Bedford Institute Of Oceanography



(This page Blank in the original)

(This page Blank in the original)



Bedford Institute of Oceanography Biennial Review 1971/72

Bedford Institute of Oceanography Dartmouth, Nova Scotia, Canada

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

(1) The ATLANTIC OCEANOGRAPHIC see LABORATORY, which is part of the Marine Sciences Directorate of the Department of the Environment

(2) The MARINE ECOLOGY LAB-ORATORY of the Fisheries Research Board of Canada, also of the Department of the Environment

(3) The ATLANTIC GEOSCIENCE CENTRE, which is part of the Geological Survey of Canada of the Department of) Energy, Mines and Resources

SECTION B of this review

see SECTION C of this review

see SECTION D of this review





Bedford Institute of Oceanography



The three directors. Left to right: Dr. Bosko D. Loncarevic, Dr. Lloyd M. Dickie, Dr. Wm. L. Ford.

Foreword

This volume of the Biennial Review marks the tenth anniversary of the founding of the Bedford Institute of Oceanography. The Institute was officially opened on October 25, 1962, by the Hon. Paul Martineau, Minister of Mines and Technical Surveys, before a distinguished group of guests, among whom were the Hon. Robert L. Stanfield, Premier of the province of Nova Scotia and now leader of the Opposition in the Parliament of Canada, and Dr. W. E. van Steenburgh, the Director General of the Department of Mines and Technical Surveys and the acknowledged father of the Institute.

Ten years later, our well-wishers of that day would find that many of their good wishes had been realized. There has been a substantial growth of the Institute to an establishment of 700 scientific and support staff and an annual budget approaching \$15 million. Through fostering the spirit of a marine research oriented community, this staff has developed numerous common and interrelated projects and support services, many of which have been not only productive but remarkably viable in the face of administrative upheavals of government reorganization and irrespective of formal reporting channels through different organizations. The ships operated by the Institute have worked in all eastern and northern Canadian waters and in the Atlantic. Pacific and Arctic Oceans. Collected reprints of the Institute publications, work on task forces and special projects, and an increasing number of invitations to the staff to give lectures and contribute to policy formulation, all testify to the maturity of the Institute program and the stature of its staff. These first ten years were our adolescence: we look forward to new levels of achievement in a long and productive adulthood.

This edition of the Review differs significantly from previous issues in that it reports on the work of three research laboratories instead of two as before. In June 1971 Federal legislation creating the Department of the Environment was put into effect. The new Department is a consolidation of a number of elements of the Federal service concerned with the management of the air, water, fish, land, wildlife, and forest resources of the nation. Among the numerous changes brought about by the re-organization was the transfer of the Marine Sciences Branch, and hence the Atlantic Oceanographic Laboratory (AOL), from the Department of Energy, Mines and Resources to the new Department, with the exception of the Marine-Geology and -Geophysics sections of AOL, which were retained in Energy, Mines and Resources. Concurrently other functions of the latter department - the analysis of mandatory core samples from offshore drilling for petroleum, and the stratigraphic mapping of the continental shelf - were being built up at the Institute. In January 1972 these functions were combined to form the Atlantic Geoscience Centre within the Geological Survey of Canada, thus creating a third major laboratory in the Bedford Institute of Oceanography, and a third component to this Review.

The Review continues the feature of special essays introduced in the preceding edition to which the response of readers was gratifying. These essays have again been printed in a separately bound format for additional distribution; over 800 copies of the 1969/70 edition were supplied to Information Canada for distribution and sale in their bookshops. In the current Biennial Review there are six essays which together serve to highlight the activities of the Institute over the past two years. The titles are:

The Gulf Stream off the Tail of the Bank by R. A. Clarke and G. T. Needler;

The interaction between fishery management and environmental protection by L. M. Dickie;

The Gulf of St. Lawrence by M. J. Dunbar;

The Bedford Institute of Oceanography and industry - experience and progress in the past decade by R. L. G. Gilbert and C. S. Mason;

Marine pollution research by D. C. Gordon, Jr. and A. Walton; Baffin Bay - one piece in the jigsaw puzzle of global tectonics by D. I. Ross.

Each year the Institute regularly plays host to several thousand visitors - university, business, government, as well as the generally curious. It was our privilege to offer a special welcome to the following distinguished guests:

Honourable Jack Davis, Minister of the Environment and of Fisheries;

Honourable Alastair W. Gillespie, Minister of State for Science and Technology;

Honourable Donald MacDonald, Minister of Energy, Mines and Resources;

Honourable Robert Stanbury, Minister of Communications;

Sir Peter Hayman, the British High Commissioner;

Mr. Adolph W. Schmidt, Ambassador of the United States of America;

Dr. Colm O hEocha, Professor of Biochemistry, University of Galway and Chairman of the National Science Council of Eire;

M. J. Farre and M. J. Rocket, French Petroleum Institute, Paris: Dr. Kurt Lillelund, Director, Institute of Hydrobiology and Fisheries Research, University of Hamburg;

Dr. Amann, Chief, Department of Maritime Technik, Preussag A. G. Hanover;

Professor P. Welander, University of Gottenburg;

Professor Walden, Institute Head, Physical Sciences, German Hydrographic Services;

Dr. Hanato Tsuraga, Tokai Regional Fisheries Laboratory, Tokyo; J. P. Staubo, Continental Shelf Division, Royal Norwegian Council for Scientific and Industrial Research, Oslo;

Lars Emmelin, Environment Unit, University of Lund, Sweden; Chiao Li-jen, Director, Petroleum Department, Ministry of Fuel and Chemical Industries, and Sun Chen-ming, Vice Chairman, Revolutionary Committee of the Taching Oil Field, from the People's Republic of China;

Dr. N. A. Ostenso, Deputy Director, Office of Naval Research, U.S. Navy, Washington, D.C.;

Members of the National Research Council, Ottawa; Marine Technology Mission, Federal Republic of Germany; Delegates from the 24th International Geological Congress;

Dr. L. J. L'Heureux, Chairman, Defence Research Board, Ottawa; Dr. P. D. McTaggart-Cowan, Executive Director, Science Council of Canada;

Dr. W. G. Schneider, President, National Research Council of Canada;

Professor Tuzo Wilson, Principal, Erindale College, University of Toronto;

Among the ships which visited the Institute were:

- the research vessels *Vilikitsky, Liman* and *Kolequev* of the Union of Soviet Socialist Republics;

- the RV Trident, University of Rhode Island;
- the U.S. Naval Ship Wymen;
- the RV Cirolana, Lowestoft, United Kingdom.

Many persons have contributed of their time and talent in the production of this volume but acknowledgement is especially due to Mr. Brian Nicholls, Head of Scientific Information Services and Library in the Institute who had overall charge of the project with the responsibility of seeing it through to a quality product on schedule, and to Dr. Gillian Elliott whose editorial skill converted the draft manuscripts of the many contributors to the finished text we have before us.

Wm h Frid

1 di char

Wm. L. Ford Director Atlantic Oceanographic Laboratory

Lloyd M. Dickie Director Marine Ecology Laboratory

Molon corror.

Bosko D. Loncarevic Director Atlantic Geoscience Centre

Acknowledgements

As project manager for the production of this review I wish to acknowledge my indebtedness to a number of people. Dr. Gillian Elliott edited the draft manuscripts. Norm Fenerty, Roger Belanger and Heinz Wiele took most of the photographs. John Lord, Garry Cook and Art Cosgrove prepared the illustrations. Olive Ross typed the final manuscript, Barbara Countway, Jo-Anne DeCoste, Debbie Peck and Colleen Rhodenizer provided secretarial and proofreading assistance.

H. B. Nicholls

Table of Contents

	Page
Organization chart	v
Foreword	vi
Acknowledgements	х
A. Ocean Science Reviews.	I
The Gulf Stream off the Tail of the Bank by R. A. Clarke & G. T. Needler	3
The interaction between fishery management and environmental	Ū
protection by L. M. Dickie	15
The Gulf of St. Lawrence by M. J. Dunbar	34
The Bedford Institute of Oceanography and Industry -	
and C. S. Mason	56
Marine pollution research by D. C. Gordon and A. Walton	67
ballin bay - one piece in the jigsaw puzzle of global tectorics	75
by D. I. Ross	10
B. Atlantic Oceanographic Laboratory	85
Director's remarks	87
Organization chart	91
Research, survey and senior support staff	92
Chemical Oceanography	96
Inorganic chemistry	98
Organic chemistry	101
Physical chemistry	103
Nutrient chemistry	109
Stable isotope chemistry	110
Data processing	112
Coastal Oceanography	114
Gulf of St. Lawrence	116
Estuaries and coastal embayments	120
Wave climate and extreme sea state.	126
James Bay	128
Support activities	128
Metrology	129
Application of underwater sound	132
Radio-controlled launch	139
Oceanographic sensors for data logging	140
Eddy flux measurements over the sea	144
Wind stress measurements over ice	145
	145
Wave follower program	146
Rock core drills	148

New devices for water sampling	151 152
Support facilities	152
Ocean Circulation	155
North Atlantic	156
Currents in Drake Passage	161
Theoretical Studies	161
Microstructure studies.	165
Instrument development	169
Hydrography	171
Hydrographic charting	173
Hydrographic development	180
Navigation	183
Tidal	184
Technical Services	185
Shins	187
Administration section	188
Research and survey fleet	189
Engineering Services	194
Marine electronics	196
Systems engineering	202
Depot workshops	208
Buildings and grounds	211
Computing Services	212
Scientific Information Services & Library	216
Drafting and Illustrations.	219
Photography	221
Appendix B1 - Major publications and reports by AOL	
staff, 1971172	225
Bedford Institute of Oceanography Contributions	225
Bedford Institute of Oceanography Report Series	226
Appendix B2 - Affiliations	228
C. Marine Ecology Laboratory	229
Director's remarks	231

