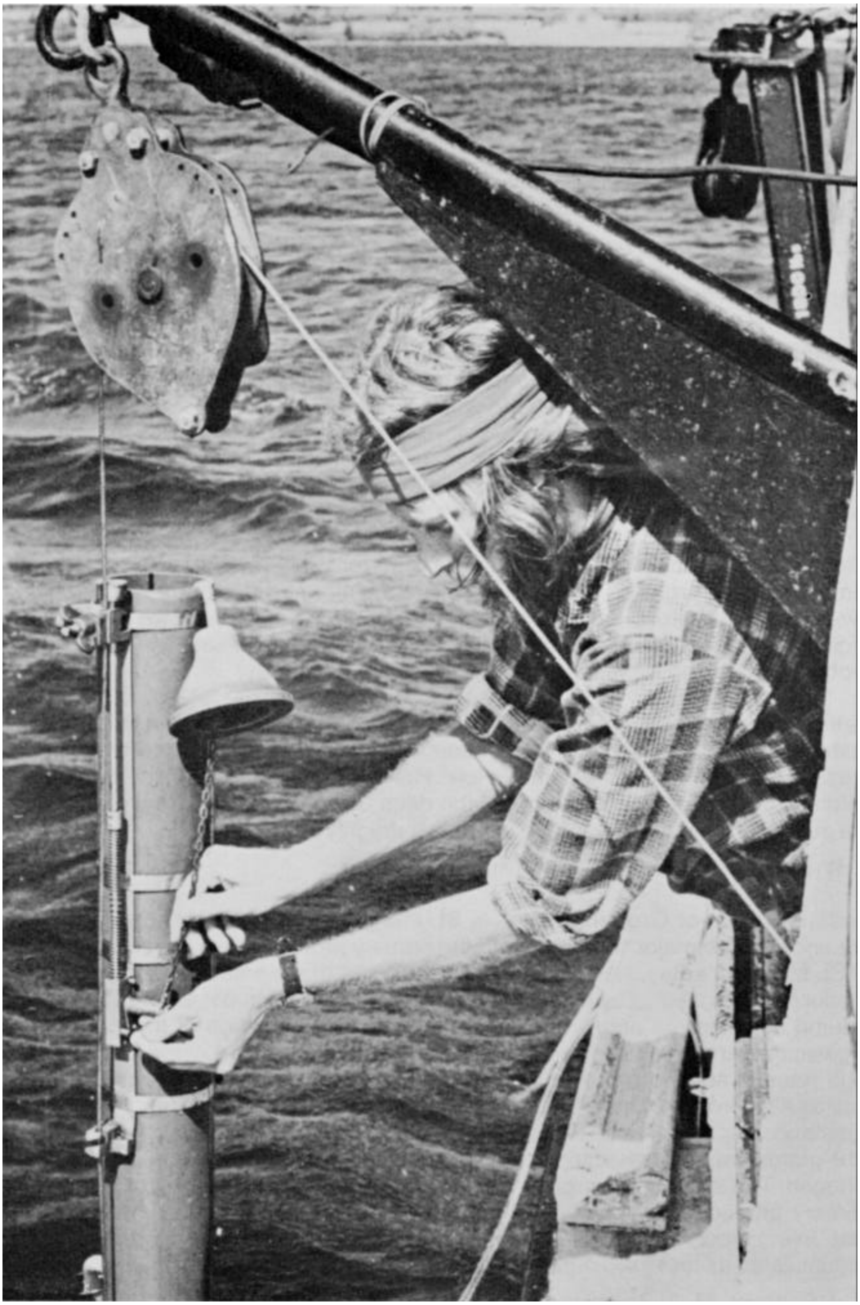
R. J. Conover, P. Mayzaud

Grazing Studies on Natural Particulate Matter. The Coulter Counter and chemical techniques for evaluating the quality of particulate matter such as the ATP method are being used to study the response of suspension feeders to their natural food supplies. In a relatively rich environment such as the Bedford Basin, the size-frequency spectrum of particle abundance generally shows at least two distinct peaks. The common *copepod Pseudocalanus minutus* feeds opportunistically on those choosing the largest particles initially and shifts its grazing pressure to subsidiary peaks once the largest is grazed down. In more oceanic eaters or deep water, the peaks may be less distinct in which case the larger sized particles seem to be somewhat more ‘available’ to the copepod than the smaller. Hence, there would also seem to be some threshold level of concentration necessary to promote feeding on a given size particle and this threshold is probably higher for small particles than for large. In Bedford Basin, a significant portion of the particulate matter is non-living as shown by the ATP method even during bloom periods. On the basis of studies to date there is no evidence that *Pseudocalanus* selects living cells in preference to detritus and non-living material may constitute over 60 per cent of material ingested.

The suspension feeding bivalve *Mytilus edulis* would seem to be a non-selective feeder capable of retaining particles down to 1 micron on its branchial feeding apparatus. Mussels often inhabit high energy environments containing such

The Phoenix moored at the Compass Buoy in Bedford Basin during a 24-hour station. (Photographed by K. Lee.)

non-living suspended particulate matter. Such suspensions are usually unimodal. If the total amount of suspended matter in the water is low, the mussel removes equal proportions of particles from each size frequency. However, as the



A scintist prepares a VanDorn watar bottle for sampling. (Photographed by K. Lee.)

particulate load increases the mussel selectively rejects the finer particles and takes a higher proportion of its rations from the large end of the spectral distribution of sizes.

R. J. Conover, S. Poulet, F. Knipps

Structure and Stability of the Bedford Basin Plankton Communities. The community structure of the Bedford Basin plankton (both phytoplankton and zooplankton) is being studied in collaboration with Dalhousie University, Halifax. These field studies are tied closely to the testing of hypotheses in theoretical ecology concerning community stability, the concept of the niche, and the applicability of loop analysis. Particular attention is given to predation interactions studied by fluorescence staining.

R. J. Conover, P. Lane (Dalhousie University)

Studies on Particulate Matter

Studies on Oceanic Particulate Material. The standing stock of particles in the surface waters of the ocean is roughly constant when taken over logarithmically equal size intervals from bacteria to whales. This fact indicates that much of the particulate material in the ocean is alive, that the particle growth rate varies logarithmically with size, and that the oceanic systems are dynamically stable. The first inference has been checked experimentally, the second is known, and the third is self-evident.

Gross particle production per unit volume of water varies with standing stock and temperature. It is greatest in the temperate regions and least in the subtropical gyres. However, gross production per unit area of ocean is much the same in all regions. The lower standing stock of the subtropics is compensated for by a higher production rate and a deeper zone of high productive activity.

Particle concentration varies logarithmically with depth. Particle production occurs at depth but the rate is low. This together with the low standing stock means that gross production per unit volume is low. However, this is compensated to some extent by the considerable volume of the deep ocean. Total particle production in the euphotic zone and in the deep ocean are roughly equal.

R. W. Sheldon

Sedimentation of Organic Matter in St. Margaret's Bay. Aquatic macrophytes are known to be major contributors to the primary productivity of the coastal areas of St. Margaret's Bay, Nova Scotia. It was thought that a small percentage of this production was utilized by pelagic herbivores and the remainder entered the water column as dissolved and/or particulate matter. Sedimentation of this particulate organic matter studied over a period of a year in a deeper part of the Bay showed high rates of sedimentation in winter, which coincides with high growth rates as well as high erosion rates of macrophytes in this area. A total of 1700 grams of dry substance per square metre was deposited yearly. Out of this nearly 7 per cent or 118 grams was organic carbon and about 1 per cent or 17 grams was organic nitrogen. The sedimented organic carbon was equivalent to 15 per cent of the total primary production by phytoplankton and aquatic macrophytes. It also appears that this carbon has a high turnover rate and, thus, not much would be accumulated as fossilized organic matter.

R. J. Conover, M. A. Paranjape

Studies in the Benthos. Random grab samples from an anchored vessel have shown that marine benthic organisms have a contagious distribution. The degree of contagiousness has an effect on their availability as food for fishes. A program was undertaken to measure such small scale variations in benthic organisms. Two lines of continuous samples were taken. One consisted of 56 samples, the other of 83. The samples were adjacent rectangles 0.5 metres long and 0.1 square metres in area. Numbers of individuals and wet weight biomass were obtained from each sample for 14 species of benthic invertebrates. The mean, median, and variance were calculated for each of the 14 species from each transect and from combined data. The mean and variance had a positive linear correlation - a condition common to benthic data obtained from this size of sample and interpreted as an indication of contagiousness.

The ratio of patch to background density was calculated for each species from those values above to below the median. This ratio was found to have a direct positive correlation with Fisher's Index for both numbers and wet weight biomass.

The distribution of the data could be closely approximated by negative bionomial. The exponent 'K' of the negative bionomial was inversely correlated with both the patch to background ratio and Fisher's Index but the relationship was not linear When the above indexes of contagion were calculated for each species separately on each of the two transects there was a good correlation between transects for each species.

Autocovariance analysis was carried out on a lag of 0 to 5 metres. No periodicity could be demonstrated within this range of samples.

D. L. Peer

Offshore Studies

Year-to-Year Fluctuations in Environmental Production. Studies of discharge records of the St. Lawrence River and yearly catch of several commercial species in the Gulf of St. Lawrence indicate that freshwater influx into the Gulf is well correlated with the annual catches if the River is lagged for a period of years appropriate to the age of the species at commercial size. Further investigations of environmental factors (mainly temperature) southward along the Nova Scotia coast point to effects, probably originating in the Gulf of St. Lawrence, as important influences in the local oceanographic climate as far south as the Gulf of Maine. Examination of catch records of a number of commercial species in the Gulf of Maine shows evidence of fluctuations of the species in response to the environmental factors.

W. H. Sutcliffe

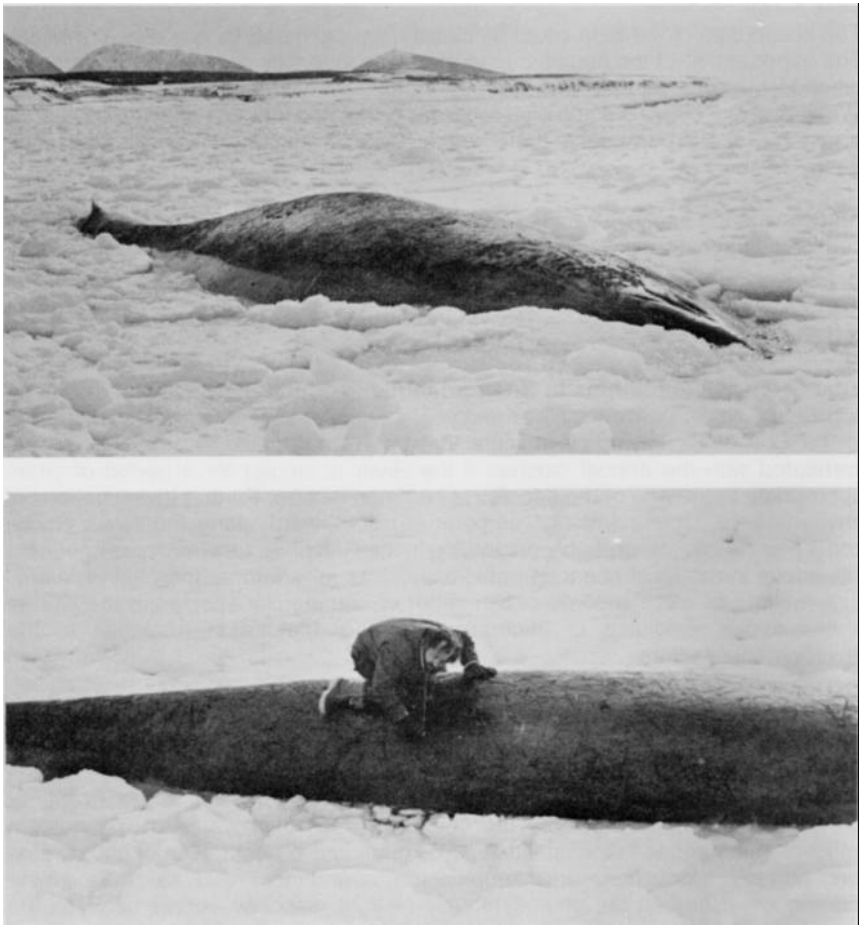
Upwelling Cruise. A cruise was conducted during August 1974 into the Nova Scotian coastal waters and Bay of Fundy with the following objectives: (1) to obtain information on the origin and formation of inshore cold water in the vicinity of Brown's Bank; (2) to elucidate the impact of such cold water on the nutrient enrichment, changes in the qualitative and quantitative abundance of phytoplankton, primary production, and zooplankton abundance, and (3) to examine differences, if any, in the photosynthesis - light response curves between the nearshore and offshore phytoplankton populations.

During this cruise a total of 47 stations was occupied and at three stations observations were made every 2 hours over 26 hours to follow diurnal variations in the phytoplankton production. Data were collected on the nutrients, qualitative and quantitative abundance of phytoplankton and zooplankton, photosynthetic pigments, particulate carbon, nitrogen, and photosynthetic rates.

T. C. Platt, S. R. Durvasula, D. D. Sameoto

Marine Bio-acoustics

Active sonar has become increasingly useful for biological studies of the oceans. Because of the complicated nature of the biological targets, however, the optimum acoustic characteristics of the sonar are to a large extent unknown. This is particularly true for zooplankton because the animals may be 'acoustically transparent' at too low a transmitted frequency but at too high a frequency the water will absorb most of the acoustic energy. Compromises in the acoustic properties of the transmitted sound are often required and a study of such compromises involves a close interaction of both biology and physics.



A Blue whale, 22 metres long, was entrapped by ice on March 21, 1974 on the southwestem coast of Newfoundland but by sunrise of the following day it had escaped. In the bottom photograph, a scientist uses a stethoscope to record the whale's heart beat.

Cetacean Bio-acoustics. Large baleen whales must locate and consume tons of zooplankton each day. In May 1969, hypotheses were developed regarding the existence and nature of echo-location sonar from these whales. Obviously, if the signals existed, their properties might be useful to aid in the design of man-made sonar especially if the signals of whales that prefer different zooplankton prey species were different.

Short repetitive sounds suitable for a whale sonar have been recorded in the presence of Blue, Fin, Humpback, and Minke whales. Hydrophone arrays have been useful in localizing the sound source and measuring directivity of the acoustic signals.

In March 1974, three young Blue whales were entrapped by ice on the southwest coast of Newfoundland. One animal, 22 metres long, rested on a gently sloping shoreline in 2.5 metres of water. The whale escaped when the ice moved offshore. Recordings of short repetitive pulses of sound received on hydrophones 5 -10 metres from the animal revealed unique properties of directivity. Sounds were also studied with a stethoscope and localization of the sound source together with anatomical considerations give evidence that the upper jaw is an acoustic waveguide.

The physiology and acoustic properties of the upper jaw of Fin, Humpback, and Sei whales are being studied in an attempt to understand the acoustic focussing mechanisms of the animals. The middle ear bones, which may be the acoustic receivers, are being studied in the laboratory. The acoustics of these bones show relationships to the acoustic parameters of the recorded sounds. Physiological studies have been carried out in co-operation with the Arctic Biological Station of the Department of the Environment, Sainte Anne de Bellevue, Quebec, and the Nova Scotia Research Foundation, Dartmouth, Nova Scotia.

P. C. Beamish

Fish Metabolism

The long-term objective of the studies of fish metabolism is the development of indicators of routine metabolic levels suitable for field studies with fish. Previous techniques for determining metabolic rates in natural fish populations have included observing post-capture oxygen consumption or nitrogen excretion rates. These methods are clearly vulnerable to short-term or acute modulation and are therefore unsuitable. The main effort of these studies has thus been directed to identifying physiological variables that do not vary significantly but that do acclimate to routine metabolic levels.

Part of the work has consisted of observing the relations between body weight and the levels of a number of hematological parameters in the American plaice population of St. Margaret's Bay.

The relationships of a number of cardiac and hepatic enzyme levels to body weight have been observed in the American plaice to assess the usefulness of these variables as possible indicators of overall metabolic levels.

J. C. Smith

Environmental Oceanography

The main research activities of Environmental Oceanography include:

- Studies (often interdisciplinary) of the inter-relationships between physical and biological production in the coastal regions
- Studies of the sedimentary geology and geochemistry of the coastal regions

This group forms a major direct linkage with the Atlantic Oceanographic Laboratory (AOL), with staff members engaged in physical oceanographic studies functioning with the larger Coastal Oceanography group from AOL. The emphasis in the Marine Ecology Laboratory (MEL) portion is on studies designed to shed light on the basic physical mechanisms operative in marine production systems and to develop physical indices related to fish production. These include water mass types and quality, upwelling, embayment flushing, currents, etc. Additionally, two staff members in the group are involved in the description, understanding, and prediction of sedimentary environments and processes, and their geochemical behaviour with reference to their importance for management of renewable resources.

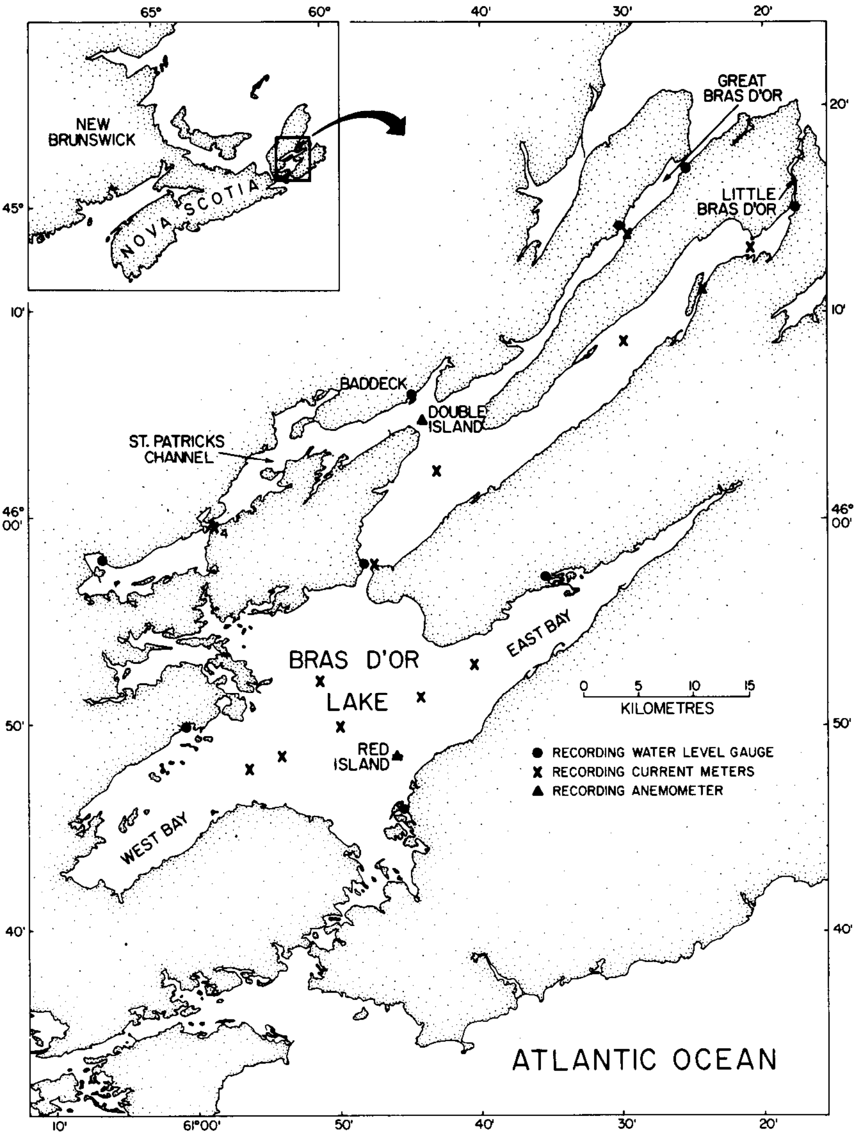
R. W. Trites

Environment - Ecosystem Inter-relationships

River Discharge - Temperature Correlations. In conjunction with the exploratory work of Biological Oceanography on the correlations between Gulf of Maine and Scotian Shelf fish catches and St. Lawrence River discharges, a study that investigated the effects of the discharges on the physical oceanography of the Gulf of Maine is now nearing completion. The effects of the River discharges probably progress at ocean drift speeds from the Gulf of St. Lawrence to the Gulf of Maine. Transport and salinity data also support this contention. Therefore, variability in the St. Lawrence River discharges can cause some of the variability in the physical oceanographic characteristics that in turn affect fish productivity in this region. A systems approach to the variability of the physical oceanographic characteristics attempted to place the River's role in relation to the role played by other oceanic, hydrological, and meteorological factors.

R. H. Loucks, K. F. Drinkwater

Bras d'Or Lake, Nova Scotia. An intensive study of the circulation and mixing in Bras d'Or Lake on Cape Breton Island was begun in the summer of 1973 and continued in 1974. The program was initiated to provide physical oceanographic data for the aquaculture investigations of the Cape Breton Development Corporation (DEVCO). However, once the program was commenced it was realized that the findings were of interest to many other groups. Discussions concerning the Lake were held with investigators from St. Mary's University (Halifax), Sydney College of St. Francis Xavier University (Antigonish, Nova Scotia), other federal departments, the Nova Scotian Fisheries Department, the General Electric Co., and the Canadian Armed Forces, as well as DEVCO. These discussions led to some joint projects or modified plans so that all objectives could be met more efficiently.



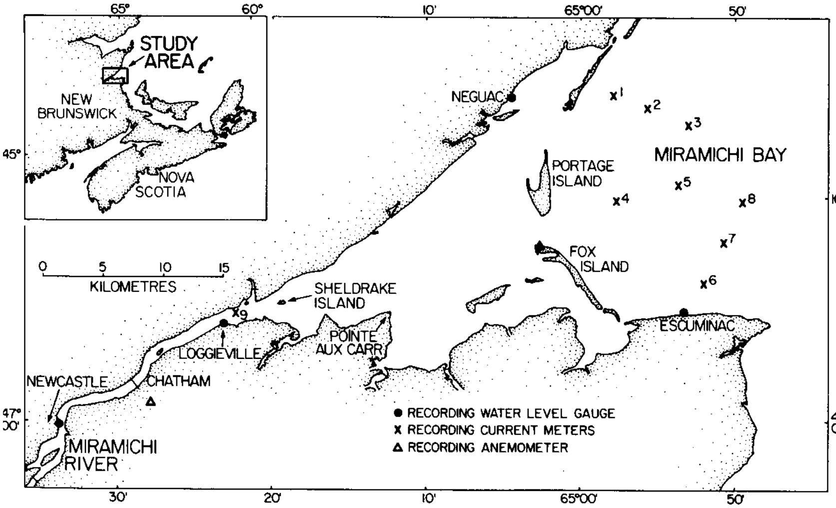
Bras d'Or Lake, Cape Breton Island, Nova Scotia, where a study of circulation and mixing was begun in the summer of 1973. Recording instrument locations for the study are shown. (AOL 3638.)

Continuous water level and water current data were recorded at locations throughout the system and wind and barometric pressure were recorded at two sites. Temperature-salinity data at a grid of stations covering the Lake were observed repeatedly throughout the study period.

Preliminary analysis reveals that in Bras d'Or Lake proper, the currents are of the order of 20-30 centimetres/second on the surface and decrease to less than 0.5 centimetres/second at a depth of 20 metres. The tide enters the system through the channels from the north as a progressive wave but is attenuated to a fraction of its range by the time it enters the Lake. Despite this lack of tidal mixing, the horizontal distribution of temperature and salinity is extremely uniform. Also, a survey of oxygen concentrations revealed that most of the Lake is near saturation. The drainage area is small so that freshwater runoff has only a minimal local effect on the salinity distribution. Maximum currents in excess of 1 metre/second occur in the restricted channels, which cause these areas to be well mixed vertically. Horizontal salinity gradients of about 5 parts per thousand exist in the surface waters along St. Patricks Channel caused by freshwater runoff and along Big Bras d'Or Channel due to the higher salinity of Cabot Strait. But, in general, the surface salinity is about 20 parts per thousand and reaches a maximum of about 25-26 parts per thousand at depth. The continuous data have been digitized and spectral analysis is being carried out to determine the physical response of the system to wind and barometric pressure.

D. Krauel

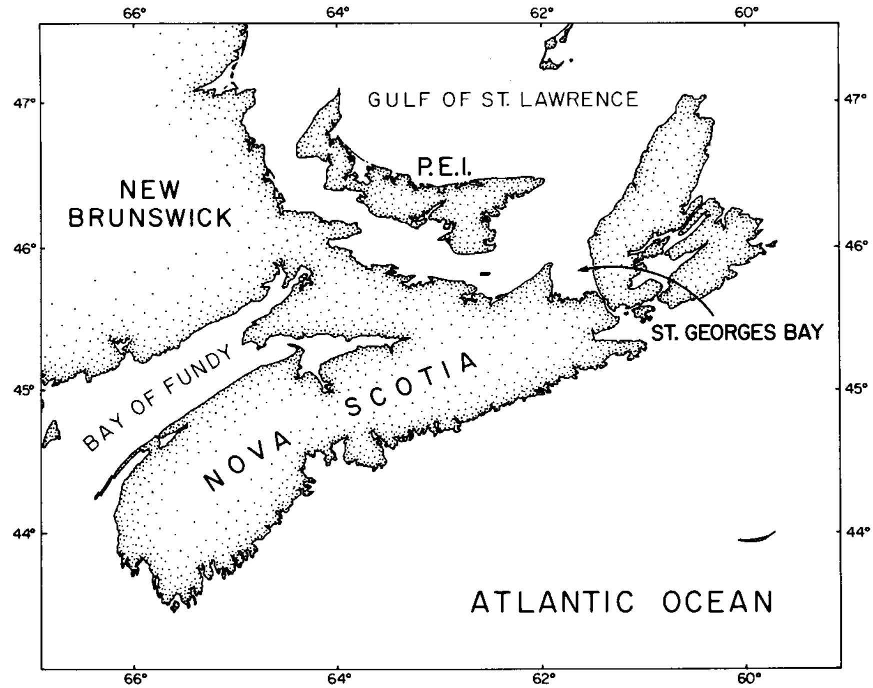
Miramichi Estuary. The Miramichi is Canada's most important Atlantic salmon river. Mining operations in one area of the watershed as well as pulp mills at the freshwater end of the estuary pose threats to the salmon. Recent studies of the salmon by the St. Andrews, New Brunswick, Biological Station of the Department of the Environment have focussed on the behaviour of salmon as they move upstream through the estuary. In order to provide pertinent physical environmental data, an investigation of the circulation and mixing both within the Miramichi



Miramichi Inlet, New Brunswick, where circulation and mixing were investigated in the autumn of 1973. Recording instrument locations for the study are shown. (AOL 3565.)

estuary and in the zone immediately offshore was undertaken in the autumn of 1973. Efforts were directed at determining the distribution of fresh water in the estuary and its fate after leaving the mouth seaward of the offshore bars. The effects of tide and wind on the water movements were investigated in detail over 7 weeks. The field program was co-ordinated with a study of the distribution and character of suspended particulate matter in the estuary (see Coastal Oceanography, AOL).

D. Krauel



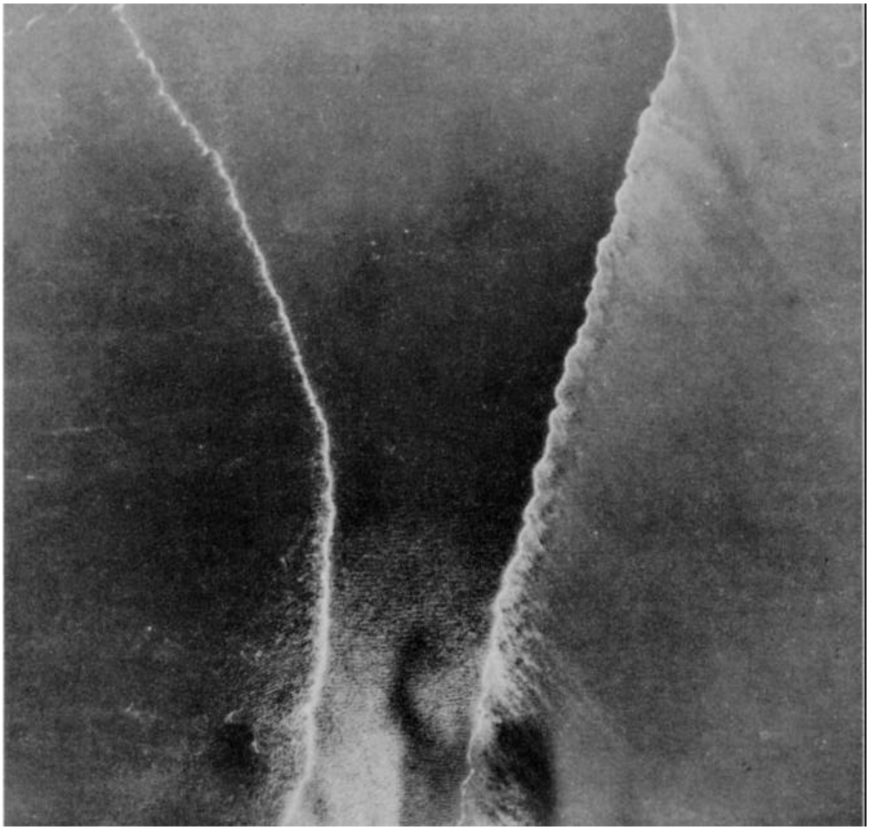
St. *George's* Bay, *Nova Scotia. (AOL 3653.)*

St. George's Bay, Nova Scotia. A field program to study the circulation and the physical properties in St. George's Bay, Nova Scotia, was initiated during the summer of 1974 in conjunction with the MEL biological study presently being conducted there (see Biological Oceanography). Of particular interest are the exchange processes between the Bay and Northumberland Strait that determine the extent to which St. George's Bay can be considered a closed biological system to the fish eggs and larvae. As a result several current meters were deployed at six sites across the mouth of the Bay for periods varying from 1 to 3 months. Another current meter was located in the centre of the Bay. These current meter data together with temperature, salinity, drogue release, and sea surface and sea-bed drift bottle release data are being used to provide information on the tidal and non-tidal circulation within the bay.

K. F. Drinkwater, R. W. Trites

Gulf of St. Lawrence. During the past 2 years field work in the Gulf has been largely confined to the St. Lawrence estuary. This work was fully integrated with other program objectives of Coastal Oceanography (AOL). The oceanographic conditions at the mouth of the Saguenay River have long been recognized to be of an intricate nature. In that vicinity, the bed of the Laurentian Channel rises steeply, affecting the inflow of water in the estuary, and a major river, the Saguenay, discharges into the main stream of the St. Lawrence. In May-June of 1973. current meter strings were moored in the deep channel of the St. Lawrence near the mouth of the Saguenay River, and information on the salinities, temperatures, and depths was collected using a vertical CTD (conductivity, temperature, depth) profiler and a CTD mounted on a Batfish. Two ships, CSS *Dawson* and CFAV *Sackville,* were used in a 4-day co-ordinated effort to get better synoptic coverage.

E. M. Hasssn



An aerial photograph of upwelling in the St. Lawrence River just off the mouth of the Saguenay River. (AOL 3517.)

St. Lawrence River. In the fall of 1972, a request was made to the Canada Centre for Remote Sensing (CCRS) for a high level overflight of the south shore of the St. Lawrence River. The imagery collected during this flight (colour, infra-red colour, and multispectral black-and-white photography, and infra-red line scanner data) indicated quite dramatically the areas of potential for the remote sensing of oceanographic parameters in the River. The most important feature observed in the imagery was the upwelling found just off the mouth of the Saguenay River. Since the occurrence of upwelling has been correlated with areas of high biological productivity throughout the world's oceans, further studies were suggested.

On June 26, 1973, colour photography and infra-red temperature sensing (radiometer and line scanner) were obtained on three overflights made at 10,000 feet (3050 metres) at the mouth of the Saguenay River. Chemical Oceanography (AOL) personnel using CSS *Dawson* carried out surface and subsurface measurements simultaneously to those made by the aircraft. Areas where the surface temperature was lower (interpreted as upwelling) were observed at the same stage of tide (falling tide) but in a slightly shifted position as those areas observed in October 1972. A plot of the depth of a particular isotherm as a function of distance from the north shore of the St. Lawrence using CTD data collected by *CSS Dawson* revealed a linear relationship for the 4 and 5°C isotherms that could be extrapolated to the surface. The place where these isotherms broke the surface corresponded exactly with the position of upwelling found on the thermal infra-red imagery taken in the aircraft. The infra-red temperature also agreed with the CTD measurements within the accuracy of calibration.

P. E. Vandal

Geological and Geochemical Studies of Marine Sediments

Geology. A major report on the morphology and sediments of the Gulf of St. Lawrence was published in 1973 (see Section E, Major Publications of 1973/74, Fisheries Research Board of Canada Bulletins). This report assesses the submarine morphology and the characteristics of the sediments of the Gulf of St. Lawrence. It contains a synthesis of geological and geochemical data collected and interpreted over the past 10 years and integrates these data with the studies of other workers. Nine chapters and seven separate charts, which give detailed bathymetric and sedimentological information in colour at a scale of 1:1,000,000, provide a comprehensive description of the morphological and sedimentological conditions. This publication is intended especially for those engaged in economic activities who require a knowledge of the sea floor for activities such as fishing, pollution control, pipeline and cable routing, and borehole positioning. It is also intended for earth scientists with an interest in glacial marine sediments in a modern context.

Geochemistry. In co-operation with the Chemistry Division of AOL the abundance, distribution, and geochemistry of heavy metals such as mercury, zinc, copper, cobalt, nickel, and vanadium in the Gulf of St. Lawrence have been examined. These studies are undertaken to : (1) determine baseline levels; (2) define areas of heavy metal accumulation; (3) determine natural and industrial sources; and (4) describe the pathways by which heavy metals enter and remain or leave the Gulf.

Mercury is one of the heavy metals that has been studied. This element has received considerable attention as a pollutant and a biological toxin in other parts of Canada as well as elsewhere. It was found that mercury concentrations range from 10 to 12,000 parts per billion in the marine sediments of the Gulf with the greatest enrichment occurring in the Saguenay fjord and the St. Lawrence estuary. Some of the mercury is from natural sources but high concentrations (1000 to 12,000 parts per billion) can be attributed to industrial mercury pollution at the head of the Saguenay River. It appears that terrestrial organic matter, most likely wood fibres, is the major carrier of the industrally-derived mercury. This material has been dispersed downstream from its source and has been deposited from suspension along with the fine-grained sediments. Although mercury concentrations decrease rapidly away from the source, small but significant amounts of mercury-rich organic matter have escaped from the Saguenay River into the St. Lawrence estuary. In the estuary, the industrially-derived mercury accumulates along with fine-grained organic and inorganic matter in response to the present depositional conditions. There is no evidence, however, to indicate that industrially-derived mercury has reached the open Gulf of St. Lawrence.

In the open Gulf, mercury values are at or near the natural levels (10-500 parts per billion) found in the source rocks and this element is presently accumulating at the same rate as natural sediment particles.

D. H. Loring

Environmental Quality

The main activities of Environmental Quality include:

- Study of the behaviour and transport of pollutants through sea water and sediments
- Monitoring the presence of pollutants in the marine environment
- Investigation of the uptake, distribution, metabolism, and clearance of pollutants in a wide range of marine organisms
- Study of the sublethal effects of pollutants on physiological and ecological processes
- Provision of advice, instruction, and opinion to international organizations such as the UN and NATO, all levels of the Canadian government, universities, renewable resource-related industries, and the international scientific community

The principal objective of this program is to study the long-term effects of pollutants on the general health and productivity of marine ecosystems in Atlantic Canada. We are striving to determine which pollutants may constitute a significant hazard, what concentrations of these pollutants can be safely tolerated in the environment, which organisms and biological processes are most suitable for studying potential long-term effects, and, most important, what is the capacity of marine ecosystems to react to and assimilate specific pollutants without suffering irreparable damage. Our interest in the direct toxic effects of pollutants is limited. Interdisciplinary research of this nature requires a diverse staff working together on problems of common interest.

During the last two years, most of our attention has been devoted to chlorinated hydrocarbons (PCBs DDT, and metabolities) and petroleum hydrocarbons. These compounds are of great significance to Canada's Atlantic region. DDT has been used extensively in Atlantic Canada by both farmers and foresters to control insects. It is estimated that approximately half the DDT applied on land eventually enters the sea where it can accumulate in organisms. In recent years increased control of DDT has sharply reduced the annual input to the sea. However, because of the persistence of DDT and its degradation products, these chemicals will remain in our environment for some years to come. PCBs (polychlorinated biphenyls) are industrial chemicals and it now appears that most of the PCBs found in the marine environment of Atlantic Canada are carried here via the atmosphere from the St. Lawrence River valley region and the northeastern U.S.A. Initial interest in petroleum hydrocarbons was stimulated by the *Arrow* oil spill of 1970 in Chedabucto Bay. Further impetus has been provided by the recent development of the petroleum industry in Atlantic Canada; for example, offshore oil exploration on the Scotian Shelf and Grand Banks, refinery construction, and increased oil-tanker traffic. Limited attention in our programs has also been given to organic carbon and nitrogen, mercury, fatty acids, and mining floatation agents.

In order to detect the harmful effects of pollution, it is essential to understand how unaltered ecosystems function and change with natural environmental variations and how uncontaminated organisms function and multiply. Some attention in the program is therefore devoted to studying the structure of unpolluted ecosystems and the cycling of organic matter within them.

Approximately three-quarters of the program's resources are applied to conducting research, the results of which are summarized and interpreted in scientific reports and papers. This research provides information on the state of health of Canada's marine environment, on steps that should be taken to protect Canadian marine renewable resources, and on how natural and polluted ecosystems operate. Our remaining resources are devoted to providing scientific advice, instruction, and opinion.

The specific research projects undertaken during the last two years are grouped according to general purpose and summarized below. The scientific staff involved in each are identified in parentheses.

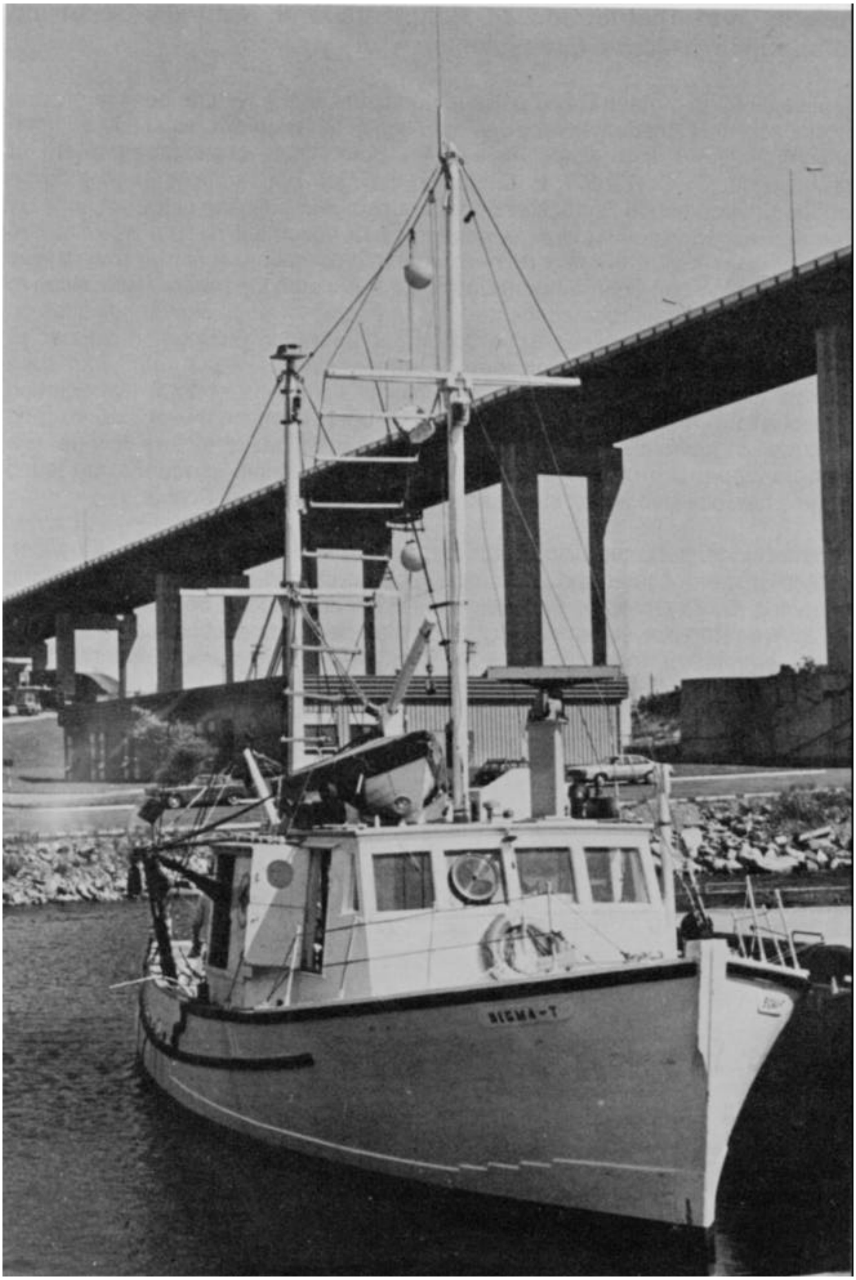
Development of Sampling and Analytical Methods

Accurate and sensitive sampling and analytical methods for monitoring many of the compounds of interest in organisms and the environment have not always been available. In many instances, therefore, we have had to alter existing methods and develop new ones. For example, standard oceanographic sampling procedures were found to be inadequate for collecting uncontaminated seawater samples for hydrocarbon analysis, thus, new sampling equipment and techniques were developed *(D. C. Gordon, P. D. Keizer).* The analysis of hydrocarbons (both naturally-occurring and petroleum-derived) in sea water is extremely difficult because of the very low concentrations encountered (low microgram per litre range) and their chemical complexity. Improved analytical procedures employing fluorescence spectroscopy and gas-liquid chromatography have been developed and adopted for routine use *(P. D. Keizer).* The effects of filtration on the apparent particulate organic carbon concentrations in sea water have been studied *(D. C. Gordon,* W. *H. Sutcliffe).* Also, a new dry-combustion method for determining organic carbon and nitrogen in sea water, which yields higher carbon concentrations than are obtained with traditional wet oxidation methods, has been developed. An analytical method has been developed for the analysis of certain ore floatation agents in mining waste water using gas-liquid chromatography *(R. F. Addison).*

We are also interested in the chemical analysis of different types of marine sediment and have developed a technique employing fluorescence spectroscopy that can characterize and quantify oil in sediments *(B. T. Hargrave).*

Behaviour of Pollutants in the Environment

It is important to understand what happens to a pollutant once released into the environment. Does it dissolve, adsorb to particulate matter, settle out of the water column quickly, etc.? The physical and chemical forms a pollutant assumes greatly affect its availability to marine organisms. Laboratory studies indicate that DDT added to sea water is rapidly adsorbed to particle surfaces *(B. T. Hargrave, G. Phillips).* Laboratory experiments have also demonstrated that most oil entering sea water from a spill does so in the form of small particles less than about 25 microns long *(D. C. Gordon, P. D. Keizer, N. J. Prouse).* The behaviour of artificial oil spills has been studied in large outdoor sea water tanks (10,000 litres) *(D. C. Gordon, P. D. Keizer).* About 10 per cent of the spilled oil penetrates into the water column and sediments. As an extension of this project, the effectiveness of oil dispersants has been tested in conjunction with the Environmental Protection Service.

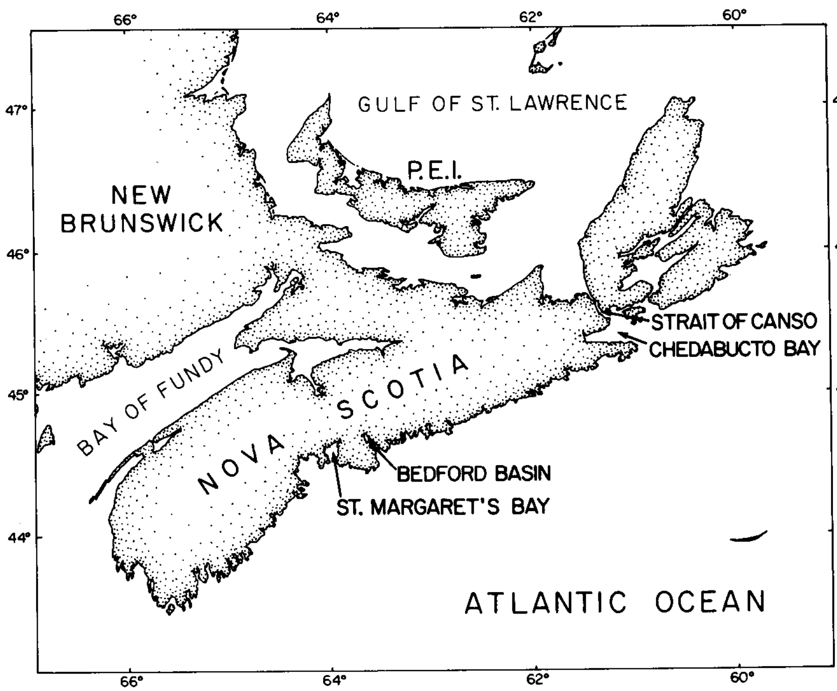


The nearshore research vessel Sigma-T moored at the Bedford Institute of Oceanography's wharf. (Photogrqahed by K. Lee.)

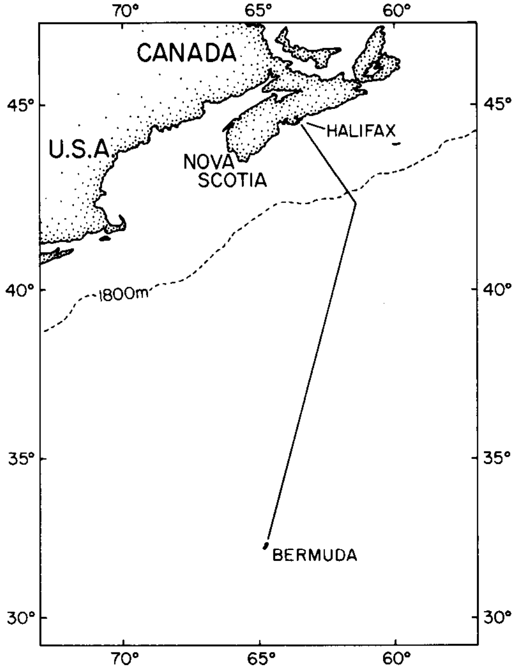
Quantity and Distribution of Pollutants and Naturally-Occurring Compounds in Marine Ecosystems

The examination of natural and polluted conditions in the waters, sediments, and biota of Atlantic Canada has received attention in our program. Total hydrocarbon concentrations in sea water have been determined in a wide variety of environments *(D. C. Gordon, P. D. Keizer, J. Dale).* For example, in conjunction with the Environmental Protection Service, a two-year baseline study at Come By Chance Bay, Newfoundland, was conducted to document natural hydrocarbon concentrations before the new refinery went into operation. A similar project was conducted in co-operation with the Eastcoast Petroleum Operators Association to measure total hydrocarbon concentrations in sea water at oil exploration sites on the continental shelf between Nova Scotia and Labrador. Exploration companies collected the samples and sent them to us for analysis. Much effort has been devoted to studying the temporal and spatial variations of total hydrocarbon concentrations in Bedford Basin and in the open ocean between Halifax and Bermuda. In general, total hydrocarbon concentrations are very low (a few micrograms per litre or less) and definite oil contamination appears to be found only in a few localized areas, such as the Bedford Basin, Nova Scotia.

To better understand the distribution and cycling of organic matter in sea water, detailed studies of total and particulate organic carbon and nitrogen are being conducted *(D. C. Gordon).* Samples have been collected in both Bedford Basin and at five reference stations along the Halifax-Bermuda section (see map). The results emphasize the importance of microstructure in carbon distribution, a phenomenon largely overlooked in the past.



Bedford Basin, St. Margaret's Bay, and the Strait of Canso - Chedabucto Bay area, Nova Scotia. (AOL 3584.)



The Halifax-Bermuda Section, along which numerous environmental studies have been conducted since 1971. (AOL 3584.)

Sediment analysis is important because large amounts of many pollutants are incorporated into sediments. Oil has been detected in sediment collected from Bermuda, Bedford Basin, Eastern Passage, and Chedabucto Bay (Nova Scotia), and at Come By Chance (Newfoundland) *(B. T. Hargrave, G. Phillips, P. D. Keizer).*

We have measured organochlorine concentrations in a variety of marine organisms. For example, PCB residues were detected in zooplankton collected from the Gulf of St. Lawrence near Prince Edward Island *(D. M. Ware, R. F. Addison).* DDT residues have been detected in euphausiids collected in the upper estuary of the Gulf of St. Lawrence *(D. D. Sameoto, D. C. Darrow).* Various organochlorine compounds have been detected in seals and beluga whales from the Gulf of St. Lawrence and the Canadian Arctic *(R. F. Addison, P. F. Brodie).* The significance of these residue levels, if there is any, is not well understood.