Organization chart	234 235
Biological Oceanography Phytoplankton productivity and nutrient measurements in coastal inlets Studies on spatial distribution of phytoplankton Humic compounds and coastal fertility Dialysis culture of marine planktonic algae Pollution-induced eutrophication and aquaculture Productivity of seaweeds and marsh grasses Bacterial decomposition of seaweeds Aquatic macrophytes as sources of particulate and dissolved organic matter Particulate transport and nutrient chemical balances in Petpeswick Inlet Preliminary studies of some coastal processes Standing stocks and production rates of particles in the ocean Laboratory models of planktonic food chains Biochemistry and physiological ecology of zooplankton nutrition St. Margaret's Bay zooplankton and ichthyoplankton Gulf of St. Lawrence euphausiid study The food chain leading to lobsters Energetics of sea urchins Uptake and metabolism of metals by decapoda Studies on the benthos - distribution	237 238 240 241 242 244 245 246 246 247 246 247 248 250 251 251 252 253 254 256
Environmental Oceanography Coastal embayments Diffusion studies Mesoscale inhomogeneities Remote sensing Geochemistry of the major elements in marine sediments from the Gulf of St. Lawrence Distribution of <i>Clostridium botulinum</i> type E in marine sediments from the Gulf of St. Lawrence	257 258 259 260 261 261 262
Fisheries Oceanography and Population Studies Fish of the Gulf of St. Lawrence Larval and postlarval studies Energetics of American plaice Mackerel biology study Southern fish species in St. Margaret's Bay and Prospect Bay	263 264 264 265 267 270

Metabolism and enzyme activity in fishes	270
Marine mammal energetics	271
Marine bio-acoustics	272
Acoustic echo counting system for demersal fishes	275
High frequency acoustic survey system	277
Bellows differential compressimeter	277
Continuous flow fluorometer	270
Food abains and fish production	270
	278
The European oyster - Ostrea edulis	279
Aquaculture research and development - Cape Breton, Nova	
Scotia	281
Environmental Quality	283
Analysis of hydrocarbons in seawater	284
Concentration of oil in marine waters off Eastern Canada	204
Miscibility of oil in segwater	204
The effect of various eils on marine phytoplankton photo	200
	000
The concentration of total measure in converter	286
Distribution of dissolved and particulate experies matter in	286
Distribution of dissolved and particulate organic matter in	
seawater	286
Pesticide studies	287
Organochlorine residues in seals	289
DDT transport and metabolism	289
PCB studies	291
Gulf plankton studies: PCB contamination	291
Phosphorus studies	292
Hydroxamic acids	293
Mine waste water surveys	293
Pelagic and benthic carbon budgets.	293
Substrate - surface area interactions	294
Sublethal effects of pollutants	205
	200
Appendix C1 - Major publications and reports by MEL staff,	
1971/72	296
Bedford Institute of Oceanography Contributions	296
Fisheries Research Board of Canada Technical Reports	299
•	
D. Atlantic Geoscience Centre	301
Director's remarks	303
Organization chart	305
Research, survey and senior support staff	306
Regional Reconnaissance and Mapping	307
Continental shelf and margin	308
Multidisciplinary surveys.	315

Deep sea	320 323
Resource Potential Evaluation Sasin analysis	326 327
Environmental Geology	335
Geochemical pathways in water column and sediments	336
Ecological pathways of Recent microfossils	340
Sediment dynamics	349
Appendix D1 - Major publications and reports by AGC staff,	
1971/72	355
Bedford Institute of Oceanography Contributions	355
Bedford Institute of Oceanography Report Series	357
Appendix D2 - Affiliations.	358
Visitors to the Bedford Institute	361

(This page Blank in the original)



Ocean Science Reviews 1971/72

(This page Blank in the original)

The Gulf Stream off the Tail of the Bank

R. A. Clarke, G. T. Needler, Atlantic Oceanographic Laboratory

The Gulf Stream has long been known as a narrow intense current which emerges from the Florida Straits and flows northward along the eastern seaboard of the United States leaving the continental shelf at Cape Hatteras to flow generally eastward to about 50°W, the longitude of the Tail of the Grand Bank. In this region, the stream encounters shoaling water over the Southeast Newfoundland Ridge, and a complicated pattern of properties, observed originally in the surface layer and subsequently at depth, has led to various theories of Gulf Stream branching or spreading. It is known that some of the heat transported north by the Gulf Stream enters the northern part of the North Atlantic and contributes in some measure to the moderate western European climate. What still remains to be determined is exactly how the waters of the Gulf Stream are partitioned east of the Tail of the Grand Bank and what mechanics control this behaviour. In this paper we will review some of the observations that have led to various theories of Gulf Stream branching and describe some of the aims and successes of the present work being conducted by the Bedford Institute of Oceanography and others.

A good review of early references to the Gulf Stream and theories of its origin is given by Stommel (1964). According to Stommel the stream was first noted by Ponce de Leon in 1513 as he sailed southward along the Florida eastern seaboard, and by 1515 the first speculations concerning its origins were reported by Peter Martyr of Anghiera. The existence of currents such as the Gulf Stream was of great importance to shipping in the North Atlantic during the sixteenth and seventeenth centuries, and the surface currents along the major shipping routes were mapped by numerous navigators. Many theories were advanced to explain these currents; however, the observations were far better than the theories. Systematic investigations of the currents of the North Atlantic based on ships' logs were initiated in the nineteenth century by the British Admiralty Office and the U.S. Navy Hydrographic Office. The U.S. Coast and Geodetic Survey also began a careful series of observations of the Gulf Stream from the Florida Straits to Cape Hatteras.

By the end of the first decade of the twentieth century the equations of state and of motion appropriate to the ocean were reasonably well formulated. Combined with the known general features of surface currents, temperature, and salinity one obtained a picture of the North Atlantic circulation as consisting mainly of a large clockwise rotating warm and saline gyre centered in the Sargasso Sea and bounded on the south by the North Equatorial Current, the west by the Gulf Stream and Antilles Current, and on the north by the North Atlantic Current. It is worthwhile noting that the nomenclature for the currents of the North Atlantic is far from standard. The name Gulf Stream has always been applied to the current flowing along the eastern seaboard of the United States and marked by a rather striking shallowing of the isotherms; for example, the 10°C isotherm rises from a depth of 800-900 metres offshore to 200-300 metres inshore over a distance of about 100 miles. East of 40°W the name North Atlantic Current has generally been applied to a broad eastward current that has been associated with a shallowing of the isotherms over some 20 degrees of latitude. Several authors, most notably Iselin (1936), have noted that this shallowing is not a steady gradual slope of the isotherms but instead occurs in several sharper steps; the most northerly of these steps is called by Dietrich (1964) the Polar Front.

Between the Gulf Stream and the North American continental shelf, and east of Cape Hatteras, a large body of water lies outside the Sargasso Sea gyre. Deeper than several hundred metres, this water has the same temperature-salinity relationships as does the water in the Sargasso Sea; its surface water, however, is less saline (I-2‰ less) than water of the same temperature found in the Sargasso Sea. This water is a mixture of the upper waters of the Gulf Stream and the colder less saline waters found on the continental shelves which are transported southward along the Labrador and Newfoundland coasts by the Labrador Current (McLellan, 1957). Some of this water flows eastward, inshore of the Gulf Stream, forming the Slope Water Current.

The earliest measurement of temperature and salinity south and east of the Grand Banks was made by Helland-Hansen in 1910 from the *Michael Sars* (Helland-Hansen, 1912). As the ship proceeded northward along 50°W in the warm saline water of the Sargasso Sea, it encountered at about 39°N colder and less saline surface waters, then warm saline water again, and finally at about 41°N cold fresher water which continued onto the Grand Banks. He observed a similar warm saline core beside the Grand Banks as he then proceeded eastward from the Grand Banks towards Ireland. He interpreted these observations as showing that the Gulf Stream had split near 50°W into a northern branch which curved northward around the Tail of the Bank as a tongue of warm water and a southern branch whose path could not be determined by the observations.

Later Iselin (1936) used all available data to construct a chart for the whole of the North Atlantic of the depth of the 10°C isotherm which, across the Gulf Stream, varies in depth from 800 to 200

metres. Iselin assumed that the strength of flow was inversely proportional to the rate of change of depth of the 10° isotherm - an assumption somewhat consistent with flow along lines of constant pressure, i.e. geostrophic flow. The resulting current system showed a Gulf Stream which split into three parts near the Tail of the Bank; the southernmost third feeds back into the Sargasso Sea, the middle continues eastward along 40°N and the northernmost third moves northeast as the North Atlantic current.



Diagrammatic chart of the Gulf Stream system (after Iselin, 1936).

In 1951 Fuglister (1951; Fuglister and Worthington, 1951) combined a series of sections made by the International Ice Patrol around the area of the Grand Banks with those obtained during a multi-ship U.S. expedition between Cape Hatteras and the Grand Banks called Operation Cabot and constructed a chart of the temperature at 200 metres depth to determine the current system. If the currents are shallow and geostrophic the isotherms on such a chart correspond approximately with streamlines, with warm water

to the right of the direction of flow and cold water to the left. On Fuglister's chart the isotherms indicated ridges of warm and cold water, which lay more or less parallel to the continental shelf to the west of the Grand Banks. East of the Grand Banks he interpreted these ridges as three separate currents, only the southern of which was identified as part of the Gulf Stream; the northern two involved slope water mixtures. Similarly Dietrich (1964) also prepared charts of the temperature at 200 metres using data collected during the International Geophysical Year when a series of sections were obtained across the entire North Atlantic. These charts showed strong thermal fronts which, when interpreted in the same manner as Fuglister, indicate that the North Atlantic Current, like the Gulf Stream, is a continuous, narrow meandering current. Unfortunately, because of the spacing of the sections, the data used in both Fuglister's and Dietrich's charts may be contoured in different ways so that the results must be treated more as interpretations than as observations.

A new dimension to the problem was given by Worthington (1962) who examined historical data giving the oxygen content on the 10°C temperature surface in the region east of the Grand Banks and noted that there appears to be a tongue of water of rather high oxygen concentrations stretching to the southeast of the Grand Banks above the Southeast Newfoundland Ridge. Furthermore, he found that the oxygen content in the North Atlantic Current as it flowed northward past Flemish Cap along 50°N was higher than that of the Gulf Stream as it crosses 50°W although the temperature and salinity relations appeared the same. He proposed that these observations could be accounted for if most of the Gulf Stream's transport returned to the Sargasso Sea after crossing 50°W, thereby forming a closed gyre, and that the North Atlantic Current was part of a second clockwise rotating gyre to the east between the Grand Banks and the Azores and north of the Sargasso Sea. On the basis of the oxygen budget Worthington estimated that only 20% of the Gulf Stream transport was transferred into this second gyre.

By the time the Bedford Institute of Oceanography opened in 1962 it was known that the Gulf Stream between the Grand Banks and Cape Hatteras did not maintain a smooth path but rather meandered, shifting its position over a hundred miles or more in a period of several weeks. As was noted during Operation Cabot (Fuglister and Worthington, 1951), large loops are sometimes formed which break off and become eddies in the Sargasso Sea. Since there was no reason to believe the current path was any steadier once it reached the Grand Banks and beyond it was apparent that previous results in this area, which were based on data of limited spatial extent or collected at different times,

could be leading to erroneous conclusions. For example, a pattern of alternating eastward and westward flow across a single north-south section might be due to multiple currents, an S- or Z-shaped single continuous current, or one main current plus an eddy on either side.

With these limitations in mind, the Bedford Institute of Oceanography undertook in 1963, 1964 (Mann 1967) two cruises in the area between the southern Grand Banks and the Azores. During the first of these cruises oceanographic stations were taken in a concentrated area over and to the east of the Southeast Newfoundland Ridge. From temperature and salinity data Mann was able to construct in some detail the accompanying chart of the dynamic height relative to the 2000-metre surface; such a chart is analogous to a meteorological chart



Dynamic topography of the sea surface relative to 2000 decibars, April-May 1963 (from Mann, 1963). Note: Hydrostatic pressure in decibars very nearly equals the correspond-

note: Hydrostatic pressure in decibars very nearly equals the corresponding depth in metres.

of surface pressure. If the flow is geostrophic, and is zero at a depth of 2000 metres, the surface currents will be parallel to the contours of dynamic height and inversely proportional to the spacing of the contours. The dynamic height chart yields the surface currents more accurately than the temperature charts used by Iselin and Fuglister but still only gives these currents relative to the current at a reference level, in this case 2000 metres. Classically, oceanographers have assumed the deep currents were negligible but as we shall discuss later this is not necessarily the case. Nevertheless, Mann's chart of dynamic topography gives what we still believe to be a good picture of the surface currents.

Used in conjunction with the corresponding salinity and temperature data, the chart suggests that the Gulf Stream, indicated by the strong concentration of dynamic height contours, is deflected to flow along the flank of the Southeast Newfoundland Ridge. Near the end of the Ridge, the Stream branches, the southern part turns back into the Sargasso Sea and forms the northern boundary of the '18°C' water mass, i.e. that water between 17° and 18°C that forms a lens-like body of water in the Sargasso Sea at depths as great as 400 metres. The northern branch crosses the ridge, flows back to the north along the eastern flank of the ridge and presumably becomes the North Atlantic Current. Between the two branches was found a rather intense clockwise rotating eddy centered over the Newfoundland Basin although the rather sparse data available from this region of the North Atlantic did not allow its total extent to be determined. Inshore of the Gulf Stream, water with slope water characteristics flows across the upper part of the ridge and joins the North Atlantic Current.

During the 1964 cruise more data was obtained in the same area as well as to the east and northeast. The main features were the same as observed in 1963 although the Gulf Stream was observed to make a loop south of the Tail of the Grand Bank and then shed an eddy into the Sargasso Sea. The eddy to the north was again observed, this time in more detail. On the basis of the data from the two cruises Mann constructed a model for the region which is shown schematically in the following figure. According to the model, the Gulf Stream transports



Diagrammatic chart of the currents off the Tail of the Bank (from Mann, 1967).

50 x $10^6 \text{ m}^3 \text{ sec}^{-1}$ eastward in the top 2000 metres across 50° "W. Of this 30 x $10^6 \text{ m}^3 \text{ sec}^{-1}$ returns to the Sargasso Sea, while the remainder of 20 x $10^6 \text{ m}^3 \text{ sec}^{-1}$ turns north to join 15 x $10^6 \text{ m}^3 \text{ sec}^{-1}$ of slope water and form the North Atlantic Current.

Although Mann's model seems plausible, it has to be remembered that the main features of Mann's model and Worthington's two-gyre approach remain the same. These are supported by almost all the available data and include a strong well defined narrow Gulf Stream at 50°W, the North Atlantic Current flowing north along the continental slope beside Flemish Cap, and the fact that the '18°C water' characteristic of the Sargasso Sea is not found north of 40°N and that its boundary represents a rather strong thermal front. The differences occur in the interpretation of the data over and to the east of the Southeast Newfoundland Ridge. One prominent feature of Mann's model is the eddy sitting northeast of the ridge. From the available data its seems that if this eddy is a permanent feature it is not fixed in position. The eddy is, however, an essential part of Mann's model since he pointed out that the oxygen content observed in the eddy was higher, apparently due to overturning of the top 400 metres or so of water in winter. He hypothesized that the eddy interacted with the water flowing north causing the increase of oxygen which had led Worthington to propose his two-gyre model. No detailed mechanisms could, however, be given for this interaction and a quantitative oxygen balance was beyond the scope of the data. Worthington's model suggests only a limited flow of water from the Sargasso Sea into the regions northeast of the Grand Banks while Mann's suggests that this exchange is considerable.

By the late 1960's it was obvious that more classical oceanographic cruises by single ships would not improve our understanding of the region greatly. One useful measurement which had not been utilized up to this time was direct current measurements using deep sea moorings and current meters. With this in mind the Bedford Institute, in both 1970 and 1971, sent CSS *Dawson* to the Gulf Stream at 50°W in order to develop techniques of setting current meter moorings up to 2000 metres in length in currents as strong as the Gulf Stream. The cruise in 1970 was especially valuable. Three moorings were in place for 8 to 12 days along 49°30'W at 38°30'N, 39°30'N and 40°30'N. Concurrently the density field along 49°3O'W between 37°N and 41°15'N was observed three separate times and the temperature field above 500 metres was obtained using expendable bathythermographs (XBT'sj in the rectangle bounded by 38°N, 41°N, 49°W and 50°W. The density (or temperature) sections along 49°30'W taken by themselves would suggest the presence of two eastward flowing currents separated by a single westward flowing current and might have been in the past interpreted as being the Gulf Stream and the Slope Water current separated by a counter current. The two southernmost current meters confirm the strong eastward flow in the south and a westward flow of nearly equivalent speed, a degree farther north. The additional temperature data along 49°W and 50°W (see figure) lead one to an



Temperature at 500 metres depth near 50°W. June 1970. Vectors indicate velocity measured by the current meters 100 m off the bottom.

interpretation of the flow as consisting of the Gulf Stream at about 38°30'N flowing to the northeast looping or shedding an eddy whose centre is at approximately 40°45'N, 50°W. The current meters, only 100 metres off the bottom, showed that the Gulf Stream at 50°W extends to the bottom as it had previously been known to do farther west off Cape Hatteras. This means that the total transports are much greater than estimated by Mann using the dynamic topography relative to 2000 metres. Indeed, the indication is that the transports lay in the range of 145 x 10⁶ m³ sec⁻¹. Secondly, the meanders of the stream and its shedding of an eddy that were observed indicate that over the short term (several days) changes can occur in the currents which lead to difficulty in obtaining meaningful long term averages of the transports.



Station and current meter positions, April 1972.

From mid-April to mid-June in 1972, scientists on the CSS Hudson ioined those from Lowestoft, U.K., on the Cirolana and the Woods Hole Oceanographic Institution on the Chain in a new and ambitious joint study of the region east of the Newfoundland Banks. In an effort to measure directly and simultaneously the transports of water in the Gulf Stream and North Atlantic Current, 14 current meter moorings were laid along 49°40'W, 8 along a line running from 43°N, 47°30'W to 41°6'N, 42°30'W and 3 across Flemish Pass, and the currents were recorded over the two-month period of operations. A closely spaced grid of stations was occupied in the region east of 49°40'W and south of the Flemish Pass. The station and current meter positions (except the three across Flemish Pass) are shown in the figure. The stations along the first two current meter lines were occupied three successive times, once when the moorings were laid, then two to three weeks later. and finally during the recovery of the moorings. All stations were observed to within a few decimetres of the bottom using water bottles and reversing thermometers. Oxygen content, silicates and some nutrients were observed.

The data has not yet been analyzed; however, preliminary plots of temperature surfaces prepared at sea contain all the main features of Mann's 1963 data. It is hoped that the sections along the current meter mooring lines will provide accurate absolute measurements of the velocity field through these sections. By integrating the fluxes of various parameters across the sections we will be able to calculate the transports of mass, salt, oxygen and silicates into the area across 50°W and out of the area across the second line of current meters, and by this means obtain the partition of the water transported by the Gulf Stream. The set of oxygen data, having been obtained by identical procedures, will be used to see if the oxygen anomaly seen by Worthington is a significant property and whether horizontal mixing of oxygen as proposed by Mann can take place.

Although the station spacing was much less than previously obtained in this region, the observations were still too coarse to study in detail the dynamics over the Newfoundland Ridge itself. In order to obtain this detail, *Hudson* steamed back and forth across this ridge and used XBT's to observe the temperature field in the upper 800 metres. The results are shown in the accompanying figure. These data show that the cold, less saline water found on the shelf spreads southeast in a long narrow tongue over the axis of the ridge. It appears that most of the Gulf Stream manages to loop around the end of the ridge and return to the north as modelled by Mann (1967). The southern half of a small cyclonic gyre is centered at about 41°N, 44°W considerably to the south of its position given by the bottle data. In the south there appears to be a weak return flow, first to the east then south, of warm water from the southern part of the Gulf Stream.



Depth of 10°C isotherm as determined by XBT's off the Tail of the Bank, May 1972.

It should be recognized that even if the above study leads to answers to some of the significant outstanding questions about the area its data are bound, in hindsight, to be incomplete and to pose new problems. Many significant questions about the dynamics of the area remain. It is known that the Gulf Stream in its meandering interacts strongly with the bottom, and a detailed analysis describing the interaction of this time-dependent, stratified current with the Southeast Newfoundland Ridge needs to be undertaken. A start in this direction was made by Warren (1969) when he showed that a simplified model of the Gulf Stream could be caused to initially separate upon reaching shoaling conditions somewhat typical of the ridge. It is now thought that the eddies formed west of the Newfoundland Banks by the Gulf Stream are important in the transport of heat, salt, potential and kinetic energy, and angular momentum across the Stream and are significant in the overall balances of these quantities in the North Atlantic. The complicated system east of the Banks must be suspected as being of equal importance in some of these processes and is no doubt far from being properly understood. The current meter observations made during this joint study may provide an observation base for some of these problems. It is perhaps relevant to end by pointing out that determination of the transport of water north of the Tail of the Bank is only one-half the problem where the overall North Atlantic budget is considered. We have been unable to deduce the magnitude of the transport north because we do not know the precise location, yet alone the magnitude, of the transport south!

References

DIETRICH, G. 1964. Oceanic polar front survey in the North Atlantic. In: *Research in Geophysics, 2, Solid Earth and Interface Phenomena.* Ed. H. Odishaw. The M.I.T. Press: 291-308.