Natural levels of odd-chain fatty acids have been investigated in Nova Scotian smelt *(R. F. Addison).*

Unknown to many people, a sizable amount of the Bunker C oil spilled from the tanker *Arrow* in 1970 remains in Chedabucto Bay, principally in the intertidal area. Intertidal surveys initiated soon after the spill have continued uninterrupted for five years, with special emphasis on the effects of the oil on clams, seaweed, and marsh grass *(M. L. H. Thomas, University of New Brunswick).* Chemical analyses demonstrated that intertidal and subtidal organisms in some regions of the Bay were heavily contaminated with oil in 1974; it is thought that the contamination source may be deposits of *Arrow* oil along nearby beaches *(J. H. Vandermeulen).*

A study of total mercury in sea water along the Halifax-Bermuda section was made in co-operation with the Atlantic Geoscience Centre *(D.* C. Gordon). The results suggest that most of the mercury found in sea water is natural in origin and that the high mercury levels found in certain oceanic fish cannot be attributed to pollution.

Laboratory Studies of the Uptake, Distribution, Metabolism, and Clearance of Pollutants

The pathways that pollutants follow through organisms and the transfer rates involved are being investigated. The inability of marine copepods to metabolize DDT at normal ocean temperatures has been verified *(G. C. H. Harding, D. C. Darrow).* Laboratory experiments have demonstrated that the uptake of DDT by zooplankton is rapid and linear with time, with most DDT accumulating largely in the lipid pool (G. C. *Harding, P. Vass).* Clearance rates of DDT by zooplankton are now being investigated.

Considerable effort has been devoted to studying the metabolism of organochlorine compounds in fish. Specific projects include: the metabolism of DDT-type compounds and the effect of temperature on the conversion of DDT to DDE in brook trout *(R. F. Addison, M. E. Zinck);* the effect of starvation on the conversion of DDT to DDE in salmon *(M. E. Zinck);* the fate of different chlorobiphenyl compounds in skate *(M. E. Zinck, R. F. Addison);* the distribution, metabolism, and excretion of biphenyl in skate *(D. E. Willis, R. F. Addison);* and the metabolic clearance and distribution of DDT in skate *(D. E. Willis, R. F. Addison).* The ability of selected marine organisms to hydroxylate biphenyl has also been investigated. Attention has also been devoted to studying the possible effects of DDT on the biochemistry of the sex hormone, testosterone, in skate *(D. C. Darrow).*

Similar projects dealing with petroleum hydrocarbons have been initiated. To date, the uptake and elimination of naphthalene by mussels at different temperatures and exposure times have been studied, as have the filtering and subsequent accumulation of suspended oil particles by soft-shelled clams *(J. H. Vandermeulen, V. Fong).*

Sublethal Effects of Pollutants

The mere presence of a pollutant in the environment or in an organism does not necessarily mean that it will cause deleterious effects. It is important to learn whether pollutants affect physiological and ecological processes at the concentrations they occur in the environment.

The effects of petroleum hydrocarbons on the growth of phytoplankton have been studied. Initial work was done in field experiments employing natural phytoplankton communities from Bedford Basin and along the Halifax-Bermuda section (N. J. *Prouse, D. C. Gordon).* This project then shifted to laboratory studies using bacteria-free unialgal cultures of common phytoplankton species. The results of both projects suggest that the low levels of oil contamination observed in the sea water of Atlantic Canada are not adversely affecting phytoplankton growth. The effects of specific aromatic hydrocarbons, for example naphthalene, on the growth of laboratory cultures and on the photosynthetic mechanism are now being investigated *(J. H. Vandermeulen).*

Several projects have been undertaken to study the effects low levels of oil in sea water have on marine invertebrates; for example, on crawling and respiration in intertidal snails *(B. T. Hargrave),* on the respiration and filtering rate of soft-shell

Culture set-up for the study of the physiological effects of oil on algae in the marine food chain. (*AOL 3441-4*)

clams *(V. Fong),* and on the respiration, feeding, and locomotion of sea-urchins *(P. Phinney).* Again, deleterious effects are observed only at oil concentrations much higher than those generally observed in the environment.

Cycling of Organic Carbon in Ecosystems

We are attempting to construct a carbon budget for the Bedford Basin, which will quantify the natural flux of organic matter in this important coastal inlet and provide information on its ability to assimilate increased organic input from sewage, petroleum wastes, eutrophication, etc. Several aspects of this project have been completed, including: (1) a study of the relationship between the production of organic carbon in the water column and its subsequent consumption in the sediments below *(B. T. Hargrave),* (2) a study of the stability in structure and function of the mud-water interface, and (3) a study of the metabolism of microbial communities on solid surfaces *(B. T. Hargrave, G. Phillips).*

Miscellaneous Projects

A few projects undertaken in our program during the last few years do not conveniently fit into the above scheme. These include studying the removal of organochlorine compounds from marine oils during refining and hydrogenation for edible use *(R. F. Addison),* examining methods of measuring biological diversity, which can be an index of pollution *(G. C. H. Harding),* and conducting, with the assistance of the Environmental Protection Service, a water quality study of two Dartmouth, Nova Scotia, lakes for the Dartmouth Lakes Advisory Board *(D. C. Gordon).*

Fisheries Oceanography

The main activities in the Fisheries Oceanography program include:

- Studies on the ecology of larval fish
- Development and application of hydro-acoustic methods for estimating fish abundance and distribution
- Laboratory and theoretical studies on bio-energetics of fish and marine mammals
- Studies on coastal resources and aquaculture potential

The general program in Fisheries Oceanography is addressed to problems arising from the need to understand better the manner in which environmental variables affect fish production. The studies interact with those in other programs within this laboratory to provide a linkage between events in the physical realm, and in the lower trophic levels of biological systems, and the production of usable species.

B. S. Muir

Larval Fish Studies

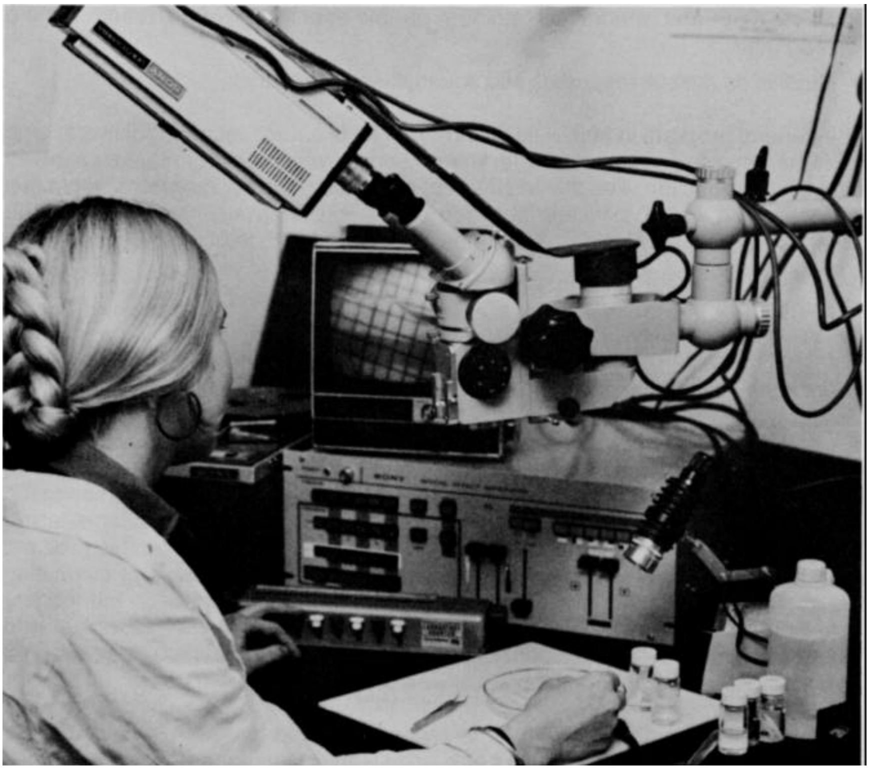
The causal factors affecting the survival of fishes are still largely enigmatic. Though there is a general consensus that the ultimate strength of fish populations is established long before recruitment to the commercial fishery, perhaps even in the first few months following spawning, often there is little factual information on the early life history. Indeed, the importance of the larval stages in determining the subsequent yield from a fishery is one of the most outstanding problems facing fisheries management. Activities of this group that are focussed on this problem include the further development of hydro-acoustic systems capable of estimating the abundance of larval and postlarval stages, laboratory studies on the feeding behaviour of larval fish, correlational studies with environmental variables, and theoretical and field studies. Considerable effort has been devoted to selecting a field study site suitable from the point of view of all these approaches.

From May to December 1973, a survey was conducted to determine whether St. George's Bay, Nova Scotia, serves as a spawning or nursery area for commercial fish populations in the Gulf of St. Lawrence. By the end of summer, larvae from over 20 species had been identified. Of these, the most important were Atlantic herring and mackerel. Both appeared to reside in the Bay throughout the sampling period, and were sufficiently abundant to allow assessment of their growth and survival during the first few months of life.

Following this preliminary survey, a more detailed study was launched in 1974. The purpose was to obtain time-series data on the movements, growth, and mortality of herring and mackerel in relation to hydrographic factors, and particularly the distribution of plankton.

The circulation pattern of St. George's Bay is being studied by the Coastal Oceanography group. In 1974, drift bottles, seabed drifters, and drogues were released regularly at eight drop-off points. Several fixed current meter stations were also established.

Biological data on the abundance and size composition of plankton and fish larvae were collected every two weeks at 16 stations, and at three depths per station. Sampling was more frequent in June and July, which is the period of peak reproductive activity for mackerel.

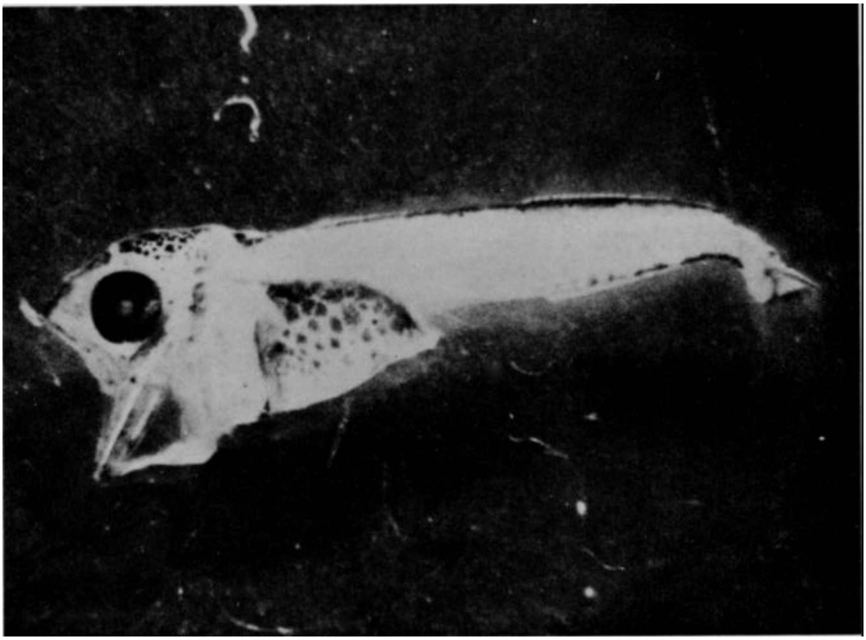


Technician using video-camere for feeding behaviour studies of fish larvae. (AOL 3523.)

Herring normally spawn in St. George’s Bay in May and September. However, in 1973 there was evidence of summer spawning, probably in July, somewhere outside the Bay. The growth rates of the spring-, summer-, and fall-spawned cohorts compare favourably with growth estimates for other herring populations in the Gulf.

Large numbers of mackerel eggs were encountered in St. George’s Bay in 1973; peak spawning occurred in mid-June. By contrast, in 1974 the total egg deposition was about ten times less, and peak spawning was nearly 20 days later. The growth and mortality of the 1974 population will be particularly interesting to compare with the previous year-class, since 1973 was a noticeably warmer year.

D. M. Ware, T. C. Lambert



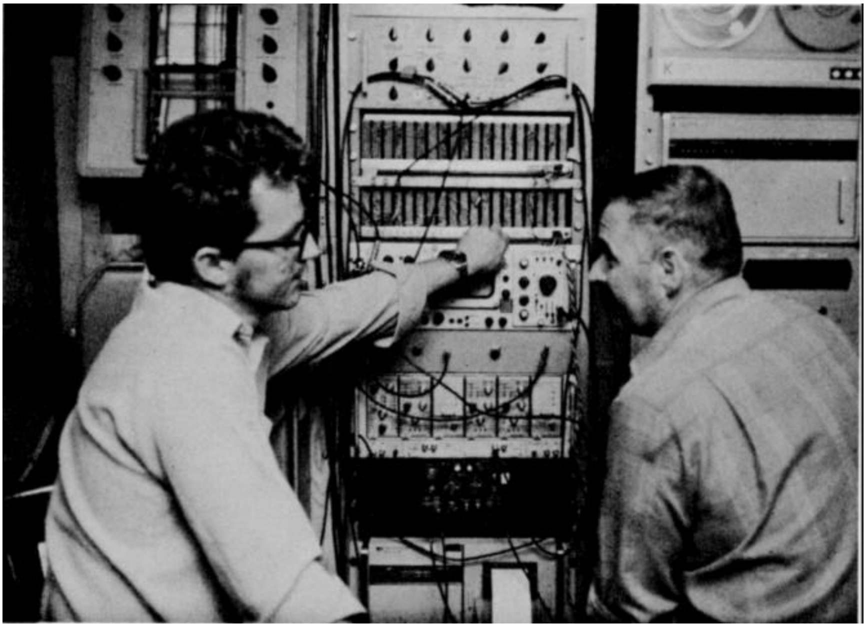
Mackerel larva about 8 millimetres long feeding. (AOL 3588.)

Hydro-acoustic Assessment of Fish Stocks

Canadian scientists have regularly monitored variations in fish abundance over thousands of square miles of the continental shelf. As more and more stocks have come under quota regulation by the International Commission for the Northwest Atlantic Fisheries (ICNAF) in this region, the demand for estimates and stock assessments has grown enormously. In an attempt to improve the quality and timeliness of abundance estimates, considerable world-wide effort has gone into developing hydro-acoustic methods for stock assessments.

The Marine Ecology Laboratory (MEL) has developed a computerized echo-counting system for cod, haddock, and redfish, and is currently expanding the system's capabilities for counting pelagic species. Briefly, the system contains a Simrad EK-50 sounder, a Honeywell computer, a teletype, and a high-speed paper-tape reader and punch. The system's analytical programs sort the incoming echoes into four size categories and calculate the number of fish in each group per 1000 cubic metres of water. Fish densitites are calculated in real-time, and are printed out by teletype at selected intervals. The operator can therefore make an immediate evaluation of fish abundance at sea.

Besides the cumulative teletype information acquired during surveying, individual echoes are recorded by a read-write magnetic type system. These data provide a permanent record of the cruise and can be analyzed in detail in the laboratory.



Checking echo levels at sea. (AOL 2135-4.)

In 1973-74, MEL contracted Montreal Engineering Company to conduct an extensive survey of the groundfish stocks on the Nova Scotia Shelf and, particularly, to determine if the system was capable of providing continuous reliable data under inclement conditions.

The survey was to cover over 40,000 square nautical miles of the continental shelf. Based on theoretical studies conducted by the Nova Scotia Research Foundation, a zigzag cruise pattern totalling nearly 4300 nautical line miles was considered to be the most efficient design. To supplement the acoustic data, the composition of fish species was determined by test fishing at 129 predetermined stations randomly situated along the cruise track. The survey required nearly 54 days to complete. Due to difficulties with the charter vessel, the survey was extended over a five-month period - October 1973 to March 1974.

The equipment performed remarkably well, thus, demonstrating that it can supply the large-scale estimates of stock abundance required by fisheries managers. Results from the 1973-74 program have, not unexpectedly, suggested hardware and software improvements. Theoretical studies in the area of survey design are continuing, particularly with reference to optimizing the cruise pattern when faced with compromising statistical precision with monetary and effort considerations. The hardware and software changes now in progress will be assessed as part of the current contract with Montreal Engineering Company.

Several manuscripts describing the echo-counting system and methods for interpreting acoustic data are being prepared by the project's principal investigators. (See also the essay "Acoustic Fish Counting with a Computerized System" by R. Shotton and R. G. Dowd in Ocean Science Reviews, Part D of this Biennial Review.)

R. G. Dowd. D. M. Ware, R. Shotton

Instrument Development

During the period of this report, research and development was carried out on two major data acquisition systems to assist in the studies of the spatial variability in the distribution of both phytoplankton and zooplankton (see Biological Oceanography). These two systems have been used singly and jointly to study the interaction between these groups of organisms.

The equipment used for phytoplankton studies was designed around towed submersible pumps and modified commercial fluorometers. The fluorometers were modified for faster response to give greater detail of the spatial variability, and the sensitivity was increased at the longer wavelengths. A variety of recording times was designed into the system to cater to different modes of data analysis. The submersible pumps can be used individually or in groups to help delineate the horizontal and vertical variability of the phytoplankton concentrations. The experience to date indicates the future development of this pumping system should be concentrated on the design of a compact *in* situ fluorometer, which would avoid many of the inherent problems with the submersible pumps and their electro-hydraulic towing cables.

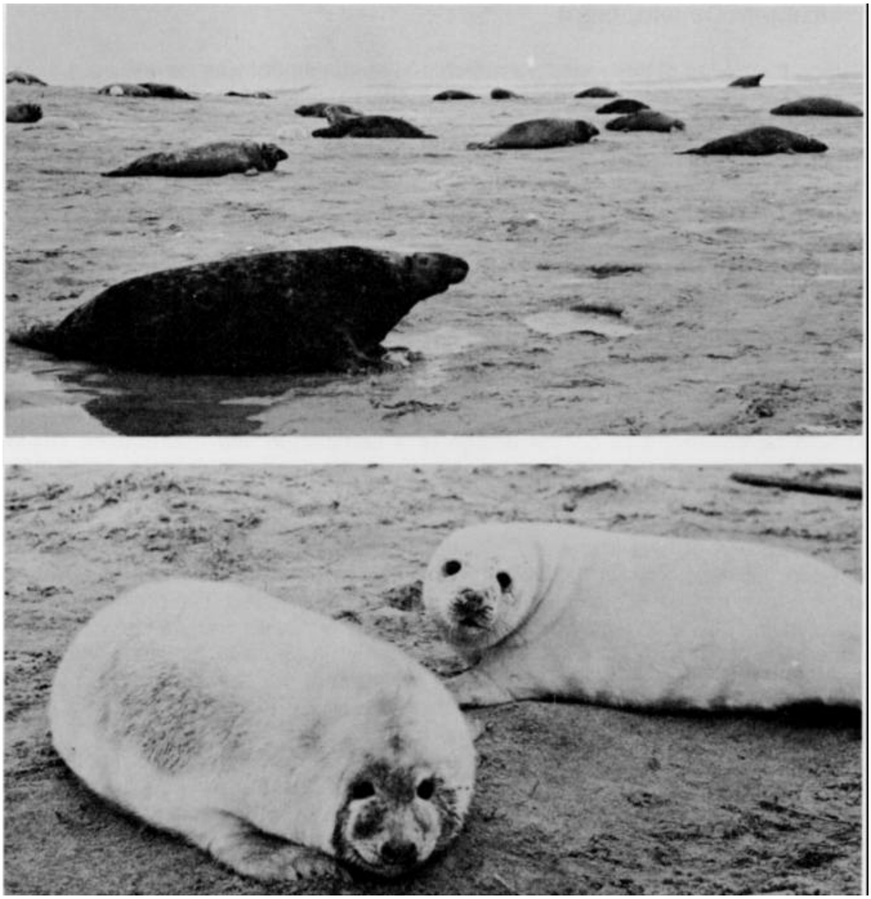
Extensive use of high-frequency (greater than 100 kilohertz) acoustics is being used in the development of a system for zooplankton variability and distribution studies, and a number of acoustic systems have been tested. The present system used in our study of spatial variability consists of towed transducer packages containing 120 and 200 kilohertz acoustic sources; one package has the transducers sounding down while being towed near the surface and the other, towed at a depth of 50 metres, has the transducers sounding upward to map the near-surface distribution. This technique has proved useful in mapping the gross zooplankton distribution and its variability, and the data acquired is used to improve future survey patterns. Although this acoustic system gives a great deal of information about the spatial distribution of zooplankton, there is still insufficient data on the target strengths of organisms and the effect of the changes in densities on scattering strength to lend the data to numerical methods of analysis.

Under development, but not completed and field tested, is a system for vertically profiling zooplankton densities and correlating these with ambient light. This system consists of a small instrument package, which can be raised and lowered to map the vertical distribution or used to follow the isolumes (equal light intensities) during the diurnal vertical migration of the plankton layers. The acoustic transducers being used are in the 1 to 2.5 megahertz range and provide a small aperture and high resolution, which gives good measurements of densities, thus, providing data to calibrate the towed transducer systems. With good calibrations, we will be able to use numerical methods to analyze zooplankton distribution and variability.

S. Paulowich

Bio-energetics Studies

Marine Mammals. Seals and whales are natural indicators, and important consumers, of marine production. Their energy is provided by preying upon commercial fish stocks or by competing with them for a common food base; a better understanding of their impact on fish stocks is important for local fisheries managers as well as the international community.



Grey seals on Sable Island, N.S., during the January-February pupping /breeding season.

The food requirements of marine mammals has been a controversial subject with estimates varying tenfold. Through studies of morphology, behaviour, and thermoregulation (P. F. Brodie; *Ecology,* in press) a realistic basis for energy requirements can be established. For example, a 30-ton fin whale requires 100 -120 metric tons of fish and euphausiids annually to maintain itself, excluding calf production. This estimate is well below those of previous studies, which did not closely consider the physiological parameters.

Knowledge of the impact of mammals on marine production permits estimates of fish stocks 'released' to commercial fisheries as a result of declining mammal stocks: conversely, it permits estimates of the consumption of fish, if the mammal stocks increase through under-exploitation.

This approach is being used in conjunction with standard acoustical and statistical methods of fish stock assessment.

P. F. Brodie

Growth, Feeding, and Bio-energetics of Fish. Re-analysis of published data on the energetics of a small pelagic fish indicates that it swims at a speed that maximizes its growth rate. This finding might be relevant to the evolutionary strategy of other fishes, and can be readily tested because the optimal speed can be calculated from typical feeding and metabolic measurements (D. M. Ware; *J. Fish. Res. Board Can. 32:* 1).

Laboratory studies, which evaluated the importance of food size on the feeding success of postlarval stages of several species, show that the optimum sized food particle increases as the predator grows. This relationship is being coupled with metabolic estimates to assess the feeding potential offered by different size compositions of plankton normally encountered in northwest Atlantic waters. The results will give some indication of how much growth rates and, perhaps, mortality might vary between years of 'good' and 'poor' food quality.

D. M. Ware

Coastal Resources and Aquaculture

The activities in this subprogram range from attempts to develop indices of aquaculture potential in coastal embayments, based in part on biological productivity and coastal circulation studies of other programs, to participation in a large, applied aquaculture enterprise in Bras d'Or Lake, Cape Breton.

(1) Mollusc Studies. In 1974, a program was commenced at Luke Island in St. Margaret's Bay to study growth, mortality, and productivity of three edible mollusc species. This program is an extension of investigations of benthic productivity begun several years ago by MEL and is also a continuation of the study of potentially exploitable local shellfish species of which a section on the blue mussel *(Mytilus edulis)* has been completed. The additional species are the soft-shell clam *(Mya arenaria)* and the razor clam *(Ensis directus)* and to date work has nearly been completed on the design and installation of containers and support systems for these two.

In the summer a simple raft was anchored to Luke Island and from it were suspended ropes covered with mussel spat collected in Bedford Basin where the settlement has been shown to be greater than in St. Margaret's Bay. The object of this experiment is to assess, on a pilot culturing scale, the yield after two to three years, and to test the raft system under adverse weather conditions.

K. R. Freeman

(2) Flounder Studies. The winter flounder *(Ps. americanus)* is a near-shore Atlantic species that has been fished commercially in the U.S.A. since the late 1800s. In view of its established place as a food fish and its local abundance, it may have potential for cultivation for commercial purposes. As little is known of the growth characteristics of this animal, a preliminary study of its growth was begun using juvenile stocks from two widely separated locations in the Maritimes. The study is intended to determine the capability of this animal to adapt to conditions of captivity, and to feed and grow under these circumstances. In addition, the study may illustrate growth differences, if any, between the genetically isolated stocks.

K. R. Freeman

Growth chamber for productivity studies of Mya arenaria *illustrating 15 millimetres growth over winter. (AOL 3509-5.)*

(3) Oyster Studies. In preparation for a quarantine laboratory study of the potential for the spread of the Malpeque disease of oysters to Cape Breton, so far uninfected, a two-year histological study of susceptible oysters held in Prince Edward Island, where the disease is endemic, has been completed. This shows a drastically different result, especially in the rate of development of recognizable infection, from identical studies carried out 15 years ago, when apparently typical epidemic mortalities were observed.

This presumably reflects the contrast between endemic and epidemic situation and results from differing levels of concentration of the infection agent. The results have important consequences on the planning of the proposed quarantine study and also on our understanding of the disease, its distribution in endemic areas, and the interpretation of earlier observations of the natural epidemic in eastern Canadian oyster populations.

Analysis of oyster samples from a number of areas in Cape Breton shows a wide variation in the pigmentation of the mantle. A number of degrees of pigmentation have been recognized, the distribution of which varies widely between populations. Shell pigmentation and gross mantle pigmentation show little or no correlation. Light has been shown to be an important factor in the development of the black pigments, presumably melanins.

The distribution in Cape Breton of *Urastoma,* a turbellarian commensal on the gills of the oyster shown in Prince Edward Island to be associated with mortalities of transplanted oysters, has been investigated. The animal is abundant and widespread; it is present in all areas used for seed production. The previously undescribed reproductive phase of this animal has been discovered in the gut of oysters in the winter hibernation period.

The European Flat Oyster *(Ostrea edulis)* was introduced to eastern Canada by hatchery breeding from adults of a Dutch stock held in quarantine in 1969. The final phase of experimental field evaluation of this species is now under way. Stocks of the third hatchery-reared generation are being held under observation in four sites in Nova Scotia and one in Prince Edward Island. The species continues to show great commercial promise. Growth and survival have been excellent. Gonad maturation and spawning appear to be normal and in phase with native molluscan species. Regular histological examination has detected no parasites or disease symptoms.

R. E. Drinnan

(4) Aquaculture in Cape Breton. Nineteen-seventy-four is the third year of an aquaculture development program in Cape Breton, sponsored by the Cape Breton Development Corporation. Conception and co-ordination of the technical input and field direction of the research program have been provided by a staff member of MEL.

Commercial-scale production is now well advanced with both molluscan and fish species. Apart from direct input to the technology of such production and its attendant problems, a broad-based research program is aimed at definition of the potential of the restraints on development and provision of a basis for maximum ecologically responsible and economically viable production. The relevant biology of a number of target species is under study, and the physical, chemical, and biological parameters of the marine areas of interest have been described.

Organic detritus has been identified as an important source of food for molluscan filter-feeders. The demonstrated low levels of planktonic primary production associated with low nutrient levels suggest a considerable potential for increased secondary production through controlled fertilization.

R. E. Drinnan

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Atlantic Geoscience Centre
Geological Survey of Canada
Department of Energy, Mines
and Resources
1973/74

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B. D. Loncarevic

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  B. Ft. Pelletier

- **Eastern Petroleum Geology**
  L. P. Purcell

- **Environmental Marine Geology**
  D. E. Buckley

- **Regional Reconnaissance**
  D. I. Ross

Support

- **Program Support**
  K. S. Manchester

- **Administration**
  R. A. Eden

[1]Organization of Centre as of December 1974.

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Director's Remarks

Scientific surveys and data gathering are the backbone of geoscience. Since the early sixties, the major thrust of government agencies responsible for offshore programs has been the collection of a data base. Canada has taken an early lead and remains in the forefront with offshore multi-disciplinary hydrographic-geophysical surveys. As a result of these surveys, a folio of charts at a scale of 1:250,000 is in preparation. To date (October 1974), 72 bathymetric, 33 magnetic, and 34 gravity (free air anomaly) charts have been issued. In addition, all the data points used in the preparation of these charts have been released in digital format on magnetic tape. This is a long-range program initiated 10 years ago. If the momentum of the program is maintained, by the end of the century Canada will have the best mapped continental shelf in the world.

Surficial and bedrock mapping is proceeding in parallel with the above program. Careful analysis of echo sounding and high resolution seismic reflection records is combined with selective sampling of surficial sediments to produce interpretative maps. A number of sheets have been published covering the Nova Scotia continental shelf and parts of the Grand Banks of Newfoundland. A part of the surficial studies is the evaluation of terrain sensitivity with respect to pipeline construction, pollution of beaches, dredging, dumping, etc. Studies of pipeline crossings in the Arctic and of beach morphology and dynamics around the southern Gulf of St. Lawrence are in progress. This field of research is picking up momentum.

A major contribution to the knowledge of offshore geology has been the spin-off from offshore oil exploration. For resource inventory purposes, the offshore industrial geoscience data are available to the Federal Government. The samples from offshore wells are curated by the Government and are made available for study by qualified scientists two years after the completion of a well. During 1974, nineteen wells or 60,000 metres of stratigraphic data on the east coast of Canada have been released. The Geological Survey of Canada (GSC) is establishing a biostratigraphic reference system for the east coast and is compiling and integrating all the available data as a part of the Basin Analysis Program. Some of the results of these studies as well as studies by universities and industry were presented at the International Symposium on 'Canada's Continental Margins and Offshore Petroleum Exploration' held in Calgary, Alberta, September 29 to October 2,1974.

Despite these advances, Canadian marine geoscientists suffer from a lack of scientific exchange and interchange schemes. This is especially true for younger scientists who are often trained in a rather parochial atmosphere. One of the reasons for this is the absence of global oceanographic expeditions originating from Canada. Only two Canadian scientific expeditions have ventured outside the North Atlantic and Northwest Pacific Oceans (HUDSON-70 circumnavigation of the Americas, and the *Parizeau* voyage to Japan in 1972).

Another big gap in the Canadian program is the weakness and paucity of research projects in the coastal zone. Canada has failed to develop an ambitious and well-supported program of research in this zone. As pressure on the environment from industrial activities increases, as recreational demands expand, and as the public becomes more conscious of the need for conservation in the littoral zone, the present gap in the Canadian program will become even more obvious.

The weakness of Canadian deep-ocean geoscience is impairing our ability to play an active role in the search for and eventual exploitation of deep-sea mineral deposits. This rapidly expanding activity is dominated at present by the U.S.A., Germany, Japan, and France. A major mining nation like Canada will experience economic dislocation if deep-sea mineral exploitation becomes an economic competitor to conventional, land-based mining.

The list of weaknesses includes a concern for the availability of modern research ships. The existing fleet is fast becoming obsolete. Even if a construction program were initiated tomorrow, a major research ship would not be available before 1979.

People are our most important resource. Today, the GSC employs approximately 60 professionals who are working on problems offshore. Other government agencies may employ 20 professionals and it is possible that the provinces engage another 10. There may be as many as 50 professionals in universities (including graduate students). An estimate of the total number of professionals in Canada engaged in marine geoscience would not exceed 150 (excluding those working directly in industry).

The noted geologist, Sir Edward Bullard, when asked by a funding agency to present a 4-year plan of research, retorted: “If I knew what I was going to do in four years’ time, I’d do it now.” Nevertheless, consideration of outstanding problems, of the strengths and weaknesses of ongoing programs, and of the availability of resources inevitably leads to selection of some topics and activities and rejection or postponement of others.

The Canadian marine geoscience program is strong in scientific data collection and mapping, in basin analysis and regional geological synthesis, in petrology of deep-sea crustal rocks, and in some aspects of environmental geology. The program is weak in the development of conceptual models and synthesis, in coastal zone research, in the study of the engineering properties of sediments, and in instrument development.

An inventory of outstanding problems could be the starting point for the planning process. Such an inventory can be compiled after a wide canvass. A small selection of the problems to be studied might include the following:

- The mechanisms, timing and place of continental break-up and reconstruction of pre-drift fit
- The nature of tectonic processes associated with the break-up
- The nature of the deeper crustal structure at the continental margin (transition zone)
- The origin of deep-seated evaporites and the nature of diapirism at the base of the continental slope
- The nature of unconformities within the sedimentary sequence on continental shelves
- The source and nature of continental shelf sediments and neritic zone sedimentary processes
- The engineering properties (consolidation, mobility) of surficial sediments
- The geochemical flux through the water-sediment interface

While a scientist can perceive the problems, it is society that decides on priorities through its adopted political mechanism. A scientific organization must be responsive to society as well as to the beckoning of the unknown and the need to challenge the boundaries of scientific knowledge. It is this balanced appreciation of all social influences that is the cornerstone of well-managed, well-supported, and successful scientific programs.

B. D. Loncarevic

Eastern Petroleum Geology

Eastern Petroleum Geology directs its main efforts towards:

- Geological investigations of the sedimentary basins of eastern Canada in the onshore and offshore areas
- An analysis program of these basins that will facilitate an assessment of resources, especially oil and gas potential

To meet these objectives individual and co-operative scientific programs are carried out in the following areas (see map next page): (1) the Mesozoic and Cenozoic basins that lie along the continental margins of Eastern Canada from Georges Bank to Baffin Bay, an area of nearly 2,560,000 square kilometres, (2) the upper Paleozoic (Late Devonian to Permian) basins of the Atlantic Provinces, Gulf of St. Lawrence, Grand Banks, and Northeast Newfoundland Shelf, an area of 512,000 square kilometres, and (3) the Lower Paleozoic basins, including the St. Lawrence Platform, which contain Lower Paleozoic rocks (Cambrian to Devonian) in a 256,000 square kilometre area, and the Hudson Platform and adjacent southeast Baffin Shelf, which comprise the onshore-offshore Lower Paleozoic rocks (Ordovician to Devonian) in a nearly 1,200,000 square kilometre area.

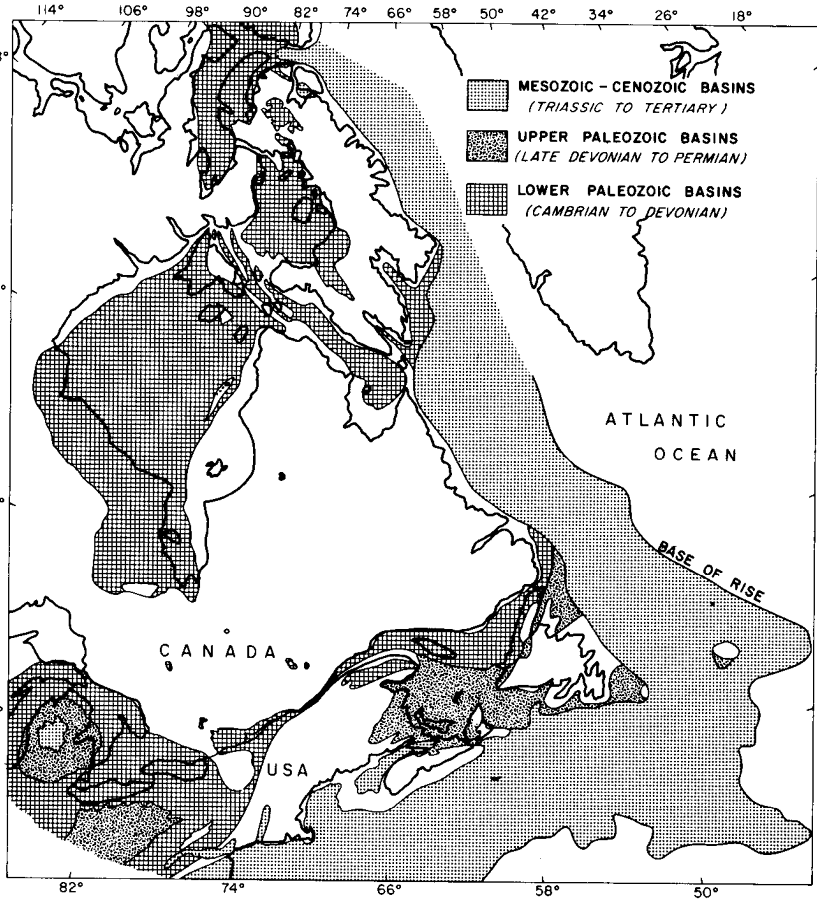
Projects are underway in each of the above areas but the degree of work varies significantly with the hydrocarbon potential of the area. These projects cover many geological disciplines and are co-ordinated, one with the other, to make the best use of the manpower available and to meet the demands placed on the Subdivision. Biostratigraphers, lithostratigraphers, geophysicists, and petroleum geologists combine their efforts in an integrated basin analysis program. However, some scientists also pursue more independent lines of research to the benefit of their particular discipline and, ultimately, to the basin analysis objectives.

Mesozoic-Cenozoic Basins - Atlantic Margin

This area (see map) is currently recognized to have most of the hydrocarbon potential and as a result much of our effort is concentrated here.

Our biostratigraphical studies in this area are aimed at the recognition of stratigraphically successive microfossil assemblages (zonation) 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 (age). The shelly and organic-walled microfossils also provide clues to the environment of deposition of the rocks in which they are embedded.

To date we have established a comprehensive Middle Triassic to Quaternary biozonation of the Grand Banks and Scotian Shelf subsurface with an interpretation of environment of deposition and rates of subsidence and sedimentation. More basic lines of research are pursued in the systematics of Jurassic-Early Cretaceous foraminifers (larger foraminifers, protoglobigerinids, and epistominids) and calpionellids, and in the systematics and paleoecology of dinoflagellates.

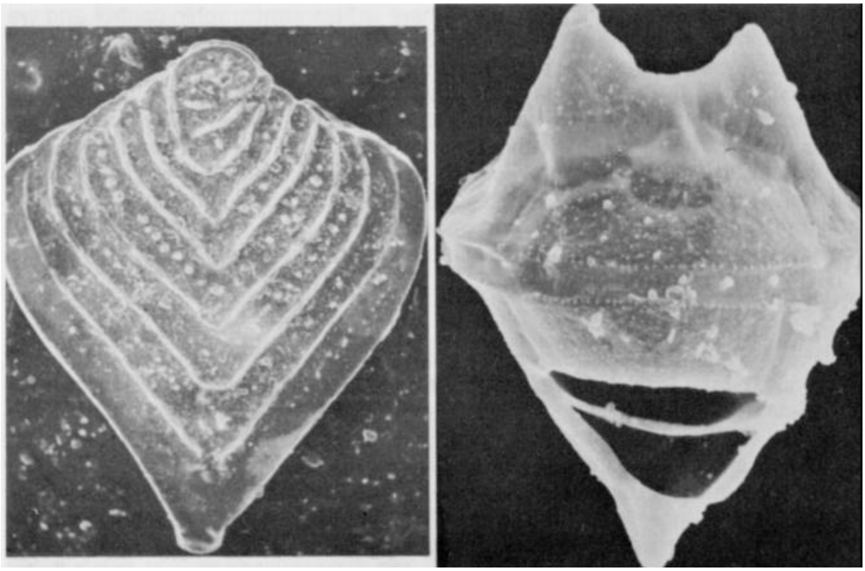


Sedimentary basins of eastern Canada and adjacent areas. (AOL 3573.)

An interesting offshoot of the biostratigraphic work is the study of the geographic distribution of Triassic to Quaternary fossil assemblages as found in the continental margin. The degree of affinity of the above assemblages to European and other North American assemblages of the same age may help interpret the relative positions of the paleo-continents and the paleo-circulation in the North Atlantic Ocean. The warmer and colder water pelagic species found in the continental margin provide insight into the paleo-Gulf Stream and paleo-Labrador Current patterns, and the paleoclimates.

Because of the current interest in the hydrocarbon potential on the Labrador Shelf, we are planning to continue the biostratigraphic and environmental interpretation of this area as data become available.

Lithostratigraphy and Sedimentology. In close co-operation with the biostratigraphers, the Mesozoic and Cenozoic lithostratigraphic units for individual wells on the Scotian shelf and Grand Banks have been established and a well-to-well correlation completed. The units were established from the study of mechanical logs, cores, and samples from about 60 wells. Once correlations were established



Left: Neoflabellina rugosa *(d'Orbigny), an Upper Cretaceous foraminifera from the Grand Banks magnified 700 rimes. Right:* Deflandrea phosphoritiea *Eisenack, an Eocene dinoflagellate from the Grand Banks magnified 800 times.*

on mechanical logs, a series of maps was prepared in which depositional environments are reconstructed and thickness, lithology, and sand-shale ratios are plotted. A detailed study of potential carbonate reservoirs is currently in progress. Reconnaissance field work in coastal Mesozoic basins of Morocco was initiated and stratigraphical and paleontological data were obtained. Preliminary results indicate that a genetic relationship of stratigraphical sequences and tectonics exists on the Canadian Atlantic and Moroccan margins that can best be explained in terms of continental drift.

Geophysics and Subsurface Geology. Analysis of deep reflection seismic data is being carried out continuously to facilitate our subsurface geological studies. Biostratigraphy, lithostratigraphy, geophysics, and petroleum geology are effectively integrated to complete our basin analyses.

The Scotian and East Newfoundland Basins have been major active centres of deposition, at least since the Late Triassic, and each has accumulated in excess of 10 -12 kilometres of sedimentary fill. These basins are separated by a large post-Jurassic structural element - the Avalon Uplift - that underlies the Grand Banks. Within these areas sedimentary rocks representing seven systems from Late Devonian to Pleistocene have been indentified overlying a metasedimentary and igneous basement complex. Post-Paleozoic sedimentation has occurred in three major cycles: a Triassic-Lower Jurassic red bed and evaporite cycle, followed by a Middle and Upper Jurassic marine shale/carbonate cycle, and, finally, a Cretaceous-Tertiary, paralic to marine, elastic cycle. The distribution and facies of the Mesozoic-Cenozoic sequences in the Scotian Basin relate to the opening of the central North Atlantic Basin in the early Middle Jurassic.

In the Labrador Sea - Baffin Bay area, there is little stratigraphic control and we must rely on the analyses of geophysical data. The seismic data indicate that thick sedimentary sequences are present and these are probably of Cenozoic and Mesozoic age. It is believed that Paleozoic rocks extend northward from Newfoundland along the Labrador coast, but their extent is highly speculative. Pending stratigraphic control in this area, it appears that the structural style of the continental margin is best explained by differential vertical movements of continental crust. It also appears that continental crust may extend further seaward than previously expected and that marine sediments of Mesozoic age (and possibly earlier) are present, at least in the Labrador Sea area.

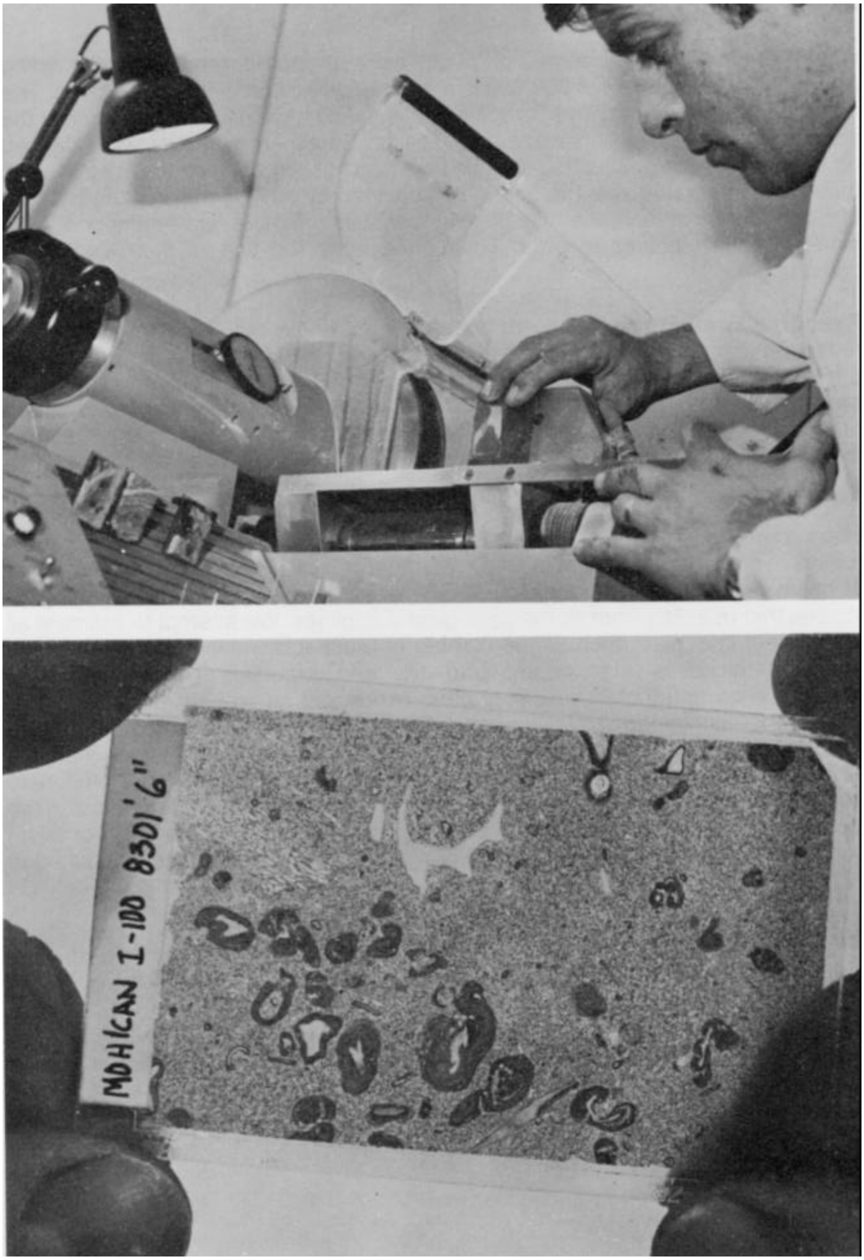
Upper Paleozoic Basins

Surface and subsurface studies of the basins in the Atlantic Provinces, Gulf of St. Lawrence, Grand Banks, and Northeast Newfoundland Shelf make excellent use of biostratigraphic zonations from fossil spores to sort out stratigraphic complexities. Cross-sections and isopach, paleogeographic, and facies maps have been prepared to show the distribution of the sedimentary Upper Paleozoic rocks, which attain thicknesses of greater than 9000 metres in some areas. Our basin analysis suggests that the continental collision of Africa with North America and Europe during Upper Paleozoic time resulted in uplift, folding, faulting, and granitic intrusion in an area of over 770,000 square kilometres in the Atlantic Provinces, Gulf of St. Lawrence, and continental shelf east of Newfoundland and Nova Scotia. As the effect of this (Acadian) orogeny decreased, differential subsidence formed a complex series of northeast-trending basins. Late Middle Devonian, Upper Devonian, and Early Mississippian Piedmont and fluvio-lacustrine sediments of the Horton Group covered or partially filled depressions of the orogen. During the last Mississippian Epoch, the area continued to subside thus permitting the advance of the Windsor Sea. Restricted circulation resulted in the accumulation of Windsor Group evaporites until near the end of Mississippian time when renewed uplift expelled the Windsor Sea and continental sedimentation occurred throughout the Pennsylvanian into the early Permian Epochs.

Lower Paleozoic Basins

The St. Lawrence Platform and the Hudson Platform. On the basis of detailed and broad regional studies carried out to date in the Hudson and St. Lawrence Platforms and intervening Lower Paleozoic outliers, it is possible to reconstruct the probable paleogeographical limits of epicontinental seas and to reconstruct local and regional tectonic events that directly affected the processes of sedimentation. The latest compilation of Lower Paleozoic rocks has integrated the geology of both areas. It appears that during the Lower and Middle Paleozoic (Cambrian to Devonian Epochs) there were at least nine transgressions of epicontinental seas onto and eventually extending across the craton.

As an extension of these studies, a regional synthesis outlined the tectonic and depositional evolution of parts of the Appalachian, Caledonian, and Variscan orogenic belts and adjacent cratonic areas in eastern Canada, northeastern United States, western Europe, and northwestern Africa. The evolution is consistent with the concepts of global tectonics. We believe this work will facilitate the economic evaluation of the Paleozoic sedimentary basins of the onshore and offshore areas of these regions.



In the upper photograph, a technician is preparing a thin section of a well core from the east coast offshore. (AOL 3548) The resulting thin section is ready for petrographic examination. (AOL 3568)

Other Projects

Regional Mapping. A series of maps were prepared (and are now being published) at a scale of 1:2,000,000 in a co-operative effort of the Subdivision. The maps depict the surface physiography, geology, and basement configuration of the various onshore-offshore sedimentary basins. Basement contours were defined on the basis of deep-reflection seismic data purchased from industry. The seismic data were integrated with the field data collected by other groups of the Bedford Institute of Oceanography. Geological contacts offshore were mapped from high-resolution seismic records. These maps are the first of their kind to be constructed.