FUGLISTER, F. C. 1951. Multiple currents in the Gulf Stream system. *Tellus, 3:* 230-233.

FUGLISTER, F. C., and WORTHINGTON, L. V. 1951. Some results of a multiple ship survey of the Gulf Stream. *Tellus*, *3*: 1-14.

HELLAND-HANSEN, B. 1912. In: *The Depths of the Ocean.* Eds. J. Murray and J. Hjort: 210-306.

ISELIN, C. O' D. 1936. A study of the circulation of the western North Atlantic. Pap. Phys. Oceanogr. Met., 4: 1 - 101.

MANN, C. R. 1967. The termination of the Gulf Stream and the beginning of the North Atlantic Current. *Deep-Sea Res.* 14: 337-359.

MCLELLAN, H. J. 1957. On the distinctness and origin of the Slope Water off the Scotian Shelf and its easterly flow south of the Grand Banks. J. Fish. Res. Bd. Can., 14: 213-239.

STOMMEL, H. 1965. *The Gulf Stream, a physical and dynamical description.* Univ. of California Press. 248 pp.

WARREN, B. A. 1969. Divergence of isobaths as a cause of current branching. *Deep-Sea Res., 16, Supp.:* 339-355.

WORTHINGTON, L. V. 1962. Evidence for a two gyre circulation system in the North Atlantic. *Deep-Sea Res.*, 9: 51-67.

The Interaction Between Fishery Management and Environmental Protection

L. M. Dickie, Marine Ecology Laboratory

All living creatures are dependent on their physical environment. But this dependence may be expressed in many ways. Some are direct and relatively obvious. Others are so subtle or take place against a background of such great natural variation that the relationships are difficult to detect without special techniques. It is almost axiomatic that this variation reflects some interaction between environmental change and the capacity of the biological system to respond to 'stresses' such as predation. The important question then becomes, "how great is such interaction?" Significant interaction in an exploited fish population implies that, to be effective, management strategy must take account of both environmental and biological parameters. If there were no significant interactions, regulations could be framed on the basis of biological dynamics alone.

The appreciation of interaction involves a study of the predictability of fisheries production from parameters which index both environmental and biological variables. The research literature contains many examples of the approaches which have been taken. It is not the purpose of this paper to review the research history exhaustively. But there is a discernible pattern in the growth of our understanding of factors controlling population production. This growth pattern has implications for the development of effective management schemes in fisheries, and for establishing research priorities.

For the sake of discussion it will be necessary to agree on a meaning for two words: 'adaptation' and 'interaction', which in other contexts may vary in usage.

The term 'adaptation' will be used here to signify a homeostatic or compensatory response of a biological population to disturbance; for example, an increased growth rate following a reduction in biomass, or an increase in the success of spawning with a decreased spawning stock. The biomass reductions in either case may be due to a variety of factors: possibly to oceanographic or pollution conditions which dispersed the adults or to fishing which harvested them. In general, the adaptative response may be classed as 'density-dependent'.

Many important events affecting stock production are not generated by changes in the fishing stocks but by environmental factors and are generally referred to as 'density-independent'; for example, growth may be affected by temperature, or eggs and larvae may be swept away from feeding grounds. The term 'interaction' will be used here to refer to situations in which the presence of one factor significantly affects the degree of response to another by magnifying or reducing the relative effectiveness of the density-dependent responses. Examples of situations which will be discussed later are, "does heavy fishing significantly reduce the capacity of the spawning stock to produce large year-classes¹ in favourable environments?", and "do pollutants become distributed and acted on in the environment in such a way that they effectively reduce population production responses to fishing or to other environmental factors?"

It is the hypothesis of this paper that once the temporal and spatial scales of variability have become better defined, and more accurately measured, the interaction of biological and physical phenomena will come to be recognized as more and more important. The evidence leaves little doubt that it is changes in oceanographic systems which give rise to the primary changes observed in fisheries yields. Within environmental constraints, natural populations exhibit a high capacity for adaptative response. While the mechanisms are not well understood, there is evidence that the capacity to respond is significantly affected by changes in population structure and abundance resulting from heavy selective fishing activity. That is, fishing reduces the response to natural environmental change. In addition, there is evidence that man-induced changes in environment can be of such an order of magnitude as to induce gross responses in biological production.

The combined result suggests that in the absence of effective management the more extreme environmental variations, although within the normal pattern which in the past have elicited adaptative response, may in certain situations now have to be considered hazards to continued maintenance of population production levels.

These effects are deduced from interpretation of variations at the low-frequency (of the order of years) end of the spectrum exhibited in fisheries data. There remains a vast class of high-frequency or small-scale variations (hours to months) which are as yet difficult to define or measure with any assurance. The effects of pollution, as well as most of the mechanisms underlying production changes, appear to be felt directly within this scale of variability. Recent work on the detailed functioning of ecosystems reveals something of the significance of these 'local' events to population control and hence to the development of management strategies. Taken together with the evidence from larger-scale phenomena, results confirm the necessity for joint consideration of biological and environmental parameters in fisheries management.

¹year-class = all fish in a particular population of a species which are born in the same year; e.g. 1968 year-class of haddock on the Scotian Shelf.

Development of Biological Models

The principal aim of fisheries research has been to develop management strategies which will maximize the benefits of exploitation. This has required prediction of yield from fish populations with respect to fishing variables which are subject to management; such as, season, size of capture, and amount of fishing. Because of the practical importance of fisheries, but because of difficulties with independent sampling, research has been directed to the analysis of commercial statistics with very little opportunity for controlled experiments to test hypotheses. Given the complexity of natural events, this objective of optimizing fishing yields has required the maximum possible conceptual simplification, often with the result that the kinds of data collected and the conclusions reached were strongly influenced by prior assumptions about the nature of the system being fished and the state of the fishing technology.

With emphasis placed on the need for practically useful results, problems of adaptation and interaction in fish populations might almost be considered as nuisance phenomena which cause the actual catch to deviate from expectation. Catch variations have often been treated this way. However, if adaptations and interactions have important influences on long-term yield, careful collection and treatment of data provide the possibility of measuring their effects as deviations in the structure and quantity of yield from yields predicted by simple population models. With time the possibilities, as well as the need for this approach, have grown.

The first important development in this research was based on the work of Hjort on the Norwegian herring fisheries. Hjort showed that major changes in herring catch were associated with the occurrence of occasional exceptionally strong year-classes. Given this major condition, subsequent changes in catch appeared to be more or less orderly, and took place gradually, often over periods of many years. That is, fishery effects appeared to be small and systematic relative to the influence of the natural environment. It was therefore reasonable to conclude, as a first approximation, that environmental effects should be treated more or less independent of effects within the fish-stock itself, possibly even as random variables whose long-term net effect would average to zero.

It was on the basis of such reasoning that Baranov (1918) first proposed a simple population dynamics model in which the effects of fishing would be investigated in terms of the yield per unit year-class strength, or more familiarly 'yield-per-recruit'. That is, it would be assumed initially that major changes in year-class strength, as reflected in their abundance at the time of entry to the fishery, were largely independent of fishing. First-order density effects (those which determine the number of 'recruits') were to be ignored for the purposes of optimizing practical management, and attention focussed on the direct effects of fishing on changes in density and yield, once the year-class was vulnerable to capture. Developments based on this approach were virtually responsible for growth of the whole field of fisheries population dynamics in which the names of Ricker, Beverton and Holt have played a prominent role.

There are many aspects of this development which are of interest in themselves. What is of most importance here is that fisheries models constructed on a 'per-recruit' basis appeared to predict changes in the average age-composition of exploited age-groups in fish stocks. This observation led to methods of estimating mortality rates from relative age-composition and comparisons with changes in the amounts of fishing (Ricker, 1958). A knowledge of the growth-rates and weights of animals involved then provided a simple basis for calculating relative yield changes under a variety of fishing conditions. A logical approach to management appeared possible even though the results would be difficult to verify from simple trends in catch.

Ricker (1954) made the first major advance in the theory and practice of fisheries management beyond the developments of Baranov. On the basis of a review of data for a number of exploited and experimental populations, he observed that over-all changes in year-class strength were consistent with the theoretical expectations of a relationship between the abundance of parent and filial generations of fishes living in a resource-limited environment. If this were generally true, long-term predictions and management strategies based on simple models may be in error in neglecting the first-order density effects. His formulations indicated the manner in which fishing could either enhance or reduce the productive capacity of the exploited natural populations.

Density-dependence within fish stocks has not often been questioned as a concept which may have general applicability. The problem was to find out whether or not it was important enough to require alteration of the simple models on which prediction was based. While analysis in terms of 'yield-per-recruit' had provided explanation of some relationships among various parameters without invoking density effects, with the advent of computers adaptative responses could be built into the models and their potential influence explored. The results (e.g. Paloheimo and Dickie, 1965, 1970) suggested that the effects on long-term yields could be large. However, the data showed such unexplained variability that there was always the problem of testing the validity or applicability of any model. Interpretations were question-
able even in cases of 'natural experiments' created by abrupt changes in fishing rates and yield during and after two world wars.

An alternative analytic approach was advocated by Schaefer (1967) who for many years had worked towards the development and application of models which had the concept of density dependence in a 'limited environment' built into them. His models predicted effects of fishing different from those given by the yield-per-recruit models and implied that different types of regulation were necessary to achieve optimum yields. However, the problem of variability remained; the data appeared to exhibit such scatter that they could not be used to indicate which type of basic model was the more appropriate.

Gulland (1955, 1961) in further studies of the variability problem found that statistical data on catch and fishing activity by area and season could be identified and collected in such a way as to permit weighted running means of relative abundance change. He then applied running means of two- or three-year periods to the long series of statistical data available for the Icelandic fisheries. The smoothed data permitted him to explore the possible applicability of resource-limited as opposed to yield-per-recruit models to describe them. In the Icelandic data for cod fisheries he found that a resource-limited model appeared to be more satisfactory than did the yield-per-recruit model, while the yield-perrecruit model provided a better description for other species. However, upon re-examining the data series he further concluded that the data deficiencies were such that the available smoothed data were unsuited to providing an objective assessment of the importance of densitydependent effects on long-term natural fish production.

This situation roughly characterizes the nature of some of the problems facing fisheries research and management to the late 1960's. In the next section we review more recent studies which indicate the considerable advances made in this area, particularly when indices of environmental change were explicitly re-introduced into the analyses.

Production-Environment Relations in the Low-Frequency Range of Variations

With the hypothesis developed by early modellers, that methods of optimizing the fishery yield might well be independent of changes in year-class abundance, it is hardly surprising that studies of environmental impact on abundance should have developed almost independently. In fact, the literature shows that the scientific community often became polarized between two camps. One of them espoused the view that fishery exploitation was responsible for all important trends in yield, and called for more comprehensive management. The other claimed evidence that important catch trends were associated with abundance changes related to environmental, or climatic, trends and questioned the efficiency of all or most restrictive fishing regulation.

This state of affairs is well portrayed in the review of Bell and Pruter (1958). They describe in detail a number of papers which develop correlations between yield and environmental indices (mainly temperatures) and discuss weaknesses in the basic data. Three deceptively simple conclusions seem to emerge from their study. The first, which supports the general experience of population dynamics workers, is that the year-to-year changes in catch data appeared as much to reflect change in catchability as in true abundance, hence data refinements are likely to lead to significant advances in understanding. The second is that development of correlations between environmental and fishery data is not likely to be profitable until at the very least there is evidence that the data reflect phenomena in an identifiable physical and biological system. The third conclusion is that the correlations must remain suspect unless there is some evidence of the nature of the mechanisms involved. No one expects that it is a simple matter to overcome all the weaknesses in fisheries data which are implied in these conclusions. There may be no studies which can satisfy all three requirements simultaneously. However there are a number of excellent recent studies which taken together leave little doubt of the direction of future results.

Refining the catch data

Garrod (in press) in a paper presented to the recent Stock-Recruitment Symposium treats his fisheries data in a manner which meets many of the criticisms of earlier analyses. He employed the 'virtual population' method to calculate mortalities and population sizes of individual year-classes in a number of the major world fisheries. This method uses estimates of catch of a particular year-class at each age throughout its life-history in the fishery, and associates the integrated abundance changes with parallel estimates of relative fishing mortalities. Given the strength of individual year-classes at a particular pre-recruit age, Garrod then calculated a replacement index, as the ratio of the strength of a given year-class to the estimated average strength of all the year-classes which were parents contributing to the spawning of that vear-class. For ease in exposition. Garrod also observed that to maintain abundance any increase in fishing which decreased the spawning stock must be associated with a commensurate increase in the spawning success. He therefore rescaled the parent stock estimates to their equivalent in an unfished stock. This rescaled index he named the 'relative survival index'. If this index changed in proportion to fishing

mortality, it would indicate a compensatory response of recruitment to fishing. That is, his analysis was designed to test the hypothesis of significant departure from a curve representing compensatory or density-dependent survival response to changes in the accumulated fishing mortality per year-class.

The results of Garrod's calculation provide what appears to be the strongest general case yet made for density-dependent resource limitation among the pre-recruit phases of fish populations. Despite apparent vicissitudes in natural conditions for survival, there was an increase in the rate of recruitment as fishing increased. Apparently the survival of young was determined by the 'carrying capacity' of the environment rather than by the number of eggs produced. His data also suggested, however, that in certain cases as spawning stock decreased there was an asymptotic change in survival rates so that at the lowest spawning stocks a maximum egg production and survival may be reached which results in a larval population below the carrying capacity of the environment in a 'good' year.

It may be that clarification of the relationships found by Garrod will only emerge once there is a better understanding of the apparently different response among species and areas. In his analysis, North Sea haddock appeared to be much more heavily exploited than the Arcto-Norwegian cod and yet did not show similar signs of recruitment failure. The California sardine showed it at even lower fishing mortalities. Such differences invoke the guestion of mechanism, an area which clearly has high-priority for future research. For present purposes, what seems of particular importance is Garrod's demonstration that careful treatment of the fisheries data can overcome some of the difficulties in abundance estimation noted by Bell and Pruter. At the same time Garrod's work exposed the possibility of significant interpretations of the higher frequency variations. He suggested, for example, that residual scatter of the points about the 'relative survival' regression line provides a relative measure of the density-independent variations in survival, or the 'fitness of the environment' for the survival of young fish between the time of spawning and recruitment. This is an acceptable definition to the extent that the virtual population method is capable of eliminating the biases or correlations in the higher frequency sources of variation treated as sampling errors.

Defining the environmental system

Garrod's analysis used data for a number of species occurring in well-known historical fisheries. In general, these probably correspond with definable physical oceanographic systems, although this is not explicitly established. Moreover, the analysis does not by itself define the mechanisms through which the population responses operate. In these two areas other investigators supply valuable information.

Sutcliffe (1972) deals with specific physical phenomena in an identifiable oceanographic system, and provides an illustration of the potential of this approach in explaining fisheries changes. His studies began with measurement of experimental parameters relating to the nitrogen budget in a small bay. From it, he concluded that of the order of half the nitrogen supply comes from the upwelling of deeper water into the mixed-layer or euphotic zone. This upwelling appeared to be related to the estuarine vertical mixing generated by fresh-water outflow. The possible consequences of such a mechanism were then tested in the Gulf of St. Lawrence. The St. Lawrence River is known to undergo marked seasonal and annual fluctuations in discharge and the readily definable area under its immediate influence supports significant fisheries. The results for four different species indicated that more than 60% of the annual variation in fisheries catch was associated with prior fluctuations in annual river discharge. The average time-lag for the different species suggested that the mechanism of action involved survival at the pelagic larvae stages. Since periods of higher outflow appeared associated with improved survival, the relationship was consistent with the explanation that high nutrients were creating more favourable survival conditions rather than alternative theories that survival of larvae somehow depends on effects of circulation on their dispersal.

Sutcliffe's hypothesis for the mechanism underlying abundance changes supports the findings of Saville (1959, 1965) who studied the survival and drift of larvae of a number of species in northeast Atlantic oceanographic systems.

Saville and Sutcliffe's results provide evidence for the kind of basic density-dependent mechanism required by Garrod's hypothesis, that is, a long-term compensatory survival of 'recruits' operating in a field of high environmental variation. Their results also substantiate the conclusion of many authors that survival effects determining year-class abundance must operate primarily at early life history stages. Saville's work further suggests that important nutrient-enriched areas may be found in the vertical mixing generated at boundaries of major oceanic currents, while Sutcliffe's work indicates that they may be identified with regions of strong estuarial action. In the latter case, it is known that the outflow of the Gulf of St. Lawrence has a strong influence on oceanographic conditions along the continental shelf to the south of Cabot Strait and may broadly affect survival and distribution of fish larvae (Serebryakov, 1971). Many other major river systems may be expected to have comparable, potentially wide-spread effects.

Sutcliffe found significant effects on catch of changes in annual outflow over a range of approximately 1:1.5. However if, as he suggested, the mechanism involved larval survival, these annual data must in reality reflect correlated changes in outflow over relatively shorter seasonal periods when the larvae are pelagic. This is confirmed by a more recent study in which the catches are most strongly associated with outflow in particular months (Sutcliffe, in press). It becomes of considerable significance then to note the conclusion of Neu (1970, and pers comm.) that regulation of the St. Lawrence river system has altered the within-season outflow pattern of the estuary from an initial ratio of 1:2.9 between season minimum and maximum. to a present 1: 1.7. That is, there has been a reduction of the seasonal differences in flow by about 50%. Further flow control of this, as of most major river systems, is contemplated for hydro-electric power development. The within-season flow changes involved are clearly comparable in magnitude to the annual and monthly changes which from Sutcliffe's work appear to affect biological productivity and fisheries yield in the entire system. While the biological effects of seasonal change in river flow patterns and the size of the area within which they may be important cannot now be predicted, production declines in the Azov Sea following regulation of the Don River (Moiseev, 1969) or in the Mediterranean affected by the Nile (Aleem, have left little doubt that they can be large. Fisheries management which failed to take account of such effects would have about the same significance as regulation of commercial marine salmon catches when the river in which they spawn is in the process of being dammed.

The possibilities for multiple correlation

While both density dependent and density independent effects on larval survival appear to have a major bearing on year-class strength and yield, it would be foolhardy to conclude that biological and environmental variables associated with larval survival alone are sufficient predictors for management purposes. This point has been made by Backiel and LeCren (1967) who point out that survival is likely to be the major density-dependent biological response at larval life-history stages, but growth responses may be of major significance to production among older animals. Cushing and Bridger's (1966) calculations showed how important growth changes may be, whether or not they are actually density-dependent. There is also abundant evidence for growth rate changes in relation both to feeding (Kohler, 1964), and temperature (LeCren, 1958). We thus have every reason to expect both density-dependent and density-independent influences to operate over the post-larval period. To these must be added the expectation that there will be significant interactions between adult growth and larval

survival, because of correlations between growth and fecundity, egg size, and age at maturity (Hempel, 1965; Nikolskii, 1962). Garrod's evidence for compensatory survival rates in the pre-recruit phases may well have involved a number of such effects for fishes. Density effects among adults are well known for sea-mammals, and at least in these cases do not appear sufficient to compensate for reproductive losses under fishing pressure (Chapman, 1961; Laws, 1962).

Studies such as these often suggest that in natural populations there are so many sources of variation in situations of such complexity that analysis, even with multiple regression techniques, is unlikely to be very enlightening. From this viewpoint a study reported by lles *(in press)* is an exception of particular importance. In a paper to the Stock Recruitment Symposium he re-analyzed the much discussed California sardine data in a manner which permits more detailed consideration than was possible from Garrod's study. He noted that among fisheries generally, changes in year-class strength were sometimes reflected in changes in growth rate, especially among the O-group fish, although this density effect was not always evident from simple correlations, perhaps because of simultaneous large but unmeasured changes in environmental 'carrying capacity'. He therefore calculated a survival index as the ratio of year-class or brood strength to parental abundance.

lles then studied the rate of change of growth of fish in relation to his density (year-class abundance) and environmental (survival) indices. Their average effects were of about the same order of importance, but the growth response to density changed with the survival index, and became very small under best survival conditions. Considering these observations lles deduced that the relative growth might be used to 'grade' estimates of year-class survival in a given year, in relation to the maximum possible survival expected for that year. That is, he could compare estimates of observed recruitment with that expected under 'standard' conditions. Iles' analysis of the California sardine shows parallels with that of Garrod, and it is unfortunate that at the present time the published data do not permit detailed comparison of their indices of survival. If subsequent study reveals that the two sets of survival or replacement indices are in substantial agreement. Iles' results provide strong support for the hypothesis that actual replacement rates of sardines in the latter years of the fishery were lower than the environment could have permitted. That is, the spawning stock was severely reduced by a combination of naturally poor brood years with an intensification of the fishery. The combination prevented recovery in later good brood years. On this basis, the development of the anchovy population on the sardine grounds must be seen as a consequence, rather than a cause, of the sardine fisherv failure.

lles carried his analysis an important step further and compared indices of (environment) survival among various fisheries and areas (Pacific salmon and herring, Alberta whitefish). While it is important to remember that the treatment of the catch data is not necessarily comparable to the analyses of Garrod, the results are striking. They show strongly associated variations in relative survival for different species within oceanographic systems. They also indicate significant associations over wider geographic areas, which suggest that the mechanisms giving rise to year-class fluctuations may ultimately be measurable in terms of changes in meteorological systems. We are thus brought back full circle to the subject matter reviewed by Bell and Pruter, but with the conclusion that improvements in the data appear to verify the reality of the relationships which they questioned.