Resource Evaluation. Our basin analysis program as outlined above is closely related to resource evaluation. Although advice is often given on other resources, our main work is estimating the hydrocarbon potential of the sedimentary basins of eastern Canada. The work involves the identification of potential hydrocarbon prospects or ‘plays’ and the determination of the effectiveness of trap, seal, source rock potential, and preservation within each prospect or play. It is a co-operative effort with several agencies within the Government of Canada that provide representatives to a Subcommittee on Geological Potential. During the past two years there has been a significant improvement in our methodology, which now relates hydrocarbon potential to an assessment of oil and gas ‘plays’ within a basin or basin segment. ‘Plays’ are identified, where possible, from routine geological studies that use data from all the geological disciplines. We attempt to estimate all parameters in a ‘play’ such as the number of prospects within it, its areal extent, reservoir thickness and depth, trap fill, and porosity. These and other oil-occurrence parameters are most often expressed as probability distributions, which, when combined in a computer program using a Monte Carlo method, give the unrisked potential of the basin. We combine our estimate of marginal probability in the same program to produce a probability distribution of the ultimate recoverable potential for that play. The individual play curves are added using the Monte Carlo technique to produce a probability distribution for the basin or basin segment. The first detailed evaluation of hydrocarbon potential was completed in 1974.

(See also the essay “Micropaleontology and the Search for Offshore Oil” by Felix M. Gradstein in Ocean Science Reviews, Part D of this Biennial Review.)

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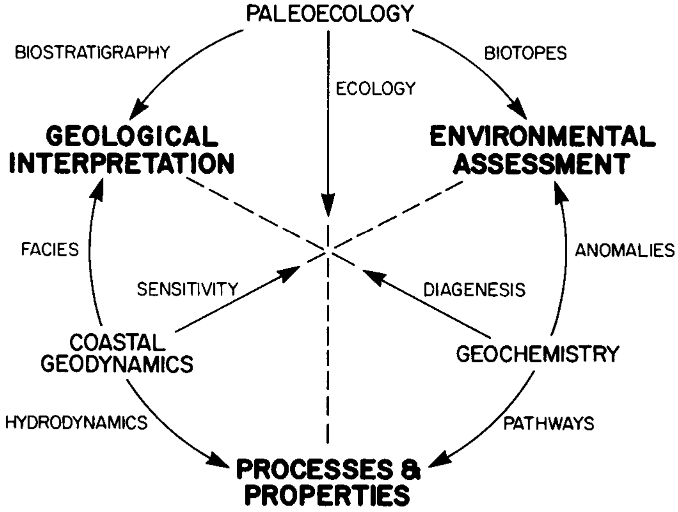
Environmental Marine Geology

The main research activities of Environmental Marine Geology include:

- Development of qualitative and quantitative methods of geochemical and paleoecological analysis
- Studies of the chemical nature and reactivity of organic compounds in contemporary marine environments
- Studies of the distribution and migration of metals in marine waters and sediments
- Studies of the distribution, evolution, and ecology of post-Pleistocene foraminifera and Mollusca
- Studies of sediment hydrodynamics in coastal zones
- Environmental analyses of coastal areas
- Studies of organic compounds in ancient sediments to help determine the hydrocarbon potential of offshore sedimentary basins

With the reorganization of the Atlantic Geoscience Centre late in 1972, the Environmental Marine Geology Subdivision came into being. This new subdivision was founded on the basis of the expertise developed in the fields of paleoecology, marine geochemistry, and coastal geodynamics.

Research that had been conducted in co-operation with other components of the Atlantic Geoscience Centre, the Geological Survey of Canada, and the Bedford Institute of Oceanography emphasized the need to understand the significance of contemporary processes in controlling the quality of the contemporary environment as well as in defining paleoenvironmental conditions and trends. The central theme of Environmental Marine Geology has thus become the integration of multi-disciplinary research teams to investigate contempory processes. The objectives are to define potential environmental hazards due to the impact of man's utilization of ocean resources and to improve our interpretation of the



Scientific integration of the Environmental Marine Geology Subdivision. (AOL 3571.)

mechanisms that gave rise to geological features and resources. This endeavour has provided a unique challenge to the individual scientists and technicians of the Subdivision and has required new scientific and technological approaches.

The scientific integration of Environmental Marine Geology is conceptually depicted in the schematic diagram. The three disciplinary groups (paleoecology, marine geochemistry, and coastal geodynamics) are linked by the sharing of research objectives and information as represented by the arrows in the schematic illustration. The results of this integrated effort are used to make an assessment of the environmental impact of modifying the natural processes in a coastal zone or estuary and sometimes to improve geological interpretations of ancient environments. In the following paragraphs our activities are discussed under: (1) Process and Properties Studies, (2) Environmental Analysis, and (3) Geological Interpretations. These headings were chosen because they emphasize the natural interrelationships between discipline groups.

Process and Property Studies

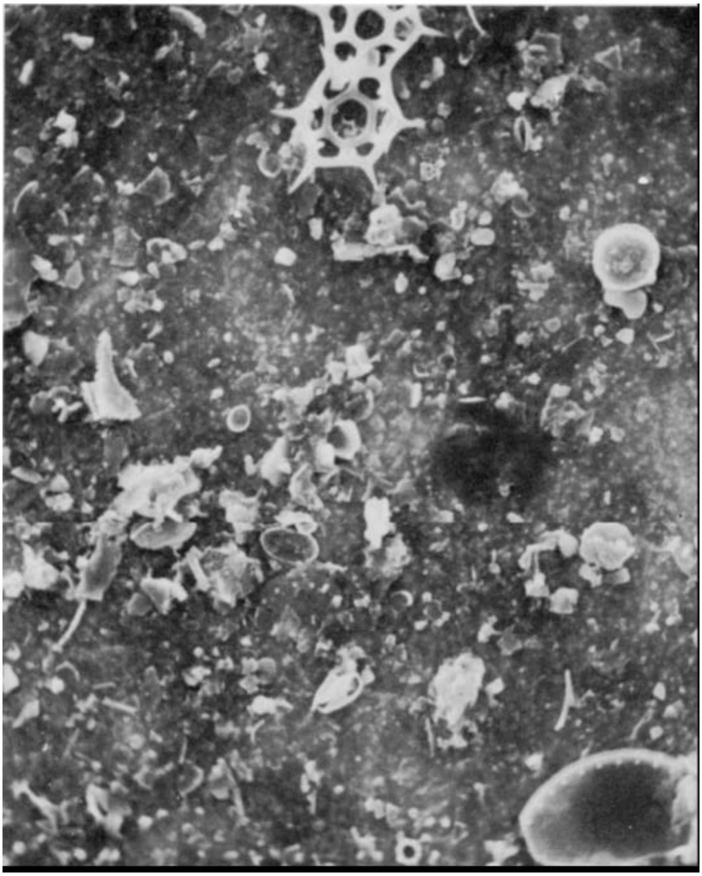
Organic geochemical research on the nature and distribution of natural organic compounds in marine sediments has confirmed the important influence these compounds exert on the physical and chemical nature of marine sediments. The complex nature of humic compounds and their role in effecting the release of metals, formation of metal complexes, biological productivity, and diagenetic transformations of marine sediments have been revealed by organic geochemical investigations. It was demonstrated that each gram of humic acid isolated from a marine sediment is capable of complexing from 40 to 200 milligrams of transition metals; the greatest affinity shown was for copper. Natural peat moss, which contains an abundance of humic compounds, was found to absorb a maximum of 29 milligrams of zinc per kilogram of moss, and lesser quantities of Cu and Fe, from sea water.

The geotechnical properties of marine sediments are significantly influenced by organic material. A series of tests conducted on remoulded fine-grained sediments indicated that all Atterburg limits increased with increasing organic content. Remoulded shear strength and compressibility were greater in sediments containing organic matter as compared to those in which organic matter was absent or at a low concentration. Field investigations in the Strait of Canso revealed that sediments have a reserve resistance to shear and one-dimensional consolidation; this was attributed to chemical alteration and the effect of organic compounds.

Studies of Recent sediments obtained from the continental shelf off Labrador and local basins in the Gulf of St. Lawrence have shown that under conditions of rapid deposition followed by anaerobic or fermentative degradation of organic matter, methane is produced and trapped in the shallow sediment layers at concentrations up to 16,000 parts per million. These depositional environments are excellent for the preservation of diverse foraminiferal assemblages.

(See also the essay “The Importance of Organic Compounds in Geological Oceanography” by M. A. Rashid in Ocean Science Reviews, Part D of this Biennial Review.)

Inorganic geochemical investigations have continued to emphasize the mechanisms of geochemical equilibrium affecting the distribution and migration of



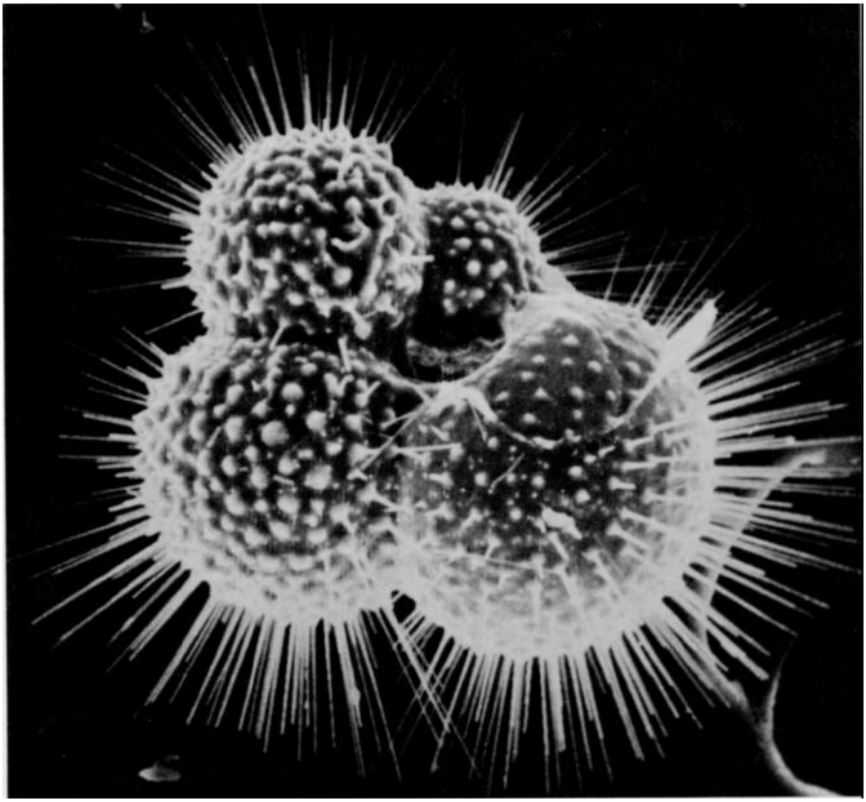
Scanning electron micrograph magnified 500 times of suspended matter (biogenic and mineral particles) from the Gulf of St. Lawrence.

metals in the marine environment. These investigations have included detailed research on analytical methods for the detection and characterization of trace metals in aqueous media by means of atomic absorption spectroscopy. Considerable data have been compiled on the distribution of metals in water and sediments from the Strait of Canso and Chedabucto Bay and from Chaleur Bay.

As a result of co-operative research between Environmental Marine Geology and Environmental Quality (Marine Ecology Laboratory), the concentration and distribution of total dissolved mercury in sea water from the North Atlantic were investigated. This work underscored the need for valid analyses on samples immediately after their collection in order to determine the concentration of total metal accurately. The results showed that nearshore concentrations were significantly higher than those at great distances from the land; this implies that significant amounts of mercury are being added to the oceans from the land.

Basic research on the geochemical interactions between suspended sediments and water has been undertaken. It was found that large amounts of suspended particulate matter can alter the pH as well as the dissolved silicon and calcium concentrations of sea water. In coastal marine waters, the control of pH is by means of equilibria that involve the total ionic strength of the water as well as the particulate and dissolved silicon and calcium. In fresh and brackish water, the pH is controlled to a large extent by the silicate in solution. These fundamental equilibria must be understood if we are to reconstruct the evolution of sea water, and assess the geochemical impact of high turbidity water dispersed into coastal environments.

Paleoecological and micropaleontological studies during the period covered by the Review have ranged over wide geographic areas and varied environments. The occurrence and distribution of Holocene benthonic foraminifera in the bays of St. Lucia Island in the Caribbean Sea, and the carbonate lithogenesis of foraminifera-rich sediments from the Mid-Atlantic Ridge, were studied. Studies of foraminifera in arctic waters and sediments have been continued and combined with studies of distribution of Mollusca. The most recent studies have been focussed on investigations designed to produce a better and more detailed understanding of the life environment of certain fossil-forming groups, such as the planktonic and benthonic foraminifera, Mollusca, and Ostracoda.



Scanning electron micrograph of a planktonic foraminifera, Globigerina bulloides, *magnified 360 times.*

Recent morphological investigations of planktonic foraminifera have been greatly enhanced by the use of the scanning electron microscope. Taxonomic classifications have been resolved by detailed examination and photomicrographic evidence. Detailed investigations of the spinal ultrastructure of planktonic foraminifera suggest that morphological variations reflect genetic codes. These subtle codes are useful in tracing the functional evolution of the animal and they can be useful for paleoenvironmental interpretations or biostratigraphic zonation in ancient sediments.

The response of sediment movements to hydrodynamic forces in the coastal zone is a process of primary interest in studies of coastal geodynamics. The majority of projects undertaken during 1973 and 1974 have emphasized the relationships between littoral processes and morphodynamics (the change in geomorphic features, such as beaches, bars, and bed forms as a result of wave and current action). Nearshore studies of this type were undertaken along the coastline of the southern Gulf of St. Lawrence. Specific investigations of the effect of winter ice on the littoral zone processes in parts of the southern Gulf of St. Lawrence revealed that the ice acts as a barrier to along-shore movement of sediments during winter but causes some local development of ridges and furrows parallel to the shoreline. These ridges and furrows are rapidly dissipated as the ice melts in spring. As a result of extensive reconnaissance and some detailed studies of the southern Gulf of St. Lawrence, a coastal-environment classification has been developed that describes coastlines in terms of 10 orders of geomorphological and sedimentological features, from glocal (1) to micro-environmental (10). The southern Gulf of St. Lawrence was described as a fifth-order subdivision. It is a microtidal environment characterized by a low physiographic relief that is dominated by storm wave processes. Within this fifth-order environment, the northeastern coast of New Brunswick, parts of Prince Edward Island, and the Magdalen Islands are dominated by the development of barrier island coastlines. The sediment supply for these barrier beaches comes mainly from the offshore areas of the open Gulf.

Sediment dispersal studies were carried out in the Bay of Fundy, Beaufort Sea, and Baffin Bay-Davis Strait areas. In the Bay of Fundy, sediments and their derived textural parameters such as elastic ratios, moment measures, and sorting are distributed in transverse bands across the Bay. The bands outline areas of greater and lesser hydrodynamic vigour and are important for any evaluations dealing with construction of tidal power dams in the area. In the Beaufort Sea, the distribution of recent sediments (mostly fine-grained clays and sands) reveals that the modern sedimentary discharge from the Mackenzie River drainage system is depositing a blanket of fine sediments over ancient sands, which are probably of beach or inshore origin. These studies are important because of the environmental and engineering aspects that must be considered in advance of the proposed exploratory drilling in 1976. In a geological study of Baffin Bay-Davis Strait, it was shown that the classical dispersal pattern of coarse sediments nearshore and fine sediments in the deep central basin is modified somewhat by ice-rafted deposits along inshore areas.

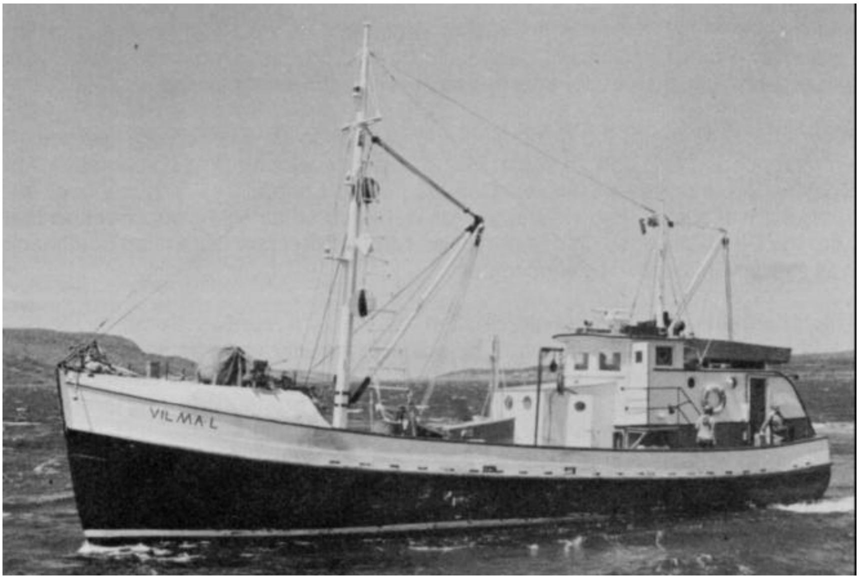
Environmental Analysis

A number of studies have been conducted by all discipline groups within Environmental Marine Geology to determine the imprint of environmental quality on the geological record. The environmental analyses are heavily dependent on the availability of good baseline data that must be gathered in contemporary environments where the geological processes are well understood. Only on this

Upper photograph: west coast study area, Magdalen Islands, P. Q, August 1974 (AOL 3242-1A) Lower photograph: beach profiling, Magdalen islands, November 1974. (AOL 3336-13)

basis is it possible to measure the impact of changing conditions or the effect of pollution on the quality of the environment.

The major project carried out by Environmental Marine Geology in the period of this Review was a comprehensive environmental analysis of the Strait of Canso and Chedabucto Bay, Nova Scotia. This integrated multidisciplinary project was designed to establish: (1) the effects of a causeway on the marine environment, especially on the distribution of sediments and benthonic ecosystems, (2) the impact of urban and industrial development and waste disposal, as measured by environmental quality surveys including chemical, biological, and sedimentological parameters, and a comparison of paleoenvironmental and present-day indicators, (3) the degree of restoration of the beach and nearshore environments of Chedabucto Bay from the Arrow oil spill of 1970, and (4) the geotechnical properties of bottom sediments in the Strait of Canso for use in planning future development. The results of the study have indicated that the Strait now resembles a bisected fjord. There are differences in the sedimentology and benthonic ecology between the northwestern and southeastern portions of the Strait. Effluent



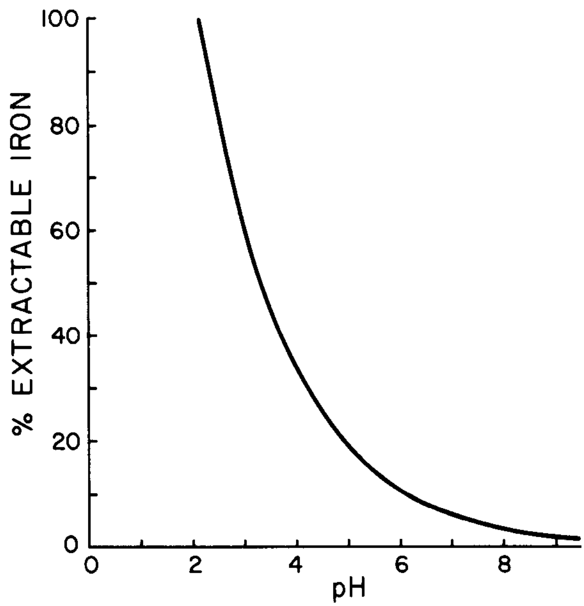
The Vilma L, shown cruising in the Strait of Canso, was the vessel used to carry out research in the Strait and Chedabucto Bay in 1973. For location map, see Environmental Quality, MEL. (AOL 2835-157)

Sawing through the protective core barrel prior to removal of the Canso Strait sediment core within. Later these cores were subjected to various chemical analyses. (AOL 2835-235 and - 169) discharges in the Strait affect the water quality and have produced geochemical and biological anomalies in the recent sediments of the Strait southeast of the causeway. Some beaches in Chedabucto Bay are gradually recovering from the oil spill of 1970, but the few low-energy beaches remain contaminated.

A dynamical model of the dispersion and interaction of water quality parameters with suspended and bottom sediments is under development in co-operation with Coastal Oceanography (Atlantic Oceanographic Laboratory). The concept and application of such a modelling approach were carried out using geochemical data from the Strait of Canso. In this particular case, mixing and dispersion of effluents was strongly influenced by wind forces.

The aftermath of beach contamination by oil is a serious threat to coastal environments, especially in areas adjacent to heavily used shipping terminals. Some emergency clean-up operations can cause considerable damage to the stability of beaches and this damage can have more pronounced long term effects than the original oil contamination. Geochemical studies of residual oil on the beaches of Chedabucto Bay have shown that the Bunker-C oil is degraded most readily by physical processes and chemical oxidation on beaches where the sediments have a sandy texture and are exposed to high wave energy. Protected shorelines, such as lagoons, contained oil for up to three years after the spill, and the character of this oil remained virtually unchanged.

The quality of environmental data has continued to be a major concern of all researchers. Considerable effort has been applied to verifying chemical data through intercalibration experiments and by careful review of existing data banks. A careful review of analytical methods has shown that some techniques previously used in environmental studies may have provided misleading results. Two



Relationship between pH and ‘active metal’ in sea water. If the water sample is acid, more ‘free’ metal is made available for extraction and potential reaction. (AOL 3571.)

examples of this type of problem have been intensively studied: (1) chelation and solvent extraction techniques for the concentration and measurement of trace metals in sea water and (2) staining techniques for distinguishing living from non-living foraminifera (described below).

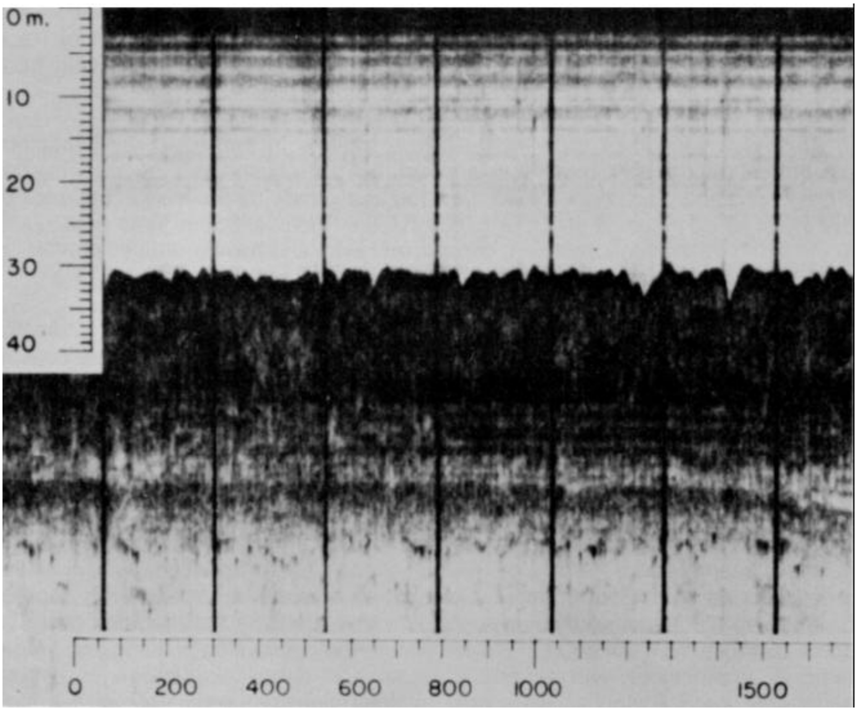
In the determination of trace metal concentrations in sea water by chelation-solvent extraction techniques, it was found that pH adjustments made during the storage and analysis stages could affect the analytically determined abundance of the metal by as much as an order of magnitude. Such variations were particularly acute in the determination of iron, copper, and zinc, and have produced conflicting data in intercalibration experiments.

The identification of living foraminifera is important because these indicator organisms reflect the degree of environmental stress existing in sensitive coastal areas. A Sudan Black B stain was found to be superior to the previously used rose Bengal stain to distinguish living from non-living foraminifera. A new staining technique consistently marks the lipid content of the protoplasm in numerous foraminifera tests and is not readily absorbed on non-living organic matter.

In surveys of the benthonic foraminifera distributions in Chaleur Bay, it was established that some species are sensitive to pollutants. In the extreme case, this sensitivity can result in total mortality of all species (all forms killed) as well as the creation of an abiotic zone. Slightly less extreme cases have resulted in a great diversity and abundance of species (hypertrophic species) in subnormal zones at some distance from the source. By correlating the distribution of living and empty tests of foraminifera with several physical and chemical qualities of bottom sediments, paleoecologists were able to determine that sediments with a high percentage of organic wastes from a pulp mill outfall also contained the lowest diversity and abundance of foraminifera. Similar relationships were also found in the Strait of Canso where the concentration of Zn in the sediments is proportional to the amount of sediment polluted by urban and industrial wastes. In these areas, the foraminifera populations tended to be more tolerant to stress than Mollusca or Ostracoda.

Other ways in which micro-organisms may be used to define contemporary and ancient environments have been studied. In some arctic waters of the Northwest Passage, it was found that the reproductive cycles of the planktonic species *Globorotalia pachyderma* can be arrested by certain adverse conditions. In some cases, specimens will secrete thick skeletal walls in response to adverse conditions. Under more optimum conditions, such as in the mixed waters of eastern Lancaster Sound and northern Baffin Bay, a thin-walled form developed but was dissolved soon after deposition on the sea bottom. In older arctic sediments that contain large numbers of the thickened robust form, the sedimentation rates were relatively low and the overlying waters were stratified and ice-covered for much of the year.

Sediment dispersal studies in the Beaufort Sea and on the Labrador Shelf have revealed that some natural processes such as ice scouring of the sea floor can pose a threat to underwater installations such as oil pipelines. A morphological study of the nature, distribution, and frequency of such scours has shown that furrows 1 to 10 metres deep are abundant in the inshore region of the Beaufort Sea continental shelf.



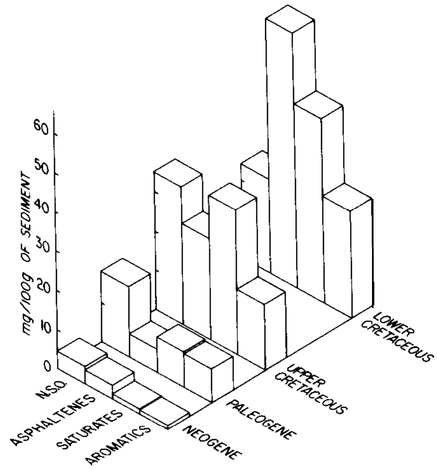
Echo sounding profile showing typical ice scours in the Beaufort Sea.

It is feasible that tidal power can be harnessed in the Bay of Fundy and consequently more emphasis is being placed on assessing the possible environmental hazards of such a major development. The first phase of a project to study the estuarine geodynamics of several estuaries around the Minas Basin has begun. This study will attempt to determine the mechanisms responsible for mud-flat development, especially in areas adjacent to recently constructed causeways. Past studies have emphasized the interaction between ebb and flood tide currents and the resulting bed forms of the intertidal sediments in Cobequid Bay, Minas Basin, Nova Scotia.

Geological Interpretation

One of the major efforts of the organic geochemistry work is to determine the nature and concentration of hydrocarbons in ancient sediments from the offshore areas of eastern Canada. Projects are designed to provide data that will contribute to the inventory of hydrocarbon resources. The basic geochemical data required for this objective are analytical determinations of the concentration of organic carbon and low molecular weight hydrocarbon gases (C_1 to C_4) in samples of well cuttings. This work began in 1972 and over 7000 canned (core cutting) samples from 33 different exploratory wells on the Scotian Shelf and the Grand Banks have been analyzed for gaseous hydrocarbons (C_1-C_4) and organic carbon.

High molecular-weight organic fractions (compounds with more than 15 carbon atoms) were also extracted from 400 selected samples from 8 wells. These hydrocarbon and non-hydrocarbon components were studied to determine the maturity of the organic matter and the quality of the source rock. Investigations are now being conducted to determine the influence of various geological and geochemical factors on the conversion of organic matter to hydrocarbons. These factors include overburden pressure, geothermal heat, time, rock matrix, and the nature of the early diagenetic transformations of the original material.



Concentrations of hydrocarbons and non-hydrocarbons with age.

Much of the research conducted in recent sedimentary environments can be considered to be contributing to improving geological interpretations. Examples of this type of interpretation include studies of the Quaternary sediments of the Bay of Fundy, of the Pleistocene sediments of the Mid-Atlantic Ridge, and of the Holocene sediments in Chaleur Bay.

A highlight of the Subdivision's work during the Review period was the publication of a volume on the offshore geology of eastern Canada (see Section E of this Review, Major Publications of 1973/74, Geological Survey of Canada Papers, Pelletier (1974)). The volume contains several papers by scientists of the Subdivision and a 12-year historical review that traces the growth in sophistication of instrumentation and data interpretation that has taken place and lead to the development of new scientific principles that can be applied to the solution of practical problems related to rational and economical development of natural resources.


Property of

Program Support

Program Support divides its efforts into three areas:

- Field project support
- System and equipment development
- Archival storage of marine geoscience data and geological samples

By far the major thrust of this group is towards the support of the field projects undertaken by the Atlantic Geoscience Centre (AGC). The group becomes involved in each project in the initial planning stages where it advises project leaders on survey guidelines. In the later stages of planning, Program Support assigns equipment and some of its personnel to each field project and draws up specifications for the acquisition of equipment. In preparing for each project, equipment is assembled, tested, and installed aboard ship or at the field site. Logistical support is also provided.

Program Support personnel work in the field, in liaison with project leaders from other AGC subdivisions, maintaining and operating equipment, providing special services, and collecting and processing data and samples.

Upon return from the field, equipment must be maintained, calibrated, and stored, data must be processed and stored, and samples must be curated and stored. Modifications are also made to equipment, or data and sample collection procedures, in the light of field experience.

The second major field of endeavour of Program Support is system and equipment development. Two examples of the many projects the group has worked upon are given below.

Flatbed Plotter Applications

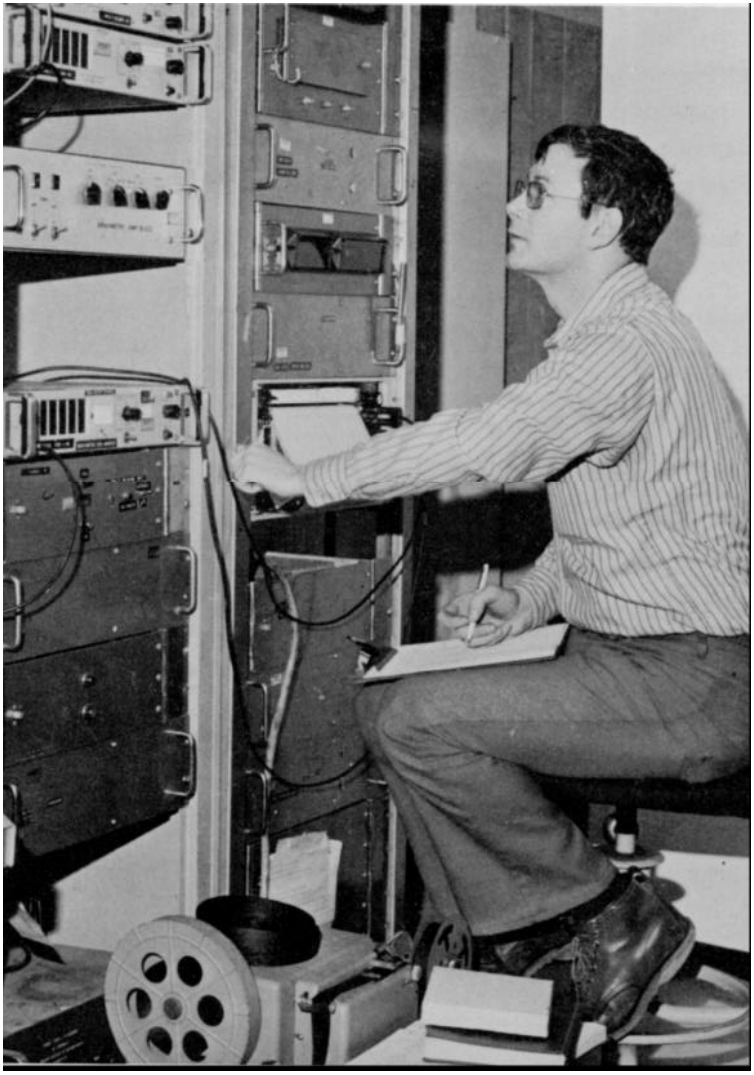
The purchase of an EAI 350 flatbed plotter early in 1974 has greatly improved AGC's data display potential. Prior to this, data were displayed on an early model EAI flatbed and a CalComp 630 drum plotter. The new flatbed plotter provides a better quality plot and is much faster than the older instruments when the symbol printer is used.

Program Support has developed software for posting any data recorded in a standard format at any scale of one of three map projections - Mercator, Lambert Conformal, or Universal Transverse Mercator. Very high quality data postings can be obtained using the pen option but a good quality plot can also be obtained in a fraction of the time if the symbol printer is used. When using the pen option, ship's tracks or geophysical measurement anomalies along the ship's track can be plotted at any scale in any of the three projections mentioned. Colour-coded plots can be obtained by using the plotter's four pens. Positive and negative anomalies can be more easily distinguished by using this feature of the plotter.

In the future, additional software will be developed to accommodate the changing needs of scientists at AGC.

Improving our Measurement of the Earth's Gravity

The decision to improve the method of gravimetry measurement was brought



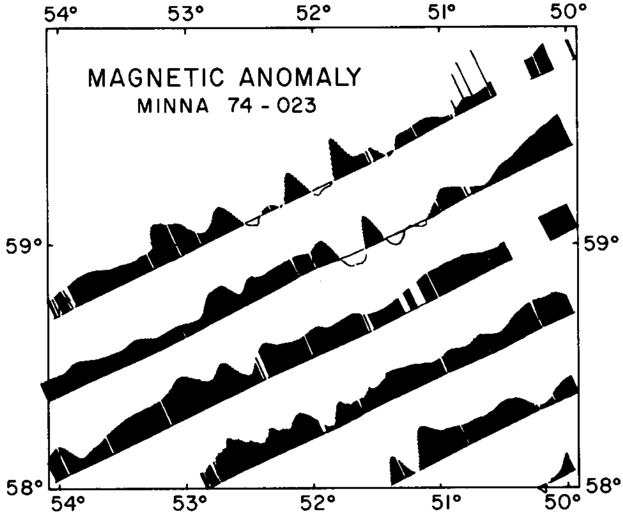
Field technologist comparing VCO counter readings of gravimetry equipment (left) against chart recorder output of data logging system (right). (AOL 3447.)

about by the many failures of a chart recording device that functioned in series with the data acquisition segments of the system.

In the old system the gravimeter's photocell beam current was amplified, integrated, and displayed on a two-channel chart recorder where retransmission potentiometers resolved a voltage proportional to the chart recorder pen-mechanism deflection. This voltage was used to control an oscillator in the voltage-controlled oscillator (VCO) chassis whose output was then counted by an electronic counter for a preset period of 50 seconds. The resultant of this counting was a Binary Coded Decimal (BCD) output, which was fed via programming to a data storage device (a paper tape punch or magnetic tape drive).

A new system has been developed in which the recorder is now only a monitor. The photocell output of the gravimeter is integrated, amplified by an operational amplifier, and fed to a VCO and chart recorder, which are in parallel. The output of the VCO is counted by an electronic counter and stored in BCD output as before. The output from a cross-coupling computer can also be fed into the system and the output of this second VCO can be digitized and stored. Built-in power supplies are used to check and calibrate the VCO and operational amplifier to ensure reliable data. All electronic filtering is identical to the original system.

The third major area of effort within the subdivision is in archival storage of marine geoscience data and geological samples. This involves the development and maintenance of systems for the storage and retrieval of data and samples. Three systems are in operation at present: (1) GEOFILE, (2) the Map and Document Storage and Retrieval System, and (3) the Seismic Profiling Data Indexing System. GEOFILE is used to store and retrieve geophysical, navigation, and bathymetric data. An example of its application is shown in the figure below where the magnetic anomaly data from Cruise Number 74-023 of the charter ship MV *Minna* are shown plotted in profile along the ship's track.



Computer-produced plot of measurements of the Earth's magnetic field using the ship's track as the abscissa of the magnetic anomaly profile. (AOL 3583.)

Other systems, which are in various stages of development, include GEOFILE 2, which will store and retrieve geological station data, the Well Data storage and retrieval system, and the geological sample curation system. These systems are designed to allow scientists fast, accurate, and selective access to the large amount of data, documentation, sample information, and sample material in storage at AGC.

In the future, Program Support will be acquiring new equipment and expertise to improve AGC's ability to collect and handle data. Some of the areas, which will soon require a considerable effort from the Subdivision, are the operation and maintenance of the Bedford Institute's underwater electric rock core drill, the operation and maintenance of new side-scan sonar equipment, and the evaluation and possible implementation of a generalized data base management system.

Regional Reconnaissance

Regional Reconnaissance directs its main efforts towards:

- Crustal and upper mantle studies of the continental margins and adjacent ocean basins of eastern Canada
- Regional geological and geophysical mapping of the continental shelves of eastern Canada
- Surficial geological studies of the eastern Canadian offshore

The continental margin of Atlantic Canada was formed by the rifting of continental masses in some areas and by the strike-slip motion between continental blocks in others. These motions imparted different structural characteristics to the basement. The subsequent development of the margins was controlled by thermal contraction and sediment loading. Regional Reconnaissance has been acquiring data relating to these processes along the Atlantic Seaboard from the Scotian Shelf to Baffin Bay during the Review period. The field projects and studies towards which these projects are oriented are grouped and summarized under: (1) Bedrock and Surficial Mapping Program, (2) Regional Geophysical Surveys, and (3) Ocean Basin and Margin Studies.

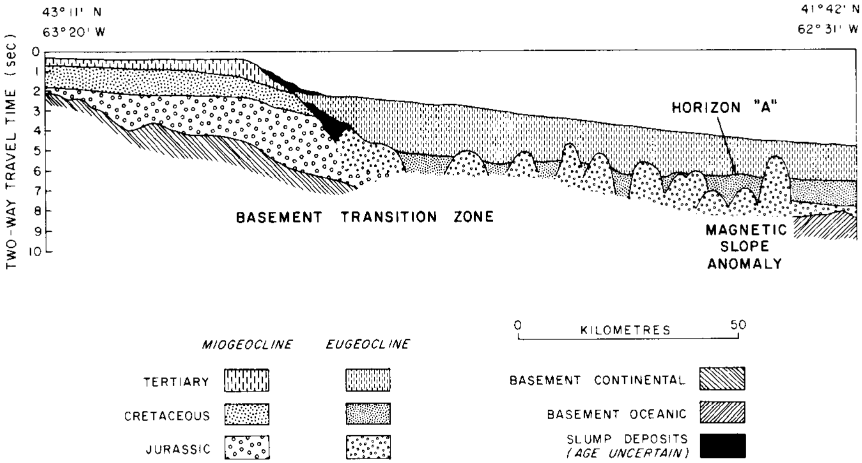
Bedrock and Surficial Mapping Program

Scotian Shelf and Grand Banks. A geological map of the pre-Pleistocene surface from the Scotian Shelf sector of the East Coast Geosyncline was published in 1974 at a scale of 1:1,000,000. The map shows the distribution of the East Coast sediments and adjacent Appalachian rocks, and a manuscript to cover the map is in preparation. A similar map is currently being prepared for the Grand Banks and Flemish Cap and constitutes the second in the series. One field season on CSS *Dawson* was completed in 1973 on this sheet.

These studies have led to the consolidation of ideas on the formation of the East Coast Geosyncline and the consideration of the application of these ideas along eastern margins north of the Grand Banks. Studies concerned with the morphology, internal structure, vertical succession, and subdivision of the East Coast Geosyncline have been completed. The geosyncline is divisible into a miogeocline encompassing the Mesozoic-Cenozoic succession underlying the continental shelf, and a eugeocline comprising strata of similar age underlying the continental rise and abyssal plain. The boundary between the miogeocline and eugeocline is in many areas represented by the modern and ancient continental slope. Further studies related to fossil continental slope development within the geosyncline and its relation to the development of the geosynclinal couplet are in progress.

The series of surficial geological maps for the Scotian Shelf area has been reported on previously. Other maps are in progress for the Bay of Fundy and eastern Gulf of Maine, Chedabucto Bay and adjacent areas, and the western Grand Banks. These maps are used extensively for engineering studies and by the fisheries.

Labrador Continental Shelf. Surficial geology studies on the Labrador continental shelf have been concentrated on the Hamilton Bank area. This bank was selected as an area where exploration efforts were concentrated and where a concerted effort could provide a type study for other banks on the Labrador Shelf.



An interpreted, processed, seismic section across the Nova Scotia continental margin showing the miogeocline and eugeocbne. (AOL 3587)

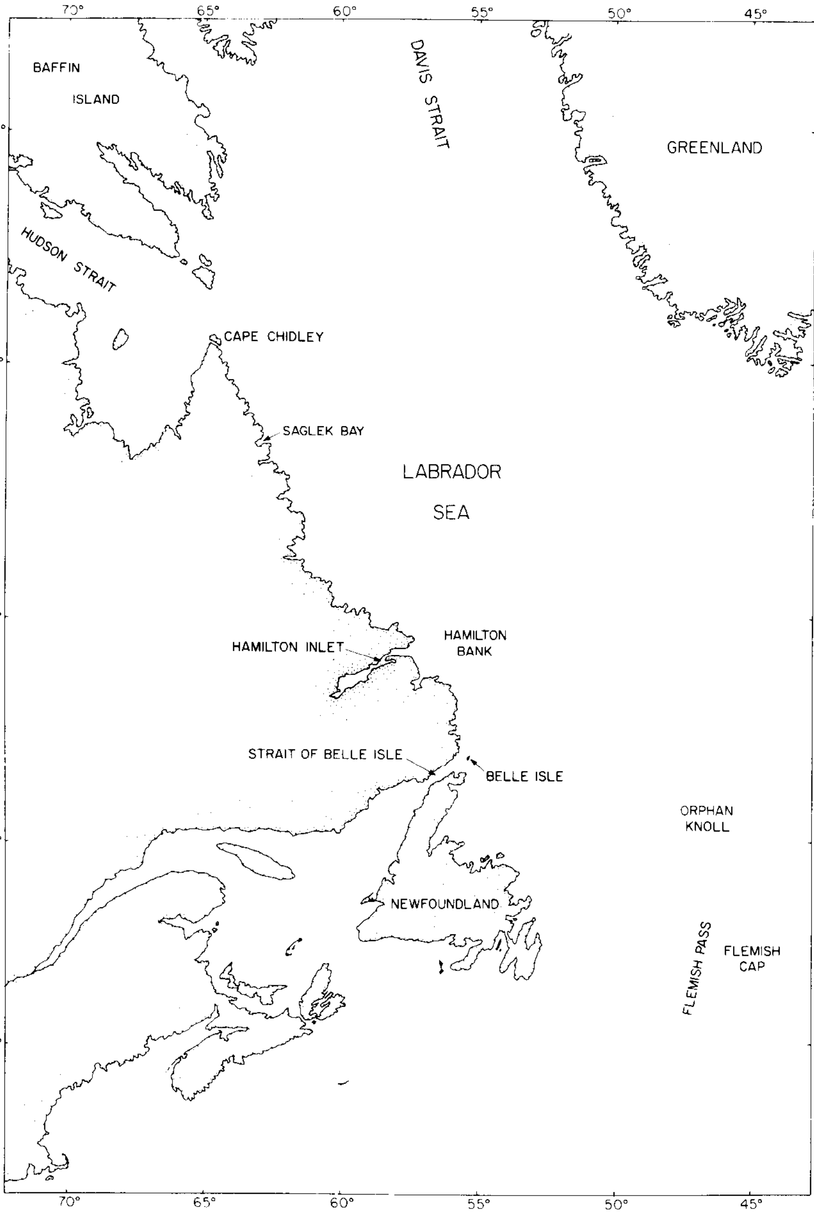
Field work was carried out on CSS *Dawson* during August 1973 and included the collection of shallow seismic and bathymetric data along with a program of bottom sampling and coring. Initial compilation of the data was carried out under contract by Geomarine Associates, a local firm. Data were also obtained with the Nova Scotia Research Foundation deep-tow sparker system to provide high-resolution seismic profiles over the bank. This latter work was funded as a co-operative project with Eastern Petroleum Corp. of Calgary, Alberta.

A series of three maps showing detailed bathymetry, surficial geology, and sediment distribution is being prepared for publication in co-operation with the Bathymetric Research Section of the Canadian Hydrographic Service. The important landforms and their significance in relation to glaciation of the shelf have been identified.

(See also the essay “Geological Evolution of the Labrador Sea” by Willem J. M van der Linden in Ocean Science Reviews, Part D of this Biennial Review.)

Arctic. In 1973, surficial geology and bedrock studies were initiated in Lancaster Sound in co-operation with the Terrain Sciences Division of the Geological Survey of Canada (GSC) as part of the Canadian Hydrographic Services survey program on CSS *Baffin.* Shallow seismic data and bottom samples were obtained and incorporated with the bathymetric survey data to provide sediment thickness and bedrock topography maps of the area of survey (longitudes 86 to 90°W). The preliminary compilation of data and preparation of maps were carried out under contract by Huntec (70) Ltd. of Toronto, Ontario.

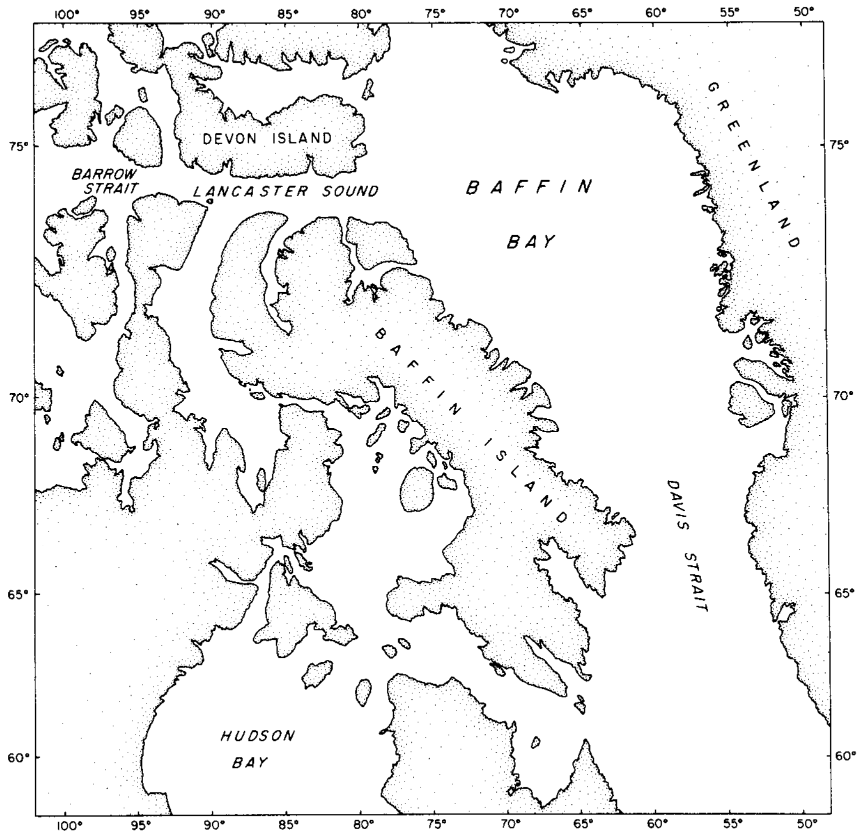
The data obtarned in 1973 were used as a basis for planning additional work in Lancaster Sound for the field season of 1974. The work was expanded to cover the Lancaster Sound - Barrow Strait region as part of the CSS *Hudson* Arctic cruise undertaken In 1974. Surficial studies were again carried out in co-operation with the Terrain Sciences Division and attempts were made to obtain both regional coverage over the Sound and detailed information along proposed pipeline routes.



The Labrador Sea. (AOL 2793.)

Compilation of the data and publication of a series of maps similar to those in preparation for the Hamilton Bank are planned in the near future.

An important addition to the 1974 project was a co-operative venture with the Institute of Sedimentary and Petroleum Geology of GSC in which an industry participation program with Kenting Exploration Services of Calgary, Alberta, for shallow bedrock drilling in Lancaster Sound, northern Baffin Bay, and Davis Strait was organized. A total of 25 shallow drill holes (up to 9 metres depth below the sea floor) were drilled on shallow bedrock structures in water depths to 550 metres. In most areas, core recovery was less than anticipated largely on account of the limited coring capability of the drill and the difficulty in defining the depth to bedrock surface in the arctic environment with existing seismic equipment. However, in all areas the project proved to be most instructive and additional work is planned both by the participating companies and ourselves.