As frequently seems to be the case in science, the return to the original subject matter is not so much a circle as some form of spiral. From the more recent analysis we may now conclude that within the broad constraints of environmental carrying capacity, fish populations show a remarkable capacity for density-dependent response. This response clearly involves reproduction, apparently in important association with the feeding opportunities during the youngest life-history stages. It further appears that severe predator pressure, such as is now experienced by some long-lived adult fish stocks, measurably reduces the effectiveness of the biological compensating mechanisms, and increases the probability that fisheries on them will suffer economic collapse. In at least the Californian sardine situation the population balance appears to have been sufficiently upset that the structure of the producing community has changed to some new kind of 'equilibrium'.

These conclusions do not represent anything new in concept in ecological theory or experiment. What is new is the demonstration that even with existing high levels of natural variability, interactions can apparently be induced in large wild population systems by predation pressures generated by present economically and technologically supportable rates of fishing. To this conclusion must be added the likelihood that current man-induced environmental alterations in estuarial regions are within the order of size which significantly affects the level of production in biological systems.

As was pointed out earlier, we are still not in a position to understand the larger question of why the limits of adaptative response by fish populations should be different among species or between areas. Riley (1972) reviews information on productive efficiency and community structure in three oceanographically different ecosystems and indicates that while differences in overall primary production seem quite clearly related to nutrient supply conditions, it is not easy to understand differences in the subsequent pathways of energy flow. We are thus far from being able to anticipate the long-term effects of heavy fishing. On balance, it is likely that as our knowledge grows we will find that the adaptative responses shown by Garrod for single species apply *a fortiori* to the complex of fish species comprising most communities. That is, we may find it possible or even necessary to deal in management with the multi-species population, as suggested by Parker (1962).

The foregoing has at least two important implications for future fisheries science. In the first place we may recognize with earlier workers in population dynamics that environmental variables are random or stochastic. But when they operate on a biological system their effects do not average to zero even though their expectation values may be zero. Once an extensive event has occurred, its influence is felt in the system for years to come. The effect on future stocks of a severe winter this year will not be removed by an exceptionally mild winter next year. Therefore even without significant changes in environmental patterns, any reduced adaptability from fishing or other causes implies that variations which in the past elicited adaptive response may appear as factors representing a hazard, which can result in catastrophic change. The management system must necessarily consider environmental as well as fishery variables.

The second consequence is that under present conditions the concept of continuous models of fishery ecosystems may be inapplicable at the species level. In fact, the problem of determining at what level of population or of 'community' of organisms continuous models may be used, and the relation of their population systems to their component 'species' has changed from an intellectually interesting exercise to a question of practical importance requiring early understanding. The importance of these interactions is underlined by the California sardine history.

The Pollution Problem - Interpretation of High-Frequency Variability

From the foregoing we infer that the general properties of single-species fish populations are reasonably well established as a basis for predicting shorter-term trends - of the order of 3 to 5 years. However, such predictions rely undesirably heavily on running averages of data, necessitating an assumption that the higher-frequency variabilities are effectively cancelling out. To increase accuracy and reliability of

prediction the immediate task of the resource research program must therefore be to study the short-term variability in sample data, with two principal objectives in view: first, to ensure that testable predictions can indeed be made; and second, to ensure that predictions for a system can be based on fewer data than were required for its initial description,

In these respects the approach of research programs in resource management becomes very like that which we require in our concern with pollution. Pollution research has, of course, requirements of study which are more or less peculiar to it: it must provide information about the effects of a great variety of chemicals on feeding, growth, reproduction, activity and survival of various life-history stages of many aquatic organisms - a very large laboratory program indeed. But while pollutants are taken up by individuals, it is their collective effects on natural productivity and exploitable yield that are the chief concern of fisheries management. That is, we have to measure the effects of pollutants on the same adaptative responses that have been the subject of resource research. This requires that we understand pollutant distribution, uptake and effects in relation to rather precisely defined details of the ecological production mechanisms.

Evidently, assessing pollution effects in nature and monitoring to detect significant changes in levels of hazard requires that we face the problem of describing and interpreting the high-frequency variability of samples. While this is an area in which we are still weak, our experience has grown rapidly in the past two to three years. Recent scientific literature indicates some of the problems involved in carrying out pollution sampling studies, identifies methods by which they may be resolved, and gives some indications of the more promising lines of research.

The problem of uptake of pollutants has been considered in a recent review by Kerr and Vass *(in press),* with particular reference to the apparently ubiquitous DDT and PCB compounds. They conclude that uptake in aquatic systems is overwhelmingly associated with diffusion through respiratory surfaces and is therefore a function of metabolic rate and available concentrations. On this basis it would be expected that concentration per unit volume would be generally higher among the smaller organisms than the larger, a fact which is generally confirmed by sampling (Ware, *pers. comm.).* Food chain transfer appears to be secondary in importance in aquatic systems, a fact which may make them different from terrestrial systems and have important implications for differences in regulatory measures. Given this information as a basis for preliminary pollution models, it still appears that where aquatic animals are large and relatively long lived, the larger of them may show increasing pollution concentrations, especially where they are feeding on small particles as do the whales and the fast-growing large pelagic fishes. In these cases, metabolic conversion and elimination rates of pollutants play an important role in explaining observed concentrations. There is relatively little information about these physiological properties of the larger animals and fishes.

If this basic uptake model is upheld by further work, it suggests that the study of local distribution of pollutants in relation to the life history stages of fish, particularly of the pelagic larval and O-group stages, is an area for high-priority research. Pollutants seem most likely to be concentrated in the surface layers or in coastal embayments and estuarial mixing zones, those very areas where year-class success is most likely to be determined.

Platt and Conover (1971) have studied in detail the processes of production and exchange of waters in and out of a small coastal bay. They sampled hourly, over a period of a day, for physical, phytoplankton and zooplankton parameters, supplementing the field observations with laboratory experiments to determine certain physiological rates. Their results indicated that about 60% of the daily chlorophyll production was exported from the bay, the remainder being almost all taken up by zooplankton grazing. Production of zooplankton could not be accurately measured, but the amount exported was measured in wet weight terms and found to be equivalent to approximately half the export of the phytoplankton.

The most important aspect of their study was the examination of mechanisms of transport of organisms in relation to the physical water transport. The hourly data showed a strong negative correlation of the concentration of organisms with rate of transport (obtained using continuously recording current meters), with the result that only 35% of the daily export of phytoplankton and less than 1% of the zooplankton exchange were associated with the mean flow. That is, 65% of the phytoplankton and almost all zooplankton export from the bay were associated with the fluctuations (hourly) in the flow, apparently associated with tidal influences, although some 2.5 hours out of phase with it.

These observations suggest three conclusions of significance to pollution studies in relation to fisheries production. First, a high proportion of the daily biological production of coastal inlets is exported from them, and the amount exported is very much higher than the measured net mean water exchange. Evidentially, coastal inlets and estuaries are much more important in supporting production systems of coastal waters than has been estimated in the past by multiplying the net physical exchange by the average primary production. Since coastal inlets are also especially liable to pollution effects, this finding alone suggests that coastal inlets require much more priority in fisheries research programs than has generally been given them. Of second importance is the finding that a high proportion of the production exported from coastal embayments may be at a relatively high trophic level, and that the amount exported at various trophic levels or particle sizes may be very different. A relatively high trophic level of the export would make coastal inlet production that much more important as a source of nourishment for larval and juvenile fishes, which are commonly found to congregate in the near-shore areas at some stage in their life history. Since pollutants are generally associated with particulate material in the water, but their concentrations vary with particle sizes, we must conclude that a considerable number of detailed experiments and observations are necessary to permit generalizations about the dissipation or flushing of pollutants from inshore areas or the significance of their contributions to the coastal waters. Finally, Platt and Conover's work shows that mean water exchange from coastal inlets is not by itself a reliable estimator of biological exchange. The more significant parameters are associated with phenomena at the very high frequency end of the scale of variability. Such observations suggest that requirements for pollution monitoring programs are far from simple and, at least for the important coastal and pelagic zones, would have to be carefully designed around a knowledge of existing conditions if the results are to bear any relationship to reality.

Platt (1972) has studied the nature of high-frequency or local-scale variability in phytoplankton in the mixed layer. Chlorophyll concentrations were continuously measured at a point station in the Gulf of St. Lawrence at 8 metres, using a fluorometric technique. The station was occupied during midsummer, that is, outside the main spring bloom period. He found that the fluctuations in concentration of chlorophyll were satisfactorily described by a minus 5/3 power relationship over space scales of from 10 to 1000 metres or time scales of from 1 to 100 minutes. This suggests that not only do the high-frequency fluctuations present in oceanographic sampling exhibit a definite pattern, but that for phytoplankton this pattern may be strongly influenced by small scale events in the physical medium. The possible relationship with, say, turbulent flow suggests that analogous generating mechanisms may be of considerable significance to the design of appropriate predictive models of dispersion and uptake of pollution in biological systems.

Steele (*in press*) has examined the nature of fine-scale zooplankton distribution in nature, in relation to zooplankton dynamics. Using estimates of growth, mortality, and grazing rates from laboratory experiments he calculated time series of phytoplankton-zooplankton

biomasses, which under certain conditions show considerable fluctuations. From the models he was able to estimate their joint probability distribution for different population abundance states. This he compared with the frequency distribution of biomass samples taken over a relatively short time in a dispersed zooplankton patch. The fit of the natural variations was satisfactorily close to the calculated distribution, although it was somewhat dependent on estimates of 'rate of sinking' of zooplankton from the population, a phenomenon which seemed not to be satisfactorily identified and measured in nature. This result suggests once again that fine-scale distributions of zooplankton are far from random. In the case of the zooplankton, in contrast to the phytoplankton, fluctuations appear rather more dependent on the population dynamics than on the medium, but the important result is that the distribution can be understood in relation to environmental and biological generating mechanisms.