Baffin Bay, Lancaster Sound, and Barrow and Davis *Straits. (AOL 3597.)*

Regional Geophysical Surveys

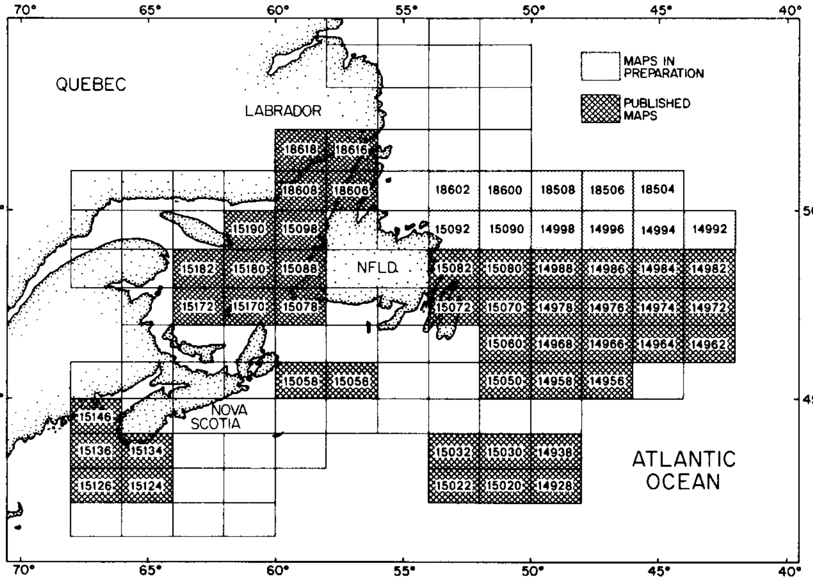
Survey Program. The Canadian Hydrographic Service and the Atlantic Geoscience Centre have been co-operating in systematic geophysical surveys of the Atlantic Seaboard of Canada since 1964. In the last three field seasons, these surveys have moved up into the Labrador Sea. During 1974, the emphasis was changed from a program of detailed surveys of the continental shelf to provide an opportunity for obtaining regional data over the entire Labrador Sea before continuing with the detailed surveys required for accurate mapping. The program was cut short when the charter ship MV *Minna,* carrying out the regional survey, went aground and sank off Resolution Island. A little more than half the proposed program was completed.

A number of gaps in potential field coverage remain in areas covered by the Canadian Hydrographic Service program prior to the incorporation of geophysical measurements. The most notable of these was on the Tail of the Grand Bank where operations were interrupted in 1966. During the fall of 1973, the CSS *Dawson* was used to collect gravity and magnetic data on lines 9 kilometres apart to complete the coverage. Poor weather for most of the 3-week cruise meant that gravity cross-coupling corrections were large. Software was developed to cope with these corrections, and the other data previously collected in the area have been reprocessed prior to contracting out the Natural Resource Series map preparation.

Operations in the Gulf of Maine in 1970 were hampered by the malfunction of the sea-surface gravimeter. Analysis of discrepancies between measurements made at the intersection of ships' tracks led to the apparent correction of the majority of errors incurred. A check of the corrections made was carried out during 1973 by the measurement of gravity by a sea-bottom gravimeter at selected points within the 1971 Gulf of Maine survey area. The results showed that the previously deduced corrections were valid. Poor weather and failure of equipment did not permit the planned extension of measurements outside the earlier survey area.

Data Processing and Interpretation. The acquisition of large quantities of accurate geophysical data obtained on the hydrographic/geophysical survey program, and the logistical problems associated with mounting these surveys on an annual basis, have resulted in a lag in the preparation of maps, and the release and interpretation of data in past years. In 1972, an attempt to alleviate these problems was made by assigning the responsibility for compilation and mapping of the data to a Canadian geophysical company. This has proved to be extremely successful and has resulted in the preparation of 270 Natural Resource Series maps displaying bathymetry, gravity, and magnetic data. These maps are plotted at a scale of 1 : 250,000 and cover an area 1° in latitude by 2° in longitude.

The elimination of the backlog of data compilation has enabled our scientists to concentrate on the interpretation of the information. Maps at a scale of 1 : 1,000,000 of Bouguer gravity and magnetic anomalies for the continental margin of the Atlantic provinces have led to two important interpretations. Concepts with regard to continental collision in Atlantic Canada during mid-Paleozoic time were developed based on the regional variations of the gravity and magnetic fields. Crude sand model experiments show the development of two sets of transcurrent faults - one parallel to the colliding margins and one in the direction of approach. Faults comparable to those produced in the models have been recognized as the boundary faults of the developing Fundy Eugeosyncline



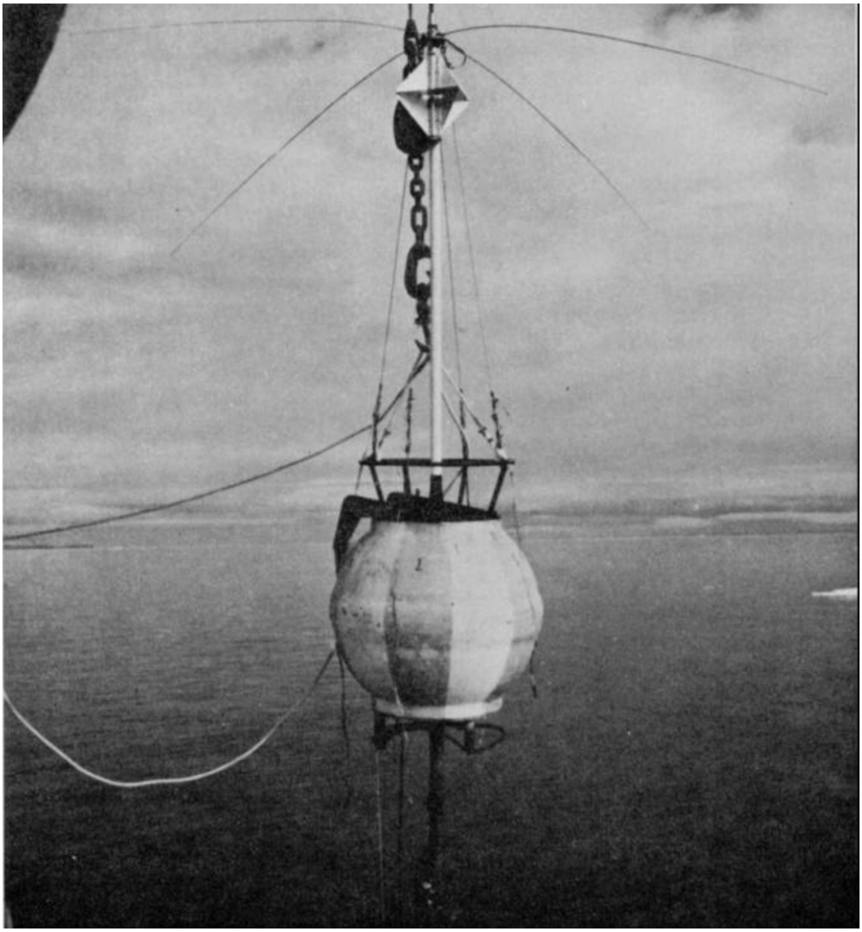
Areas of Natural Resource Chart coverage as of December 1974. (AOL 3415.)

and the Cobequid-Chedabucto fault system. The outline of the mid-Paleozoic North American margin and the collision-initiated faults can be recognized by variations in the potential fields. The Cobequid-Chedabucto fault system is associated with the land fall of a major anomaly (the Collector Anomaly), which seems to represent a shear zone along which Nova Scotia moved westward. Granites were intruded along the leading edge when Nova Scotia collided with New Brunswick and Maine. North of the shear all trends are flexed into the Collector Anomaly, which denotes major deformation of that block. The subsided portion of the northeast Newfoundland shelf has been defined and the inshore fracture line is the locus for the development of a sedimentary basin.

The second major interpretational thrust has been in the northern areas of the survey. Models of the positive gravity anomalies on the northeast Newfoundland shelf that are coincident with a deep sedimentary basin are being built. Lithospheric flexure models cannot account for the complete anomalies, and it is necessary to invoke crustal fracture and subsidence. It seems that much of the area between Avalon Peninsula and Orphan Knoll is continental, even in deep water. The 1972 survey data from the Labrador Sea led to the initiation of further projects in this area. The regional coverage obtained during the 1974 *Minna* survey has expanded significantly on these projects and provided an excellent opportunity to tie together the isolated earlier work of other institutions.

In order to utilize the data obtained on the geophysical survey program effectively, considerable effort is being put into developing interpretative software that can be used to extract representative profiles across any anomaly of interest and determine reasonable causative geological models. This study involves both in-house effort and outside contract work by Canadian data processing companies. Results to date have been encouraging and it is hoped that some aspects of the interpretation, such as depth to basement calculations, can be made a routine part of the data processing and map compilation contract in the future.

Ocean Basin and Margin Studies



Recording, telemetering sonobuoy used for seismic refraction studies of the ocean margin. (AOL 3260-10-3)

This program represents the more problem-oriented research of the Subdivision as opposed to the research associated with the systematic programs of geological and geophysical mapping outlined in the preceding two programs. In a program of field-oriented geoscience studies, it is important to maintain a balance between these two different aspects of research.

In the past two years the work within the program has been concentrated in studies of the ocean-continent margin off Nova Scotia and southeastern Newfoundland, northern Labrador, and Baffin Island, and in the oceanic basins immediately seaward of the margin. Emphasis has been placed on the nature of the transition zone separating the continental shelves of eastern Canada from the ocean basins and the history of formation of this boundary.

Nova Scotia and Grand Banks Margin. The recent work on the transition zone was initiated in 1972 after geophysical studies in the Eastern Arctic during 1971 showed that without a better understanding of the nature of a continental margin it was impossible to unravel the history of the continental shelves themselves. During 1972 and 1973, seismic refraction studies of the ocean-continental transition zone off Nova Scotia and the southern Grand Banks were carried out. Reconstruction of the development of the North Atlantic suggested that the margin off Nova Scotia was a simple rifted margin while that off the southern Grand Banks was a transform-faulted margin along which significant strike-slip motion of continental blocks had occurred. The comparative study of these two margins provided a type study of the two most important marginal structures occurring on the East Coast of Canada. The results of this work identify the geophysical characteristics associated with the two types of margin and demonstrate the differences in the structure. At the same time the work has extended out into the Quiet Magnetic Zone east of Nova Scotia and has shown this zone to be truly oceanic. Evidence of lineations in topography and magnetic anomaly field have shown that the absence of normal oceanic magnetic anomalies is due to the formation of this part of the oceanic crust during a period of a few reversals in the Earth's field. Preliminary work has been initiated in the anomalous region of the Newfoundland Basin east of the Grand Banks.

Labrador Sea. In 1973, a similar seismic study of the northern Labrador margin was initiated in part with Eastcan Petroleum Corp., the operating company in that area. This work, completed in 1974, suggests that the Labrador continental shelf extends considerably further offshore than was previously thought. The gravity and magnetic data obtained across the margin in the area of Hamilton Bank were modelled with the aid of existing seismic refraction control and areas of anomalous crust, presumed to be of continental origin, were established in deep water.

The major new field data obtained during 1974 in the Labrador Sea came from the hydrographic/geophysical survey on MV *Minna* already referred to and the CSS *Hudson* Arctic cruise. As part of the planning for these cruises all available geophysical data in the Labrador Sea were compiled. The data coverage now available extends up into Davis Strait. These data offer probably the most complete coverage of any oceanic basin and they will likely lead to a wealth of new ideas on the development of the Labrador Sea.

Baffin Bay. Following the earlier work in Baffin Bay carried out on CSS *Hudson* in 1971, a review of present geological knowledge of Baffin Bay and the adjacent continental areas was completed, but no new field effort was mounted until 1974. During the 1974 Arctic cruise in CSS *Hudson,* the seismic refraction studies in the oceanic basin of Baffin Bay were extended into the Baffin Island continental margin to provide information on yet another portion of the Eastern Canadian ocean-continent boundary. At the same time the opportunity was taken to carry out a detailed magnetic survey over a portion of the ocean basin. The low amplitude and generally uncharacteristic nature of the magnetic anomaly field over the ocean basin have posed a major question on the nature of the oceanic crust underlying the Bay. Analysis of the 1974 data should help answer this question.

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1973/74

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Navigation in Oceanography

R. M. Eaton and R. F. Macnab, Atlantic Oceanographic *Laboratory*

If research and survey work at sea are to succeed, the oceanographer must be able to determine his position accurately. No observation is completely independent of position, and some observations depend critically on knowing where the point is, both in relation to other observations nearby and to the overall geographic framework. Prior to the introduction of electronic aids to navigation only dead reckoning, a running plot of the ship's position utilizing the speed and heading of the vessel, and celestial navigation were available for positioning ships, and these could not provide the desired accuracy.

History

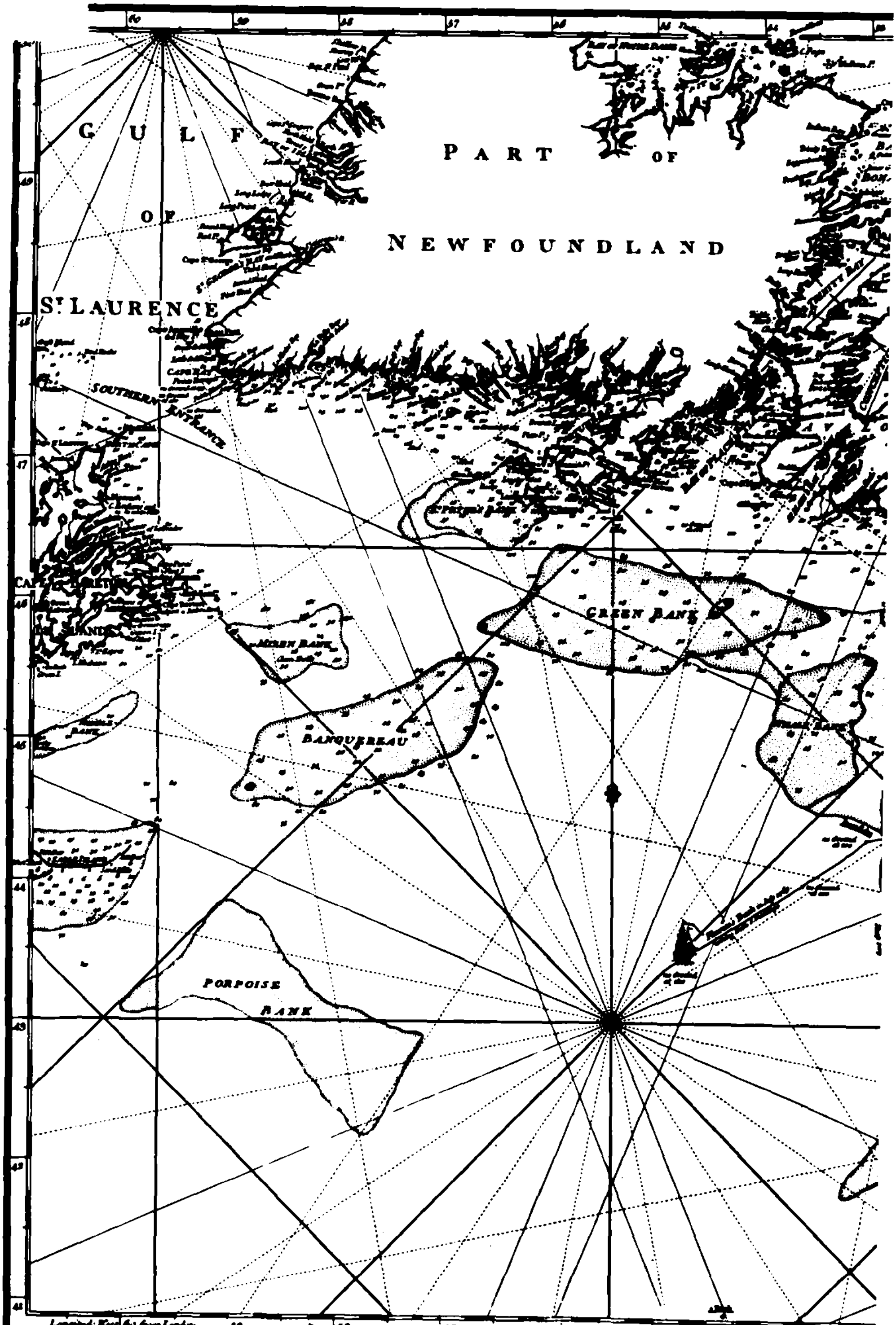
Vikings, and then fishermen from Europe, have been in Eastern Canadian waters for a thousand years, but little was recorded about their means of navigation. Samuel de Champlain was the first scientific explorer. From 1604-1607 he explored and described the coasts of *L'Acadie,* visiting, among other places, Chebucto Bay - now Halifax. His biographer Morison (1972) says "Any yachtsman today, lacking modern charts, would be happy to enter port with one of Champlains's in hand."

One remark in Champlain's 'Treatise on Seamanship' illustrates the outstanding problem in navigation at that time: "The dead reckoning that should be kept on sea voyages is very essential to sea navigation, although it can never be altogether accurate ... one meets with tidal currents. besides the violence of storms which drive the vessel before the wind preventing an accurate dead reckoning being kept, and this is the cause of countless ships being lost" (Morison, 1972). Dead reckoning was vitally important because there was no other way of determining longitude.

In 1714, appalled by the loss of life due to faulty dead reckoning, the British Board of Longitude offered the fabulous prize of £20,000 for a practical method of determining longitude. Although longitude can be established if the local time of noon is known relative to noon at the meridian of departure, this method was not possible in 1714; clocks of that age used pendulums, and were not satisfactory at sea. Latitude, on the other hand, could be accurately determined by measuring the Sun's meridian altitude with an astrolabe. By 1759 John Harrison had produced his clock No. 4, which looks remarkably like the chronometer in any ship's chart room today and had an error of less than 1/10 second per day. It won the prize. An interesting chart of this period, made without the aid of a No. 4 clock, is the accompanying 'Chart of the Banks of Newfoundland.' One contributor to this chart was James Cook, who surveyed around Newfoundland for four years.

If Cook had gone aboard a survey ship in 1939 he would have felt quite at home, recognizing nearly all the techniques used, although there would have been some new equipment such as the gyro compass, radio, and echo sounder. In another

On the following page is a Chart of the Banks of Newfoundland: an eighteenth century chart of an area where the Bedford Institute of Oceanography still does a lot of work. The fishing banks are prominent, as one would expect, with 'ghost' extensions probably due to erroneous reports by bad navigators. Thanks to Cook's surveys, the Newfoundland coastline is shown in detail. The criss-cross rhumb lines were used for picking off the course to steer. (Courtesy of the Provincial Archives of Nova **Scotia.)**


GULF
OF
St. LAURENCE
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GREEN BANK
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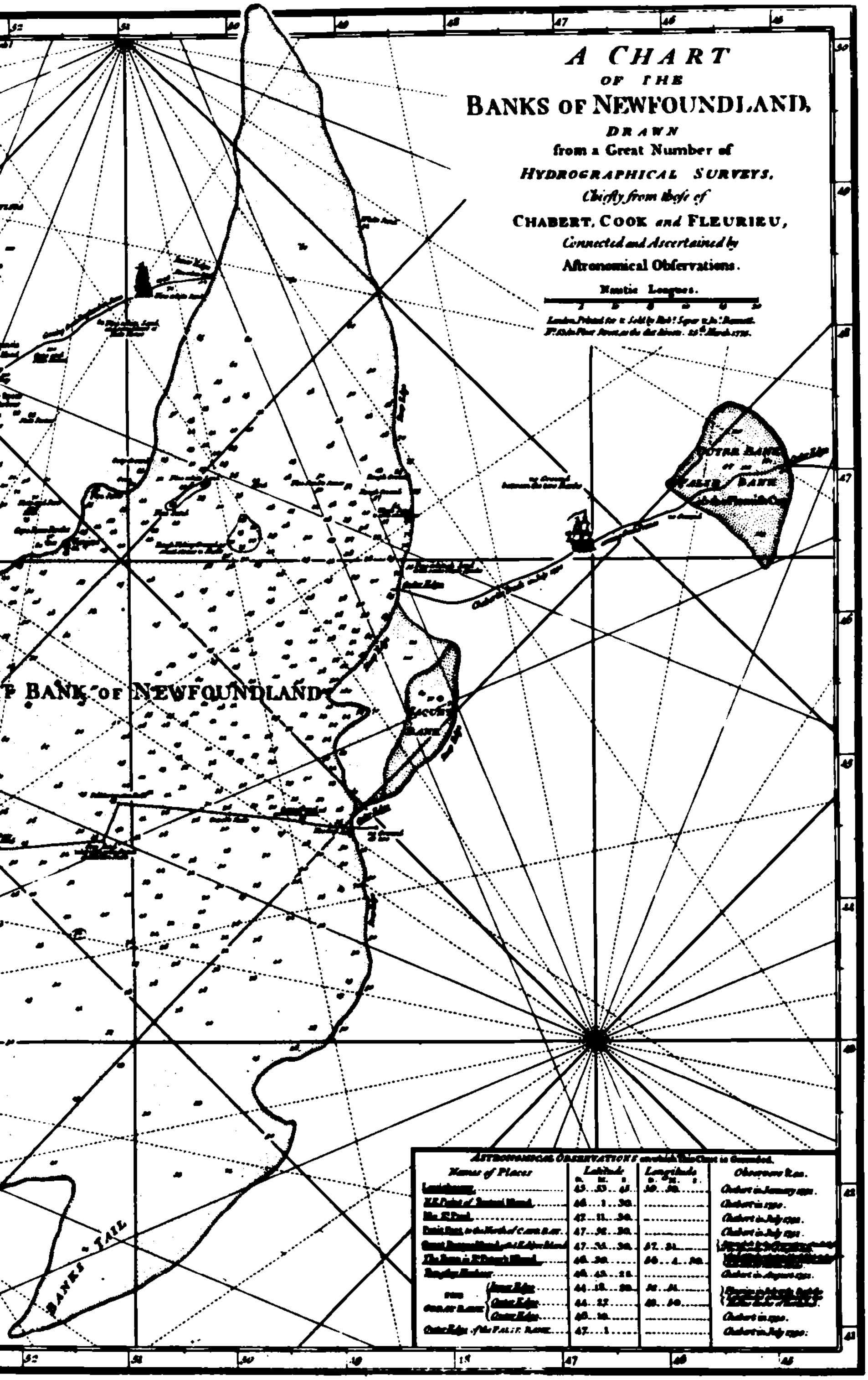

A CHART
OF THE
BANKS OF NEWFOUNDLAND,
DRAWN
from a Great Number of
HYDROGRAPHICAL SURVEYS,
Chiefly from those of
CHABERT, COOK and FLEURIEU,
Connected and Ascertained by
Astronomical Observations.
BANK OF NEWFOUNDLAND
BANKS TAIL
Names of Places
Latitude
Longitude

twenty years, however, he would have been faced with a revolutionary change in equipment. The 1939-45 war brought radar and radio navigation aids (navaids). Then the cold war followed up with inertial navigation (for guiding missiles) and satellite navigation (for guiding submarines). Acoustic navigation was a spin-off from the enormous effort put into anti-submarine warfare. Computers have completed the transformation. By coincidence, the most recent advance is another clock, this time with an error of less than 1/10 microsecond per day. It is used to 'remember' the transmission cycle of a Loran-C chain, described later.

Position Finding

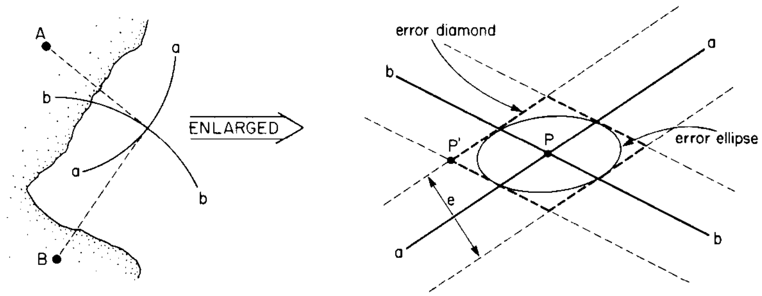
The problem Champlain had with dead reckoning is still with us. A navigator with a normal bias of 1.5° in the compass and 0.5 knot in speed would be out in his reckoning by 3 per cent of the distance run or 100 kilometres on an Atlantic crossing. Instruments for measuring the speed and distance travelled by a vessel are known as logs. One of these, a Doppler sonar speed log, is a device that gives a continuous indication of position by integrating the speed derived from measurements of the Doppler effect of echoes from sound beams transmitted from the ship. Doppler logs operate at all speeds and in ice-covered water, a significant improvement over the old pressure-differential and electro-magnetic logs with their protruding sensors. Tests at the Bedford Institute of Oceanography (BIO) have shown that Doppler logs have an accuracy of better than 1 per cent of distance run. But even with a good log and compass, dead reckoning accumulates errors, and it must be corrected at intervals by a position 'fix' taken on some external reference.

Dead reckoning was once a major part of navigation, but its importance is declining as the interval between reliable position fixes shrinks. It still bridges between intermittent satellite navigation fixes in the wide areas of the ocean not covered by adequate radio navaids, but inshore its main contribution will soon be in the smoothing of continuous radio fixing.

Position-finding is accomplished by observing a signal from a known reference point, whether this be the light from a star or the sonar response from a seabed transponder. Propagation characteristics determine the type of signal to be used; a navigator on the Grand Banks of Newfoundland cannot rely on star sights because he will rarely see the sky, and a scientist in a submersible can only use sound because neither light nor radio waves penetrate water for more than a few metres.

All fixes are derived from the intersection of two or more lines of position (LOPs). For example, radar ranges measured simultaneously to two transponders (automated receiver/transmitter for transmitting signals when triggered by an interrogating signal) at known points on shore define two range circles that intersect at the ship's position (see figure). The error in range measurement can be estimated (preferably from calibration under operational conditions) but the way this measurement error transforms into position error varies widely, depending on the fix geometry. For range measurement, the relationship is determined only by the intersection angle, but where the measurement is range difference, as in a hyperbolic navigation system (see under Electronic Navigation Systems), the LOP error is magnified by the 'lane' expansion as the hyperbolas fan out from the baseline.

Error statistics is a complex subject. A simplified though extreme approach is to assume 100 per cent correlation in LOP errors; the resultant position error is the long semi-axis PP' of the error diamond (see figure). BIO hydrographers regularly plan their positioning control by drawing limiting contours, outside of which the expected error e will cause position errors PP'. BIO staff are currently working on an alternative approach using error ellipses.



Two-range fix: the anatomy of a fix by two intersecting position lines, showing how the error in LOP transforms into error in position. (AOL 3478.)

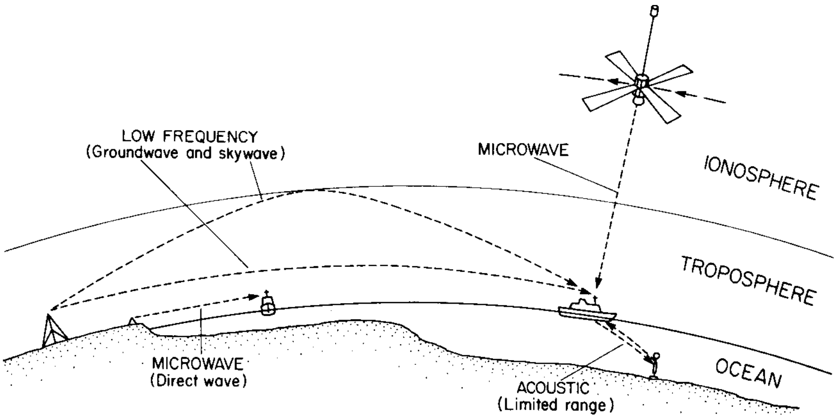
Electronic Navigation Systems

A ship within sight of land can receive microwave radio signals by direct path from hand-sized, battery-powered transponders on shore, and can be positioned within 30 metres at a relatively low cost. Once below the shore horizon, the navigator loses microwaves. Fortunately, groundwave signals from low frequency radio transmissions follow the Earth's curvature, and at a predictable velocity. A second component from low-frequency radio transmissions, known as the skywave, travels to the receiver via refraction in the lower layers of the ionosphere (see figure). However, the travel time of the skywave cannot be predicted exactly, and it interferes with groundwave reception, especially at a long range when the groundwave is the more attenuated of the two. This skywave contamination severely limits the range of continuous-wave (CW) low-frequency radio transmission systems, such as Decca 12f, which BIO hydrographers use widely for charting surveys.

The Decca navigation system was developed in Great Britain and is now used in many parts of the world. It is a continuous wave system in which a receiver measures and indicates the relative phase differences between signals received from two or more synchronized ground stations. Comparison of the signals from two stations of known position determines a line of position in the form of a hyperbola. The intersection of two hyperbolic LOPs determines the position of the ship (International Hydrographic Bureau, 1965).

One way of avoiding skywave interference of the groundwave is by transmitting pulses. The groundwave pulse, travelling directly to the receiver over a shorter distance than the skywave, will be first to arrive. This lead is generally about 40 microseconds, and in that interval a pulse at 100 kilohertz (period 10 microseconds) will deliver four cycles of 'pure' groundwave to the receiver before skywave contamination begins to arrive. Loran-C, another hyperbolic navigation system, uses the pulse technique to extend operating range to more than 1000 kilometres, compared to about 350 kilometres for Decca 12f.

Loran is the acronym for Long RAnge Navigation - a family of radio position-fixing systems that determine location by measuring the time difference in arrival of pulse signals from a number of fixed transmitters. A master and two slave stations are generally used in any Loran-C chain. These define two hyperbolic LOPs, the intersection of which determines the position of the mobile receiver (Powell and Woods, 1967).



Selection of the method of navigation: direct wave *(radio or acoustic) is used where there is "line of sight" to shore, to* a *satellite, or to an acoustic transponder. In other situations, groundwave radio propagation, which suffers interference from its own skywave, is resorted to. (AOL 3478.)*

Wave Propagation

The measurements needed for position finding by sonar and radio are the radio signal travel times and signal propagation velocities. If these parameters are known, distances from respective reference points of signal origin can be calculated.

Medium and low frequency radio groundwaves travel at a velocity that depends on atmospheric refraction and ground conductivity. Velocity at Decca frequencies (about 100 kilohertz) has been measured over sea water by Brunavs and Wells (1971), and over sea ice by Gray (1975) and others. Measurements at frequencies of 2 megahertz over sea water have been made by the Bedford Institute of Oceanography. One problem now under study is radio wave velocity over land, as this is known to be more variable than over water. Knowledge in this area is becoming increasingly important as Loran-C, with inland transmitters, is used more for surveying at sea.

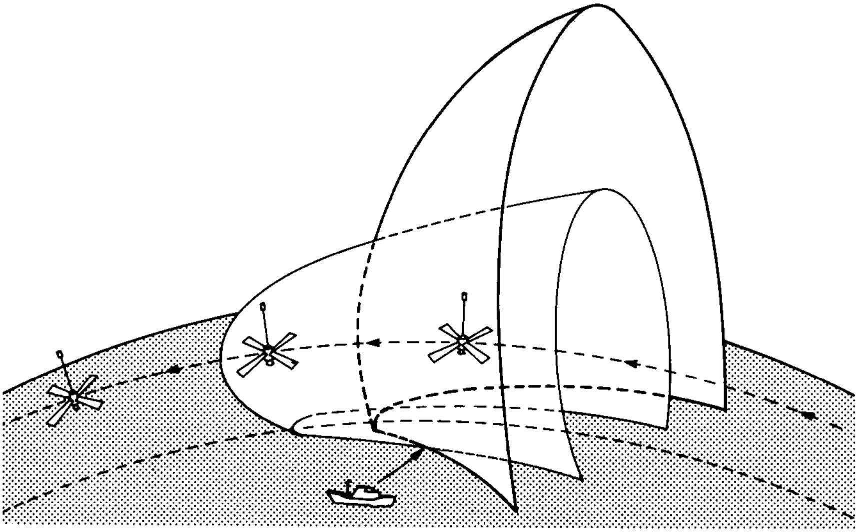
The velocity of sound in water depends on temperature, salinity, and depth, all of which can be measured. Propagation in this media is compounded by ray bending. McKeown (1974) found that in deep water, at medium ranges, the maximum range error caused by assuming straight-line travel at a harmonic mean velocity was 7 metres. Further experiments are needed to determine range errors for shallow water.

Greater range demands more power. Since attenuation is frequency dependent, greater range can be achieved by lowering the frequency. However, this can only be done at the expense of increasing the wavelength, which in turn makes the resolution coarser. Bigger antennas are required to radiate lower frequencies and, with the increased power requirements, the cost of equipment, installation, and maintenance all increase rapidly.

Atomic Clocks, Satellites, and Acoustic Beacons

Three recent developments have improved long distance navigation. The first of these is atomic frequency standards, which have found application in a development of the Loran-C system known as rho-rho (range-range) Loran-C. The U.S. Coast Guard pioneered the first rho-rho Loran-C system in 1969 following the modification of Loran-C stations by the incorporation of cesium-beam frequency standards. For operation in the rho-rho mode, the station on the ship is equipped with a very stable frequency standard (an atomic clock). This standard is synchronized with the standard controlling the Loran-C net being used so that, at the instant the master station transmits a pulse, the mobile station standard starts a time interval counter that is stopped when the master station pulse is received by the mobile station. The counter then reads the one-way transmission time from the master station to the mobile station, which is readily converted to a range. In a similar manner the range from a slave station to a mobile station is determined. The position of the mobile station is determined by the intersection of the two range circles from the respective stations (Marchal, 1971). Because only two stations are needed for a range-range fix, instead of the three needed to generate a pair of hyperbolic LOPs, this rho-rho modification greatly extends the coverage of Loran-C in the North Atlantic where transmitters are widely separated. Portable frequency standards are now sufficiently stable that Loran-C systems operate with a 'clock-rate' error of about 10 metres per day between receiver and transmitter.

A much more revolutionary boost was given to oceanic navigation when the U.S. Navy de-classified its Doppler satellite navigation system (Satnav). This system was soon put into use at BIO (Wells and Ross, 1969). In a 1973 comparison against a calibrated survey Decca chain, the standard deviation of a satellite fix was found to be +120 metres. Satnav does not give a continuous position, but it is extremely useful as an absolute position reference in combination with a higher



A navigation satellite is a hyperboilic navigation chain in the sky. 'Doppler Counts' made by the receiver on radio transmissions between satellite positions at 2-minute intervals define space hyperboloids; the point where these intersect the Earth's surface is the ship's [psition. (AOL 3478.)

resolution positioning system that has biases or accumulates errors. BIO uses Satnav in conjunction with dead reckoning (by log and gyro) and rho-rho Loran-C.

Accurate radio-navigation does not extend across the ocean. However, work on acoustic navigation at BIO over the past four years has demonstrated that a ship, or equipment lowered beneath her, can be positioned to within 10 metres relative accuracy in mid-ocean by ranging on acoustic markers moored a few metres above the seabed. There are two stages to navigating by acoustics (McKeown and Eaton, 1974): the markers are 'surveyed' relative to each other by the ship, and Satnav is used to position them geographically; the process is then inverted and the ship is positioned by ranges from two or more of the markers. In practice, the ship can also make oceanographic observations during the survey phase, and, by post-processing, reconstruct accurate positions for the observations. The range of acoustic navigation is severely restricted compared with radio navaids due to sound-wave attenuation in deep water, to ray-bending, and to multiple echoes in shallow water. The so-called 'long baseline' approach to acoustic navigation, described above, uses one transducer on the ship and two or more markers on the seabed. The 'short baseline' alternative is to fit two or more transducers or hydrophones along the relatively short length of the ship and use only one marker, which can be expendable; the marker is fixed relative to the ship (or vice versa) over a restricted area. BIO has experimented with both systems (refer to 'Metrology' in Part A of the 1973/74 Biennial Review).

Accuracy

The user has to be clear what he wants before choosing a particular approach. Relative accuracy over a restricted area, and time-repeatability, are more easily obtained than geographic accuracy. If a survey is rerun with a different method of navigation, repeatability between the two surveys will depend on the geographical accuracy of each system.

The positional accuracy required of hydrographic and geophysical survey data varies according to the ultimate use that is to be made of the data. To satisfy the greatest number of customers, the Institute aims to be able to meet the most stringent known requirements; in deep waters this demands a geographic accuracy of 500 metres or better for regional studies and a relative accuracy of 50 metres or so for special studies.

There is little to gain in seeking a position resolution that greatly exceeds the horizontal resolving power of present-day, data-gathering instrumentation and procedures. Most survey results do not correspond to conditions at points coincident with instantaneous ship positions; rather, they represent conditions that occur over a relatively large area or portion of track. Echo sounders, for example, measure depths of the sea floor anywhere within the insonified zone (the zone 'illuminated' with sound). With a conventional 1.5° half-angle sounding beam, the zone is a circle with a radius equal to approximately 25 per cent of depth; with a 5° half-angle sounder this radius is reduced to approximately 10 per cent of depth. At normal survey speeds, and when the data is used for regional studies, magnetometer output is usually averaged over an alongtrack distance of about 400 metres, Moreover, the sensing head is towed some 200 metres astern of the ship, which is not generally corrected for. Instantaneous output from gravimeters is integrated over a similar interval of 400 metres. It is then further processed in an inverse filter, which operates over approximately 2 kilometres; under some circumstances this shifts the data by about 200 metres. Thus, for gravity and magnetics, horizontal measurement resolution matches the desired position resolution of 500 metres fairly closely. Improving the navigation will not improve the data. On the other hand, the horizontal resolution of echo sounders is a function of depth. The conventional echo sounder exceeds the required position resolution in depths of less than 2000 metres, and the narrow beam sounder exceeds it in all depths. Clearly, sounding data can be improved if navigation systems are upgraded to match the resolution of the echo sounders.

In marine gravity work there is one additional and unique factor related to navigation: the need to calculate Eötvös corrections, which compensate for the ship's travel on the rotating Earth. The Eötvös effect is the apparent change in gravity caused by the vertical component of the Coriolis force, and is a function of a ship's course, speed, and latitude. The practice at BIO has been to calculate courses and speeds from the end-points of track segments along which they are assumed to remain constant. This approach bypasses the problems commonly associated with direct-measuring speed logs. Obviously, the accuracy of the course and speed calculations will depend on the accuracy with which the end points of the track segments are known. The importance of the course and speed terms in the computation of the Eötvös correction varies with the ship's head: on north-south tracks, the course is the important variable, and must be known to better than one degree if the corrections are to be calculated to within one milligal. On east-west tracks, the speed is the important variable, and must be known to better than 0.2 knot.

Practical Considerations

The BIO Offshore Surveys Program is a good example of the use and development of navigation systems. It is a 10-year old mapping survey that has involved Institute hydrographers and geophysicists in the measurement of water depth, gravity, and magnetics over the continental shelf and adjoining deep basins off the east coast of Canada. Among other uses, the data has applications in: the description of bottom topography for fisheries purposes; defining potential reserves of offshore gas and oil; and the development and testing of theories concerning the evolution of the Earth's crust.

The navigational aspects of this program have posed the challenge of obtaining reliable positions for vessels taking measurements in a region extending from near shore (30 to 50 kilometres from land) to the open ocean (700 to 800 kilometres from land) in all weather conditions, and around the clock. These positions have to be precise enough to ensure that data points are located with an accuracy that satisfies the requirements of the end user. For a fisherman equipped with conventional navigational equipment and looking for a particular bank or gully, 1-2 kilometres is probably good enough to get him close to his favourite fishing ground; once there, he will rely mainly on his echo sounder and Loran 'bearings' to chart his course. A geoscientist studying regional features will in most cases be satisfied if gravity and magnetic anomalies are determined to within 0.5-1 kilometre of their true position.

In the early years of the Offshore Surveys Program, Decca 12f was used to supply primary positioning control. Although this system was the best available at the time, it did not meet all requirements. It did yield positions accurate to better than 150 metres close to shore, and to 300 metres at maximum ranges; however, there were frequent operating interruptions due to electrical storms, loss of signal at long range, etc. After each interruption, a check had to be made with a reference buoy to restore or verify lane counts. This procedure created some operational problems. Buoys had to be moored in relatively shallow water to restrict their motion to less than a single Decca lane; as survey areas moved further offshore and into deeper water, ships had to steam back over longer and longer distances to perform buoy checks. Moreover, storms often shifted or removed buoys altogether, so that the reliability of these markers was open to question. On account of skywave interference, long range operations were usually suspended at night, and many expensive hours of ship time were wasted. In spite of these operational difficulties, a number of technical improvements facilitated the shipboard use of the Decca 12f system: the construction of plotting lattices was automated; the detection of lane jumps was facilitated by interfacing the receivers to a digital data logger; and the inaccurate and hard-to-read decometer dials and pointers were replaced by displays that stored readings automatically at regular plotting intervals.

The development at BIO of a Loran-C/Satnav combination as a complement to Decca 12f countered many of the latter's weak points. In this combination, Loran-C provides accurate course and speed information for the Satnav computations, which in turn yield accurate positions for Loran-C clock drift and land-path corrections. While Loran-C lacks the ranging accuracy of Decca 12f, it does offer a positioning capability in the areas beyond maximum Decca range. It also reduces substantially the Decca skywave problem, and clears the way to round-the-clock operations at extreme ranges. Additionally, it has virtually eliminated buoy checks, as the Loran-C/Satnav system can easily handle the lane identification problem. Conversely, Decca 12f is useful for positioning in areas where Loran-C is degraded on account of land-path or baseline proximity, and also for checking Loran-C corrections derived by Satnav.

Further joint use of Loran-C and Decca 12f follows from a hybrid technique that uses two Loran ranges and one Decca range. This approach has been proposed for mapping in the Labrador Sea as part of the Offshore Surveys Program. There are several advantages: only one Decca slave is required instead of two, at considerable savings in cost and manpower; Loran-C can be augmented in fringe areas, as in the shadow zone along the Labrador coast; within these fringe areas Loran-C corrections can be compiled for general use on other cruises: and the 'portability' of a Decca slave station allows site selection to optimize survey coverage.

With the added power of the Loran-C/Satnav combination, we estimate that vessels can be positioned absolutely to within 200 metres (standard deviation) over most of the areas surveyed under the program. This is substantially better than the horizontal resolution of the majority of present measuring instruments and techniques, and leaves room for future improvement in methods of collecting and processing regional data. On the other hand, it is estimated that the relative accuracy of positions is only about 100 metres; further work is needed to achieve an accuracy adequate for special studies.

Most ships have a number of aids to navigation, which differ from ship to ship depending on where the ship is working. Usually, only one or two will be used at a time, and the others disregarded because it is too difficult or too time-consuming to combine them all. A method is needed of merging all available information, and weighting it so as to produce the most likely position. The system must be capable of producing not only an optimum solution after the cruise, but also on-line information for the scientist during the cruise.

BIO ships have a variety of positioning inputs, supplied through different devices at a variety of rates: Decca 12f, Loran-C, Satnav, ship's gyro, and ship's log. At present, the integration and analysis of this information is largely a qualitative operation. Because answers are usually needed in a hurry, and because detailed analysis is a complex and long procedure, much of the data is set aside after only cursory examination. Our goal is to develop an automatic method using all pertinent information in the data, so that the surveyor or scientist will have available to him the best possible position with a minimum of effort. Then he will be able to concentrate more fully on the task that brought him to sea in the first place.

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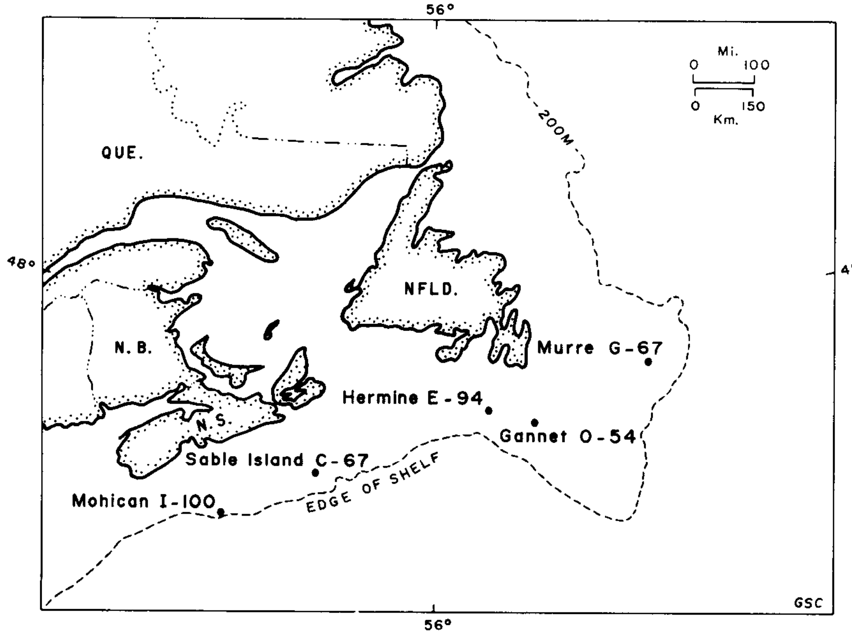
Micropaleontology and the Search for Offshore Oil

Felix M. Gradstein, *Atlantic Geoscience Centre*

The stepped-up search for oil and gas in the offshore of eastern Canada has permitted geologists to peer to a much greater depth into the geological history of this frontier region. In 1965, Pan American Petroleum Corporation drilled nearly 30 shallow core holes in the Grand Banks of Newfoundland. Between 1966 and 1975, oil companies drilled 55 wells on the Scotian Shelf off Nova Scotia, 41 on the Grand Banks off Newfoundland, five in the Gulf of St. Lawrence, and four on the Labrador Shelf. The average well was drilled to a depth of 10,215 feet (3116 metres) and over one million feet (305,000 kilometres) of well section were sampled.

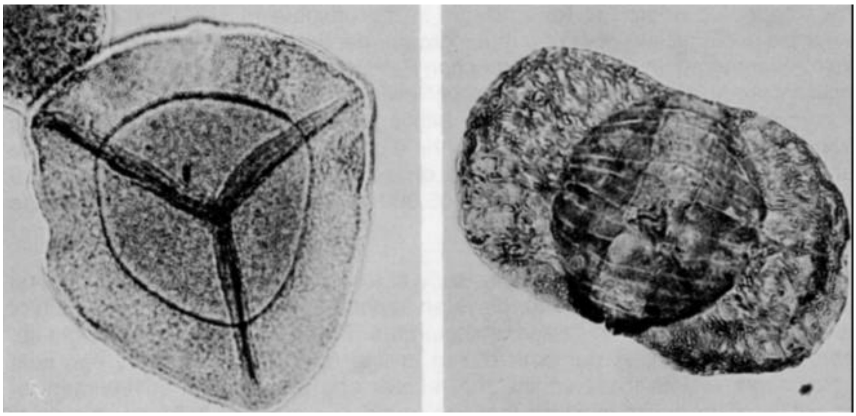
Micropaleontology, the miscroscope study of fossils from about 0.001 to several millimetres in longest dimension, plays an important part in the reconstruction of the geological history of this large offshore area. These tiny fossils are brought up, *unbroken,* in enormous numbers during drilling operations, and they can help micropaleontologists to determine the relative age and original environment of deposition of the rocks in which they are found as well as to learn something of paleo-oceanographic and paleogeographic conditions.

Microfossils are not only numerous but there are also many different kinds. In the rocks found off Canada's Atlantic coast, the most useful microfossils for geological work are the spores, dinoflagellates, foraminifera, and ostracods followed by the pollen, coccoliths, calpionellids, diatoms, and radiolarians.



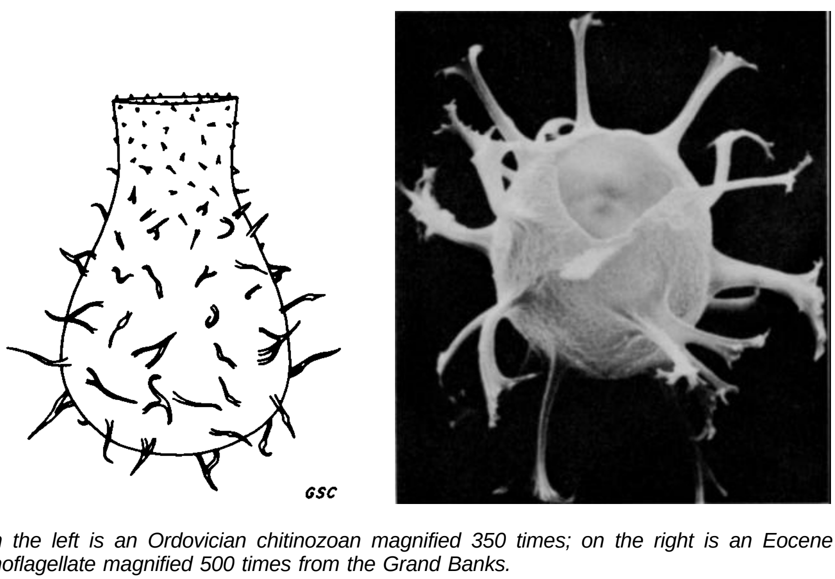
The Scotian Shelf, Grand Banks, and Gulf of St. Lawrence. Also shown are the locations of the five deep exploratory wells. (AOL 3286.)

Spores, which exist today, are the sperms of primitive land plants; they first appeared in Silurian time. Pollen are the sperms of advanced land plants and these are found in latest Paleozoic to Recent rocks. Both of these organisms had organic-walled bodies and were transported mainly by water to the rocks in which they are found and not by wind as was commonly believed. They are found in the continental and shallow marine rock deposits of the eastern Canadian offshore.



A Mississippian spore (left) and a Permian pollen (right) from the Gulf of St. Lawrence. Both are magnified 550 times.

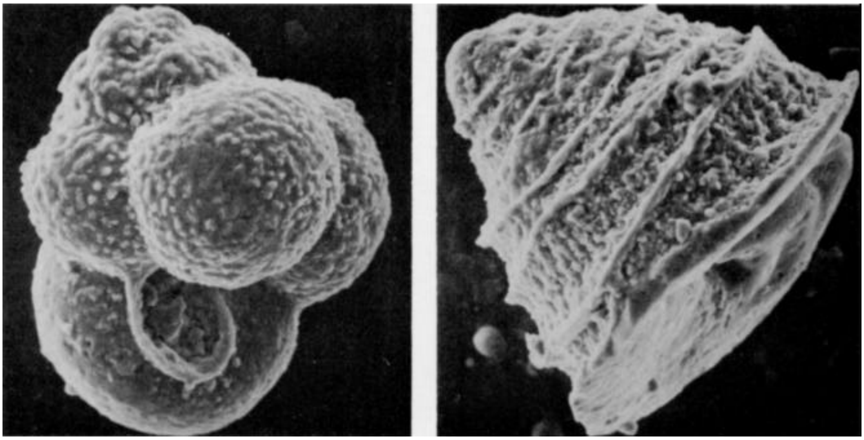
Chitinozoans, which have been found in only a few wells to date, are organic-walled microfossils, extinct today, that lived in Ordovician, Silurian, and Devonian seas. It is not known whether they were plants or animals. A dinoflagellate is a one-celled, organic-walled organism that resembles both animals (because it ingests its food and is mobile) and plants (because it carries on photosynthesis) but which belongs to the Algae of the plant kingdom. Dinoflagellates occur in great numbers and variety in eastern offshore rocks as old as the Jurassic Period. Dinoflagellates have acquired a somewhat infamous



On the left is an Ordovician chitinozoan magnified 350 times; on the right is an Eocene dinoflagellate magnified 500 times from the Grand Banks.

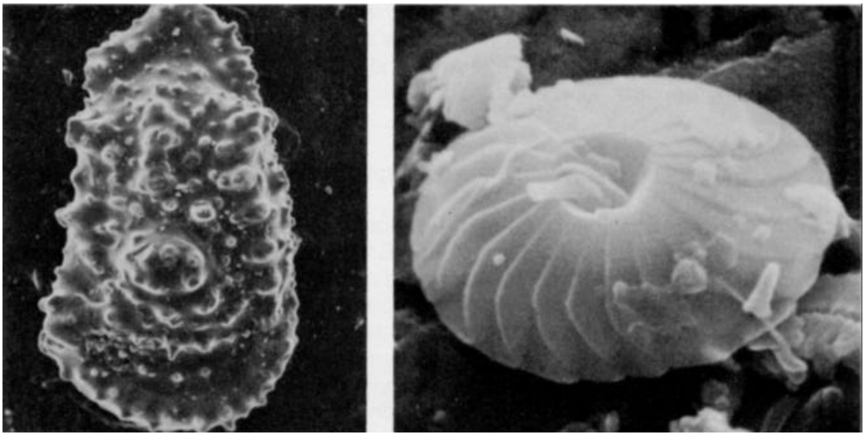
reputation as the organisms responsible for 'Red Tides,' a phenomenon where the dinoflagellates multiply so rapidly in one area that they colour the water red.

Over 30,000 fossil and 4000 living species of foraminifers are known and the fossil record of these organisms dates back to the early Paleozoic Era (Cambrian Period). Foraminifers are single-celled animals with a shelly test (skeleton) that live on the sea floor or float near the surface. The tests occur in great variety and numbers in Jurassic and younger rocks found off eastern Canadian shores.



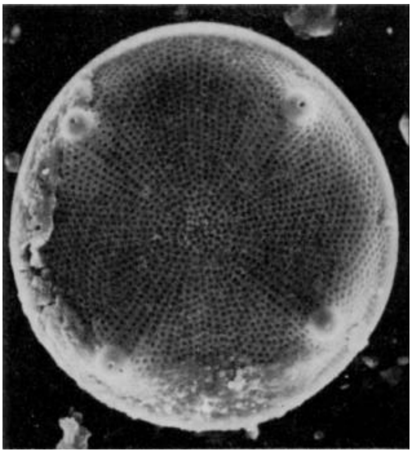
A Middle Jurassic planktonic foraminifera (left) magnified 450 times and a Late Jurassic benthonic foraminifera (right) magnified 275 times from the Grand Banks.

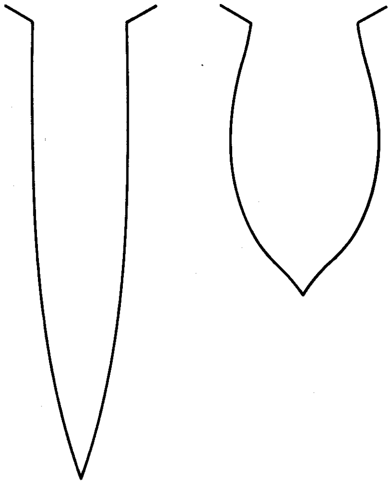
Ostracods (Paleozoic to Recent) are crustaceans with two shelly valves found in marine Jurassic and younger eastern offshore rocks. Coccoliths (Mesozoic to Recent) are the smallest offshore microfossils. The living coccoliths form part of the calcareous skeleton of marine, pelagic algae. These fossils are especially common in eastern offshore Upper Cretaceous strata.



A Late Cretaceous ostracod (left) magnified 75 times and a coccolith (right) magnified 10,000 times from the Scotian Sheff.

Diatoms and radiolarians are single-celled plants, found in pre-Paleozoic to Recent rocks, that have siliceous skeletons. Many of these microfossils are found in marine rocks of Early Tertiary age on the Grand Banks and Scotian Shelf. Calpionellids are minute, vase-shaped, marine, pelagic organisms of unknown origin that are extinct today but as fossils are found over a wide geographic area in uppermost Jurassic and lowermost Cretaceous limestone beds. The calpionellids from the eastern Canadian offshore are restricted to a few wells only.





A Tertiary diatom (left) magnified 300 times from the Grand Banks and (right) a cross-sectional view of a calpionellid magnified 500 times.

The presence of the microfossils described above and the diversity of species found in the offshore rocks is firstly a function of the organisms' evolutionary development and secondly of suitable environments of deposition for their preservation. In addition, the likelihood of finding certain species may be small. The figure on the next page illustrates the estimated species diversity of the microfossil groups based on the total number of species encountered in over 30 Scotian Shelf, Gulf of St. Lawrence, and Grand Banks wells. Individual wells may show a much reduced number of species and absence of certain microfossil groups.

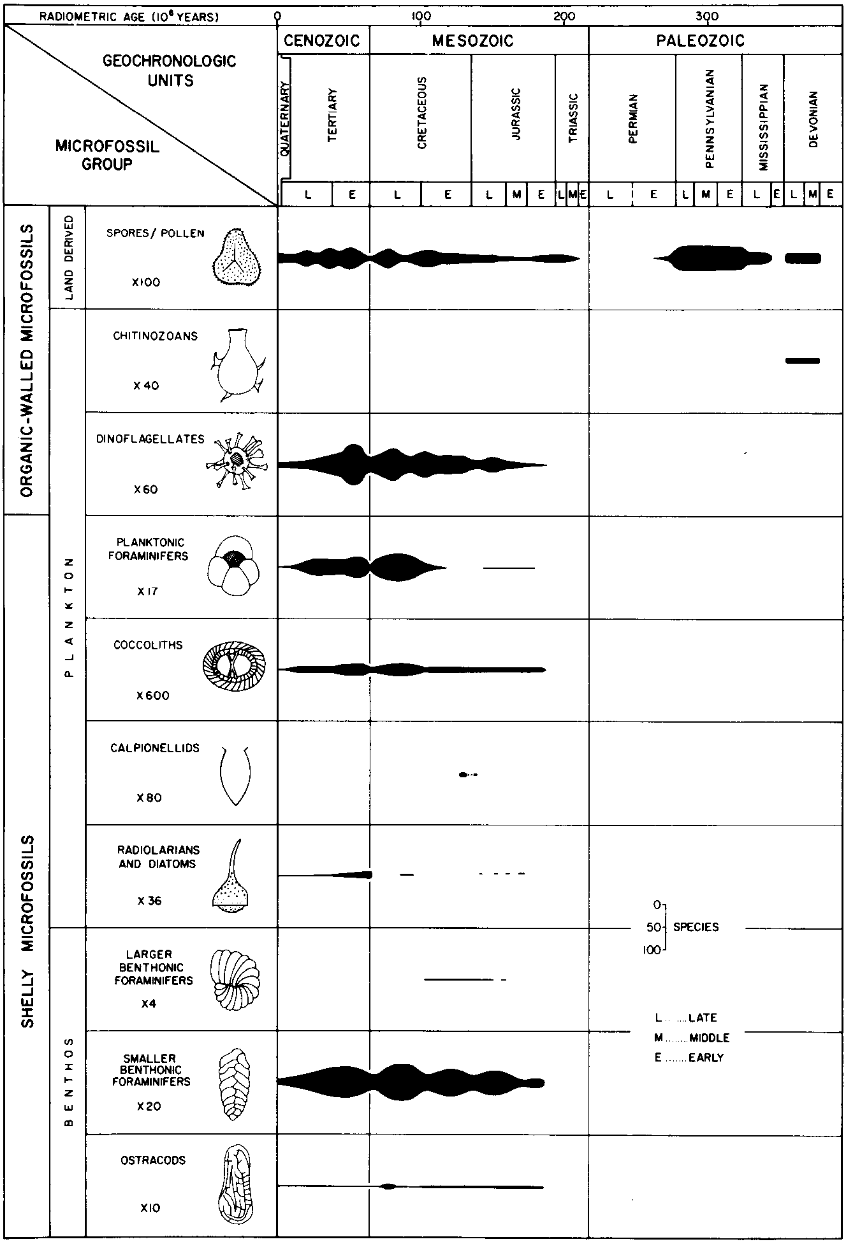
The major features of the diversity and distribution of the microfossils in the wells are given below.

(1) Certain spores and chitinozoans occur together in the bottom-most beds of at least one offshore well, e.g. Murre G-67, Grand Banks (see location map); this co-occurrence indicates that the rocks are marine and of Devonian age.

(2) Marine microfossils are absent in the Upper Devonian-Pennsylvanian, Lower Permian, and Middle Triassic-lowermost Jurassic offshore rocks, which were dated only on the basis of the age of the land-derived microfossils (spores and pollen) within them. This absence reflects widespread non-marine to possibly marginal marine conditions at intervals along the continental margin.

(3) Foraminifers, dinoflagellates, and ostracods occur first in the Lower Jurrasic offshore rocks and they are found in marine rocks of Jurassic to Quaternary age inclusively.

(4) 'Larger' foraminifers (bottom-dwelling organisms with a relatively complex test) inhabit shallow, marine environments. Their disappearance in the eastern offshore at the end of the Early Cretaceous corresponds with a marked increase in the number and species of dinoflagellates and planktonic and smaller benthonic foraminifers in Upper Cretaceous and Lower Tertiary



The estimated number of microfossil species in over 300 offshore wells on the Grand Banks, Scotian Shelf, and in the Gulf of St. Lawrence. (AOL 3586.)

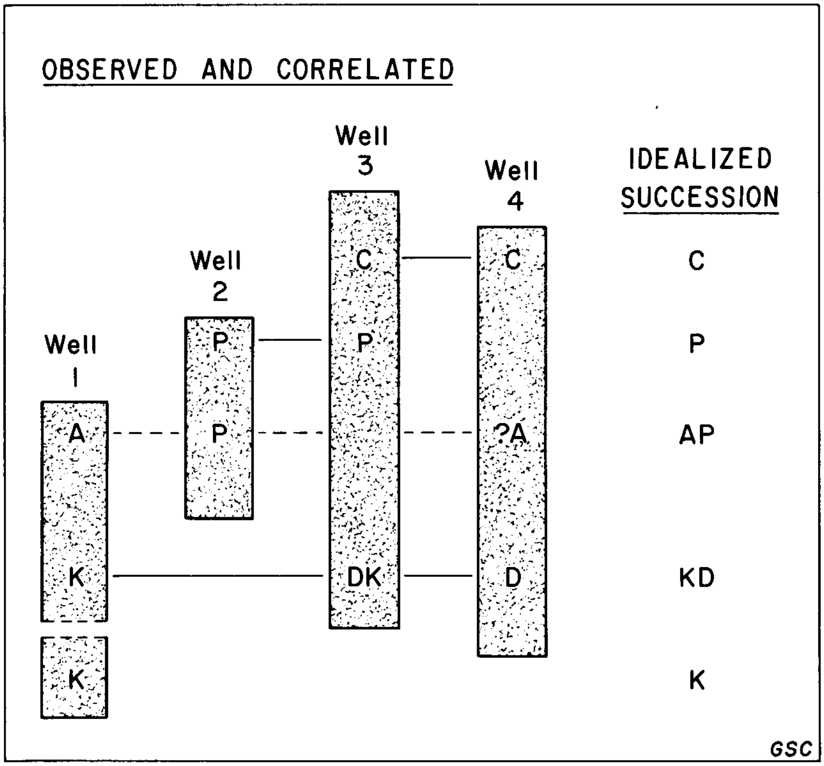
offshore strata. This change in composition of microfossil assemblages is believed to be due to a change to more widespread open marine and pelagic conditions than existed during the Jurassic and Early Cretaceous intervals.

(5) The number of both microfossil species and individual fossils is less in the Upper Tertiary and Quaternary offshore rocks than in the older rocks. This reduction is believed to be the result of widespread shallowing and progressive cooling of waters along the Canadian Atlantic margin.

Principles of Biostratigraphy

One of the first objectives of micropaleontological studies in a new, subsurface area is to get an idea of the stratigraphical (vertical) and lateral extension of microfossil species in as many wells as possible. Such an inventory will lead the micropaleontologist to recognize certain microfossils as typical of certain subsurface strata. A regional framework of stratigraphically successive microfossils or groups of microfossils (assemblages) is called a biozonation (see figure below).

A biozonation is made of the stratigraphic succession of rock bodies distinguished from each other by their fossil content. A zone is a body of strata characterized by



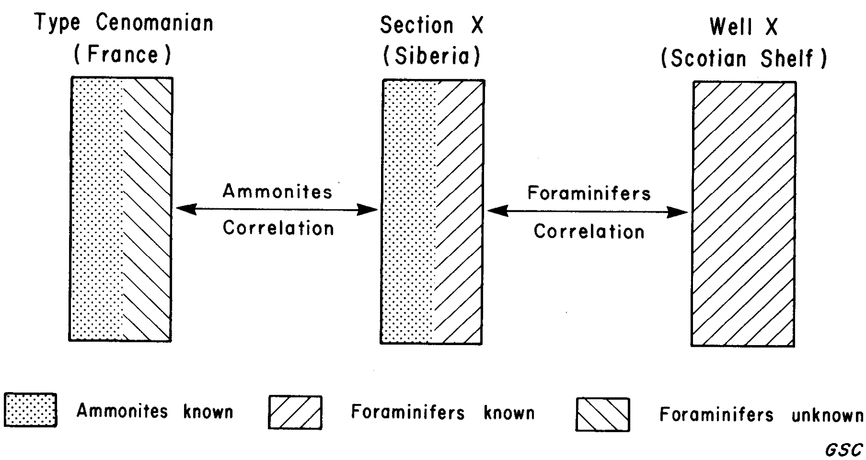
A possible biozonation based on the occurrence of microfossils K,D,A,P, and C. In this figure, wells 3 and 4 provide a clue to the relative stratigraphic position of all four wells. The likely stratigraphic succession of the microfossils K,KD,AP, P, and C as based on the wells is shown on the right. This succession may prove to be a useful zonation if it holds true in sufficient wells in the area of study. (AOL 3623.)

certain fossils. Such a biostratigraphic unit, which depends on the occurrence of one or more specific fossil taxa, at best lies between isochronous (equal age) surfaces, but such an ideal position will always remain unproved (Drooger, 1974). Nevertheless, in the absence of a better yardstick the zones are believed to be our best approximation to delineate geological time intervals.

Once the micropaleontologist has established a biozonation he attempts to determine the relative age of the zones. Such an age is normally expressed in units of the standard geological time scale. To arrive at the relative age of the zones the microfossils within it are compared to described microfossils found elsewhere, preferably from type (reference) rock sections. The relative geological age of the deposits in type sections has been determined through detailed geological and paleontological studies. This comparison leads to the relative age assignment of the strata studied.

The procedure for relative age determination may be outlined in this imaginary example (see figure below). Let us assume that Scotian Shelf wells have yielded a distinct assemblage of foraminifera, which could be of Cenomanian (Cretaceous) Age as indicated by underlying and overlying assemblages. Suppose that the Type Cenomanian is barren of foraminifera but, by means of ammonite macrofossils, it is possible to correlate the Type Cenomanian with a Cenomanian outcrop section in Siberia (USSR). The Siberian section has a described foraminiferal assemblage strikingly similar to one found in Scotian Shelf wells. On the strength of this correlation, the micropaleontologist may reasonably conclude that the Scotian Shelf assemblage is of Cenomanian Age. The correlation is a second order one as it involves two steps.

In the example above, a Cenomanian Age was assigned to Scotian Shelf strata by correlating assemblages of foraminifera. An important step in the micropaleontologic research of the offshore area is to reconcile the individual age interpretations from several microfossil groups. The fact that micropaleontologists studying different fossil groups may arrive at slightly different ages for the same rock unit (which can only have one age, not two) often creates confusion. The differences in interpretation are due to several factors. Firstly, many fossils may not occur synchronously from one area to the other; the accuracy in synchronic



An imaginary example of a Cenomanian age determination in a Scotian Shelf well (see text). *(AOL 3626)* appearance and extinction over a wide area certainly varies widely from fossil to fossil and from one group of fossils to another. Generally, pelagic (floaters) fossils are favoured over benthonic (bottom dwellers) ones when it comes to rapid, synchronic dispersal. Then there is the problem that the biostratigrapher may be able to determine relative ages only through n^{th} order correlations, as outlined above. Because type sections almost invariably represent only part of a stage (see van Hinte, 1968), and because many useful zone fossils are geographically restricted, direct correlations from type sections are more an exception than a rule.

Another factor leading to discrepancies in estimated ages is that fossils may be incorrectly identified. Also, some of the microfossils present may be derived from older rocks that were reworked by currents and other agents, and drilling contaminants may cause problems.

A common source of discrepancy, especially in operational work, stems from the fact that geologists are already asking for relative ages of rocks before the samples from the first well have been processed. As a result, it is inevitable that the biostratigrapher has to revise ages from time to time. For all these reasons, it is clear that a greater number of criteria for a biozonation will result in a better or alternative correlation of the zones. A multiple biozonation will usually give a better approximation to a time-stratigraphic framework than a biozonation based on one group of fossils only.

Principles of Paleoecology

Almost any group of organisms, be it primitive or highly developed, has a strong preference for certain environments. Foraminifers and coccoliths are almost exclusively marine; spores originate from land plants. A more detailed study generally reveals that individual species of the above organisms prefer specialized sub-environments. The science that studies the distribution of living organisms is called ecology and of fossils, paleoecology.

When fossils have present-day counterparts it is normally assumed that their present-day habitat may be extrapolated to the past. In the case of extinct organisms, their life habitat is extrapolated from close relatives still living or is reconstructed from other evidence in the rocks such as fossil association, lithology, and basin paleogeography. Paleoecological studies reconstruct the life habitat of fossils and allow the paleontologist to draw conclusions about the original environment of deposition of the rocks in which fossils are embedded.

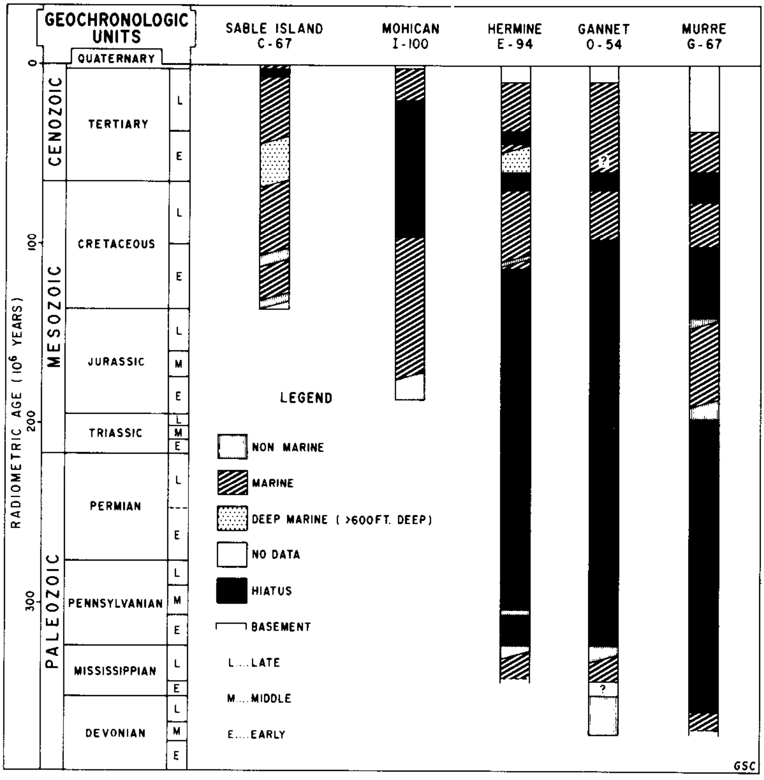
A reconstruction of the environment of deposition of Canadian Atlantic offshore strata is a routine procedure along with relative age determinations. Environments recognized include: terrestrial, marginal marine (brackish, coastal plain, lagoonal), inner continental shelf or shallow marine, outer continental shelf, and continental slope or deep sea.

The interpretation of the depositional environments in conjunction with the age and lithologic framework lead to the depositional history of the area. An understanding of the depositional history is the key to an assessment of oil and gas potential.

Stratigraphy and Depositional Environments

The oldest Canadian eastern offshore rocks dated by means of microfossils are of Devonian age; the youngest are of Quaternary age. Between the Devonian and

Quaternary, a time span of more than 300 million years, an almost continuous sedimentary record has been established offshore, that is to say within the limits of our multiple zonation. A so-called composite section, i.e., a stratigraphic section based on all the wells studied, shows that only rocks of Late Permian and Early Triassic age are missing. individual wells may have considerable hiatuses or breaks in the continuity of the geological record. Such individual hiatuses are evident from the figure below where the stratigraphic distribution and generalized depositional environment have been plotted of the sediments in two Scotian Shelf wells and three Grand Banks wells (for exact locations see previous map).



Stratigraphic distribution of Paleozoic, Mesozoic, and Cenozoic rocks in five wells on the Scotian Shelf and Grand Banks. (AOL 3586)

The hiatuses in the Grand Banks wells, Murre, Gannet, and Hermine, where younger Mesozoic sediments meet on Paloezoic strata are thought to be the result of widespread uplift and erosion, following Paleozoic subsidence and sedimentation. The latest Jurassic-Early Cretaceous hiatus in the Murre well is also the result of uplift and erosion over the Grand Banks following a period of Jurassic sedimentation. In contrast, sedimentation on the Scotian Shelf continued in the Early Cretaceous (Sable Island and Mohican wells). The hiatus in the figure above at the Cretaceous-Tertiary boundary is possibly a submarine erosional event. The Late Cretaceous-Late Tertiary gap in the Mohican well seems to be due to a local slide-down of shelf-edge sediments in Late Tertiary time (J. A. Wade, personal communication).

The Paleozoic offshore rocks as penetrated in several wells, especially in the Gulf of St. Lawrence, form parts of belts of Paleozoic strata widespread in eastern Canada and western Europe. The Late Devonian-Permian sediments sampled in the wells were deposited in non-marine to shallow marine environments and formed in small sedimentary basins; their thickness is known to exceed 30,000 feet (9150 metres) in the Gulf of St. Lawrence (Howie and Barss, in press).

Mesozoic and Cenozoic beds as found in the Canadian eastern offshore subsurface are almost nonexistent onshore. Coeval beds of similar nature, therefore, have to be looked for in Europe, North Africa, and to some extent in the United States. The oldest Mesozoic eastern offshore rocks, e.g. the lowermost Jurassic rocks in Murre and Mohican, were deposited in terrestrial to marginal marine environments. They are usually overlain by shallow marine deposits of Jurassic and Early Cretaceous age. From the widespread occurrences in the offshore wells of Late Cretaceous, open marine, pelagic, microfossil assemblages, we know that in Late Cretaceous time pelagic conditions were widespread. During that Period, a blanket of carbonates and clastics accumulated on large parts of the Scotian Shelf and Grand Banks.

In Early Teritiary time, the present outer Scotian Shelf and southernmost Grand Banks probably were largely in deep marine waters. In Late Tertiary time that area became rapidly shallower. On the rest of the Scotian Shelf and Grand Banks, shallow marine conditions may have occurred throughout the Cenozoic.

The total thickness of Mesozoic-Cenozoic sediments on the Scotian Shelf exceeds 30,000 feet (9150 metres).

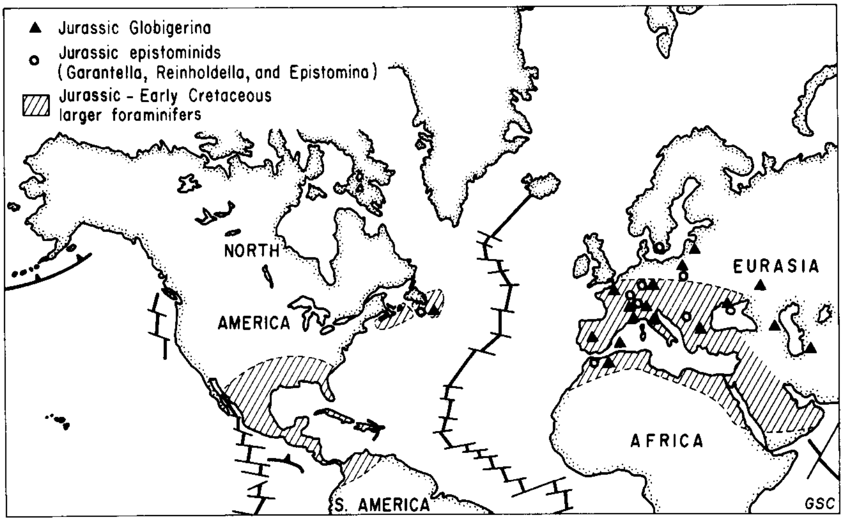
The above environmental trend of terrestrial to shallow marine to open marine to deep marine through Mesozoic and Early Cenozoic time as found in parts of the Scotian Shelf and Grand Banks may be related to the appearance and widening of the North Atlantic Ocean. As far as I know, there is as yet no clear understanding of the mechanism linking subsidence of this continental margin to widening of the oceanic basin. The widespread Late Cenozoic shallow marine realm on the Scotian Shelf and Grand Banks seems to be the result of rapid growth of the present continental shelves. This growth, which is a world-wide feature, is due in part to lowering of sea level when more ice formed near the poles.

Mesozoic-Cenozoic Biogeography

Microfossils rarely have a world-wide distribution. A reconstruction of the world-wide occurrence of microfosils of a certain age often reveals distinct patterns related to the extension during that period of a certain environment.

In the case of the Canadian continental margin, my colleagues and I are comparing Grand Banks and Scotian Shelf microfossil assemblages of Jurassic, Cretaceous, and Tertiary age to coeval assemblages in Europe, North Africa, and elsewhere in North America. The distributions reveal distinct affinities to certain areas, which to some extent may be explained in the light of ancient climates, ocean circulation, and plate tectonics.

For example, Jurassic and early Cretaceous foraminiferal, ostracod, and dinoflagellate assemblages from the Scotian Shelf and Grand Banks have strong affinities to coeval assemblages known from Europe. The areas have many species in common that are not known from elsewhere in North America. An example of the ‘old world’ affinity is provided by Jurassic foraminifers belonging in the genera *Globigerina, Garantella, Reinholdella, Epistomina,* and the Jurassic-Early Cretaceous 'larger' foraminifers. The Jurassic *Globigerina* are supposedly 'primitive' planktonic foraminifers and might be expected to have a wide dispersal in the Jurassic seaways. *Garantella, Reinholdella,* and *Epistomina* are benthonic foraminifers as are the 'larger' foraminifers. The latter are confined to shallow and very shallow marine environments. These groups of foraminifera, which occur with many species and abundant individuals in Grand Banks and Scotian Shelf Jurassic or Lower Cretaceous deposits, are well known from Europe and Africa to some extent, but not elsewhere from North America (see figure below). An exception is the occurrence of a few taxa of 'larger' foraminifers and one or two *Epistomina* species in the Gulf Coast and Caribbean regions.



Distribution of selected Jurassic and Early Cretaceous foraminifera in North and South America, Eurasia, and Africa. (AOL 3686.)

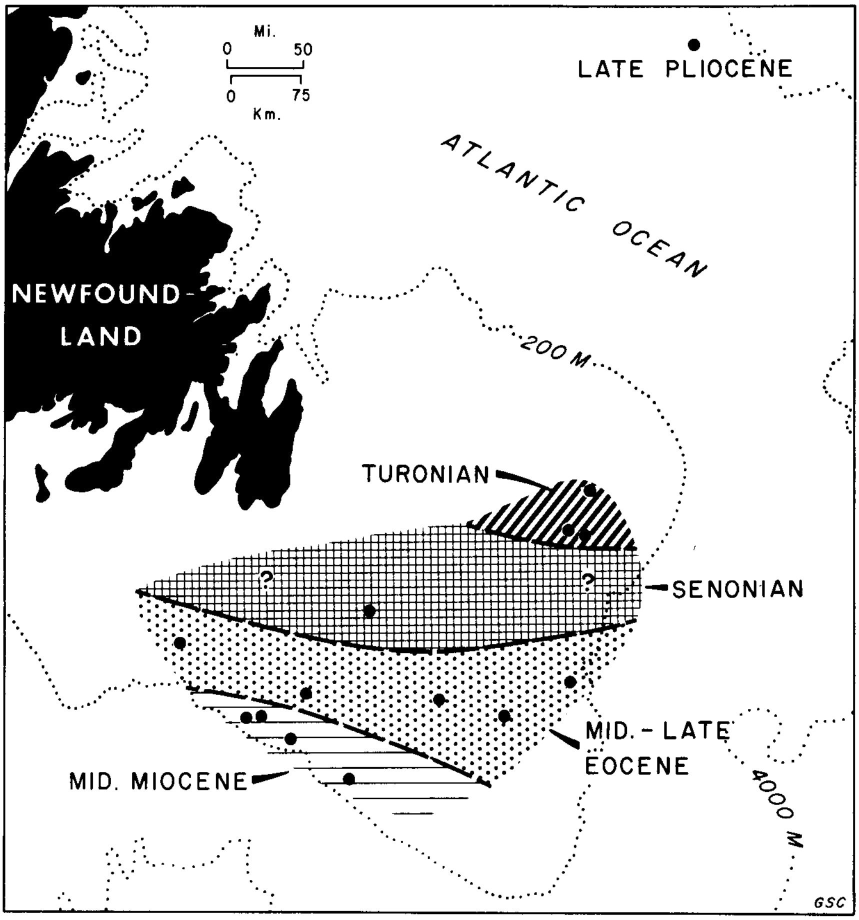
The well-known pre-drift reconstruction of the American, European, and African plates in Jurassic and Early Cretaceous time, while the Atlantic Ocean was still relatively narrow, helps to explain the striking distribution pattern discussed above.

The predrift reconstruction indicates geographic proximity of the Grand Banks and Scotian Shelf in Jurassic-Early Cretaceous time to the Mediterranean region and presumably shallow marine connections between the 'Old' and the 'New' Worlds. Shallow marine bottom dwellers like the 'larger' foraminifers probably require a shallow marine connection to explain their presence with the same taxa on both sides of the present North Atlantic Ocean. In the light of this paleogeographic configuration, it is no great surprise that the mentioned Jurassic and Early Cretaceous taxa found east of the present North Atlantic Ocean also occur in the Grand Banks and Scotian Shelf subsurface and in the case of a few species are also known from the Gulf Coast of the United States and adjacent regions.

The land mass of the Appalachians and the adjacent shield west of it delineate the western margin of the Jurassic-Early Cretaceous Atlantic province. Jurassic and Early Cretaceous foraminiferal and also ostracod and dinoflagellate assemblages of the Western Interior, west of the Canadian Shield, bear little resemblance to their Atlantic counterparts.

In Late Cretaceous time, the benthonic-foraminiferal and ostracod assemblages from the Grand Banks and Scotian Shelf do not show prominent ‘Old World’ affinities. Several of them seem to be restricted to North America or to have different stratigraphic ranges on both sides of the Atlantic. Many ‘Old World’ larger foraminifers are absent from North American Upper Cretaceous deposits. Such indications of provincialism are compatible with a widening and deepening North Atlantic Ocean, which created a barrier for many bottom dwellers.

Planktonic foraminifers and dinoflagellates as found in Upper Cretaceous Grand Banks and Scotian Shelf deposits occur on both sides of the North Atlantic in low and mid latitudes. Their dispersal seems to be largely controlled by suitable water masses and presumably by a proto-Gulf Stream, which must have reached the present Grand Banks and Scotian Shelf. Today the Gulf Stream passes east of these shelves, touching only the southeastern Grand Banks. The cold Labrador Current influences most of the present shelf region.



Disappearance in Cretaceous and Tertiary time of warmer water planktonic foraminifers from the Grand Banks region. (AOL 3640)

In Early Tertiary time, pelagic foraminifers and dinoflagellates, especially common in lower latitude deposits, also occur as far north as the Grand Banks, which again suggests the influence of a proto-Gulf Stream there. A more detailed analysis of the dispersal in Early Tertiary time of pelagic foraminifers over the Grand Banks suggests the Gulf Stream influence was limited to the southern part of the shelf (see figure opposite).

By middle Miocene (Late Tertiary) time, low-mid-latitude planktonic foraminifers all but disappeared from the Grand Banks and also from the Scotian Shelf. Only southernmost Grand Banks wells still have some Miocene warmer water planktonic foraminifers; there is no younger record of such pelagics in the area.

Late Cretaceous-Tertiary shallowing of water over the Grand Banks, first in the north and later in the south, as discussed earlier, terminated the warming influence of the Gulf Stream there and was probably responsible for the shift to the south of the gradual extinction of planktonic foraminifers. Skeletons of benthonic foraminifers testify that by middle Miocene time only the southernmost part of the Grand Banks was deep marine and soon became much shallower. On Orphan Knoll, a deep-marine seamount north-northeast of the Grand Banks that has remained at the same depth since the Early Tertiary period, the Gulf Stream's influence lasted from mid-Cretaceous through Pliocene time (Ruffman and van Hinte, 1973; Poore and Berggren, 1974). Since then, the Labrador Current has brought colder water faunas both at the seamount site and on the adjacent shelf regions.

The Pliocene-Pleistocene microfossils in the offshore subsurface include many forms that have been reworked from older rock-deposits. This reworking appears to be the result of increased erosion of hinterland deposits during periods when sea level was lowered due to several large increases in the Pleistocene ice sheets.

Concluding Remarks

Much is being learned on the micropaleontology of the Canadian Atlantic continental margin from the exploratory wells and core holes being drilled there. Micropaleontologists are providing the detailed age and environmental determinations necessary to unravel the geological history of the area, to assess oil and gas potential, and to support further drilling. The most promising returns of exploration at present are from the Labrador Shelf and the Sable Island region of the Scotian Shelf. In the near future, the Greenland side of the Labrador Sea and the Atlantic seaboard of the U.S.A. will be explored. In 1975, the Deep Sea Drilling Program (DSDP) will drill a number of deep-sea core holes in the northwestern part of the Atlantic Ocean off the U.S.A.

Micropaleontological data gathered from the North American Atlantic continental margin will be vital to the new offshore ventures and more microfossil material will become available for further studies. More detailed research on the Paleozoic and Mesozoic microfossils of the Grand Banks, Scotian Shelf, and Atlantic shelf of the U.S.A. is necessary to understand the earlier history of the Atlantic Ocean basin. Micropaleontological data from the deep Labrador Sea wells will contribute to the fuller understanding of the early history of that area.

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Geophysical Fluid Dynamics

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Geophysical Fluid Dynamics (GFD) is a branch of modern Fluid Dynamics. Its primary objective is to understand the basic mechanisms of a class of geophysical phenomena, which encompass fluid motion. The word geophysical is used here in its broadest sense and the geophysical phenomena referred to include not only those that occur inside the Earth, such as the fluid motion in the Earth's core, and those on and above the Earth, but also the fluid motions in other planetary atmospheres, in the Sun, and in distant stars.

A geophysical fluid dynamicist studies heat transport and fluid motion in a differentially heated fluid. These studies, he hopes, will shed light on such seemingly unrelated topics as the mechanism of continental drift and the formation of cloud rows in the atmosphere. He investigates electrically conducting fluid elements in motion and how they interact to create and sustain magnetic fields in and around a fluid body, and from the knowledge gained attempts to explain the Earth's magnetic field and its variation. He studies rotating and stratified fluids to understand the fundamental dynamics of the world's oceans and planetary atmospheres, in part or in whole. In trying to understand the formation and structure of spiral galaxies, he studies how rotating self-gravitating fluid discs can become unstable (a self-gravitating body is not influenced by an external gravitational field). He studies the spin-up, spin-down, and spin-over problems (discussed below), which mathematically relate phenomena as far apart as the rapid decay of a swirl in a teacup, the gravitational field of the Sun, and transient phenomena in the top layer of the ocean after the passing of a storm. All of these examples are broad and indefinite because GFD is a broad, indefinite discipline. Contributions to GFD come from scientists of all backgrounds: applied mathematicians, fluid dynamicists, oceanographers, meterologists, geo-astrophysicists, and engineers.

Broadly defined, Geophysical Fluid Dynamics is a scientific discipline concerned with the dynamics in the following fluid systems:

(1) Stratified systems where fluid density varies in space and perhaps also in time. The gravitational pull the Earth exerts on a fluid element is proportional to its density. Variations in density will give rise to varying gravitational pulls, or buoyancy forces, that are often sufficient to set the fluid in motion.

(2) Rotating systems where a fluid is subject to the constraints of rotation (the Coriolis force). For example, a fluid in motion in the northern hemisphere will be pushed by the Coriolis force from left to right and perpendicular to its direction of motion.

(3) Rotating and stratified systems where both the Coriolis and buoyancy forces are important.

We can also subject any of these systems to an external magnetic field and consider the fluid to be an electrical conductor. Such a system is called a rotating and/or stratified magnetohydrodynamic (MHD) system. As we may readily recognize, none of these is a close analogue to any of the infinitely complex environmental, geophysical, or astrophysical systems that exist.

Within the ocean, we can find examples of each of these fluid systems. If we are interested in the internal gravity waves, we consider the ocean as a stratified but nonrotating system because the periods of these waves are small compared with a pendulum day and the effect of the Earth's rotation is therefore negligible; on the other hand, to study internal tides we must include the effect of the Earth's rotation. If we are interested in large-scale ocean circulation in response to the trade winds, we can consider the ocean as a homogeneous rotating fluid system, i.e., stratification can be ignored. However, to understand the response of an ocean to differential heating and to variable wind stress, we must consider it as a rotating, time-dependent, stratified system. These rotating and stratified systems can be quite complex. Phenomena such as the westward intensification of wind-driven ocean currents in the northern hemisphere (the Gulf Stream is an example) exist largely because the vertical component of the vector representing the Earth's rotation decreases from the pole to the equator.

In order to isolate the study of various individual phenomena, a geophysical fluid dynamicist often studies 'models' of nature that are simplified to include but the bare minimum of the forces observed in nature. It is hoped that these models contain enough 'ingredient' so that any fundamental processes revealed by them will enable us to better understand phenomena in nature. Three current research topics of this type in GFD are : (1) the problem of double diffusive convection, an extraordinary transport phenomenon occurring in fluids consisting of two or more constituents or components on which the fluid density depends; (2) the spin-up problem, a transient problem in rotating fluids but a very important one; and (3) the rotating annulus problem, an example of a rotating and stratified fluid dynamical phenomenon in its full complexity.

These topics have become important because of the large variety of natural phenomena that can be explained and understood through them. In the rest of this essay, we shall examine these topics in some detail.

The Double-Diffusive Convection Problem

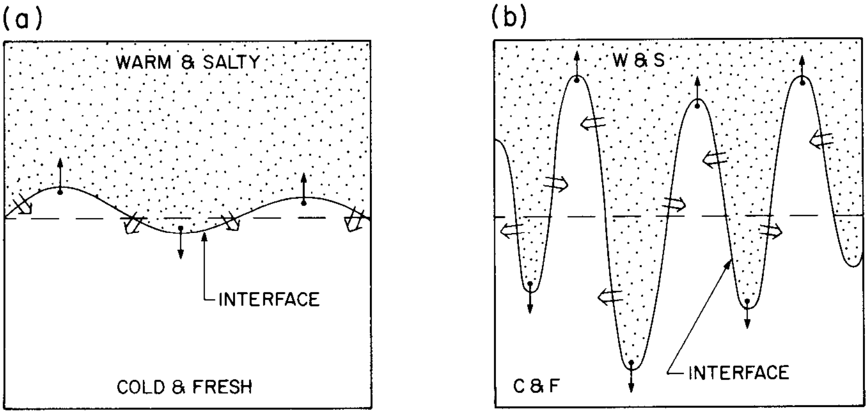
What is double-diffusive convection? Convection is a transport mechanism in a fluid by virtue of fluid motion. The motion can be induced externally (forced convection) or internally (natural convection). Double-diffusive convection is natural convection in which the fluid motion is induced by 'double-diffusion'. As the term implies, double-diffusion means the simultaneous diffusion of two constituents, or components, of a fluid on which the fluid density depends. For example, the density of sea water depends on its heat and salt content, both of which can be redistributed through diffusion. The first exposition of the underlying mechanism of this interesting class of convective motion was given by Stommel *et al.* (1956) in their celebrated paper on the salt fountain. In order to demonstrate the dynamical effect of double diffusion in a two-component fluid, we must recapture Stommel and associates' thought experiment.

Consider an ocean where temperature and salinity both decrease with depth such that the ocean is statically stable (that is, the density due to the combined effect of temperature and salinity increases with depth). Suppose a long copper pipe, which is a good heat conductor, is lowered into this ocean and that a pump is used to draw some bottom water through the pipe. The pump initiates flow and water will continue to pour out of the pipe at the surface even after the pumping is stopped, thus, creating a 'perpetual' fountain.

How is this fountain created? The column of water initially pumped into the pipe is colder and fresher than the water at the same level outside the pipe. If it is assumed that the cold, bottom water inside the pipe is heated through the wall of the pipe instantaneously to the ambient temperature of the surrounding sea water then the water in the whole column will become lighter than that outside at the same level because it is fresher. This leads to a pressure gradient and water would converge towards the pipe if the fluid outside the pipe could 'feel' the pressure inside. But because the pipe wall is solid, and no fluid pressure can be transmitted through a solid boundary, the only place where the pressure gradient can play an effective role is directly under the pipe and, consequently, the fluid travels up the pipe. The resultant fountain is not really perpetual because it draws on the potential energy of the ocean.

The important mechanism in this experiment is that while heat is permitted to diffuse from one body of fluid to another, salt is not. This upsets the natural equilibrium and the dynamical effect of the difference in the rate of heat and salt diffusion is amplified artifically by stopping the diffusion of salt altogether in the pipe.

We can carry out a second thought experiment in a more natural way. Consider a fluid consisting of two layers of different densities. The upper layer is warmer, saltier, but lighter than the lower one. Imagine some disturbance at the interface of the two layers in the form of small amplitude waves. These waves deform the otherwise level interface and displace parcels of warm salty water into the lower layer, and parcels of cold fresher water into the upper layer as shown below (part a). Because the diffusion of heat is 100 times faster than salt, the upward bulges gain heat much faster than salt, become lighter than the surrounding fluid, and rise, while the downward bulges lose heat much faster than salt, become heavier, and sink. Thus, these disturbances grow with time and the system is said to be unstable. Finally, the small intrusions grow to be like long fingers that extend from the interface in both directions (part b of the figure below). This phenomenon has come to be known as salt-fingering.



(a) *In a two layer fluid consisting of a warm and salty upper layer upon a cold and fresh lower layer, any disturbance at the interface tends to amplify. The hollow* arrows indicate *the heat transfer, and the solid arrows indicate the likely movement of the fluid elements at the crest and trough of the small amplitude waves, because they have become lighter or heavier than the surrounding elements due to gain or loss of heat. (AOL 3665.)* (b) *The disturbances tend to grow with time. Eventually they become finger-like intrusions from one layer into another. (AOL 3665.)*

In the reverse situation, when the upper layer is fresh and cold and the lower layer is warm and salty, the upward bulge would lose heat and sink back to its original position; also, the downward bulge would gain heat and rise. Thus, a displaced fluid element would be restored to its original position. This system is said to be stable.

There are a whole range of secondary phenomena associated with double-diffusion of which Dr. J. S. Turner, Reader of Geophysical Fluid Dynamics at Cambridge University, has made numerous laboratory studies during the past 10 years. His important findings are described in his book (Turner, 1973) and a recent review paper (Turner, 1974).

Where in nature does double-diffusive convection occur? The onset of double-diffusive convection requires a delicate balance between buoyancy and diffusive forces. The first requirement is that a fluid must contain two different components or more on which the fluid density depends. An additional requirement is that the initial distribution of these components must be such that they make opposing contributions to the vertical density gradient. Heat is a universal component. In the ocean, we have a second one, salt; in the atmosphere, water vapour; in the stars, different chemical compositions in different regions. All are areas where double-diffusive convection may occur.

In recent years, oceanographers have been able to collect data in the ocean sufficiently dense in space to enable them to study the so-called microstructure of the ocean, i.e., phenomena ranging from millimetres to metres in scale. They have found numerous step-like distributions of temperature and salinity in many areas of the oceans. It appears that many of these step-like distributions (although not all of them) can be explained by double-diffusive convection. For example, turbulent mixing due to diffusive convection in the ocean can generate well-mixed layers away from the interface. In each of these layers the temperature and salinity are almost constant, but they are different in adjacent layers. A salinity or temperature trace across these layers would give step-like distributions. Some steps tens of metres deep have been observed in the ocean.

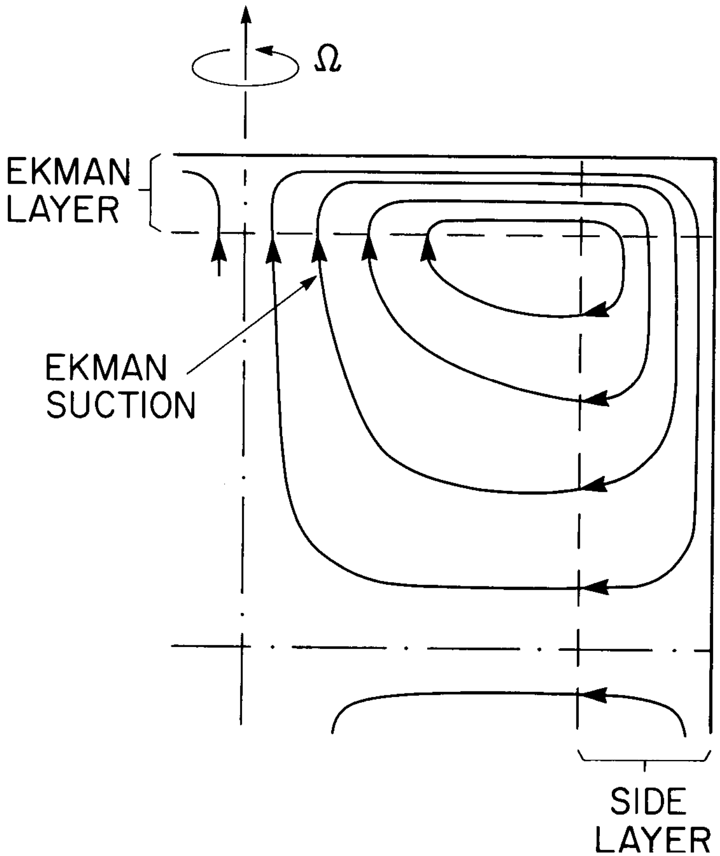
The Spin-up Problem

What is spin-up? Assume that we have a contained fluid rotating in unison with the container at a uniform speed R radians/second. (The fluid is said to be in solid body rotation.) Now let the speed of rotation be changed from Ω to $(1 + \epsilon)\Omega$, ϵ being the change in speed from Ω. A positive ϵ means an increase in speed and a negative ϵ means a decrease. Though the container would attain the new rotational speed instantaneously, the bulk of the fluid would take considerably more time to catch up with the new speed. The description of the transient dynamics of the fluid from one state of solid rotation to another constitutes the spin-up problem (Greenspan and Howard, 1963; Greenspan, 1968; Benton and Clark, 1974). It sounds simple because we can easily predict what the new state is going to be - just another solid rotation - and because we can conceptually visualize the whole experiment very easily. But to describe the transient behaviour of the fluid between the two steady states is a very complicated problem. The spin-up problem in a stratified fluid is even more complex. In fact, the latter problem created a lively controversy in the mid-1960s. Up to 1974, the spin-up problem in stratified fluid was never completely solved, because none of the mathematical theories could satisfy *all* the boundary conditions. St. Maurice and Veronis (1975) used multitiming analysis to break up the transient processes into different time scales and to study them sequentially. They have resolved some discrepancies between theory and experiment.