The results of Steele's work support those of Platt and others which indicate that assessment of the influence of various factors, such as pollutants, on ecological production processes is not yet a job for amateurs. The results clearly indicate, however, that such assessment can be done, provided we are prepared to put the effort into studies of the kinds of variations that have frustrated fisheries resource research in the past. That is, it should be possible to make the kinds of generalization which will permit pollution assessment without invoking the astronomical expense of detailed study of each individual potential pollution site.

Conclusions

In studies of fisheries resource management problems, the limited amounts of physical research resources have frustrated many of our attempts to understand the basis for observed catch changes, sometimes for no other reason than that we have been too busy trying to cope with measurement of the symptoms as they showed up again and again in important fisheries. In retrospect this situation may not have been so very 'bad'. For one thing, the longer series of annual data now available have made it possible to measure production changes in relation to a much wider range of fishing mortalities, and are only now on the point of exhibiting significant interactions. Perhaps we could not have anticipated these effects very much sooner in any case. In addition, it appears that fishing effects alone have not led to irreversible population changes. The Antarctic whale fishery is perhaps the most seriously affected and it is gone for many years. But this situation was detected by the scientific community some time ago; the failure was a result of slow international administration, accompanied by a poorly or insufficiently informed public. The populations may recover in time. The California sardine fishery collapsed, but the geological record indicates that the sardine has been replaced by the anchovy at various periods in the past, so that the effect of heavy fishing may only have been to increase the probability of a natural 'adaptation' of the productive community. And now the research results have indicated that there appears to be rather clear-cut short-term alternatives for the Arcto-Norwegian cod. Thus, while we are still unable to foresee the longer term consequences of ecosystem change of the kind which lead to fishery collapse, the possibilities for short-term diagnosis of symptoms is encouraging and justifies continued efforts towards the understanding of fishery conditions.

Unfortunately, pollution problems are not quite the same. Effects of pollutants arise from chemicals of which we have disposed, and which have accumulated or are accumulating in the environment. We cannot afford to wait until the symptoms of their action show up in significant production changes in order to test the validity of scientific models describing their effects. By the time we are able to test the theories by the *results* or *symptoms*, the time scale of recovery is likely to be SO long as to make it a practical impossibility. It is necessarily involves a knowledge of mechanisms responsible for production control and pollution effects in nature. That is, it requires specific and detailed studies of the sort which have been slow to develop in traditional fisheries research.

It must also be emphasized that effects from pollution appear likely to be most profound in those very parts of our world where pollutants are most likely to become concentrated: the coastal fringe and the mixed water layer over the continental shelves. That is, they occur in those areas where our studies indicate that control of production of commercial species takes place. Given the evidence that interaction of fishing and natural environment change is significant, it is inconceivable that pollution effects will not be found to magnify the interaction.

We can only conclude that fishery resource management has special reason to promote our understanding and prediction of pollution effects, and to insist on their control. In its simplest terms, it is clear that resource management of our continental shelf fisheries cannot effectively take place independent of the insurance against deterioration of the quality of the environment. We have every reason to believe that the resource science community is relatively well prepared to carry out the work. However, it is virtually certain that this will require a more intensive, detailed and sophisticated study of natural ecosystems than has so far been our custom. Solving this problem is very much the responsibility of government administrators, politicians and the public.

References

ALEEM, A. A., 1972. Effect of river outflow management on marine life Mar. Biol., 15: 200-208.

BACKIEL T and **LeCREN**, **E D.** 1967. Some density relationships for fish population parameters. In: *The biological basis of freshwater fish production*. Ed. S. D. Gerking, Blackwell, Oxford: 261-293.

BARANOV, F. I. 1918. On the question of the biological basis of fisheries. Nauchnyi issle dovatelskii ikhtiologicheskii Institut, Izvestiia, 1: 81-128.

BELL, F. W., and PRUTER, A. T. 1958. Climatic temperature changes and commercial yields of some marine fisheries. J. Fish. Res. Bd. Can., 15: 625-683.

CUSHING, D. H., and BRIDGER, J. P. 1966. The stock of herring in the North Sea and changes due to fishing. *Min. Agric., Fish. and Food, Fish, Inves., Series II,* 25: 1-123.

CHAPMAN, D. G. 1961. Population dynamics of the Alaska fur seal herd. Trans. 26 North American Wildlife and Natural Resources Conference, 1961: 356-369.

GARROD, D. J. (in press) The variation of replacement and survival in some fish stocks. In: *The symposium on stock and recruitment*. Eds. B. B. Parrish and P. A. Larkin.

GULLAND, J. A. 1955. Estimation of growth and mortality in commercial fish populations *Min. Agric., Fish. and Food. Inves., Series II, 18: 1-46.*

GULLAND, J. A. 1961. Fishing and the stocks of fish at Iceland. Ibid., 23: 1-52.

HEMPEL, G. 1965. Fecundity and egg size in relation to the environment. In: International Commission for the Northwest Atlantic Fisheries, Special Publication No. 6, ICNAF Environmental Symposium: 687-690.

ILES, T. D. *(in press)* The interaction of environment and parent stock size in determining recruitment of the Pacific sardine as revealed by the analysis of density-dependent O-group growth. In: *The symposium on stock and recruitment.* Eds. B. B. Parrish and P. A. Larkin.

KERR, S. R., and **VASS, W. P.** *(in press)* Pesticide residues in aquatic invertebrates. In: *Environmental pollution by pesticides.* Ed. C. A. Edwards, Plenum, London.

KOHLER, A. C. 1964. Variations in the growth of Atlantic cod (Gadusmorhua L.). J. Fish. Res. Bd. Can., 21: 57-100.

LAWS. R. M. 1962. Some effects of whaling on the southern stocks of baleen whales. In: *The exploitation of natural animal populations.* Eds. E. D. LeCren and M. W. Holdgate, J. Wiley & Sons, New York: 137-158.

LECREN, E. D. 1958. Observations on the growth of perch (*Perca fluviatilis L.*) over twenty-two years with special reference to the effects of temperature and changes in population density. J. Anim. Ecol., 27: 287-334.

MOISEEV, P. A. 1969. Living resources of the world ocean. Pishchevaya Promyshlennost, Moscow.

NEU, H. J. A. 1970. A study of mixing and circulation in the St. Lawrence estuary up to 1964. Atlantic Oceanographic Laboratory, Bedford Institute, Rep. No. 1970-9. (MS Rep.).

NIKOLSKII, G. V. 1962. On some adaptations to the regulation of population density in fish species with different types of stock structure. In: *The Exploitation of Natural Animal Populations*. Eds. E. D. LeCren and N. W. Holdgate, J. Wiley, & Sons, New York: 265-282.

PALOHEIMO, J. E., and DICKIE, L. M. 1965. Food and growth of fishes. I. A growth curve derived from experimental data. J. Fish. Res. Bd. Can., 22: 521-542. 521-542.

PALOHEIMO, J. E., and DICKIE, L. M. 1970. Production and food supply. In: Marine Food Chains. Ed. J. H. Steele, Oliver and Boyd, Edinburgh: 499-527.

PARKER, R. R. 1962. A concept of the dynamics of pink salmon populations. In: Univ. Brit. Columbia, Inst. of Fish., H. R. MacMillan Lectures in Fisheries, Symposium on Pink Salmon 1960.. (Fish. Res. Bd. Can., Studies No. 714): 203-211.

PLATT, T. 1972. Local phytoplankton abundance and turbulence. *Deep-Sea Res.*, 19: 183-187.

PLATT, T., and CONOVER, R. J. 1971. Variability and its effect on the 24-hour chlorophyll budget of a small marine basin. *Mar. Biol., 70: 52-65.*

RICKER, W. E. 1954. Stock and Recruitment. J. Fish. Res. Bd. Can., 77: 559-623.

RICKER, W. E. 1958. Handbook of computations for biological statistics of fish populations. *Bull. Fish. Res. Bd. Can., 119. 300* pp.

RILEY, G. A. 1972. Patterns of production in marine ecosystems. In: *Ecosystem structure and function*. Ed. J. A. Wiens, Oregon State Univ. Press: 91 -110.

SAVILLE, A. 1959. The planktonic stages of the haddock in Scottish waters. Scottish Home Dept., Mar. Research, 3. 23 pp.

SAVILLE, A. 1965. Factors controlling dispersal of the pelagic stages of fish and their influence on survival. In: *International Commission for the Northwest Atlantic Fisheries Special Publication No. 6. ICNAF Environmental Symposium:* 335-348.

SCHAEFER, M. 6. 1967. Fishery dynamics and present status of the yellowfin tuna population of the eastern Pacific ocean. *Bull. Int. Trop. Tuna Comm., 72:* 89 - 136.

SEREBRYAKOV, V. P. 1971. On haddock spawning in the northwest Atlantic area. International Commission for the Northwest Atlantic Fisheries, Research Document 71/42, Serial No. 2529. 7 pp. (MS Rep.).

STEELE, J. H. (in press/ Structure of marine ecosystems. Harvard Univ. Press, Cambridge, Mass.

SUTCLIFFE, W. H., Jr. 1972. Some relations of land drainage, nutrients, particulate material, and fish catch in two eastern Canadian bays. *.l. Fish. Res. Bd, Can., 29: 357-362.*

SUTCLIFFE, W. H., JR. (in press) Correlations between seasonal river discharge and 3 commercially obtained species in the Gulf of St. Lawrence. J. Fish. Res. Bd. Can.

The Gulf of St. Lawrence

M. J. Dunbar, Marine Sciences Centre, McGill University, Montreal

The map of Canada shows four main drainage basins: one drains westward into the Pacific, another northwards to the Arctic coast, a third (the largest of them in area) drains into the Hudson Bay complex (Hudson Bay, Foxe Basin, Hudson Strait and Ungava Bay), and the fourth, containing all the Great Lakes, drains eastward into the Gulf of



The main watersheds of Canada.

St. Lawrence. Hudson Bay and the Gulf of St. Lawrence are large inland seas with obvious estuarine characteristics. There are other smaller drainage systems, such as that draining to the Labrador coast. The total amount of fresh water in Canada represents some 14% of all the fresh water supply of the world, which is a handsome endowment. The total flow from Canadian rivers, averaged over the year, is about 117,200 m³ /sec.