Before explaining the dynamics in spin-up, note that, strictly speaking, spin-up applies to the case when $0 < \epsilon$, an increase in speed; it is spin-down if $0 > \epsilon \geq -1$, a decrease in speed; and it is spin-over when $\epsilon < -1$, a reversal in the direction of rotation. Spin-up has been commonly used, however, to refer to all three transient phenomena when the angular speed of a rotating system is abruptly changed. Most mathematical theories are for $|\epsilon| << 1$, which means the change is only a fraction of the original speed.

Now consider a vertical cylindrical vessel with rigid top, bottom, and side walls that is filled with fluid and put in solid rotation at an angular speed Ω. Let us increase the rotation rate abruptly from Ω to $(1 + \epsilon)\Omega$, ϵ being small. The fluid particles on the bounding surfaces must change speed instantaneously with the container, but the bulk of the fluid lags behind. Thus, 'viscous boundary layers' are formed due to viscous drag, which is strongest near the boundaries. Within these layers, fluid velocities undergo transition from the wall speed to the slower fluid speed in the interior of the vessel. For the bulk of the fluid the balance of forces is between the original centrifugal force (which is directed radially outward and is proportional to Ω^2 at a given radius) and a pressure gradient. However, in the boundary layers near the top and bottom, which are also known as Ekman layers in rotating fluids, the fluid rotates near the speed of the bounding surfaces and hence experiences a centrifugal force larger than the existing pressure gradient can support. Fluid particles thus move radially outward in these boundary layers. Fluid from the interior moves into these layers to replace the fluid moving out of them thus creating a secondary flow, which is known as 'Ekman suction'. The fluid particles moving radially outward in the Ekman layers will move down (up) the vertical boundary layer near the cylindrical wall from the top (bottom) when they approach the corners, and eventually return to the interior as shown roughly in the figure (next page). A fluid element from an outer ring has to spin-up as it moves inward towards the axis of rotation in order to conserve angular momentum, which is proportional to $\Omega^* r^2$, r being the radial distance of the fluid element from the axis of rotation and Ω^* being the instantaneous angular velocity of a fluid element. Hence, in order to keep $\Omega^* r^2$ constant, Ω^* must increase while r decreases. This is the spin-up process, which will continue until the whole body of fluid has attained the new rotational speed, i.e., when the whole contained fluid has reached a new state of solid rotation, or $\Omega^* = (1 + \epsilon)\Omega$ everywhere.

There are three natural time scales for the whole process. (1) $t_1 \simeq 0(1/\Omega)$, roughly of the order of a few rotational periods. Within this time scale, the Ekman boundary layers have fully developed. (2) $t_3 \simeq 0(L^2/\nu)$ called the viscous diffusion time, L being some typical length scale, for example, the radius of our vessel, and v being the coefficient of viscous diffusion. During t_3, momentum has diffused throughout the whole vessel and the residual small oscillations set up by the original impulse are finally destroyed by viscosity. (3) A third time scale known as the spin-up time is the geometric mean of t_1 and t_3, or $t_2 = (t_1 t_3)^{1/2} = (1/\Omega \bullet L^2/\nu)^{1/2} = E^{-1/2}\Omega^{-1}$ where E is known as the Ekman number, and is defined as $E = \nu/\Omega L^2$. During this time scale, the whole body of fluid would have attained the new state of rotation at $(1 + \epsilon)\Omega$ in the above example. If we 'nondimensionalize' these time scales by multiplying them with Ω (second^{-1}), they become $t_1 \simeq 0(1)$, $t_2 \simeq 0(E^{-1/2})$, $t_3 \simeq 0(E^{-1})$. For small E (say for a given vessel, we let Ω become very large), we can order the time scales: $t_3 >> t_2 >> t_1$. Therefore, we can distinguish different modes of motion with some accuracy because their time scales are so different.



Schematic diagram showing the stream lines and boundary layers in spin-up of a fluid contained in a cylinder. The weak interior velocity is induced by Ekman suction. (AOL 3665.)

This helps to explain why multitiming analysis as used by St. Maurice and Veronis has turned out to be a very successful approach for the spin-up problem when E is small. In their analysis, motions of precisely these time scales have been separated and studied.

The most common example of spin-up can be observed in a teacup. Suppose a teacup filled with tea has a radius of about 4 centimetres. Stirring the tea with a spoon going around the cup once every 4 seconds would set the tea into a swirl with an angular speed $\Omega = 2\pi/4 = \pi/2$ radians/second. If we take out the spoon, the swirl will begin to slow down. Taking the molecular viscosity to be $v = 10^{-2}$ square centimetres per second, the radius of the cup, 4 centimetres, for L, and $\Omega = \pi/2$ radians/second for angular speed, we easily obtain $t_3 \simeq 0.5$ hour, $t_2 \simeq 1$ minute, $t_1 \simeq 1$ second from the formula given above. The most probable time for the swirl to die down completely is about 1 minute, which is t_2, the spin-down time. Common sense would have suggested that the slowing down might be due to viscous drag and hence it would take one-half an hour for the swirl to die down. We know that assumption is incorrect.

The dynamics of the decay of a swirl in a teacup is just the reverse of the spin-up dynamics explained above. The swirl of the tea is maintained by a centrifugal force and a radial pressure gradient (that is why we have a parabolic surface, which provides that radial pressure gradient). However, the fluid in a thin layer attached to the bottom of the cup is not swirling as fast because of viscous drag. The centrifugal force in that small boundary layer is hence inadequate to counteract the pressure gradient imposed from the interior. The fluid in the boundary layer thus moves inward (not outward as in spin-up). Fluid in other parts of the cup has to move outward radially to compensate for the fluid that has moved inward in the bottom layer. The swirl eventually decays because of the depletion of angular momentum due to continuous replacement of the outer fluid, which has more angular momentum, with the inner fluid, which has less. This also explains why the tea leaves tend to cluster in the centre at the bottom of the teacup after stirring.

Spin-up in a stratified fluid is more complex. For one thing, stratification tends to suppress vertical motion and makes the Ekman suction less effective in drawing interior fluid into the boundary layer. Consequently only a small area of scale δ adjacent to the boundary layer is affected, δ being defined by $\delta^2 = L/S$. S is the stratification parameter, a measure of the relative control of stratification and rotation, and defined as $S = (N/2\Omega)^2$, N being the well known Brunt-Väisälä frequency, which is proportional to the square root of the vertical density gradient, an effective measure of the strength of stratification in the system. The fluid in this small region is spun up in a time scale $t_2^* = t_2\,(\delta/L)$. This simply means that we replace L by the smaller length scale,, δ, in calculating the spin-up time because the area affected by the spin-up mechanism is much smaller. What happens to the rest of the fluid? Unlike a homogeneous fluid, the bulk of the stratified fluid is not directly affected by the spin-up process. It will eventually catch up with the new rotation rate only through the much longer time scale, namely the diffusion time scale.

Spin-up in MHD is yet more complicated. We shall identify some of the geo-astrophysical problems that may be understood through spin-up.

Where in nature does spin-up occur? Since Greenspan and Howard (1963) published their rigorous analysis of spin-up in homogeneous fluids, the application has expanded very rapidly. We shall identify only a few here.

(1) The problem closest to home for oceanographers is the following. When we apply a wind stress on the surface of a homogeneous, or stratified, quasi-steady ocean, what happens? Ekman asked a similar question in 1905. The boundary layer that bears his name provides a steady solution to that question. More detailed answers to the related transient phenomena such as coastal upwelling, response of a stratified ocean to moving storms, etc., have only been sought in recent years. These transient phenomena are closely related to spin-up.

(2) When a hurricane is travelling over land, it will eventually decay. The process through which it decays is similar to that of a swirl in a teacup. The updraft in a hurricane sucks in air through a boundary layer near the ground to replace the rapidly swirling air, which escapes at the top of the hurricane. This process depletes the angular momentum of the hurricane and slows it down. This is, of course, an oversimplified picture, but a reasonably good analogue.

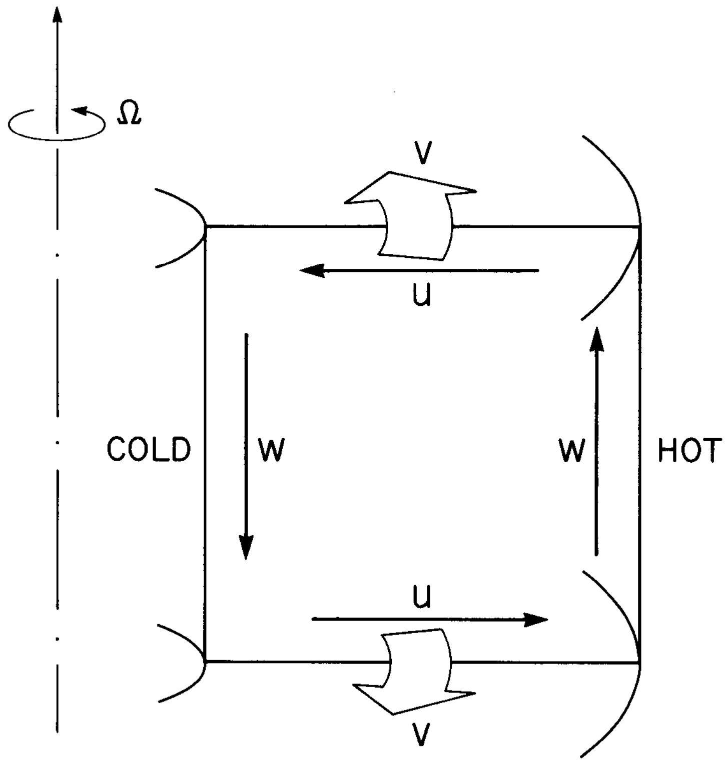
(3) Within the last 15 years or so, solar physicists, who study the physical processes in the Sun, have discovered that the Sun continuously emits from its

surface particles, which rotate very fast in comparison with the inner part of the Sun. This process can create a deficit of angular momentum on the surface layer. Some scientists have suggested that the decrease of angular momentum on the surface layer may slow down the Sun through spin-down and thus change its gravitational field. Though this change is certainly small, it is, however, large enough for some scientists to throw doubt on Einstein's theory of general relativity, which has been supported in part by astronomical phenomena that can also be explained by solar spin-down.

(4) The Earth, Sun, Jupiter, magnetic stars, and other rotating astronomical bodies as remote as pulsars are known to possess magnetic fields. If, for any reason, these astronomatical bodies change their rotation rate slightly, they are in a state of MHD spin-up, which in turn creates all sorts of secondary but possibly observable phenomena. Spin-up is in fact one of the most active areas of research in MHD at present.

The Rotating Annulus Problem

What is the rotating annulus problem? An annulus consisting of two vertical concentric copper (or aluminum) cylinders and an insulated bottom is filled with fluid. Assume that we have some mechanism to maintain the two cylinders at two

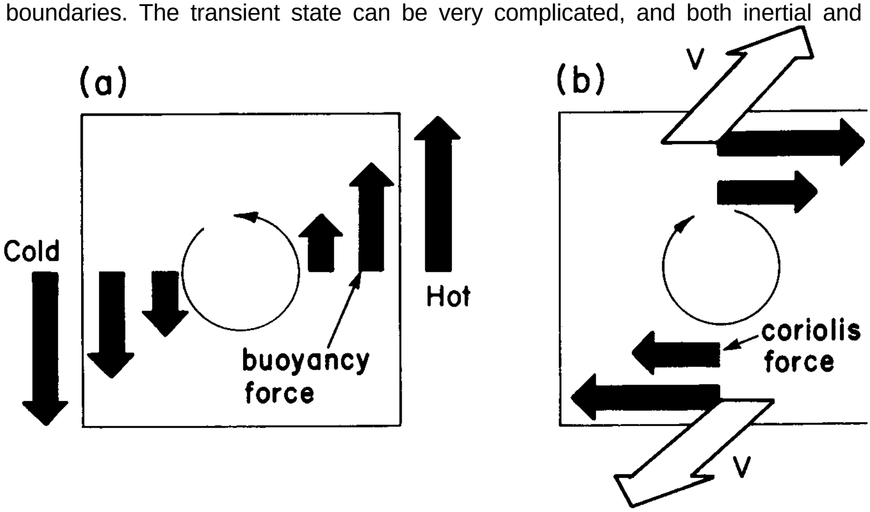


Schematic representation of the velocity field in a differentially heated rotating annulus. The arrows indicate the directions of velocity components. For a free upper surface (no rigid lid), the zonal current, v (hollow arrows), is stronger at the top than at the bottom, but the horizontal velocity, u, is stronger near the bottom, because a rigid boundary can induce a stronger Ekman layer. (AOL 3665.)

different temperatures, say the outer hot and the inner cold (or vice versa), and rotate the annulus about its vertical axis. This is the basic set-up of the rotating annulus experiment.

It was discovered by Fultz (1953) and Hide (1953) that, depending on the impressed temperature difference and the rotating rate for a given fluid in a given annulus, there are three different regimes of flow: (1) the axisymmetric regime, in which the flow is independent of the azimuthal angle; (2) the wave regime, where the flows are in the form of waves when viewed from the top of the annulus. These waves can maintain their form (steady waves) or vary their shape or amplitude with time (unsteady waves); and (3) the turbulent regime where the flows are irregular. The questions concerning the underlying dynamics of any aspect of these three categories of motion form the rotating annulus problem. For example, one may ask, how do the dynamics of the axisymmetric flow depend on rotation rate and the imposed temperature differential? What is the difference in the controlling mechanisms between the steady and unsteady waves? What is the three-dimensional structure of these highly nonlinear waves, which have been shown to be baroclinic waves? (An example of a baroclinic wave is the strong west-east flow in the atmosphere commonly known as the jet stream.) What are the structures of the turbulence and the energy transfer processes?

In order to have a simple understanding of the flow fields, let us consider the axisymmetric flow of an annulus with a rigid lid. Assume an initial state of solid rotation before heating and cooling of the cylinders. After heating and cooling have begun, the fluid near the cold wall will sink and that near the hot wall will rise due to the buoyancy effect. Because the fluid is practically incompressible, conservation of mass would require the rising and sinking fluid particles to turn the corners literally when they approach the end of their vertical paths at the top and bottom of the annulus. Eventually, Ekman boundary layers will develop near the horizontal boundaries. The transient state can be very complicated, and both inertial and



Schematic representation of the dynamic balance in the interior of a rotating annulus, or the thermal wind balance. (a) *shows that the torque produced by the buoyancy force due to differential heating (warmer on the right and colder on the left) is counterclockwise. This is counterbalanced by an opposite, clockwise torque* (b), *which is produced by the Coriolis force due to the vertical shear in the zonal current, v. In* (b), *if the lower hollow arrow is in the same direction as the upper one but smaller in magnitude, it will produce a similar effect.* (AOL 3665) internal waves may be excited by it (Quon, 1969). After all transient disturbances have died down, a steady state may roughly appear as shown in the figure (page 224). The hollow arrows indicate two opposite 'zonal currents', *v,* initially induced by the Coriolis force acting on the two horizontal boundary currents, *u.* In the interior region away from the boundary layers, a sheared zonal current is supported by a horizontal temperature gradient. This current 'matches' the boundary layer flow just outside the boundary layer. Despite the appearance that the zonal current is in all respects a continuous current from top to bottom, the dynamics in the boundary region are very different from those in the interior. The boundary layer is an Ekman boundary layer where the Coriolis force is balanced by the viscous force. The picture in the interior is totally different: a torque produced by a *horizontal temperature gradient,* or by buoyancy forces, is counterbalanced by an opposite torque produced by the Coriolis force, as a result of the *vertical shear* of the zonal current (see figure previous page).

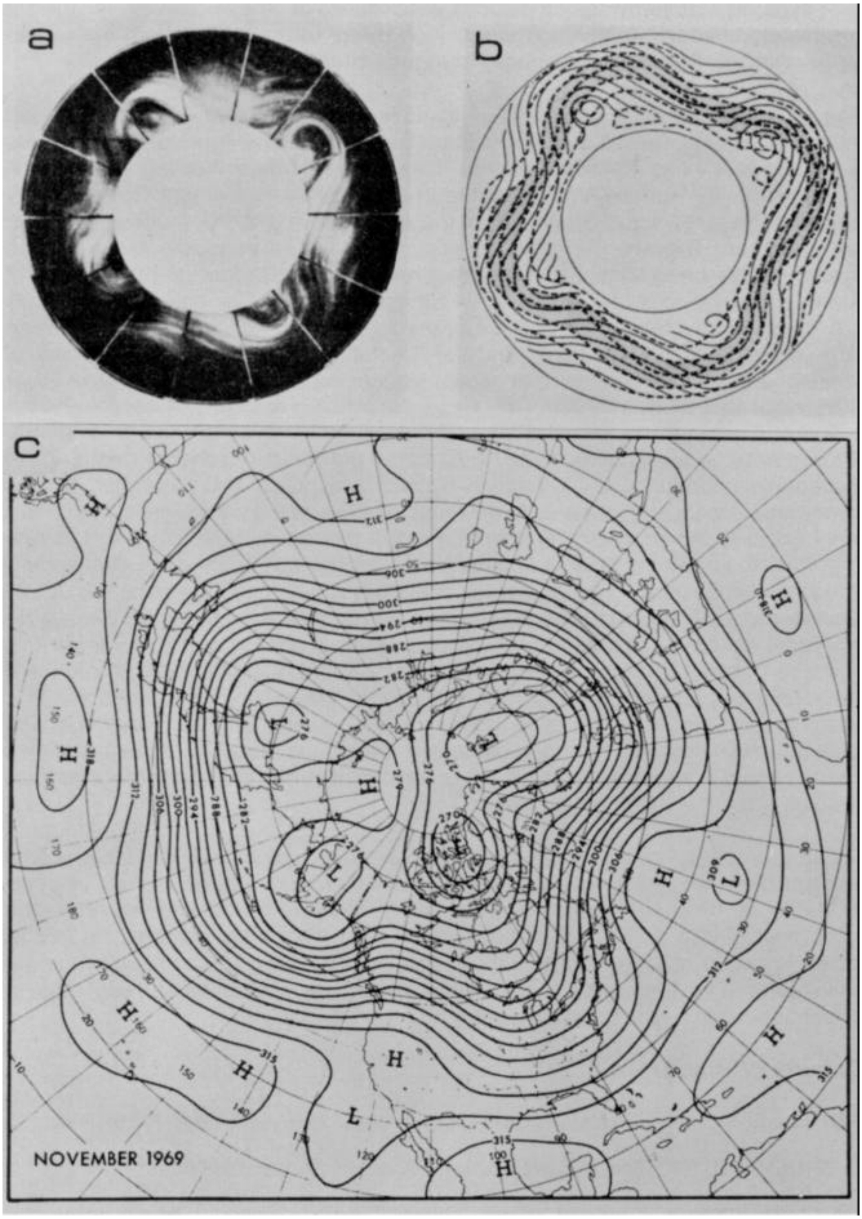
This latter balance keeps the interior fluid in equilibrium, and is known as the 'thermal wind' balance, which is the combined result of non-hydrostatic and Coriolis balances. The current itself is also called a geostrophic current. Geostrophic current is a very common large-scale geophysical phenomenon in the atmosphere and the oceans.

Under certain conditions, long waves will form in these zonal currents. Under other conditions, the organized waves will break down into turbulent flow. The dynamics of the wave regime is still under active investigation (Pfeffer *et al, 1974;* Quon, 1975), while study of the turbulent regime has hardly begun.

Geophysical Relevance of the Rotating Annulus.

(1) *Convection in the Earth's core.* It is believed that fluid motion in the Earth's core is responsible in some way for its magnetic field. Therefore, a satisfactory theory of the Earth's magnetic field requires a comprehensive theory of the hydrodynamics of the Earth's fluid core. The rotating annulus experiment was originally designed by Hide (1953) to seek inferences on large-scale motion due to differential heating in the Earth's core. Its geophysical application in recent years, however, has shifted to the Earth's atmosphere.

(2) General circulation of the atmosphere. In the atmosphere, as in the ocean, there are various scales of motion. However, research in general circulation of the atmosphere usually examines only the major features of the atmospheric motion, which remain after the flow has been averaged in time and/or space. Dynamical meteorologists have studied the so-called zonally averaged circulation, i.e., the distribution of various flow parameters as functions of latitude and height. They have found, to a very good approximation, that the dynamical balance in the atmosphere in mid-latitudes is essentially quasi-geostrophic and very similar to the interior flow of a rotating annulus. The main flow consists of a zonal current, flowing from west to east, heated in the south and cooled in the north. Under certain conditions (for example, in the annulus when the rotation rate and temperature differential fall within certain values), the zonal current becomes unstable. This means any small perturbation in this flow will amplify, and draw, potential and/or kinetic energy out of the main current. In the annulus, as in the atmosphere, the waves grow at the expense of the potential energy of the main flow, and the growth depends strongly on the vertical shear of the current. This mode of instability is known as baroclinic instability. The study of baroclinic instability is as vital to the understanding of the dynamics of the ocean as it is to the atmosphere. After 30 years of intensive study, there is still a great deal to learn in this field. For example,



(a) *Streak photograph of the aluminum flakes showing flow from a rotating annulus experiment. The Now is counter-clockwise.* (b) *The corresponding stream lines (solid lines) and isotherms (dashed lines) of the same experiment. (c) Mean 700-mb atmospheric pressure chart of the Northern Hemisphere for November 1969. Large scale wave of hemispheric wave number 4 is dominant. The annulus and atmospheric ftows have many dynamical similarities. Parts (a) and (b) are from Pfeffer et al. (1974. Fg. 4). Part (c) is from Green (1970).*

the dynamics underlying amplitude vascillation of these waves is almost completely unknown (amplitude vascillation refers to the state where the waves expand and contract their amplitudes at regular intervals).

The rotating annulus provides a controlled system that permits detailed examination of almost all aspects of baroclinic waves. The figure on the previous page shows an atmospheric pressure chart of the northern hemisphere and the photos show the surface flow simulated in a laboratory experiment. The similarity between the large-scale circulation of the atmosphere and the annulus waves is not fortuitous. The energy transfer and the momentum transport within the two systems have been shown to bear great resemblance. In fact, at the Institute of Atmospheric Physics of the Academia Sinica in Peking, Chinese meteorologists are performing rotating annulus experiments to study the interaction between large-scale atmospheric waves and the Tibetan plateau, and the movement of atmospheric vortex centres that would cause floods along the Yantze River (Kellogg et *al.,* 1974).

(3) *Geostrophic turbulence.* In 1971, Charney put forward a theory that predicts the energy distribution as a function of the hemispheric wave number, k, in a three-dimensional atmosphere. A relationship between the wave energy and wave numbers is called an energy spectrum. From a theoretical point of view, it is very important to know that there is an equilibrium energy spectrum in the atmosphere and what it is because such an energy spectrum can help to determine the rate at which small scale disturbances propagate to larger scales, or the energy cascade, in a turbulent flow. The theory predicts a variation of energy with k^{-3} for large k. It has been observed that the atmospheric waves of hemispheric wave numbers between 7 and 20 roughly obey this k^{-3} law. Since the interior flow of an annulus is quasi-geostrophic, the turbulent regime of the rotating annulus would be well suited to test this theory under controlled conditions. Charney thinks that this theory should also apply to the oceans in regions of strong baroclinic flows such as the Gulf Stream in the Atlantic Ocean.

These are only a few examples of current research topics in GFD. Nonetheless, through them we see that geophysical fluid dynamicists, like scientists in other fundamental research disciplines, are mainly concerned with understanding the basic principles that link and govern seemingly unrelated phenomena. By far the most persistent objective of the geophysical fluid dynamicist is to establish some universality in what he studies. Happy are his rare days when he can say: “that is what happens in a teacup and in a star!”

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The Importance of Organic Compounds in Geological Oceanography

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The oceans of the world are good providers. They support the production, growth, and survival of enormous numbers of living organisms at all depths. Many of these organisms are capable of assimilating atmospheric carbon by photosynthesis to form a number of organic compounds that are eventually incorporated in sediments when the dead organisms decompose. Carbon can form an enormous number of compounds, and it is not surprising that naturally occurring organic compounds are varied and numerous. More than 500 organic constituents have so far been identified in various geological materials. This figure does not include the scores of individual organic compounds isolated from crude oils (Rossini, 1960).

The estimated total biological production of carbon in the marine environment is about 32 x 10^9 tons/year. In addition, rivers transport about 7.0 x 10^8 tons/year of organic matter to the oceans from terrestrial areas (Bordovskiy, 1965). According to Degens (1967), sedimentary deposits contain about 38 x 10^{14} tons of organic matter. By comparison, the coal deposits of the world are about 6 x 10^{12} tons. This is 1/600th of the disseminated organic matter in sediments. Estimates on the ultimate primary petroleum reserves of the world run at 2.0 x 10^{11} tons or approximately 1/20,000th of the total organic matter incorporated in sediments.

The organic compounds discussed here include the organic metabolites (compounds synthesized in a plant or animal body) present in the oceans and the products of their biochemical and microbial transformations. These compounds exist as simple constituents and complex polymers. The simple organic compounds, such as some of the amino acids, fatty acids, carbohydrates, hydrocarbons, and plant pigments, are the products of the decay of living organisms; the complex polymers, such as humic compounds (derived from humus), which constitute over 60-80% of naturally occurring organic matter, are formed from the biochemical and chemical reactions of a number of aliphatic and aromatic substances derived from the decay of dead organisms. The reactions that yield humic compounds are such that the reactants lose their individual identify and form an intricate network of polymers of high molecular weight (~700 - >2,000,000). Humic compounds are also formed in soils. A part of the humus in soils is lost by leaching and reaches coastal areas, often in large quantities, through river waters. The light brown or yellow colour of many rivers is due to humic compounds, whose concentration in some rivers of the Atlantic Provinces is between 16-30 milligrams per litre, which is several times greater than the total of dissolved inorganic constituents in the rivers (=10 miligrams per litre). These concentrations may be enough to react with and modify the geochemical behaviour of a large majority of the metals and clays in rivers and coastal waters.

All humic compounds are a complex assemblage of aliphatic and aromatic constituents. The presence of a wide variety of reactive functional groups is their most important characteristic. These functional groups (carboxyl, phenolic hydroxyl, alcoholic hydroxyl, amino, quinone, carbonyl, methoxyl, etc.) are located on the periphery of the organic molecules. Their concentration varies with molecular weight and degree of humification (the process of the formation of humus); it is high in well humified material of low molecular weight. These functional groups impart negative charges to the colloidal molecules proportional to their concentration and determine specific chemical reactivity. The geochemical behaviour or organic compounds is largely dependent on the nature and number of these functional groups. All positively charged inorganic constituents (metal ions, clay minerals, etc.) react with these negatively charged organic particles to form what are termed organo-metal or organo-clay complexes of different stabilities. The reactions begin in the water column and continue in the sediments.

Many organic compounds are stable in nature and can survive the ravages of geological time. It is often assumed that the organic matter originating from dead organisms is an inert and inactive component of the sediments, Actually, it participates in a number of geochemical reactions. Although organic matter is not a major component of sediments (only 1-3%), the extent to which it influences various post-depositional processes is out of proportion to its overall weight contribution.

Despite their geological, geochemical, environmental, and ecological significance, organic compounds have been somewhat neglected by geochemists. Knowledge of them is essential not only in tracing the geological events of the past but also for understanding the mechanisms by which oil and gas and the whole series of sedimentary economic deposits are formed.

Organo-Metal Complexes and Their Geochemical Behaviour

Many trace metals occur in coals, shales, crude oils, and other carbonaceous materials in concentrations appreciably higher than their average content in the Earth's crust. In addition, the concentrations of several metals in natural waters are much higher than was theoretically expected. For example, at the redox potential and pH values of natural waters iron is only slightly soluble but, in reality, natural waters contain 10^8-10^9 times more iron than was predicted (Siegel, 1971). The reaction rates derived from inorganic chemical principles and processes alone are too limiting to account for the amount of metals found in solution. Chemical and instrumental analyses show that chelation (where two atoms of a single organic molecule retain a metallic ion) and the formation of complexes, in which the carboxyl, amino, quinone, hydroxyl, and other groups are involved, are the most likely and predominant reactions by which organic matter traps metal ions. Once the metals are trapped, their chemical and geochemical behaviour is modified.

Rashid and Leonard (1973) demonstrated that sedimentary humic acids and their acid hydrolysates, which contain various amino acids, enhance the solubility of cobalt, copper, manganese, nickel, and zinc carbonates and sulphides. Each gram of humic acid dissolved up to 340 milligrams of the metals. Only -1 milligram of metals dissolved in the distilled water blanks. The hydrolysates dissolved even larger quantities; up to 680 milligrams of metal per gram of amino acids as compared to 0-8 milligrams of metals in the blanks.

Soluble metals will precipitate readily if they come into contact with anions such as sulphide, carbonate, and hydroxide. Humic compounds will delay this precipitation by reacting with metallic ions to form metal chelates. Once these chelate complexes are formed, the metal ions no longer exhibit any cationic properties and the complexed metals cannot be separated by the force of attraction exerted by the anions. Consequently, the metals remain in solution. It follows that toxic metals like mercury and lead are likely to accumulate in estuaries and other coastal embayments where organic matter is abundant.

Measuring geochemical parameters of a sediment core. (*AOL* 3453-2.)

Besides being excellent natural chelators, the organic compounds, especially the humic compounds, are capable of retaining large quantities of metals by cation exchange and surface absorption. The total sorption capacity of the compounds depends upon the types of metals and environmental conditions. According to Szalay (1956) the geochemical enrichment factor of uranium on peat humic acid is about 10,000 which means that under natural conditions the uranium concentration is 10,000 times higher in peat than in water. Similarly, the enrichment coefficient of vanadium, nickel, lead, and silver in petroleum ash in relation to their abundance in the lithosphere is believed to be more than 1000. Some asphalts and crude oils contain as much as 20,000 grams per metric ton of molybdenum (Manskaya and Drozdova, 1966). These examples reflect the magnitude of metal absorption reactions by naturally occurring organic compounds.

Practical exploitation of organo-metal reactions may open up several new avenues of economic interest. Peat, a natural, inexpensive material, abundant in Canada, is a rich source of humic compounds. The peat humic acids can be modified and improved by suitable chemical treatments that increase their total metal sorption capacity and improve their selectivity for trace or transition metals. Such modifications are of considerable commercial and economic interest not only in the possible recovery of trace metals from sea water but also in the purification of industrial waste waters containing various toxic metals.

Influence of Organic Matter on the Geotechnical Properties of Sediments

Organic compounds bond clay particles and these bondings modify the physical characteristics of the sediments that govern the geotechnical or mechanical behaviour of the sea floor in response to applied load. Oil rigs and pipelines, jetties, breakwaters, piers, offshore towers, etc., have become quite common in these days of ocean exploration and exploitation. The performance characteristics of all these structures and installations depend upon the supporting capacity of bottom sediments. Of the various factors that contribute to load-bearing capacity none occupies a more important place than organic matter. A careful evaluation of the engineering properties is important and essential in order to avoid the high performance risks of marine operations.

The deep sea drilling platform SEDCO I undergoing tests in Bedford Basin, N.S. (AOL 1843-6.)

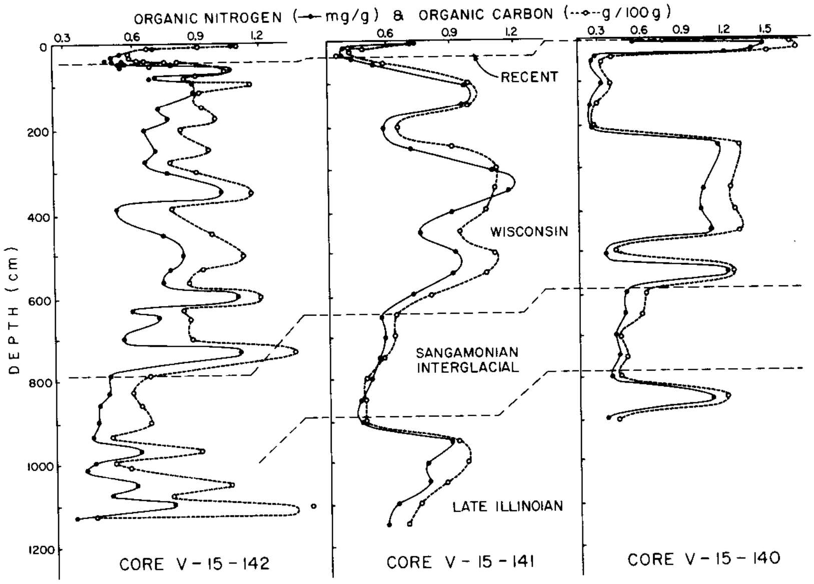
Rashid and Brown (in press) found that the characteristics of sediments are significantly affected by relatively small concentrations of organic matter. For example, the liquid limit, plastic limit, and plasticity index increased in a linear fashion with increasing organic content. Sediments containing 2-4% organic matter were nearly twice as compressible as sediment devoid of organic matter. In the presence of organic matter, the sediments exhibited much greater creep tendencies and consolidated under load at about one-seventh of the rate of the inorganic sediments. Remoulded shear strength increased with increased inorganic matter.

Variations in the geotechnical properties of sediments containing organic compounds could be related to the changes in the properties or organo-clay complexes. For example, organic matter increases the moisture-holding capacity of sediments by increasing the bound waters of hydration and, at the same time, the relative mobility of individual grains and consequently the plasticity. Electrostatic bonding between organic matter, salts, and clay minerals increases with increasing organic content and thereby increases the shear strength, compressibility, and true stress-strain behavior.

Organic Compounds as Environmental Indicators

Few realize that organic compounds are much more sensitive to environmental influences than are minerals. Changes and fluctuations in the environment can be detected by a close examination of the organic material.

Variations in climate during sediment deposition are reflected in the quality and quantity of organic matter. Stevenson and Cheng (1972) studied in detail the distribution of carbon and nitrogen in cores from the Argentine Basin and established correlations between the distribution of these elements and climatic changes. Their results are depicted in the graph below. The zones of high accumulations of carbon and nitrogen coincide with cool weather or glacial epochs when sea levels were low. Similarly, the areas of low organic carbon and nitrogen are related to warmer climates. The differences in the levels of carbon and nitrogen



Depth-related distribution of carbon and organic nitrogen in the cores of the Argentine Basin (after Stevenson and Cheng, 1972). (AOL 3458.)

during cold and warm periods are due to the differences in erosion, rates of sedimentation, and degree of preservation of organic compounds, all of which will be higher in a glacial climate. During glaciation, aquatic life is scarce and as a result glacial sediments have a high proportion of soil organic matter relative to the organic matter of intrabasinal origin.

Sedimentary organic matter is derived from algal or terrestrial material. Under prolonged diagenesis and thermal cracking, terrestrial organic matter will often be converted to gaseous hydrocarbons and the sapropelic or ooze-like marine organic matter found in shallow anaerobic environments will produce oil. Thus, the original source material is of prime importance in determining the relative yields of oil and gas. A study of the structural components or chemical characteristics of organic matter entrapped in sediments will help identify the source of the matter and thereby predict the likelihood of oil and gas formation. For example, terrestrial organic matter has a high ratio of pristane ($C_{19}H_{40}$) to phytane ($C_{20}H_{42}$), which is indicative of its terrestrial source. Stable carbon isotopic composition (the ratio ^{13}C to ^{12}C) is low in terrestrial and high in marine organic matter. Sediments containing terrestrial organic matter are characterized by low hydrocarbon yield and the hydrocarbons will have a low saturate to aromatic ratio. The paraffins extracted from marine organisms do not show any appreciable degree of odd predominance (predominance of odd carbon numbered hydrocarbons) but terrestrial plant material does. The ratio of odd to even carbon numbered hydrocarbons of marine organisms is 1.0-1.5, whereas that of land-derivedorganic matter is 5-10.

Oxidizing and reducing conditions exert considerable influence on the degree of preservation and rates of transformations of organic matter. For example, reducing environments tend to preserve organic matter in general and plant pigments in particular. Oxidizing conditions tend to destroy the organic matter, particularly amino acids, which are lost at a much faster rate than other constituents. Variations in molecular size distribution may also reflect environmental conditions. The molecular size of an organic compound will usually be high under reducing conditions and low under oxidizing conditions because of the intense microbial activity and rapid breakdown of organic matter in the latter. The condensed high molecular-weight humic polymers will, therefore, be abundant in sediments deposited under reducing conditions whereas the low molecular-weight fulvic acids will be high in sediments deposited under oxidizing conditions. Even some of the by-products of organic transformations in Recent sediments are indicative of depositional environment. For example, methane is a well-known by-product of the fermentative decomposition of organic matter under anaerobic conditions in Recent sediments. It does not form if the depositional environment is oxidizing.

Organic compounds are proving useful in the dating of rocks. Despite its many merits the radiocarbon or ^{14}C technique for dating organic remains (based on a half-life of 5570 ± 30 years) has one major drawback - it is not applicable to materials older than 40,000 years. A new dating method based on the racemization (the process of changing an optically active compound into an optically inactive or racemic mixture) of amino acids overcomes this barrier (Bada et al., 1970). All amino acids in living organisms rotate the plane of polarized light in one specific direction. When the organisms die, these amino acids gradually change into chemically identical forms that rotate the light in the opposite direction. This process is called racemization. Different amino acids racemize at different rates. Isoleucine has one of the slowest racemization rates: its half life at a pH of 7.6 and 0°C is 4.4×10^6 years. The rates of racemization of aspartic acid and alanine are ten and four times faster respectively than the racemization rate of isoleucine. Racemization of isoleucine under suitable conditions produces alloisoleucine whose concentration increases with depth of burial and age of the sediments. The ratio of alloisoleucine to isoleucine can be used to estimate the age of the sediments and the rate of sedimentation. The isoleucine technique is best suited for deep-sea sediments where the rates of sedimentation are slow, i.e., in the order of a few millimetres per 1000 years. In areas of relatively rapid rates of sedimentation, the amounts of racemization of other amino acids that are not as temperature dependent, such as aspartic acid and alanine, may be useful.

Diagenesis of Organic Matter and the Formation of Oil and Gas

Besides influencing a series of diagenetic processes in sediments, organic compounds themselves undergo diversified metamorphic changes that yield a wide variety of products of economic and commercial interest. Peat, lignite, coal, kerogen, bitumen, asphalt, tar, petroleum, and a multitude of related compounds have all originated from the transformation of fossil organic matter.

At the sediment-water interface, when the supply of oxygen is adequate, organic compounds undergo intense microbial and biochemical changes that result in the formation of complex humic polymers. As the overburden pressure increases, the underlying strata become more anaerobic and a slower rate of transformation of organic compounds ensues. These transformations continue for long geological time periods. The series of geochemical transformations that follow are not clearly understood. It is postulated that deoxygenation splits off the oxygen-containing molecules, hydrogenation eliminates the double bond, and polymerization condenses the molecule. These and many other processes transform the initially deposited organic matter to kerogen, a highly complex and insoluble petroleum precursor. With increased overburden pressure and geothermal heat, kerogen is slowly converted to bitumens (naturally inflammable substances that are soluble in organic solvents). These soluble substances gradually lose their oxygen, sulphur, and nitrogen and, at the same time, due to thermal cracking, disintegrate into small fractions. In this way the various components of crude oils are formed. The gaseous hydrocarbons form first, followed by the high molecular-weight hydrocarbons. The process is not as simple as stated here. In spite of intense research, little is known about the exact mechanism of formation of petroleum. The very nature of that part of the organic matter that eventually becomes oil and gas is not adequately known. However, it is well established that petroleum emerges from organic matter initially deposited in shallow and nearshore marine sediments millions of years ago.

Organic geochemistry can play a unique and useful role in the search for oil and gas. A detailed study of the organic content of sedimentary strata and its diagenetically transformed petroleum precursors or products individually or in relation to total organic carbon, kerogen, or bitumen will provide valuable information on the diagenesis of organic matter and its maturation process leading towards the formation of hydrocarbons. For example, the presence of gaseous hydrocarbons, especially of ethane, propane, and butane, is indicative of the beginning of petroleum formation. Similarly, modern sediments do not contain light (C_{4-14}) hydrocarbons such as gasoline and kerosine. Only diagenetically transformed sediments will contain these compounds. Increased concentrations of soluble bitumen are indicative of approaching maturity; the immature facies are rich in insoluble kerogen. Aliphatic and aromatic hydrocarbons are the predominant and most important constituents of petroleum. In high concentrations, they pinpoint the zones of petroleum accumulation. The pattern of distribution of *n-alkanes* present in the sediments provides useful information not only about the source and origin of organic matter, but also on the degree of maturity and the type of oil expected to be formed on maturation. The hydrocarbons present in immature organic facies show a distinct predominance of odd carbon numbered hydrocarbons, whereas, in the mature oily facies the ratio of odd to even carbon numbered hydrocarbons is about one. The quantitative values of organic carbon and different hydrocarbon and non-hydrocarbon components can be used in a wide variety of useful interpretations that will provide important geochemical guidelines about the degree and rates of conversion of organic matter to petroleum, the maturation processes, the migration phenomenon, and the quality of source rock.

Organic Compounds in Coastal Waters

Coastal waters represent less than 10 per cent of total area of the world oceans, yet their primary production is twice that of the open oceans. The fertility and primary productivity of coastal waters depend upon the degree of "biological conditioning", i.e., the presence or absence of biologically active organic compounds. Dissolved humic substances present in coastal waters are particularly important in this respect.

Phytoplankton, especially the diatoms, multiply rapidly and are the main producers of organic matter in coastal waters. These organisms often become absorbed into sediments after death. Prakash and Rashid (1968) and Prakash et *al. (1973)* have shown that low concentrations of low molecular-weight humic compounds affect the rate of growth, reproduction, respiration, and carbon assimilation of diatoms and dinoflagellates. In test culture media devoid of humic acid, the yield as well as the growth of phytoplanktons was 30-50 per cent lower than the media that contained organic matter. The positive effect of humic compounds is not only reflected in increased rate of growth, but also in the rate of assimilation of ^{14}C and chlorophyll production.

How do these complex polymers stimulate the metabolic functions of the cell? The answer still eludes us. It is speculated that the response may be associated with a direct sensitization of cells by the phenolic constituents of humic acids or a chelation process or both. Whatever the mechanism is, there remains little doubt that humic compounds of marine and terrestrial origin can enhance the growth of phytoplankton. They may also be responsible for the phenomenon of "red tides" (a dense concentration of dinoflagellates that colours the water red) often noticed in coastal waters after a heavy rainfall. The bloom may be related to the fresh supply of terrestrial humic material through land drainage to coastal waters. The freshly supplied humic compounds enhance the production of the dinoflagellates.

It is unfortunate that these compounds so prevalent in nature and that play such a varied and vital role have received so little attention from the scientific community. In order to understand fully the multitude of processes affected by organic compounds or products originating from them, it is essential that we develop a clear knowledge and understanding of their origin, distribution, preservation, transformations, chemical composition, geochemical behaviour, and the effects of environmental conditions on their reactivity. The knowledge will provide not only a strong base for the re-evaluation of geochemical concepts dealing with the accumulation of metals but in all likelihood an important tool for the exploitation of the mineral, oil, and gas resources of the oceans.

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Acoustic Fish Counting with a Computerized System

R. Shotton and *R. G.* Dowd, *Marine Ecology Laboratory*

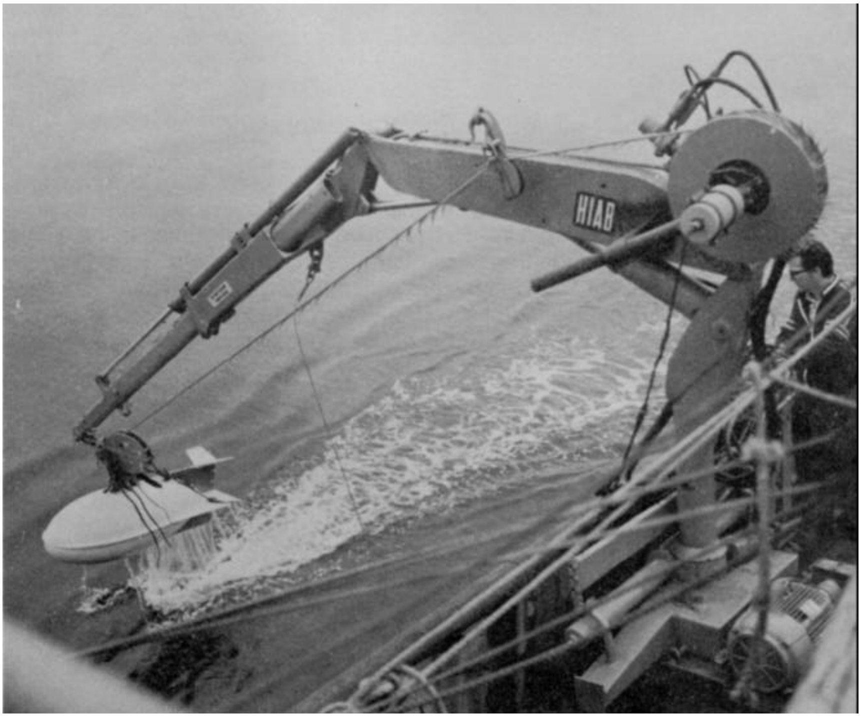
Echo sounders, or depth finders, were originally developed to help navigators determine the depth of water beneath the ship's keel. Sounders measure the time it takes a sound signal generated from a transducer, usually mounted in the ship's hull, to be reflected back to the transducer from the ocean bottom. Sound travels through sea water at about 1500 metres per second, although this speed can vary as much as 3 per cent under different salinity and temperature conditions. Knowing this, it is an easy matter to convert the time measured to a depth reading and most echo sounders do this automatically.

Echo sounders had not been in operation long when it was discovered that fish, and other animals whose acoustic impedance differs from sea water, reflect part of the sound signal back to the transducer. Such echoes are recorded as marks on the echogram record or can be seen as perturbations on a cathode-ray oscilloscope linked to the sounding system. As a result, many echo sounders have been developed especially for fish detection; they give fishermen some idea of the amount of fish present below their vessels without having to use trawls or other gear. The methods used by fisheries scientists to estimate numbers of fish in a given area involve complicated statistical methods and assumptions that cannot always be tested. The introduction of echo sounders should permit less emphasis to be placed on these complex methods.

By counting the marks on the echogram and estimating the volume of water through which the acoustic wave passed, estimates of fish density can be obtained. However, this approach is obviously tedious and unable to provide the detailed information of fish size often required for stock inventory. For these reasons, work was begun at the Marine Ecology Laboratory (MEL) in 1966 on a system that could combine automatic processing of the echo returns with data analysis and provide estimates of the numbers and sizes of different fish. This system was planned to have maximum flexibility in the choice of parameters required by the biologists using the system.

What has been developed is known as the Computerized Echo Counting System (CECS) (Dowd, 1974). Its basic components are a Simrad E-K scientific echo sounder, a Honeywell 316 12K computer, and a transducer. The transducer is mounted in a towed body (see photo next page), which eliminates interference from the ship's hull caused by propeller or engine noise and air bubbles. The body also eliminates effects from rolling and pitching of the vessel so the transducer will be kept pointing vertically downward.

In September 1974, a large-scale stock assessment was carried out over the Scotian Shelf using this equipment. The survey involved 42 days at sea and 483 hours of CECS operation along 6240 kilometres of survey lines. The results demonstrated that the CECS could be operated for long periods over diverse marine conditions and in poor weather, and enabled those parts of the system and methods of analysis needing further refinement to be better identified.

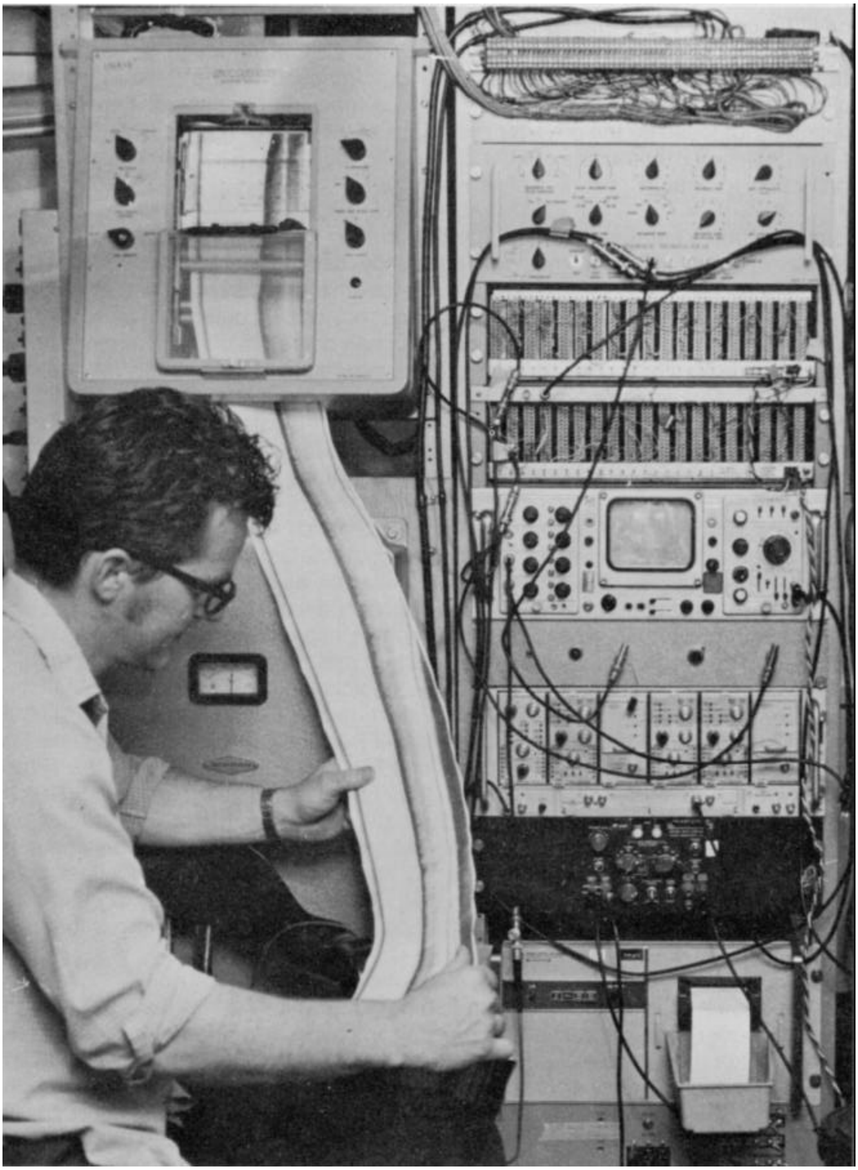


A hydraulic crane *is used to lower* and raise *the CECS towed body, which contains the echo sounder's transducer. (AOL 2535-5.)*

The CECS is a real-time operating system, that is at the end of a specified time interval, chosen by the operator, the estimates of fish density for four size classes are outputted to a teletype so that the fish density for the section of the transect just covered is known immediately. The time it takes the echo to return to the transducer is measured to within 1/10,000 second by a 10 kilohertz crystal clock and from this the depth of the fish can be specified to an accuracy of ± 7.5 centimetres. This information is used by the CECS to provide simultaneous density estimates for two different depth intervals, which again are specified by the operator and may be contiguous or overlapping. Past operational experience has shown that few counts are received from distances greater than 16 metres above the bottom, and for MEL surveys intervals of 0 to 2.6 and 2.6 to 16 metres are usually chosen. The height of the first interval corresponds to the expected headline height of a Yankee 36-trawl, the trawl-type used by the Canadian Fisheries and Marine Service for fish stock inventories. Hence, estimates of fish abundance from the CECS for this interval should be comparable with those obtained from trawl surveys.

The time interval for which fish density estimates are made can be adjusted from as little as 10 seconds up to 10 minutes. Biologists interested in the nature of the small-scale distribution of demersal, or bottom-living, fish, can, by specifying a short-time interval for echo accumulation, gain detailed insight into the changes of fish density over distance. For stock assessment work, a larger time interval provides adequate information.

Besides outputting fish density information in real time, the information received from each echo is stored on magnetic tape, together with the interval estimates of density. For example, if three fish are in the water column at different depths below the transducer, the time at which their echoes are received after pulse generation and the intensity of the return echoes are stored for each sound transmission. The bottom echo is recognized by its far greater intensity and its arrival time is also recorded on magnetic tape. Thus, much useful information can be obtained from later re-examination of the data.



Output from the echo sounder can be examined to compare results with those of the CECS and the indications of fish on the oscilloscope. (AOL 2535-14)

From a knowledge of the position represented by each density estimate, noted on either the magnetic tape or log sheets, contour maps of fish density can be subsequently obtained from a computer. From the time of echo return, the data can be re-analyzed for different depth intervals, say 0 to 50 metres, to check if any significant concentrations of fish were above the survey depth and hence missed.

Shortcomings of Echo Counting

While the results of the 1974 survey were encouraging, they have stimulated us to consider carefully the methods and models used in survey design and data analysis, and in the actual performance of the CECS. Although echo counting offers many advantages, there are limitations imposed on the reliability of data collected by acoustic systems. These may be machine dependent, they may be limitations imposed by the physical conditions of the sea, or they may be the result of the biological characters of the fish being counted. Each of these factors contributes to error in estimates of fish density.

Some electronic components undergo drift in their operating characteristics over periods of time and they must be frequently calibrated to ensure consistent treatment of the data collected. There are also limitations on how fast the system can work. Very fast pulse rates or a high frequency of data output will be limited by how quickly electronic components, such as peak detectors of the incoming signal and analogue-to-digital converters of signals, can return to their stable values after being activated. Similarly, a finite time is required to store and retrieve information in the memory core of the computer. Fortunately, for most working conditions, the nature of the electronic components does not limit the capability of the system or contribute significantly to error in fish density estimates.

To ensure an adequate return of energy from fish present in the insonified (‘illuminated with sound’) region, the pulse length (the time interval over which the transducer is activated) must not be small. However, as the pulse length increases the ability to discriminate between individual fish diminishes. The CECS uses a pulse length of 0.4 millisecond, which becomes expanded to a maximum of 0.6 millisecond due to the bandwidth of the system and pulse stretching in the target. During this time the sound pulse travels a distance of 45 centimetres. If the distance between two fish is less than 22 centimetres their return echoes will not be separated, and one continuous signal will be received by the transducer. In these cases the system may count only one fish. If the fish are exactly the same distance away from the transducer, then their return signals will complement each other and the system will record the echo as a single larger fish. This causes an underestimate of the numbers of smaller fish and, conversely, an overestimate of large fish. If the fish are at slightly different distances from the transducer (less than one wavelength of the sound wave) the signals will be out of phase and tend to cancel each other. Fish densities obtained under typical operating situations indicate that this source of error is rare.

Another source of error in estimating fish numbers arises when the fish occur in schools. Under these circumstances, echo intensity is a linear function of the square root of the number of targets and as a result fewer fish would be indicated than were actually insonified. This source of error has been found to occur when fish densities are greater than 8 per 1000 cubic metres. Schooling fish usually occur in the mid to surface region of the ocean. The CECS is intended for demersal fish, which rarely form dense schools, and for most operating conditions dense schooling can be discounted as a significant source of error. High fish densities are more accurately estimated by echo integration. In this method, the voltages induced in the transducer by the return echoes are summed over a specified period of time and the number of fish is calculated from the final value of the integrated voltage for the period. If the echoes are received individually then, for *n* echoes, the combined voltage, Y_T, would be

$$Y_T = \sum_{i=r}^{n} Y_i$$

where Y_i is the voltage contribution from the ith fish. However, if the echoes are received simultaneously, as would occur if a school of fish was insonified (Forbes and Nakken, 1972) then

$$Y_T = \sqrt{\Sigma Y_i^2}$$

Thus, with an integrating system used for either single or multiple echo recordings, the voltage must be squared first to prevent a bias in the estimates of numbers of fish.

The obvious solution is to use an integrating system for schooling fish, such as herring or capelin, and to use an echo-counting system for non-schooling fish, such as cod and haddock. In fact, Ehrenberg (1973) has shown that the lower bound of variance estimators for conditions of low density is obtained using an echo counter, whilst for conditions of high fish density the lower bound is obtained using an echo integrator. Work has begun in conjunction with the St. John's (Newfoundland) Laboratory of the Department of the Environment on an integration system that shares virtually the same hardware as the echo counter. The system will be able to operate in either echo count or voltage integrate mode on option.

Target Strength of Fish

Another area of concern with echo counting lies in determining what fraction of the incident sound wave is reflected by the fish back to the transducer.

The acoustic intensity *(EL)* received at the transducer is used to determine the size of the fish and is given by

$$EL = S - 2H + TS$$

where S = the source level or intensity of sound transmitted from the transducer,

H = the one-way loss of sound energy, which is known as the transmission anomaly, and

TS = the target strength of the fish, which is a measure of the incident energy reflected by the fish.

The source level can be found by calibrating the transducer against a standard hydrophone. The transmission loss, *H,* is due to: (1) geometrical spreading of the sound wave through water, which is inversely proportional to the square of the range, and (2) absorption and scattering of the sound wave. *H* is proportional to the range of the fish and is dependent on the frequency of the transducer.

Reflection of sound waves occurs whenever there is a change in the acoustic impedance of the reflecting material. The index of reflection, *u,* is measured by

$$u = (\rho_w C_w - \rho_f C_f)/(\rho_w C_w + \rho_f C_f)$$

where ρ_w := density of the water,
ρ_f := density of the fish tissue or organ,
C_w := speed of sound in water, and
C_f := speed of sound in the tissue or organ of the fish.

For a given fish, the total intensity returned is due to some combination of the reflection indices of the scales, flesh, bone, and swim bladder. As would be expected, the swim bladder, which is filled with gases, is a major contributor to the reflected signal.

Field studies have shown that the target strength also depends on the aspect in which a fish is insonified. For example, the dorsal aspect target strength (obtained when the transducer is directly above the fish) differs from the lateral aspect (obtained when the transducer is aimed at the side of the fish), and these target strengths are both greater than the anterior or posterior aspects. To size fish from their target strengths, it is necessary to know the target strengths of different species for different sizes and also their probable aspect with reference to the transducer.

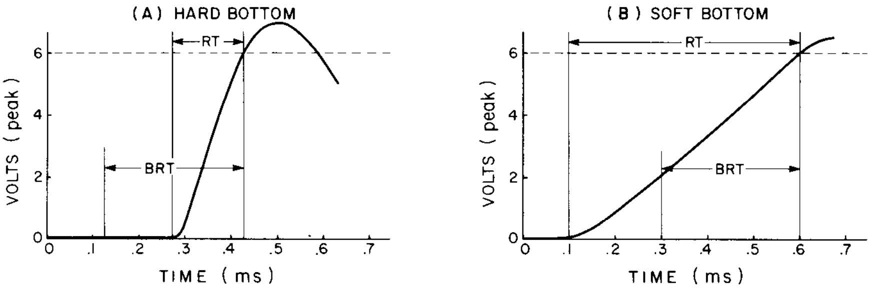
By suspending fish of known length beneath a transducer in dorsal aspect it has been found that target strength of fish is a linear function of the logarithm of their length and that the gradient of this function is a species characteristic. Studies by Norwegians (Nakken and Olsen, 1973) with cod and pollock have shown that the relation $TS = 24.4 \log L - 66.6$ is a good working estimate for sizing these fish. Future research is planned on the target strength relations for the species dominant on the Scotian Shelf, such as Redfish and Silver Hake.

It seems likely that most fish are ‘horizontal’ in the sea unless they are rapidly changing their depth or foraging on the sea floor and a target strength estimate based on dorsal aspect is probably most appropriate. However, when fish are generally inclined with respect to the transducer the target strength relation should be based on some estimate of their mean angle of inclination. Olsen (1971) used cameras to study this in cod and found that they were usually pitched head down about 5 degrees from horizontal; herring were usually pitched head down 3 degrees from the horizontal during the night and pitched head up 4 degrees during the day. If the probable angle of aspect is not considered when calculating target strengths, fish numbers will be underestimated. Also, a negative shift in the size distribution may result when fish are inclined with respect to the transducer if their target strength is less than that for their dorsal aspect.

Because only the digitized voltage induced by the return echo is stored by the CECS, when the species of fish insonified by the sounder is unknown it must be determined by test fishing or from photographs.

The echo received from the bottom is of much greater intensity than that received from fish. This difference in intensity is used by the CECS to indicate that no further echoes will be received from that sound pulse. The time of the bottom pulse return is recorded on magnetic tape and the system is prepared to receive the echoes from the next acoustic pulse.

In areas of soft bottom, there is considerable absorption of sound energy and it may take a longer time for the return intensity to reach the threshold level that indicates a bottom return. In these circumstances, to ensure that the initial part of the increasing voltage is not counted as a fish once the threshold voltage level has been obtained, any counts made from the rising voltage are discarded.

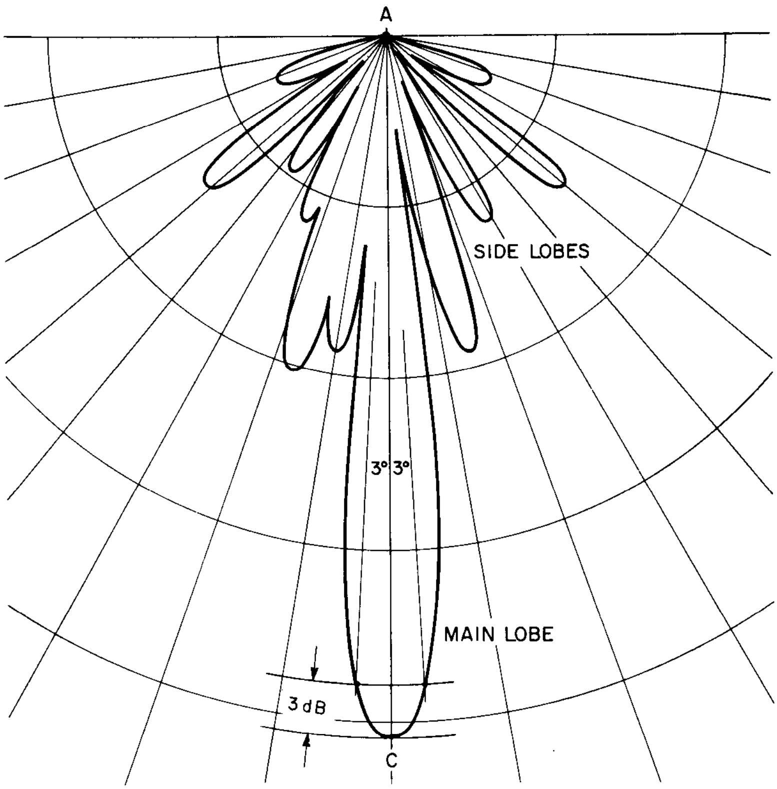


The graphs show that more sound energy is absorbed by a soft bottom than a hard bottom (see text). (AOL 3462.)

In areas of hard bottom, the specified rise time must be relatively short, 0.2 to 0.3 milliseconds, or fish close to the bottom will not be detected. Similarly, where the bottom is soft the rise time must be increased or the initial part of the rising voltage will be counted as fish. At present, the appropriate rise time that should be used is determined by observing the bottom echo analogue pulse on the system oscilloscope. When necessary, the time can be changed to suit the ambient bottom conditions by accessing that part of the computer's memory core storing the bottom rejection time. In the figure above, the dotted line indicates the voltage level at which the echo is interpreted as a bottom echo. In A, the bottom is hard and the rise time, RT, is short. The bottom rejection time, BRT, prevents any part of the rise time from being counted as fish. However, echoes in the interval BRT-RT would also be ignored. In B, a sizable bottom voltage has been reached before the BRT interval, and a much wider bottom-rejection time interval is needed to compensate for the longer rise time. If this were not the case, the voltage reached in the interval RT-BRT would be interpreted as fish by the computer. Alternatively, knowledge of the desired bottom rejection time as a function of the analogue pulse width can be determined so that a software routine can automatically change the stored value as required. We hope to make this improvement during 1975.

Estimating the Size of Fish

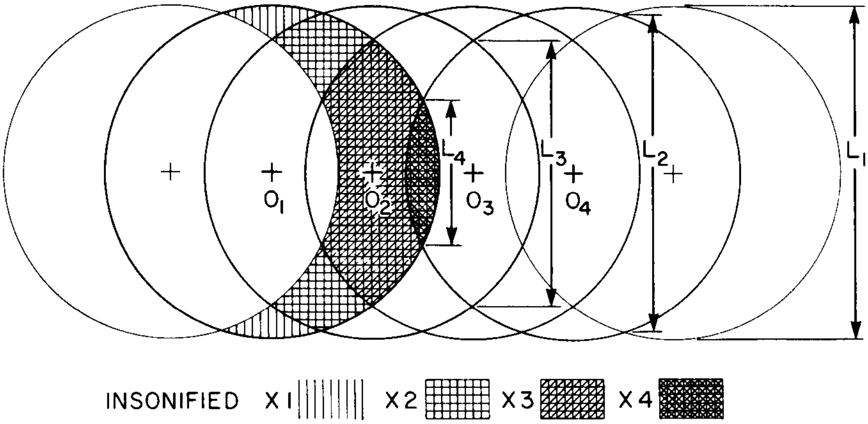
Until recently, fish were grouped into four size categories by electronic devices (Schmitt triggers) fired by the incoming voltage signals. For example, a return voltage between 0.7 volt peak and 1.3 volts peak indicates a fish 15 to 25 centimetres long. More precise knowledge of fish size is desirable for several reasons. The intensity of energy emitted by the transducer is not uniform throughout the insonified region but decreases with angular distance from the main axis of the beam. The polar diagram (next page) illustrates how the maximum intensity emitted by the transducer at *A* lies along the acoustic axis, *AC,* and decreases to either side of this axis. The beam angle is usually taken between the point in the beam where the intensity is half that on the acoustic axis, or 3 decibels lower than the maximum. Side lobes are usually so much lower in intensity that they can be ignored. However, if desired, the side lobes can be physically shielded so that they will not cause echoes. Because sound intensity depends on direction, the echo level of a large fish near the edge of the beam may be similar to that of a small fish in the centre of the beam.



This polar diagram shows how the maximum sound energy emitted by the transducer is along the acoustic axis AC (see *text).* (AOL 3462.)

A simulation model of the CECS is being constructed to determine how the voltage recorded by the system can be expected to vary as a fish of known target strength is insonified at different successive positions, relative to the beam axis, as the transducer signal passes over it. Because of the rapid pulse rate of the echo sounder (96 transmissions per minute), individual fish may be insonified and counted several times as the transducer passes over them. The number of times a fish is counted depends upon its position in the sound beam, its depth, and the speed of the survey vessel. Survey speeds of 8 to 10 knots are usual and at a depth of 100 metres a fish may be insonified up to four times depending upon its position in the beam. At this depth, as the transducer passes across the fish, their distance from the transducer varies by no more than 14 centimetres. This difference in range is just within the threshold of detection of the crystal clock and as a result each of the successive echo returns can be identified on the magnetic tape since their return times will vary by no more than 1/ 10,000 second.

The figure below indicates how the limits on the angular displacement of a fish in successive insonified volumes can be determined from the number of times the fish is counted. To develop a more accurate method of analysis, it will be



Fish in a region insonified more than once will return varying amounts of sound intensity with successive insonifications as the position of the fish changes with respect to the acoustic axis of the emitted sound beam. (See text.) (AOL 3462.)

necessary to have real data on changes in the echo levels as they actually occur with a precision much greater than that of four size levels. For these reasons, changes in the method of sizing fish have been made in which the Schmitt triggers have been replaced with a 10-bit analogue-digital voltage converter. These changes permit each echo to be sized into one of 1024 levels as compared to the previous four size levels.

Comparison with Trawl Catches

Further impetus to develop a simulation model of the CECS arose from attempts to explain differences in estimates of abundance and size composition predicted by the counter with those obtained from the trawl sample results for the same study area. Although the overall correlation between density estimates from the CECS and those from trawl samples showed a significant correlation, generally in the region of 0.6 to 0.7, it was felt that the causes of differences should be identified so as to improve the correlation, particularly at low fish densities.

As mentioned earlier, underestimates of numbers of large fish can be expected. The bias in counts of small fish arising from position effects is a little more complicated. Small fish near the axis of the beam are sized correctly while those at the edges may not register a threshold value and would not be counted. However, large fish in this position may be counted as small fish. Because small fish are much more abundant, an underestimate would seem likely.

The biases expected in results of trawl surveys appear more difficult to identify. Several studies have demonstrated that fish are herded into the trawl by the trawl doors and bridles. If this is, in part or wholly, a visual response, then diel or day-night differences may be expected. Comparisons of estimates from the CECS with those obtained with trawls, separated into day and night, show a high positive correlation for day results but near zero correlation for those obtained at night. This fact is of great importance when interpreting data from trawl surveys.

The effect of fish size (or their swimming speed) and vulnerability to capture by trawls is complex. Small fish, unable to keep station with the bridles, may fall back over them and avoid capture. Large fish may escape by swimming out of the path of the trawl. Also, different trawls built to the same design are known to fish differently. For reasons such as these, we do not expect that the results obtained from CECS data show perfect correlation with those obtained from trawl samples. Indeed, we feel that a better understanding of the biases in the CECS may provide a method of examining vulnerability of fish to trawls.

Data Analysis

Unlike most census work, the individual density estimates from acoustic surveys are not obtained at random but from successive intervals along the survey transects. These, depending on the survey design, may themselves be determined by the position of previous transects. Three models for estimating variance have been examined, based on the statistical principles of successive differences, autocorrelated series, and cluster sample designs. Of these, only the last appears suitable for analyzing data obtained with the CECS. The methods based on successive difference require normality of data and are sensitive to trends in successive estimates of fish density. The methods based on autocorrelation also require absence of such trends in fish density with distance. The cluster sample design (while not exactly describing our situation) appears to provide an acceptable method of handling the serial effects due to successive sampling. This method calculates the contribution to the variance that arises from differences within and between survey transects. In this way, additional information is gained that can be used in planning further surveys. For example, if the transects are all very similar, a few long transects offer the best design. If the transects are variable, a larger sample of shorter transects is preferable.

Smaller estimates of sample variance would be expected if the survey area were stratified according to some criteria. Past surveys have been stratified by depth. Within strata, it is desirable that the position of the transects be chosen randomly rather than via a continuous sampling scheme such as a zig-zag course across the continental shelf. Though this is possible, such an approach requires that up to 2.5 per cent of the sea time be spent steaming between transects. Current surveys are planned to examine the respective advantages of such random transects and to determine how strata vary so that the sampling time can be divided optimally among the different strata for subsequent surveys.

Future Applications of the CECS

At present only interval density estimates and their mean values are available at sea. Confidence intervals of the numbers of fish are calculated later using computer programs at the Bedford Institute. One of our objectives for acoustic surveys is that the data analysis be completed as quickly as possible. Consequently, software changes are being planned so that analysis programs can be loaded into the CECS computer and run between survey transects or strata, or possibly while the survey vessel is steaming home. Perhaps it is not too visionary to imagine that the system could be operated on demand; for example, a dispute or uncertainty between members of a regulatory body on the abundance of fish stocks at, say, Browns Bank, could be resolved within 48 hours by a survey of the area, and the results radioed to interested parties within 30 minutes of completion of the survey. For larger areas, such questions may take longer to resolve but would still be available in a much shorter time than is now possible.

Although CECS was designed with the fisheries scientists in mind, segments of the fishing industry have shown some interest in the system. Fishermen are basically interested in knowing the kind, position, and abundance of fish to minimize the effort and time they spend searching for fish and deploying their vessels. A carefully designed fish survey that mapped the existing concentrations of fish would provide the fishermen with far more reliable data of fish abundance and hence catch expectations. This method of approach could be part of a new and exciting concept for the operation of the large, Canadian east coast, trawl fisheries.

Fisheries scientists at MEL believe that a co-operative and unified approach to the demersal fisheries of Atlantic Canada is both rational and inevitable. This approach would require that fishing vessels co-operate in locating and harvesting fish concentrations and the nucleus of such a system might be specialized search vessels using quantitative fish detection systems such as the CECS. With such a system, fisheries management and exploitation become one and the same.

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Sea Ice Research in Canada

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Snow-covered pack ice floats in the Arctic Ocean throughout most of the year and along much of Canada's east coast in winter. Forecasts of the occurrence and movement of ice rely heavily on empirical rules and intuition. With the intensification of offshore oil exploration and other activities in ice-infested waters there is a need for a better understanding of the processes involved in the formation and flow of ice. In their report, *Canada, Science and the Oceans,* the Science Council of Canada (1970) pointed to the Canadian continental shelves, their surrounding waters and ice cover as a focus for a major program. This paper reviews recent research work on sea ice, particularly investigations of air-ice interaction and the dynamics of sea ice movement.

CSS Hudson *steaming through ice floes in arctic waters. (AOL* 3260-2-2)

Nansen launched the first systematic attempt to investigate ice motion aboard *Fram* during his epic three-year Arctic Ocean traverse in 1893-1896. He observed 20 to 40° deviations between ice drift and wind directions and suggested that a deflecting force due to the Earth's rotation was responsible. This led to Ekman's (1905) classical formulation of drift currents. Many theories attempting to describe ice motion have been postulated since, but sufficient field data to test and refine these theories has been lacking. To collect such essential data, ice dynamics programs have become wider in scope. With the aid of electronics, computers, satellite navigation, and mathematical models, present-day programs are applying knowledge of ice dynamics to forecasting ice conditions. The operational application of this research will expedite exploration and transportation in the Arctic.

A Summary of Current Projects

AIDJEX (Arctic Ice Dynamics Joint Experiment) is a program conducted by the University of Washington with National Science Foundation support; Canadian participation is being funded by the Polar Continental Shelf Project (see below). The purpose of AIDJEX is to develop numerical models of ice movement based on observations of the forces acting on the ice (Untersteiner, 1974). This experiment has been successful in attracting to one major research project U.S.A. and Canadian researchers from many disciplines. Pilot studies have been conducted in the late winter of each year since 1970. These studies include wind, current, and ice drift measurements, and remote sensing of the ice cover. The main AIDJEX experiment, in 1975, will obtain meteorological, oceanographic, and ice movement data at an array of manned and unmanned stations in all seasons of the year.

The Sea Ice Forecast Central of the Atmospheric Environment Service, Department of the Environment, located in Ottawa, provides ice information to the public. This agency is the one that could make practical use of the results of research into the dynamics of ice movement. Two Lockheed Electra aircraft are instrumented to fly ice reconnaissance over the Gulf of St. Lawrence and the Labrador coast in winter, and over the Canadian Arctic in summer. A smaller aircraft flies over the Great Lakes and James Bay during winter. The aerial observations are combined with reports from shore stations, from icebreakers and other ships, and with information from satellite photographs to produce weekly ice charts. In addition to distribution by mail these are transmitted by satellite to ships and shore stations equipped with facsimile receivers. Annual summaries are published, and an analysis of sea ice climatology is to be incorporated in an ice atlas.

The Polar Continental Shelf Project (PCSP) of the Department of Energy, Mines and Resources has carried out airborne sea-ice surveys since 1961. In addition, this agency has established camps throughout the Canadian Arctic that serve as bases for a wide range of research projects of other agencies.

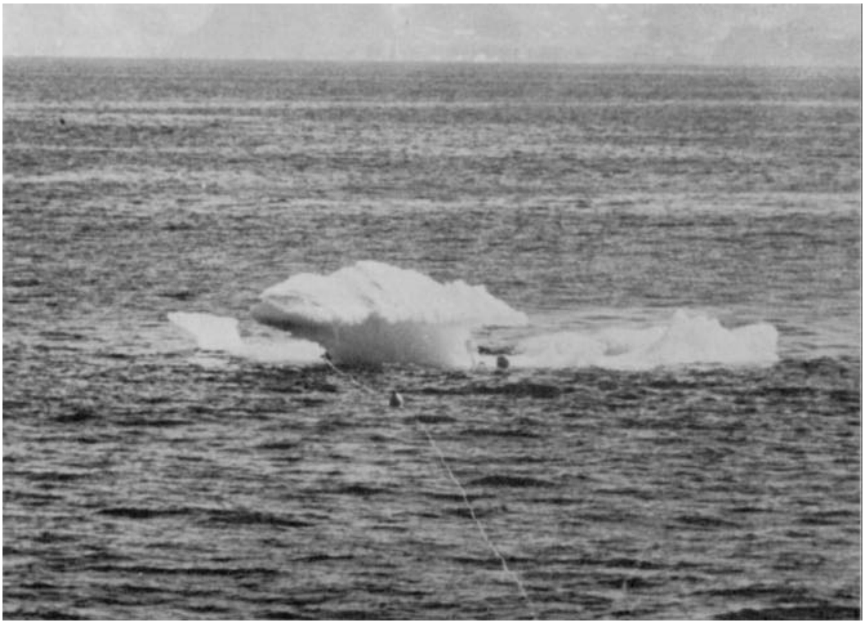
In other work of this department, Dr. J. R. Weber of the Dominion Observatory is carrying out a unique program of hydrostatic levelling to determine the tilt of drifting sea ice, with the objective of relating this to ice movement and the forces driving the ice (Weber, 1974).

The Arctic Petroleum Operators Association (APOA) supports a wide range of ice research projects related to exploration and production in areas such as the Canadian Arctic islands and the Beaufort Sea. These include studies of ice crushing strength and of the occurrence of ice ridges, both of which are related to ice hazards to fixed structures. The load-bearing capacity and movement of land-fast ice, which may support equipment in certain locations and seasons, is also being investigated.

Beaufort Sea Environmental Studies, funded by APOA, are being carried out by Ocean and Aquatic Affairs, Department of the Environment, Victoria, B.C. Aspects of these studies, such as the 'behaviour of oil in an ice-covered area', and 'bottom scour by sea ice', are related to the dynamics of ice movement. Ocean and Aquatic Affairs, Victoria, also has a longstanding interest in the freezing process and structure of sea ice (Lewis and Lake, 1971). More recently, studies of iceberg calving from glaciers and seasonal variation in salinity, temperature, and oxygen content of the waters of Greely and d'Iberville fjords have been initiated. Measurements of temperature, salinity, and currents are being made in Lancaster Sound, Barrow Strait, and Wellington Channel.

The Glaciology Division, Inland Waters Directorate, Department of the Environment, Ottawa, is conducting an inventory of the iceberg-producing potential of glaciers. This Division is also studying the mechanical and electrical properties of ice, including the radar and passive microwave remote sensing of floating ice.

The Ministry of Transport (MOT) operates a fleet of icebreakers and supports applied research into the improvement of the capabilities of icebreakers. Personnel of other agencies from time to time conduct oceanographic and hydrographic surveys from MOT icebreakers when these vessels are not fully occupied on escort duties. In addition, this department maintains coastal radio stations and aids to navigation.



Iceberg towing experiment off Labrador coast. (Memorial University photograph.)

Memorial University of Newfoundland has for the past four years been studying sea ice from an engineering point of view. A shore-based radar at Saglek, Labrador, is being used to track iceberg drift patterns. These are being analyzed, together with oceanographic measurements in the area (Allen, 1973), to develop a model to predict iceberg movement. This work is of direct interest to oil companies drilling off the Labrador coast. An iceberg-towing experiment (Banke and Smith, 1974) (see figure) carried out with support from the Eastern Petroleum Operators Association (EPOA) was a forerunner to oil industry application of iceberg towing as a routine operation (Gravett, 1974). Studies of ice movement in the Strait of Belle Isle and of ice cover in Lake Melville, Labrador, are under way.

The Defence Research Establishment Ottawa (DREO) is studying the dynamics of ice movement in Robeson Channel, between the northern tip of Ellesmere Island and the northern tip of Greenland (Pennie, 1972). Their particular interest is in the summer break-up period, usually occurring in late July, when the winter ice blocking the channel starts to drift. Radar tracking of the ice field and of a number of transponder stations was carried out from a shore-based camp on top of a 500 metre cliff during the summers of 1972 and 1974. A time-lapse camera and a television camera with video tape recorder were also used to monitor the ice movement. Weather observations, including winds both over the ice and at the camp, were recorded. Current meters and a salinity-temperature-depth recorder were used to monitor water masses and their movements. In addition to measurements of wind drag on the surface of the ice by Bedford Institute of Oceanography staff, discussed later in this paper, some preliminary studies of water drag on the lower surface of the ice were carried out by a McGill University group at this location. Preliminary analysis of the data shows that after break-up occurs the ice moves up and down the channel with the tides. In 1972 there was a large transport of ice down the channel toward the south, while in 1974 this transport was much less. The final analysis will relate the ice transport to winds and currents.

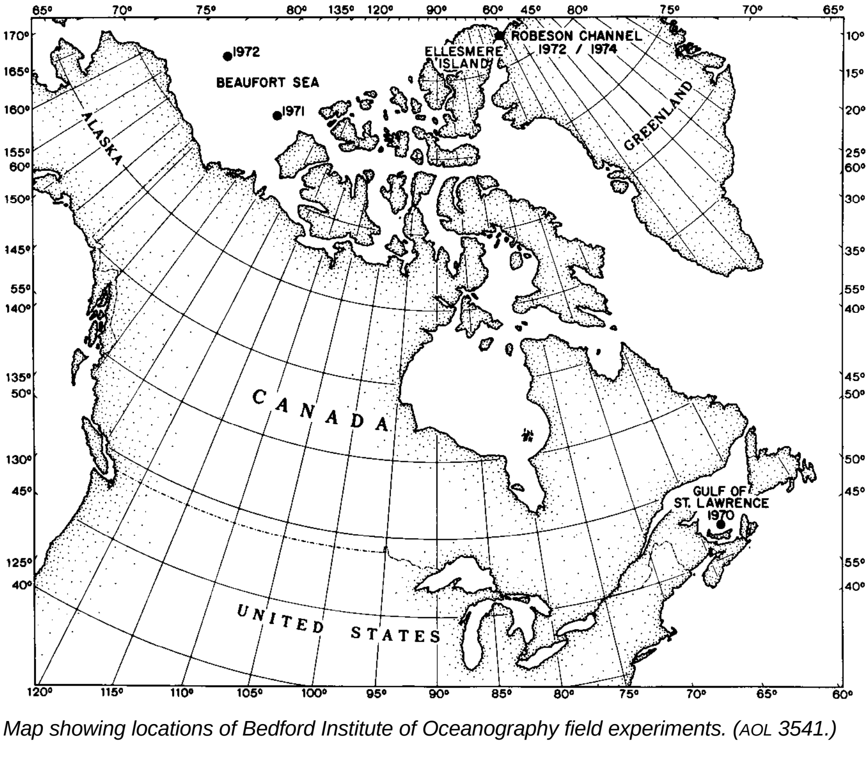
Other DREO work includes studies of the ablation of the Ward Hunt Ice Shelf, northern Ellesmere Island; aerial ice observations over Nares Strait: and airborne radar, radiometer, and laser sensing of the ice.

McGill University ice movement studies started with the establishment of manned drifting stations in the Gulf of St. Lawrence in 1968, 1969, and 1970, with DREO participation. The 1968 three-man station used an inflatable life raft as a camp, but this proved to be as much an exercise in survival as in science and relatively little time and effort could be spared for detailed scientific observations. The 1969 and 1970 expeditions used small ships allowed to freeze in and drift with the ice, and with a larger crew and better accommodations these proved highly successful (Johannessen *et al.,* 1969, 1970; Johannessen, 1970; Smith, 1972). Since that time efforts to track ice movement in the Gulf of St. Lawrence by means of an array of unmanned Decca navigation buoys have met with a frustrating series of delays and difficulties but are continuing.

McGill University's studies of wind drag by profile methods (Langleben, 1972, 1974) at AIDJEX camps and elsewhere have paralleled some of the authors' work. Recently, measurements of water turbulence under ice floes have been initiated with a sonic current meter (similar to the authors' sonic anemometer) at the DREO Robeson Channel project. Analysis of these data will give some preliminary information on water drag under the ice.

The Meteorology Department of McGill University has developed a numerical model of sea ice formation, taking air-water heat exchange and many other factors into account, and applied it to a number of regions, such as the Gulf of St. Lawrence (Lally, 1973).

To go through ice research programs on an international scale would be beyond the scope of this paper. The USSR has for many years maintained a network of manned drifting ice stations in the Arctic Ocean and is sponsoring POLEX, a comprehensive meteorological and oceanographic polar experiment. The USA has operated long-term manned drifting stations on ice islands in the Arctic Ocean and has also been a leader in Antarctic exploration. Great Britain, the U.S.A., and presumably also the USSR, have nuclear submarines capable of operating beneath the ice in polar regions and of gathering more comprehensive information on the structure of the under-side of sea ice than could be obtained from surface-based observations.



Map showing locations of Bedford Institute of Oceanography field experiments. (AOL 3541.)

Air-Ice Interaction Studies at the Bedford Institute of Oceanography

Wind Drag on Pack Ice. If ice movement is to be modelled and forecast better, the forces acting on the ice must be known. These include wind drag on the upper surface of the ice, water drag on the lower surface, gravitational force acting down the gently sloping surface of the ocean (a result of water piled up in the direction of prevailing winds), forces transmitted by pressure and stress in the ice, and the Coriolis force (arising from the Earth's rotation).

Winds and currents are the dominant forces causing ice movement (Campbell, 1965; Rothrock, 1973). In the Beaufort Sea, where currents are relatively small, the wind is the principal driving force. The wind force is more easily measured than water drag because of the more regular structure of the air boundary layer and because it is easier to place sensors on the upper side of the ice.

The wind forces on the ice are transmitted from above through the atmospheric 'boundary layer' (Kraus, 1972). At each level in the boundary layer the air above is pushing along the air below to supply the momentum that finally reaches the surface as the wind force. This transfer of momentum, known as a flux, is carried by turbulent gusts and eddies in the wind flow. In the first 20 metres or so above uniform terrain the turbulent flux is nearly constant with height. From measurements of the turbulence (i.e., wind fluctuation) at a particular height above the surface the wind stress (i.e., force per unit surface area) on the ice can be computed from:

$$\tau = -\overline{\rho u_1 u_3} = \rho C_{10} U_{10}^2$$

where τ = wind stress
ρ = air density
u_1 = downwind velocity component of wind fluctuation
u_3 = vertical velocity component of wind fluctuation
C_{10} = wind drag coefficient
U_{10} = mean wind speed at lo-metre level
(The overbar indicates an average taken over a data run of about 40 minutes.)

The 'drag coefficient', which is a function of the topography of the upper ice surfaces, describes how much influence winds have on ice motion. In general, the more rugged the top surface is, the more force winds can exert and the greater the drag coefficient.

A similar argument may be followed for water drag under flat ice sheets, but for irregular ice there may be no 'constant stress' layer and drag determination will be more difficult. The Coriolis force, which acts on any object moving on the rotating Earth, may be readily calculated once the ice velocity and thickness are known; and the slope of the sea surface may be determined if the water currents are known. The forces transmitted through the ice cover are the most difficult to measure, but they may be estimated by measuring all the other forces and the movement of the ice and solving an equation of motion for the one remaining term.

Heat Flux and Evaporation. Heat exchange at the ice surface, an important factor in ice formation, follows a process similar to the transfer of momentum described above. Heat flux is nearly constant with height in the lower part of the boundary layer. From measurements of the wind and temperature fluctuations, the heat flux can be computed as follows:

$$H = \rho C_p \overline{t u_3} = \rho C_p C_t U_{10} \Delta T$$

where H = vertical transport of 'sensible' heat per unit area per unit time
C_p = specific heat of air at constant pressure
t = temperature fluctuation
C_t = heat flux coefficient
ΔT = temperature difference between surface and 10-metre level

Water vapour is likewise transported by turbulent mixing. If the fluctuations in water vapour density are measured at the same point above the surface where the wind and temperature fluctuations are carried out, the rate of evaporation per unit area (i.e., water vapour flux) is given by:

$$E = \overline{qu_3} = C_q U_{10}\, \Delta Q$$

where E = rate of evaporation (mass per unit area per unit time)
q = humidity fluctuation
C_q = evaporation coefficient
ΔQ = difference in humidity (water vapour density) between surface and 10-metre level

Associated with evaporation is a transport of the latent heat of vapourization, which contributes to the freezing process over open leads.

The fluxes of momentum, heat, and water vapour can be computed from readings of turbulent fluctuations using these three equations. Because of practical difficulties, however, it is not easy to obtain such data. The limited amount of turbulence data available is therefore used to derive relations between the air-ice interaction fluxes and the more readily measured parameters of mean wind speed at a reference height, say 10 metres, and differences in temperature and humidity between the surface and this reference height. These relations are expressed in terms of coefficients of wind drag (C_{10}), heat flux (C_t), and evaporation (C_q) (see above equations). The aim here is to evaluate these coefficients from measurements at a point so that air-ice interaction fluxes over large areas can be determined. Other terms to consider in heat balance calculations include radiation, advection (horizontal transport of heat) by winds, currents, and ice drift.

Experimental Results. Since 1968 the Bedford Institute of Oceanography has been investigating the wind force on ice with the overall objective of specifying total wind force as a function of ice surface topography and wind speed so that, for an ice type with known surface topography and atmospheric conditions, the driving force exerted on the ice by the wind can be predicted. Using the latest techniques of data collection and analysis, wind forces on open-sea ice have been measured in the Gulf of St. Lawrence, the Beaufort Sea, the Arctic Ocean, and Robeson Channel. A three-component sonic anemometer (Mitsuta, 1966) was used to sense the wind velocity by timing sound pulses along three axes of its probe; this gave the turbulent variations in the wind velocity. A Lyman Alpha humidiometer sensed humidity fluctuations by measuring absorption of ultraviolet radiation along a path of a few centimetres, and a microbead thermistor responded to air temperature fluctuations. These sensors were mounted on a guyed mast at a height of 3 metres above the ice.

Wind drag coefficients of pack ice in the Beaufort Sea have been combined with those from a similar study in Robeson Channel to assess the variability of the wind drag with ice roughness (Banke and Smith, 1973). An ice roughness parameter ζ is the root mean square surface elevation at wavelengths less than 13 metres. Undulations of longer wavelength are believed to have relatively little effect on the wind drag. The surface elevations surveyed upwind from turbulence sensors on seven occasions (Table) are representative of areas free of large ridges. All of the corresponding drag coefficients are higher than those observed by similar methods over the open sea where $C_{10} = 1.3 \times 10^{-3}$ (Smith, 1970, 1973; Banke and Smith, 1971). Flat, snow-covered ice in the Gulf of St. Lawrence was observed (Smith, 1972) to have about the same drag coefficient as the sea surface. The presence of a drifting ice cover increases the wind stress on the sea surface. Only when the ice is shore-fast, and transmits the wind force to shore instead of to the underlying water, does an ice cover reduce the wind stress driving the water movement, as compared to that in an ice-free ocean. A regression line, $10^3C_{10} = 1.24 + 0.062\ \zeta \pm 0.06$ (standard deviation), with a correlation coefficient of 0.94, gives an empirical relation for the drag coefficient.

Temperature and humidity fluctuations observed during the 1972 AIDJEX pilot experiment (Thorpe *et al,* 1973) were analyzed to obtain mean values of $C_t = 0.9 \times 10^{-3}$ and $C_q = 0.5 \times 10^{-3}$ for nine data runs. For the same nine runs the mean drag coefficient was $C_{10} = 1.9 \times 10^{-3}$. In other words, the turbulent transfer of water vapour to and from the surface was only half as efficient as that of heat, which in turn was only half as efficient as that of momentum.

Pack ice in the Beaufort Sea near Barrow, Alaska. (AOL 3566.)

Surface profile characteristics

Location	Year	Azimuth ° true	rms Ice Surface Elevation at Wavelengths less than 13 m, ζ (cm)	No. of Data Runs	Wind Drag Coefficient, C_{10}
Beaufort Sea[1]	1971	337	5.6	2	1.68×10^{-3}
	1971	220	5.5	4	1.51×10^{-3}
Arctic Ocean[1]	1972	090	9.8	2	1.82×10^{-3}
	1972	270	6.3	3	1.56×10^{-3}
Robeson Channel[1]	1972	220	13.2	18	2.08×10^{-3}
Robeson Channel[2]	1974	200	7.3	10	1.78×10^{-3}
	1974	035	6.2	3	1.65×10^{-3}

References: (1) Banke and Smith (1973); (2) Data not previously published.

Wind Drag on Ice Ridges. Ice ridges, formed by pressures within the ice, may occasionally stand several metres high and the wind drag on these obstacles must clearly be greater than that on relatively uniform terrain. Where large ridges (over 1 metre high) occur, the drag coefficient should be increased (Arya, 1973) by an amount based on the mean height, *Z,* and frequency of occurrence, N, of the ridges. In surveys over large areas, ζ, *N,* and Z may be determined from profiles of the ice surface, obtained using airborne laser altimeters (Hibler, 1972; Hibler *et al.,* 1974). Until recently, no direct measurement of wind drag on Arctic ice ridges had been made.

Because ice ridges act as individual obstacles to the wind, it is their profile area in a vertical plane rather than the surface (horizontal plane) area that determines the wind drag. A form drag coefficient C_f may be defined so that for a ridge of height *h* and length *L* at right angles to the wind direction, the form drag on the ridge at a wind speed *U* is

$$F = \rho C_f U^2 hL$$

In 1974, pressure ports were installed in five small ice ridges in Robeson Channel (Banke and Smith, 1975) to determine form drag coefficients. Combining the form drag on ridges with the surface drag gives total wind drag on the ice.

Work is continuing and pressure ports will be mounted in newly-formed, more rugged pressure ridges by AIDJEX in the Beaufort Sea in 1975. These measurements should help to settle the controversy regarding the relative importance of pressure ridges in determining wind drag on the Arctic Ocean ice fields.

In summary, sea-ice research, like so many other areas of research in the Arctic, has been somewhat neglected. A number of nineteenth-century exploratory expeditions suffered great hardship. The International Ice Patrol was organized following the Titanic disaster in 1911, and a growth of activity in oceanography, particularly in the United States occurred in the 1950s, following in Canada in the 1960s. The discovery of Arctic oil and gas and the general recognition of the shortage of energy reserves during the past few years have provided further impetus during an otherwise difficult period for research support. We are now on the verge of being able to apply a quantitative knowledge of the thermal and mechanical processes affecting sea ice to model and forecast its formation and movement.

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Geological Evolution of the Labrador Sea

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The Labrador Sea connects the Atlantic Ocean to the waters of Hudson Bay and the Arctic Archipelago. It is bounded to the west by Newfoundland, Labrador, and southern Baffin island and to the east by Greenland; to the north, shallow Davis Strait separates it from Baffin Bay.

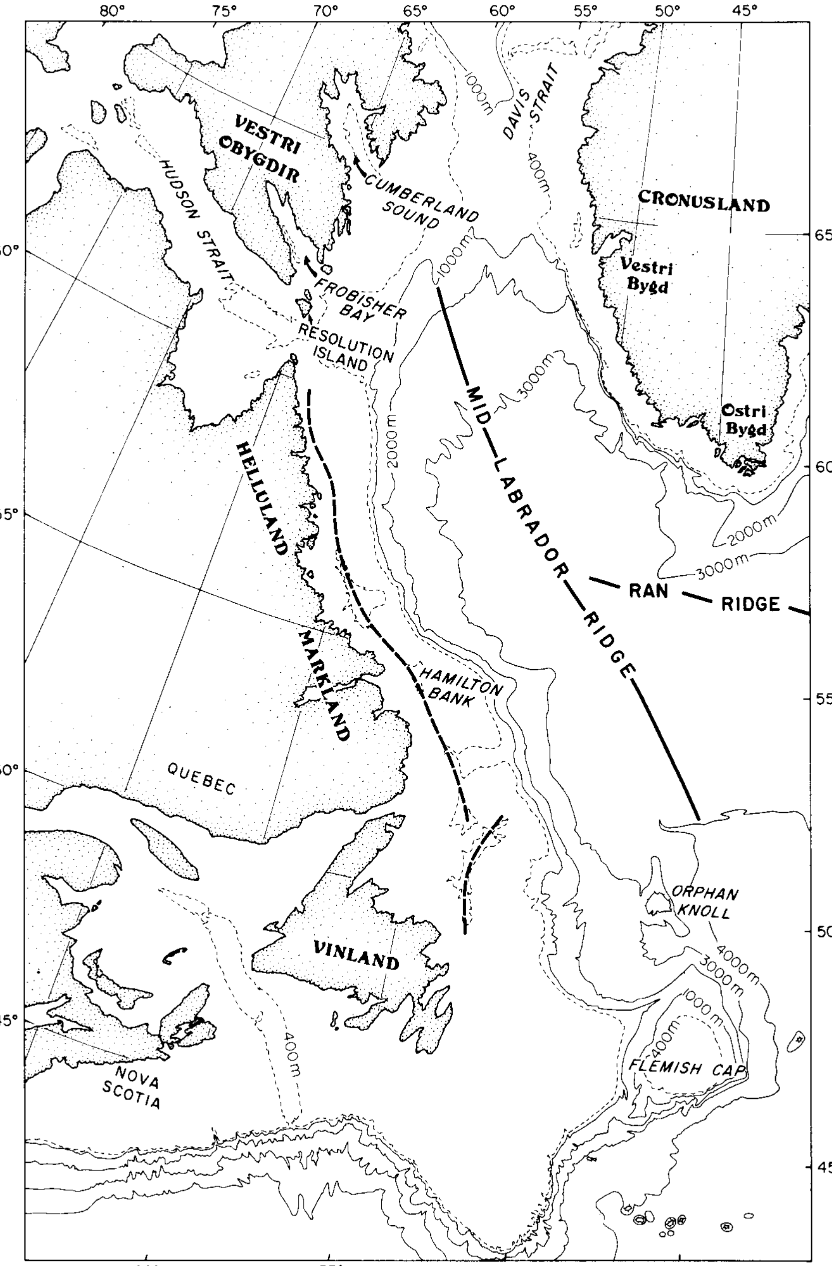
The sea and the surrounding land are inhospitable by 'civilized' standards. Yet the deeply incised steep and dark rocky coasts, towering icebergs, and bizarre display of the aurora borealis lend an awe-inspiring beauty to the region. The coasts and surrounding waters teem with life and below the bottom of the sea, under the continental margin, there is the promise of hidden wealth to fuel an energy-craving world.

Early Exploration

Man's involvement in the Labrador Sea region is revealed, rather incompletely, in archaeological findings, in Norse sagas, and in ships' logs. For perhaps tens of thousands of years, the early inhabitants, the Eskimo or pre-Eskimo people (Dorset, Thule, and Tunnit cultures), led the simple nomadic life of hunters and fishermen. Their way of life persisted until well into the twentieth century for their descendants, and the Eskimo or lnnuit to this day remain the only people that truly belong in this frozen land. In the latter part of the tenth century the Scandinavians arrived on the Labrador scene, steering their knorrir west from Iceland. The climatic conditions between 800 and 1200 (Little Climatic Optimum) suited husbandry and agriculture and Norse communities *(Vestri Bygd* and *Ostri Bygd)* were established in western Greenland *(Cronusland, Cronland,* or *Gronland).* Subsequently, the Vikings explored, first the western wilderness, *Vestri Obygdir* or Baffin Island, later *Helluland* (northern Labrador), *Mark/and* (southern Labrador), and *Vinland* (Newfoundland and New England). Their sagas tell of trade and skirmishes with the Skraelings, or natives, probably Dorset people, who were described as "swarthy, queer-looking people with ugly hair on their heads" (Mowat, 1965). Perhaps warfare, more likely, however, intermixing of Skraelings and Norse led to the gradual disappearance of the Norse culture and brought to an end over 500 years of their influence.

Basque whalers and British and French fishermen may have found their way to the land of the codfish *(Terra de baccaliaos)* well before Columbus crossed the Atlantic. Portuguese, Dutch, Italian, Danish, and German navigators appeared off Greenland and Labrador in the fifteenth century and the name Labrador seems to go back to that time. According to early maps the name was used in several places before it finally stuck to eastern Canada. Labrador most likely is named after Joao Fernandez, a Portuguese landowner, farmer, or husbandman *(Lavorador)* who was connected as a pilot in some way with the first voyages of Giovanni Cabato (John Cabot) in the last decade of the fifteenth century.

In the sixteenth century the search was on for the Northwest Passage, an alternative route to Asia, India, and the Moluccas. This was a period of great discovery that lasted well into the seventeenth century and brought many European navigators into the Labrador Sea. Later, the fur trade and the heroic polar quest attracted more explorers.



General physiography of the Labrador Sea and positions of the buried mid-ocean ridge system and of the marginal channel (heavy dashed line). Locality names in stylized print indicate Viking designation. (AOL 3594.)

Scientific exploration and detailed mapping surveys did not begin in earnest until the twentieth century. Within this latter framework the Bedford Institute of Oceanography has picked up the banner and follows in the wake of the skinboats, knorrir, galleons, and barks that plied the Labrador Sea in ages past.

Geological Exploration

Today the incentive for exploration is the search for energy and because the Labrador margin contains gas and possibly oil in economical quantities, it is imperative to understand its geological structure and history. This knowledge will improve the success to failure ratio of exploratory drilling and it will help to monitor the impact of exploitation on the environment and to safeguard against ecological disasters. Since the Government of Canada has a clear responsibility in the management of offshore resources, the Atlantic Geoscience Centre (AGC) has a job in the Labrador Sea. The Labrador Sea research effort is leading to new ideas and models of continental margin evolution that appear to have world-wide application.

Geological and geophysical investigations in the area have been going on for about ten years. Early reconnaissance work was carried out by Manchester (1964) and Grant (1972). The scientific effort in the area increased markedly in the last three years. Under AGC, a number of major projects are active in the Labrador Sea, several of these jointly with the Canadian Hydrographic Service, some with industry participation. The amount of data collected by the Bedford Institute of Oceanography, Dalhousie University, and researchers from other nations, supplemented with data that was acquired on a participation basis from prospecting companies is impressive for such a relatively small part of the world ocean. Geological and geophysical surveys in the Labrador Sea now cover more than 100,000 kilometres of track (which means an average line spacing of about 10 kilometres) and this does not include the data collected by industry in its search for oil and gas.

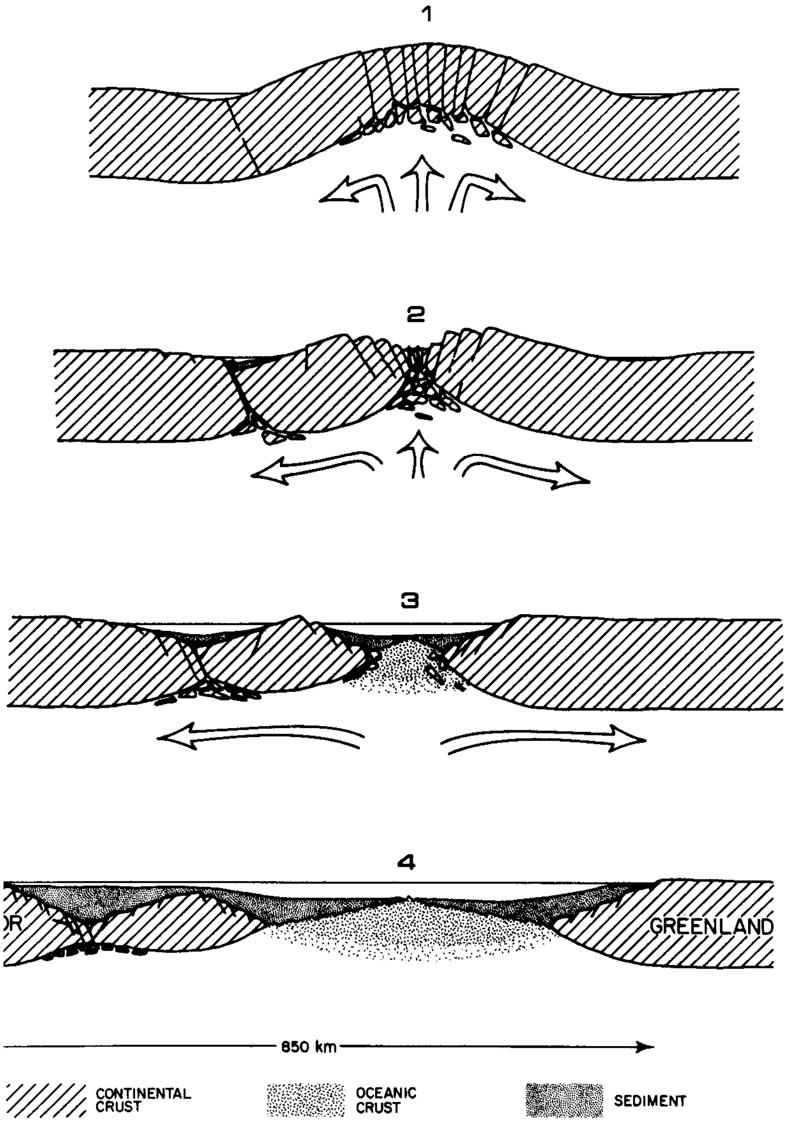
There is an obvious advantage in studying the Labrador Sea rather than the Atlantic Ocean; crossing the Sea from coast to coast can be done in about a third of the time it takes to cross the Atlantic. Notwithstanding her size, however, the Labrador Sea is a complete ocean; within her confines are most of the morphological and structural elements that are present in the Atlantic Ocean.

The Labrador continental shelf is made up of large banks separated from a coastal platform by a deep marginal channel. Seaward of this channel, a pile of sediments overlie rocks of Precambrian age (600-2000 million years old), such as are exposed on land and on the inner shelf. The sediments thicken as the basement rocks step down under the shelf and continental slope and in places accumulations of more than 10 kilometres occur.

Somewhere under the continental slope and rise there is a transition from continental to oceanic crust and under the deep ocean floor (the continental rise and abyssal plain) the oceanic basement rises to form the Mid-Labrador Ridge, about halfway between Labrador and Greenland. East of the ridge the same morphological and geological provinces are encountered - rise, slope, and shelf - when approaching the Greenland margin. In the centre of the Labrador Basin about 1 kilometre of sediment overlies the Mid-Labrador Ridge, although peaks of the ridge system penetrate to the sea floor.

The Origin of the Labrador Sea

The evolution of the Labrador Sea may be envisaged to have taken place according to the model presented in the figure below. It all started perhaps 200 million years ago with a piece of continental crust, about 30 kilometres thick, consisting of the combined Labrador-Greenland landmass. This crust, passively coupled to the Earth's mantle below, became subject to tensional forces, resulting from thermal convective processes in the mantle (phase 1 of the figure). Thermal



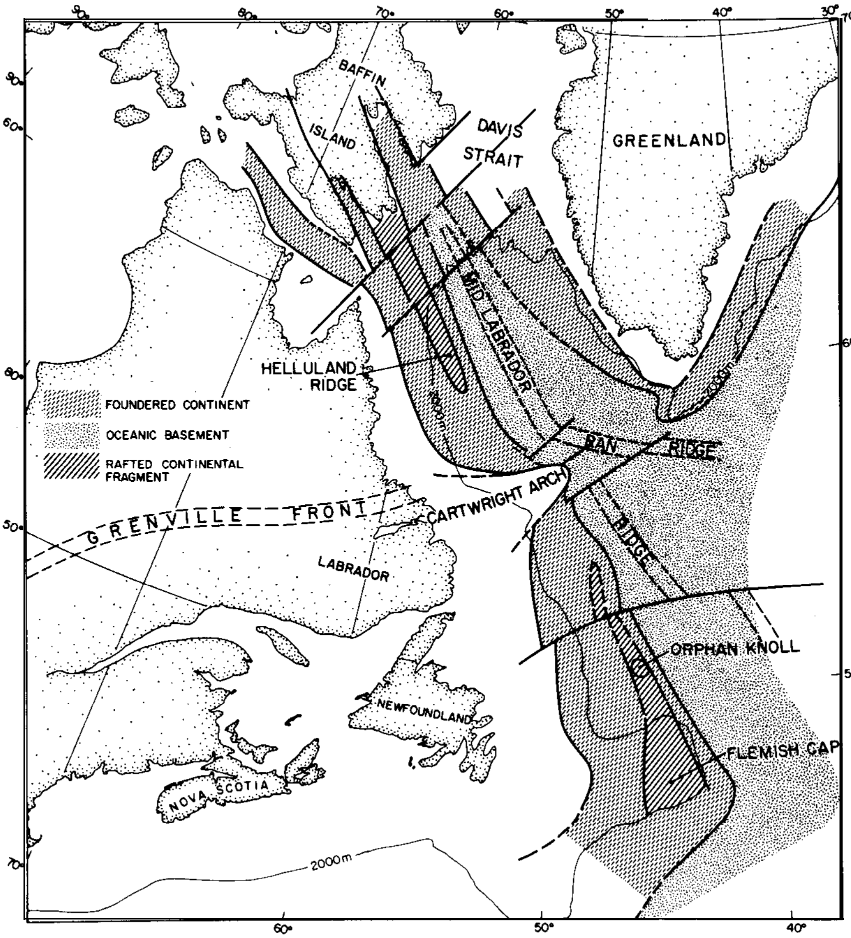
The evolution of the Labrador Sea in four stages. Especially the Greenland side of the diagram is grossly simplified. *(AOL 3415.)*

expansion elevated the crust over a wide zone and dykes intruded through a fracturing crust. Depressions formed on both sides of the elevated zone in elastic response to the uplift. Extension of the central area and failure of the crust under the western marginal basin effectively created two sedimentary basins (phase 2 of the figure) that have persisted to the present. In the upper brittle regime of the crust, rift and graben structures developed: in the deeper crust, where it was sufficiently hot, plastic deformation may have taken place. As the process continued, sediments from adjacent high areas collected in the depressions, perhaps in freshwater basins that later developed via restricted hyper-saline shallow seas into deep open marine basins. At some stage, maybe in Early Cretaceous time (van der Linden, 1975) the crust broke apart in one place and the two segments separated at speeds of a few centimetres per year (phase 3 of the figure). Material welling up from below filled the gap, solidified into oceanic crust, and moved away from the spreading centre (sea-floor spreading). At the locus of upwelling, or spreading centre, a volcanic submarine elongate ridge, the Mid-Labrador Ridge, was formed and is now buried under thick sediment.

The reconstruction of events as presented in the figure is based on seismic observations over the northern Labrador margin. A large rafted fragment of thin continental crust, herein called the Helluland Ridge, now underlies the Labrador continental rise. The ridge separates two sedimentary basins, one under the continental margin and one in the deep sea area. The thickness of the ridge and attenuated Labrador continental margin is only 17 kilometres and of the necked crust in between only about 8 kilometres; the thickness of the crust under Labrador is more like 30 kilometres. The Helluland Ridge can be observed in a number of seismic reflection profiles over the northern Labrador continental margin and it parallels the coast over a distance of at least 350 kilometres.

The process of crustal separation and foundering appears to have ended about 100 million years ago although some activity centred on an east-west spreading axis, the Ran Ridge, may have taken place during a later phase that ended 40 or 50 million years ago. As far as can be judged, sea-floor spreading stopped at that time and Greenland, Labrador, and the ocean floor in between were firmly fused together.

In the central Labrador Sea, the truly oceanic area where sea-floor spreading occurred is only 300 kilometres wide, which is only about one-third of the total width of the Labrador Sea measured from coast to coast (see figure next page). In the southern Labrador Sea, thinning and foundering of the crust separated two continental fragments, Orphan Knoll and Flemish Cap, from the Newfoundland margin. Here, too, we find two coast-parallel basins, one on foundered crust, the other over oceanic crust, separated by rafted continental fragments. Off the central Labrador Sea, there appears to be only a single basin between Labrador and Greenland. Attenuation of continental crust here is observed in the foundering of the crust over a zone approximately 250-300 kilometres wide (van der Linden and Srivastava, 1975). The difference between the margins off northern Labrador and Newfoundland on the one hand and off central Labrador on the other appears to be due to differences in original crustal thickness and strength. Approximately at right angles to the Labrador coast there is, on land, an elongate, thick, crustal segment that marks the position of an important Precambrian geological boundary, the Grenville Front. This Front, which existed prior to the formation of the Labrador Sea, appears to continue offshore in what is known as the Cartwright Arch.

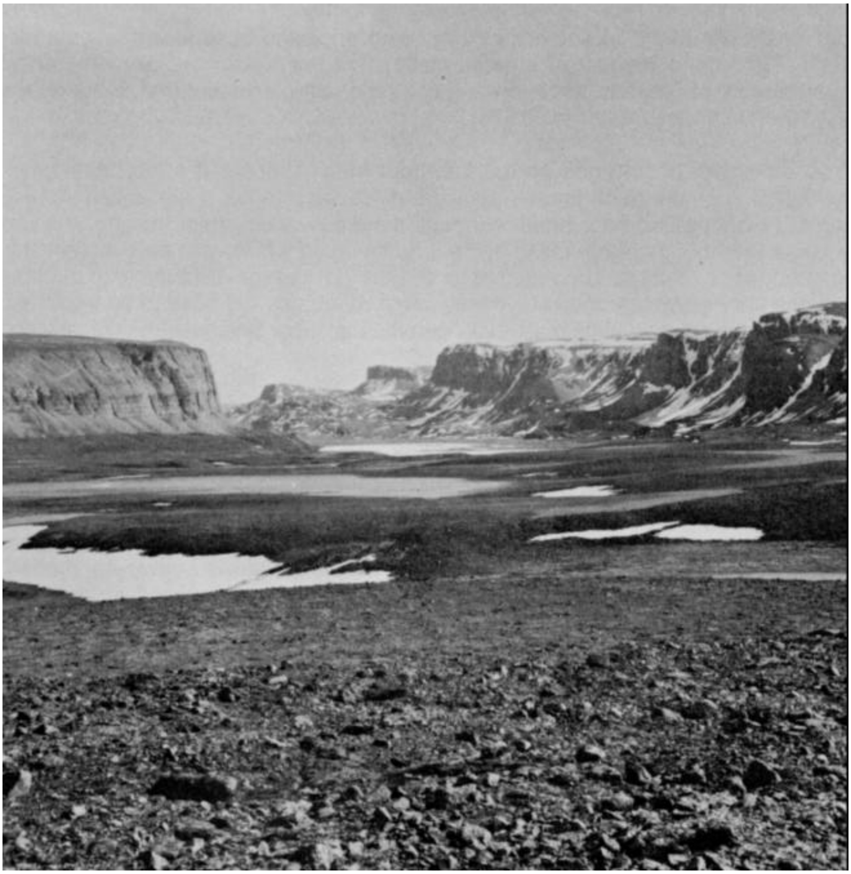


Schematic representation of the Labrador Sea structure, showing the areas beyond the shelf that are underlain by fragmented foundered continental crust and by ocean crust, generated through sea-floor spreading. Note the continuation of the Labrador Sea structures into Baffin Island. *(AOL 3476.)*

To the south, the Labrador Sea structures open into the Atlantic Ocean; to the north, the structure is rather complex and ill defined. Geographically, the Labrador Sea continues north, via Davis Strait, into Baffin Bay; the Labrador Sea deep structures, however, head for Baffin Island. There is the possibility that Frobisher Bay, Cumberland Sound (Baffin Island), and the downfaulted areas (graben) to the northwest of these inlets are the continuations or terminations of the Labrador basins. Attenuation of continental crust and sea-floor spreading, after all, were not only proceeding laterally at right angles to the spreading centre but also advanced in time along the axis, away from the initial crack. In other words, the initial crack and later the new ocean not only became wider but also longer in time. The Baffin Island rift and graben structures, therefore, may be considered to represent a stage in the opening of the northern Labrador Sea equivalent to an earlier stage of Labrador Sea development farther south (stage 2). Hudson Strait, a half graben

(Grant and Manchester, 1970) that roughly parallels the Labrador Sea and Baffin Island structures is also very likely part of the attenuated crustal segment between mainland Canada and Greenland.

It is to be understood that the map showing the different types of crust is speculative in many areas, notably in the Davis Strait region, which, as mentioned, appears structurally complex. An extension of the Labrador Sea structure, offset along northeast-southwest aligned faults into Baffin Bay as advocated by Le Pichon et al. (1971) is certainly a possible alternative. Overall, however, the figure is consistent with the geophysical observations. Magnetic anomalies over the areas underlain by oceanic crust for instance exhibit different characteristics from those in areas underlain by foundered continental crust, i.e., high frequency versus low frequency anomalies respectively, the latter forming a marginal quiet magnetic zone (Hood and Bower, 1973; van der Linden, 1975). The disturbances as indicated on the figure by the Cartwright Arch and northeast-southwest oriented faults are detected as offsets in the gravity and magnetic field and as a basement high in seismic reflection profiles (van der Linden and Srivastava, 1975).



Block faulting, graben formation, typical of an early stage of fragmentation of continental crust and ocean basin evolution, revealed in the valley of the Eqalulik River, northwest Baffin Island. *(Geological Survey of Canada photograph.)*

History of Sedimentation and Accumulation of Hydrocarbons

Sediments accumulated in the Labrador basins since the early phases of crustal attenuation and in places reached total thicknesses of more than 10 kilometres (Wade et al., 1975). They are largely gently seaward dipping, coastal plain sediments probably of Upper Cretaceous and Tertiary age that overlie older Mesozoic, possibly Paleozoic, sediments as described by Grant (1972) from seismic profiles over the shelf off southern Labrador and Newfoundland. Grant (1975) also infers Paleozoic and Mesozoic ages for sediments in Hudson Strait, Frobisher Bay, and Cumberland Sound.

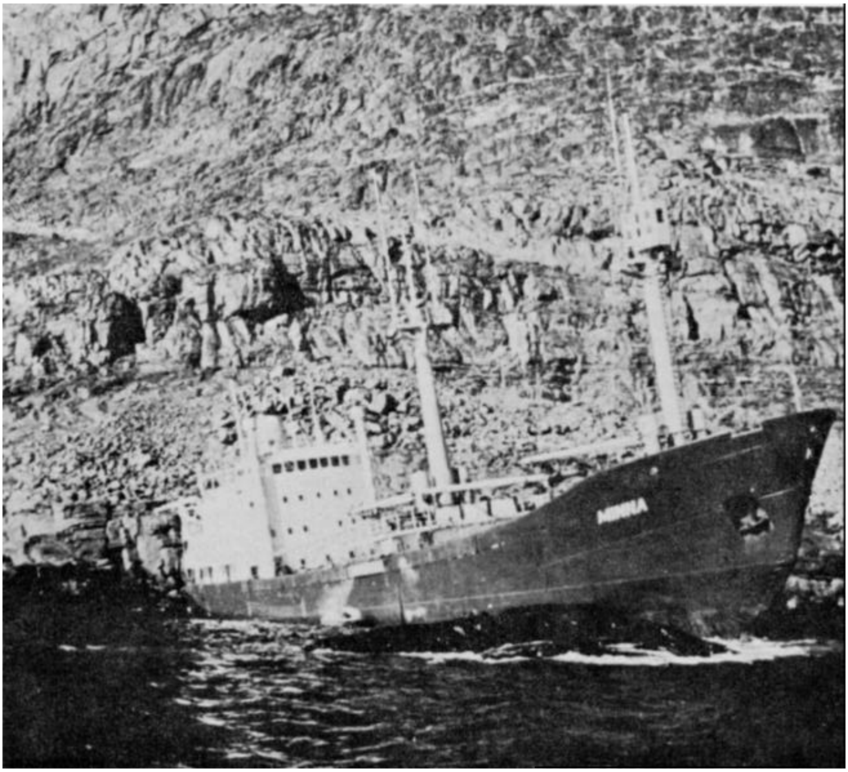
During the early stages of crustal thinning (phase 2) circulation in the newly formed basins was very restricted and conditions may have been favourable for the precipitation of evaporites, salt, and gypsum. Indeed, salt (or shale) diapirs have been recognized on seismic records off southern Labrador, Newfoundland, and Baffin Island (Grant, 1975) and perhaps also off central Labrador (van der Linden and Srivastava, 1975). Conditions also may have been favourable, again because of restricted circulation in the basins, for the accumulation of oil and gas. It is interesting to note in this respect that unusually high concentrations of methane were found in sediment cores from enclosed basins on the Labrador Shelf. The gas, a product of organic matter that decayed in an oxygen-starved environment, appears to have formed since the last glaciation, that is during the last 15,000 years (Vilks et *a/.,* 1974).

Prospecting for oil and gas on the Labrador margin received a big boost when encouraging amounts of natural gas were discovered in two wells drilled in 1973 and 1974 on the Labrador Shelf. Although the discoveries are promising, it is well to remember that the amounts of hydrocarbons found will have to be substantial to be economic to extract. The reasons for this are not just the distance to market but also the very adverse conditions under which resources will have to be exploited. Weather and ice conditions make drilling in the Labrador Sea a technologically and environmentally hazardous enterprise.

Icebergs calved from the Greenland ice cap are transported southward by the Labrador Current. When these bergs are pushed on the Labrador Banks their keels will plough and gouge furrows metres deep in the sediment. It is estimated that roughly 15,000 bergs per year are calved into Baffin Bay by Greenland glaciers, notably in Disko and Melville Bays. Most of these bergs are carried north initially by the prevailing currents into northern Baffin Bay before they are turned around and follow the Canadian coast along what is known as ‘Iceberg alley’. More than 1000 bergs pass off Cape Chidley annually and roughly 400 reach the Grand Banks. Icebergs that weighed up to several million tons have been observed to ground in water depths of more than 200 metres (Canadian Department of National Defence, 1971).

A major difficulty affecting oil and gas recovery is the surficial sediment on the shelf banks, which consists of glacial debris, moraines, and tills with many large boulders and blocks. Because all future well heads, production platforms, and pipelines have to be buried beneath iceberg gouging depth, the cost of exploitation will be high indeed.

Future AGC efforts in the Labrador Sea will be aimed at solving several specific problems. In order to fully appreciate the development of the Labrador Sea and its economic potential, the structure of the Davis Strait region will be analyzed and mapped during geophysical and geological surveys. The age of the Labrador Basin will be measured through magnetic surveys over the central oceanic region and attempts will be made to dredge or drill datable samples from the Mid-Labrador Ridge. Last but not least, AGC's surficial geology mapping program that thus far has concentrated on Hamilton Bank will be extended over the shelf and slope areas.



Last station. The MV. Minna grounded on Precambrian gneiss, Brewer Bay, Resolution Island. (AOL 3484)

That the cost of exploration in sub-Arctic, often uncharted, waters is high was demonstrated in an unorthodox but convincing way by the 1974 grounding and sinking of the MV *Minna* off Resolution Island whilst on her 1974 combined hydrographic-geophysical survey in the northern Labrador Sea. Nevertheless, the stakes are high and, as long as the returns of mineral exploration are promising, our task will be to evaluate the resources and anticipate engineering problems and environmental hazards when these resources are tapped. Whichever way exploration goes, unravelling the secrets of the Earth will be our challenge and reward for many years to come.

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Major Publications, Cruises, and Staff Affiliations
Bedford Institute of Oceanography
Dartmouth, Nova Scotia
1973/74

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Major Publications of 1973/74

Bedford Institute of Oceanography Contributions

A few 1972 papers not yet published when the 1971-72 Biennial Review went to press are included here. Bedford institute of Oceanography Contribution Numbers are given in brackets at the end of each reference.

ADDISON, R. F. 1974. Estimation of N-ethyl O-isopropyl thionocarbamate (Dow: z-200) in mine waters by *G.* L. *C. Int. J. Environ. Anal. Chem. 3:* 287-292. (429)

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LOUCKS, R. H. and INGRAHAM, D. V. 1974. Section 9. The influence of environmental conditions on the operation of oil terminals. *In* Summary of Physical, Biological, Socio-economic and Other Factors Relevant to Potential Oil Spills in the Passamaquoddy Region of the Bay of Fundy. *FRB, Tech. Rep. No. 428.*

PARANJAPE, M. A. and CONOVER, R. J. 1973. Zooplankton of St. Margaret's Bay 1968 to 1971. *FRB, Tech. Rep. No. 401.*

PLATT, T., IRWIN, B., and SUBBA RAO, D. V. 1973. Primary productivity and nutrient measurements on the spring phytoplankton bloom in Bedford Basin, 1971. *FRB, Tech. Rep. No. 423.*

PLATT, T. and SUBBA RAO, D. V. 1973. Some current problems in marine phytoplankton productivity. *FRB, Tech. Rep. No. 370.*

PORTEOUS, D. and POULET, S. A. 1973. Computer programs for processing data of suspended material collected by the Coulter Counter. *FRB, Tech. Rep. No.* 403.

SAMEOTO, D. D. and JAROSZYNSKI, L. O. 1973. Distribution of euphausiid scattering layers in the Gulf of St. Lawrence estuary. *FRB, Tech. Rep. No. 430.*

SHELDON, R. W. 1973. Direct measurement of particle concentration in natural waters with a Model T Coulter Counter. *FRB, Tech. Rep. No. 379.*

Geological Survey of Canada (GSC) Papers

Publications followed by an asterisk are also included in the list of Bedford Institute of Oceanography Contributions.

BARSS, M. S. and WILLIAMS, G. L. 1973. Palynology and nannofossil processing techniques. GSC, *Pap. 73-23.*

JENKINS, W. A. M., ASCOLI, P., GRADSTEIN, F. M., JANSA, L. F., and WILLIAMS, G. L. 1974. Stratigraphy of Amoco 10E A-1 Puffin B-90 well, Grand Banks of Newfoundland. GSC, *Pap. 74-67.*

PELLETIER, B. R. (Ed.) 1974. Offshore geology of Eastern Canada. Volume 1 - Concepts and applications of environmental marine geology. GSC, *Pap. 74-30.*

WILLIAMS, G. L., JANSA, L. F., CLARK, D. F., and ASCOLI, P. 1974. Stratigraphy of the Shell Naskapi N-30 well, Scotian Shelf, Eastern Canada. GSC, *Pap. 74-50.* *

WILLIAMS, G. L. and LENTIN, J. K. 1973. Fossil dinoflagellates: index to genera and species. GSC, *Pap. 73-42.*

Marine Science Papers

A joint publication of Department of the Environment and Department of Energy, Mines and Resources, Ottawa, Canada, 1973. Publications followed by an asterisk are also included in the list of Bedford Institute of Oceanography Contributions.

HAWORTH, R. T. 1974. Gravity and magnetic natural resource maps (1972) offshore eastern Canada. Philosophy and technique in preparation by computer. *Mar. Sci. Pap. 13/Geol. Surv. Can. Pap.* 74-22. Information Canada, Ottawa.

ROSS, D. I. 1973. Free air and simple Bouguer gravity maps of Baffin Bay and adjacent continental margins. *Mar. Sci. Pap. 12/Geol. Surv. Can. Pap. 73-37.* Information Canada, Ottawa.*

WATTS, A. B. and HAWORTH, R. T. 1974. Geological interpretation of Bouguer anomaly and magnetic anomaly maps east of the Magdalen Islands, southern Gulf of St. Lawrence. *Mar. Sci. Pap. 10/Geol. Surv. Can. Pap.* 74-55. Information Canada, Ottawa.*

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Major Cruises of **1973/74**

Cruises Operated by the Atlantic Oceanographic Laboratory During 1973

Cruise Number	Vessel	Cruise Dates	Officer in Charge	Area	Objectives
73-001	*Baffin*	January 15-April 6	S. van Dyck, AOL	Caribbean	Hydrographic training of staff
73-002	*Hudson*	January 22-February 6	D. C. Gordon (leg 1), MEL; K. S. Manchester (leg 2) AGC	Halifax-Bermuda	Studies of pollution, organic matter, zooplankton, and marine geology
73-003	*Dawson*	February 5-23	G. Fader, AGC	Coastal N.S.; Gulf of Maine	Studies of surficial sediments
73-004	*Hudson*	February 12-March 6	E. M. Hassan, MEL	Gulf of St. Lawrence	Temperature-salinity measurements
73-005	*Dawson*	February 27-March 7	J.-G. Dessureault, AOL	Coastal N.S.	Equipment evaluation; placement of moorings
73-006	*Hudson*	April 2-19	B. MacLean (phase I), AGC; L. H. King (phase II), AGC	Laurentian Channel and marginal shelves	Benthic sampling and echogram profiling for surficial and bedrock geology charts

73-007	*Dawson*	April 4-19	J.-G. Dessureault, AOL	Halifax, N.S. and vicinity; continental slope to Gulf Stream	Instrument development; retrieval of current meter moorings
73-008	*Baffin*	April 6-13	J. Wheeler, MEL	Halifax-Bermuda	Phytoplankton, organic matter, pollution, and surface chemistry-biology surveys
73-009	*Sackville*	April 9-19	D. Bidgood, NSRF	Scotian Shelf	Equipment evaluation: seismic profiling
73-010	*Sackville*				
Phase I		April 24-27, May 5-6, May 11-17	R. M. Eaton, AOL	N.S. coast	Study of phase lag of Decca HiFix signals
Phase II		April 30-May 4, May 7-11	Canada Dept. National Defence	N.S. coast	Search for downed helicopter
73-011	*Hudson*	April 25-May 18, May 23-June 15	C. E. Keen, AGC	N.S. continental margin; Grand Banks	Geophysical studies
73-012	*Dawson*	April 25-May 10	R. Pocklington, AOL	Gulf of St. Lawrence	Study of water masses (origin, circulation, mixing)
73-013	*Maxwell*	May 1-October 30	A. Adams, AOL	Maritime provinces	Chart revision surveys

73-014	*Baffin*	May 15- October 30	R. Williams, AOL	St. Lawrence estuary; eastern Arctic	Hydrographic surveys
73-015	*Dawson*	May 30- June 15	J. Allen, Memorial Univ.	Grand Banks	Iceberg and sediment investigations
73-016	*Sackville*	May 30- July 13	D. D. Sameoto, MEL	Gulf of St. Lawrence	Biology; physical oceanography
73-017	*Christmas Seal*	May 26- October 29	R. Cameron, AOL	Maritime provinces	Chart revision; navigational range surveys
73-018	*Theron*	May 26- October 29	M. G. Swim, AOL	Labrador coast	Standard hydrographic charting
73-019	*Minna*	June 27- October 15	G. M. Yeaton, AOL	East coast of Nfld.	Hydrographic-geophysical survey
73-020	*Dawson*	June 19- July 13	E. M. Hassan, MEL; W. D. Forrester, AOL	Gulf and estuary of St. Lawrence	Seismic, physical, and chemical oceanographic survey
73-021	MOT Icebreakers	July 1- November 15	M. A. Hemphill, AOL	Eastern Arctic	Hydrography
73-022	*Vilma L.*	April 31- August 31	D. E. Buckley, AGC	Canso Strait, Chedabucto Bay, N.S.	Multidisciplinary environmental impact study
73-023	*Bluethroat*	June 4- September 14	J.-G. Dessureault, AOL	Coastal N.S.	Equipment evaluation

73-024	*Dawson*	July 23- August 5	D. C. Gordon, W. H. Sutcliffe, MEL	Halifax-Bermuda	Pollution, organic matter, zooplankton, and chemical oceanography studies
73-025	*Hudson*	August 2- September 26	C. K. Ross, AOL	Denmark Strait	Studies of Norwegian Sea overflow into North Atlantic
73-026	*Sackville*	August 14- September 11	K. S. Manchester, AGC	Labrador Sea	Seismic studies and surficial sediment sampling
73-027	*Dawson*	August 14- October 4	W. J. M. van der Linden, AGC	Labrador continental margin	Geophysical survey
73-028	*Sackville*	September 18- October 2	L. Jaroszynski, MEL	Gulf of St. Lawrence	Study of euphausiids (krill) for possible commercial fishing
73-029	*Sackville*	October 10-19	L. H. King, AGC	Cape Breton Shelf; Laurentian Channel	Benthic sampling and echogram coverage for surficial maps
73-030	*Dawson*	October 15-23	D. C. Gordon, MEL	Halifax-Bermuda	Pollution, organic matter, zooplankton, and chemical oceanography studies
73-031	*Hudson*	October 15- November 15	C. Boyd, Dalhousie Univ.	Labrador coast; Gulf Stream	Multidisciplinary surveys
73-032	*Sackville*	October 22-30	R. T. Haworth, AGC	Georges Bank, N.S.; Gulf of Maine	Gravity and magnetic data collection
73-033	*Maxwell*	November 5-9	K. L. Denman, MEL	St. Margaret's Bay, N.S.	Biological surveys

73-034	*Dawson*	November 13-30	R. T. Haworth, AGC	Grand Banks	Gravity and magnetic data collection
73-035	*Sackville*	November 15-26	G. Taylor, MEL	Gulf and estuary of St. Lawrence	Temperature-salinity measurements for ice forecast
73-036	Maxwell	November 14-22	J. P. Thorburn, AOL	Halifax and vicinity	Equipment evaluation
73-037	*Sackville*	December 3-13	L. Jaroszynski, MEL	Gulf of St. Lawrence	Study of euphausiids (krill) for possible commercial fishing
73-050	*Navicula*	Summer	T. Lambert, MEL	P.E.I.	Biology
73-051	*Mallotus*	August-September	D. D. Dobson, AOL	Head Harbour Passage, N.B.	Current study

Cruises Operated by the Atlantic Oceanographic Laboratory During 1974

Cruise Number	Vessel	Cruise Dates	Officer in Charge	Area	Objectives
74-001	*Dawson*	January 7-18	W. D. Forrester, AOL	Gulf of St. Lawrence	Oceanographic observations, mooring current meters beneath ice, study algae growth under ice. ‘Ground truth’ ice observations for aerial photos

74-002	*Baffin*		T.B. Smith,		
Phase I		January 21. February 3		Halifax to Guyana, S.A.	Bathymetric, gravity, and magnetic data collection; collection of oil residue samples
Phase II		February 4- March 27		Guyana, S.A.	Update of navigational charting of approaches to Demerara and Essequibo Rivers
Phase III		March 28- April 5		Guyana, S.A. to Halifax	As for phase I plus use of Marconi Satnav Navigation System
74-003	*Hudson*				
Phase I		January 23- February 10	F. Aumento, Dalhousie Univ.	Famous Area	Geological sampling
Phase II		February 10-26	C. S. Mason, AOL: K. S. Manchester, AGC	Off Antigua	Equipment trials
Phase III		Cancelled			
Phase IV		March 27-30	D. L. McKeown, AOL	Halifax, Bedford Basin	Equipment trials; biological sampling
74-004	*Dawson*	January 28-31	J. M. Bewers, AOL	N.S. coast	Baseline chemical data collection
74-005	*Dawson*	March 2-8	N. S. Oakey, AOL	Gulf Stream south of Halifax	Testing and evaluation of Batfish and Octuprobe

74-006	*Hudson*				
Phase I		March 30- April 26	E. M. Hassan, MEL	Gulf and estuary of St. Lawrence	Temperature and salinity measurements; recovery of current meter moorings
Phase II		April 29- May 14	J. M. Bewers, AOL	Gulf and estuary of St. Lawrence	Chemical and geochemical sampling
74-007	*Sackville*	April 1-11	D. Bidgood, NSRF	N.S. coast	Bottom profiling; testing and evaluation of new equipment
74-008	*Sackville*	April 17-24	K. L. Denman, MEL	N.S. coast	Testing of *in situ* Variosens fluorometer on Batfish: phytoplankton spatial variability studies
74-009	*Dawson*	April 17-23	R. C. Cooke, Dalhousie Univ.	Halifax-Bermuda	Miscellaneous projects
74-010	*Maxwell*	April 19-24	R. M. Eaton, AOL	Halifax Harbour and surroundings	Equipment testing and evaluation
74-011	*Sackville*	April 30- May 2	D. D. Dobson, AOL	N.S. coast	Salinity-temperature measurements
74-012	*Maxwell*	May 1- November 1	J. Pilote, AOL	Atlantic provinces	Hydrographic and chart revision surveys

74-013	*Dawson*	May 3-16	C. T. Schafer, AGC	Chaleur Bay, N.B.	Investigate distributions of benthic foraminifers, molluscs, and sediments
				Gulf of St. Lawrence	Oil sampling of *Irving Whale* fuel tanks
				Chedabucto Bay, N.S.	Core sampling
74-014	*Sackville*	May 5-20	D. D. Sameoto, MEL	Gulf of St. Lawrence	Biological studies
74-015	*Baffin*	May 15-October 31	R. K. Williams, AOL	St. Lawrence estuary; Labrador and Baffin Island; Lancaster Sound	Charting; hydrographic and multidisciplinary surveys; erection of lambda stations; port aerial photos
74-016	*Christmas Seal*	May 17-October 31	Ft. M. Cameron, AOL	Nfld.; N.S.	Chart revision; range and wharf surveys
74-017	*Dawson*	May 25-June 3	R. O. Fournier, Dalhousie Univ.	Scotian Shelf, N.S.	Biological studies
74-018	*Sackville*	April 1-11	D. Bidgood, NSRF	N.S. coast	Surveys of sediment stratification; equipment testing and evaluation
74-019	*Sackville*	June 5-22	D. L. Barrett, AGC	Nfld. Basin, NW Atlantic	Geophysical studies
74-020	*Dawson*	June 10-26	R. F. Reiniger, AOL	Laurentian Fan	Ocean circulation studies

74-021	*Hudson*	June 10-27	D.J.W. Piper, Dalhousie Univ.	NW Atlantic	Deep-water dredging and coring; multidisciplinary surveys
74-022	*Theron*	June 26- October 13	M. G. Swim, AOL	Nfld. coast	Standard charting
74-023	*Minna*	June 19- August 25	G. M Yeaton, AOL	Labrador Sea	Regional survey
74-024	*Sackville*	June 24-28	A. W. Herman, AOL	St. Margaret's Bay, N.S.	Testing of *in situ* Variosens fluorometer on Batfish; evaluation of depth digitizer
74-025	*Dawson*	July 9-18	A. Y. McLean, NSTC	Halifax-Bermuda	Miscellaneous projects
74-026 Phase I	*Hudson*	July 17- August 31	D. I. Ross, AGC	Eastern Arctic	Gravity, magnetic, bathymetric, and seismic profiling; benthic sampling
Phase II	*Hudson* 'barge'	August 16- 27	C. F. M. Lewis, GSC	Eastern Arctic	Studies of surficial deposits, permafrost, ice bottom scouring
Phase III	*Hudson*	September 1-25	B. R. Pelletier, AGC	Lancaster Sound, Western Baffin Bay	Seismic refraction studies; detailed magnetic survey; geological sampling
Phase IV	*Hudson*	September 26- October 16	S. P. Srivastava, AGC	South Baffin Island Shelf, Davis Strait, Labrador Sea	Geophysical surveys, continental shelf drilling, sediment core collection
74-027	*Sackville*	July 22-31	J. P. Thorburn, AOL	N.S. coast	Equipment evaluation (CTD, acoustic transponder, Variosens fluorometer)

74-028	*Dawson*	July 29-August 15	R. Pocklington, AOL	Gulf of St. Lawrence area	Chemical and physical studies of water masses
74-029	*Sackville*	August 6-21	S. R. V. Durvasula, MEL	N.S. shelf	Biological studies
74-030	*Sackville*	September 7-27	GIROQ	Gulf of St. Lawrence	Miscellaneous projects
74-031	*Dawson*	September 4-13	R. F. Reiniger, AOL	Laurentian Fan	Recovery of current moorings
74-032	*Dawson*	September 18-October 3	B. Sundby, AOL	Scotian Shelf; Gulf of St. Lawrence	Study of temporal variations in chemical parameters, and of geochemical processes
74-033	*Dawson*	October 15 23	P.J. Wangersky, Dalhousie Univ.	Halifax-Bermuda	Miscellaneous projects
74-034	*Sackville*	October 15 28	C. Monoghan	N.S. shelf	Herring larvae exploratory survey
74-035	*Dawson*	November 4-8	R. O. Fournier, Dalhousie Univ.	Halifax and vicinity	Miscellaneous projects
74-036	*Maxwell*	November 14-18	A. W. Herman, AOL	Halifax and vicinity	Testing of *in situ* Variosens fluorometer on Batfish
74-037	*Sackville*	November 14-December 2	T. R. Foote, AOL	Gulf of St. Lawrence	Temperature-salinity measurements

74-050	*Sigma T*	Periodically	T. C. Platt, MEL	Bedford Basin, N.S.	Biological surveys
74-051	*Navicula*	Periodically	T. Lambert, MEL	St. George's Bay, N.S.	Biological surveys
74-052	*Lynn Kathleen* and *Ann Brenda*	July 17- August 17	D. D. Dobson, AOL	Minas Basin, N.S.	Current measurements
74-053	*Quadra*	June 20- September 26	R. A. Clarke, AOL	Tropical Atlantic	GARP Atlantic Tropical Experiment

NOTES:

(1) Common abbreviations used in both tables: AOL-Atlantic Oceanographic Laboratory; AGC-Atlantic Geoscience Centre; MEL - Marine Ecology Laboratory; GIROQ - Groupe Interuniversitaire de Recherches Océanographiques du Quebec; GSC - Geological Survey of Canada; NSRF - Nova Scotia Research Foundation; NSTC - Nova Scotia Technical College; N.B. - New Brunswick; Nfld. - Newfoundland; N.S. - Nova Scotia; P.E.I. -Prince Edward Island; S.A. -South America.

(2) For further information on particular cruises, contact the Officer-in-Charge; Ships Division, AOL; or the Library, Bedford Institute of Oceanography, Dartmouth, N.S., B2Y 4A2.

(3) No cruises corresponding to numbers 73-038 to 73-049 and 74-038 to 74-049 were undertaken.

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Staff Affiliations During 1973-74

Atlantic Oceanographic Laboratory

During 1973-74 several staff members of the Atlantic Oceanographic Laboratory were affiliated in various ways with the academic and research communities. Examples are given below.

Dr. Wm. L. Ford served as a member of the Board of Trustees of AIRI(Atlantic Industrial Research Institute) and as a member of the Board of Directors of the Nova Scotia Research Foundation. He and Dr. R. Pocklington are members of the Corporation of the Bermuda Biological Station for Research.

Mr. S. B. MacPhee served as a member of the Industrial Advisory Council on Science and Engineering, Memorial University, Newfoundland, and on the Engineering Advisory Board on Engineering Technology, Province of Nova Scotia.

Dr. C. R. Mann continued as Associate Professor in the Physics Department, Dalhousie University, Halifax, and Drs. G. T. Needler and H. Sandstrom as Research Associates of the Institute of Oceanography at the university. Also at the Institute of Oceanography, Dalhousie University, Dr. W. D. Forrester supervised the thesis work of several M.Sc. and Ph.D. students.

Since his return from the Geophysical Fluid Dynamics Institute, Florida State University, where he was Visiting Lecturer, Dr. C. Quon has served as Adjunct Research Associate of that university.

Marine Ecology Laboratory

During 1973/74 several members of the Marine Ecology Laboratory were affiliated in various ways with the academic and research communities. Examples are given below.

Members supervising thesis work at Dalhousie University, Halifax, included Drs. R. J. Conover, D. C. Gordon, Jr., and T. Platt, and Mr. B. Hargrave. Also at Dalhousie University, Dr. K. L. Denman taught a course in physical oceanography. Drs. T. Platt, R. W. Trites, and D. M. Ware served as Research Associates at this university.

During the 1973-74 academic year, Dr. T. Platt was Visiting Professor in Biology at Université Laval, where he taught a course on the thermodynamics of ecosystems. He was also Scientific Director of GIROQ (Groupe Interuniversitaire de Recherches Océanographiques du Quebec) during this period.

Drs. R. W. Sheldon, W. H. Sutcliffe, Jr., and D. C. Gordon, Jr., are members of the Corporation of the Bermuda Biological Station for Research.

Atlantic Geoscience Centre

During 1973-74 several members of the Atlantic Geoscience Centre were affiliated in various ways with the academic and research communities. Examples are given below.

Dr. B. R. Pelletier was Adjunct Professor of Geology at Acadia University, Wolfville, Nova Scotia, where he gave a course in sedimentology. Dr. Pelletier and Dr. L. H. King hold appointments at Dalhousie University, Halifax, as Special Lecturers, Department of Geology, and are also associate members of the Faculty of Graduate Studies at this university. Dr. Pelletier is the editor of *Maritime Sediments* and associate editor of *The Canadian Journal of Earth Sciences.* Dr. King and Dr. C. E. Keen are associate editors of *Geoscience Canada.*

Members who served on thesis committees included Drs. C. E. Keen, B. R. Pelletier, D. I. Ross, and S. P. Srivastava, all at Dalhousie University, and Dr. R. T. Haworth at McGill University, Montreal, Quebec.

Dr. C. E. Keen was a special lecturer for one term at the Scripps Institute of Oceanography, La Jolla, California.

Dr. B. D. Loncarevic served on the National Research Council Advisory Committee on Geodesy and Geophysics. He also served as special technical advisor to the Coordinating Committee on Offshore Prospecting of the Economic Commission for Southeast Asia. He is on the editorial boards of *Marine Geophysical Researches* and *Science Forum;* a member of Council, Nova Scotian Institute of Science; and is associated with the Geology Department of Dalhousie University.

Dr. F. J. E. Wagner is a Fellow of the Royal Canadian Geographical Society and a member of the Associate Committee on Quaternary Research.

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