There are three ways in which fresh water inflow can affect coastal biological productivity - (1) by the direct contribution of nutrients from the land, (2) by the 'entrainment effect', by which deeper, nutrient-enriched salt water is brought in toward the shore and upward to the surface, and (3) by the effect on the density, and hence nutrient, stratification in the water column. It seems to be widely believed among non-oceanographers that the rivers of the world are largely responsible for the supply of nutrient salts (phosphates, nitrates, silicates, trace elements) to the sea. In fact, rivers bring down each year

an amount of material that is quite insignificant compared with the enormous nutrient capital that recycles within the sea itself. These nutrients are recycled from organic detritus which often sinks well below the euphotic zone (i.e. the upper layers into which sufficient light penetrates to permit the growth of green plants), so that in order that the spring plant blooms may take place the nutrients have to be brought back to the surface. This is done in several different ways, and the global map of marine productivity is really a map of the intensity of these processes. The entrainment of salt water by outflowing fresh water at the surface is no doubt the most important aspect of fresh water inflow to coastal areas. One of the other standard mechanisms in the sea by which nutrients are brought to the surface is the increase in density in surface water owing to fall and winter cooling. By this means there is a continued exchange of surface water with the water immediately beneath. This process is progressive, reaching farther down as winter progresses. The less freshened the surface water is, the easier this process becomes, so that there is an element of conflict between this exchange process and the coastal entrainment mechanism. If the fresh water outflow were cut off completely, in a given area, the salinity of the surface layer might be increased enough to encourage the vertical winter exchange, so that the lesser run-off would enhance rather than depress the productivity. The rules therefore will not be the same in all regions; each will have to be studied for its own sake. and this applies possibly even to different regions of the Gulf of St. Lawrence, certainly to areas outside the Gulf.

The St. Lawrence River ranks seventeenth among the world's rivers, and the flow varies significantly from year to year. The total fresh water input to the Gulf, averaged over a nine-year period (1957-65), is 15,810 m³/sec, of which 13,443 m³/sec is river flow, the remainder made up of net precipitation (precipitation less evaporation) (Trites, 1971).

The term 'estuary' in this paper refers to the region between the City of Quebec and Pointe des Monts, the region east of Pointe des Monts, bounded by the Strait of Belle Isle in the northeast and Cabot Strait to the southeast, constitutes the Gulf itself (Forrester, 1967). The area of the Gulf is approximately 214,000 km² (Forrester and Vandall, 1968). It receives the drainage from a land area of about half a million square miles which includes the Great Lakes-St. Lawrence River system extending inland for 2000 miles. It is the principal sea access to our largest cities and to over 60% of the population of Canada, and it is the source of more than 40% of all Canadian sea-fish landings. It displays physical and biological properties ranging from subtropical to subarctic, and it has a far-reaching impact on the economic and social life of the eastern and central regions of the country.



The Gulf of St. Lawrence.

History

According to recent geophysical studies (Keen, 1971) the Atlantic Ocean has appeared twice since Precambrian times, with an intervening disappearance or closure. The second opening-up of the Atlantic appears to have begun in Triassic times (between 225 and 195 million years ago). The St. Lawrence River appeared in Jurassic-Cretaceous times (between 190 and 65 million years ago) as part of a river system formed on uplifted terrain by erosion; a tilting of the area toward the sea began the formation of the Gulf itself in the early Tertiary (about 60 million years ago). The physiography of the area began at that time to take on its present-day appearance. The Laurentian Channel, a deep trench that appears off the mouth of the Saguenay River, cuts through the Gulf south of Anticosti Island and passes out through Cabot Strait to the Scotian Shelf, was formed much later by glacial action in the Pleistocene (about 2 million years ago).

A bibliography of physical oceanographic work in the Gulf (EI-Sabh *et al.*, 1969) lists as the earliest scientific publications one on surface temperatures by Kelly (1837), one by Austin (1866) on fishes, and one by Whiteaves (1872) on benthic fauna. The first solid contribution was probably W. Bell Dawson's paper on tides and currents (Dawson, 1898). Particularly intriguing is a paper by H. T. Barnes of McGill University, published in 1913, on the temperature effects of icebergs. Barnes is

especially worthy of mention because his was the first effort, the first speculation, on the possibility of controlling climatic conditions in the Gulf of St. Lawrence area, and, in particular, the possibility of reducing or inhibiting the ice cover in winter.



Percé Rock, Gaspé Peninsula, Gulf of St. Lawrence

The first large-scale attack on the problems of the hydrodynamics and the biological production of the Gulf was the 1915 Canadian Fisheries Expedition under the direction of Dr. Johan Hjort of Norway (Hjort, 1919). This study produced the first description of the water masses, the circulation, temperatures and salinities, and the plankton, and it was a long time before anything approaching that scale of work was undertaken. A study of the Strait of Belle Isle was made in 1923, directed by Dr. A. G. Huntsman, and there were other local investigations in various parts of the Gulf, but research did not begin to gain momentum until the late 1930's and especially in the years since the second world war. The Atlantic Biological Station of the Fisheries Research Board and the Province of Quebec Marine Station at Grand Rivière have contributed in large part to this advance, and more recently the Atlantic Oceanographic Laboratory and the Marine Ecology Laboratory of the Bedford Institute of Oceanography (BIO). A most important study of the bottom sediments of the Gulf has now been completed by Loring (in press) and the sediments of Northumberland Strait in particular have been described by Kranck (1971). The universities have begun to play an increasing role in research in the Gulf. A continuing study of ice movements, formation and decay, and the factors controlling them, was started by Pounder and Johannessen of McGill University in 1967 (Ingram et al., 1968); McGill University also undertook an extensive investigation of the primary and secondary production for four field seasons (1969-1972) (Steven, 1971; Bulleid and Steven, 1972). D'Anglejan (also of McGill) is working on suspended

matter in the Gulf (d'Anglejan, 1970), and also on alkalinity and dissolved oxygen (d'Anglejan and Dunbar, 1968). A most significant development has been the formation of GIROQ (Groupe Interuniversitaire de Recherches Oceanographiques du Quebec), which includes the Universities of Laval, McGill, Montreal, and the Rimouski campus of the University of Quebec. This group took shape in 1970 and has been working on the physical, biological and geological oceanography of the St. Lawrence Estuary (Brunel, 1971).

A fuller measure of the history of scientific work in the Gulf can be gained by examining the two bibliographies available, that of El-Sabh *et al.* (1969), already mentioned, and the bibliography on the fishes prepared by Srivastava (1971). An attempt is made in this paper to summarize briefly the present state of knowledge of the Gulf, and to point out the large amount of work which remains to be done, in particular the study of the mechanisms, physical, chemical and biological, which make up the Gulf as a whole system, which is one of the purposes of the Gulf of St. Lawrence Project, or "Year of the Gulf", now being planned.

Water Masses

The 1915 Canadian Fisheries Expedition established the existence of the famous 'cold layer' in the Gulf, which in summer separates the warm upper layer from the deep water below. This cold layer extends from about 50 metres down to some 150 metres, varying somewhat in time and place. The salinities in it are of the order of 31 to 33%,. (in summer) and the temperatures lie at or below 0°C. It extends outside the Gulf through Cabot Strait to the Scotian Shelf. It was long thought that this cold layer consisted of Arctic or Subarctic water entering perhaps through the Strait of Belle Isle, more probably through Cabot Strait, but more recent study has shown that at least a large proportion of it must be formed *in situ* by a process of winter cooling (Forrester, 1964). It is interesting, however, that this cold layer contains planktonic species of distinctly Arctic affinities.

Although the water mass pattern shows a three-layered structure in summer, the basic pattern is in fact two-layered, the pattern exhibited in winter, when there is a cold upper layer varying in thickness from 100 to 150 metres with temperatures as low as - 1.7° C and salinities from about 32.5 to 33‰. This is underlain by the deep water extending to the bottom of the Laurentian Channel, with temperatures between 4 and 5°C (or up to 6°C) and salinities close to 34.6 ‰,. The cold layer contracts markedly in volume in spring and summer as the upper water is heated by the sun and freshened by the spring land



Temperature and salinity profiles, summer and winter (from Trites 1971).

drainage, so that a third layer appears at the surface, extending down to some 50 to 75 metres, with temperatures as high as 16°C and salinities down to 30 ‰ or lower (see also Forrester, 1964). It is interesting that the temperature of the deep layer varies, not seasonally, but rather in response to changes in this water mass outside the Gulf (Trites, 1971; Lauzier and Bailey, 1957).

Dissolved Oxygen

Walton (1971) gives typical oxygen concentrations as 8 ml/l for the surface layer (7.5 ml/l in shallow areas), and as low as 1.8 ml/l in the deep layer. The low concentrations in the deep water have been given special attention by Dunbar (1971) and d'Anglejan and Dunbar (1968), who measured oxygen concentrations over most of the Gulf, recording values as low as 2.63 ml/l southwest of Anticosti and 2.70 ml/l in the Esquiman Channel west of Newfoundland. Mann *et a*/. (I 965) recorded values of dissolved oxygen on the continental slope of Nova Scotia, and over the Grand Banks, which correspond to the lowest values found in Cabot Strait, and there is little doubt that this level of slope water is the origin of the deep layer in the Gulf (d'Anglejan and Dunbar, 1968). The lowest concentrations are found at the inner extremities of the Laurentian and Esquiman Channels. A study of the flushing time of the deep water would be valuable and would help to gain an estimate of the

total oxygen demand and hence of animal production. The oxygen profiles in the deep layer usually show the oxygen minimum in the 200-to 300-metre level. Thus oxygen depletion does not appear to be a simple function of depth, which is relevant to the location of the highest oxygen demand.



Knudsen bottle operation for the collection of water samples, Gulf of St. Lawrence in winter.

There is one area in which the deep water (below 150 metres) is not low in oxygen, having values similar to those in the upper water. A ridge between the Esquiman Channel proper (or Esquiman trough) and the region toward the Harrington coast isolates the deeper water of this region from the deeper water of the rest of the Gulf; presumably the bottom water in this pocket is derived from surface water, possibly from inflow through the Strait of Belle Isle.

A summer oxygen maximum is found toward the bottom of the thermocline just above the summer intermediate cold layer. The narrow range of density found there has a mean value close to the density of the surface layer in winter ($o_t = 25.76$). Supersaturation in the summer mixed layer and in the thermocline is frequent and it is clear that heating of waters formerly in equilibrium with the atmosphere takes place in summer. These conditions support the view given above that the summer intermediate waters are a residue of the winter-formed cold layer.

lce

Ice conditions are well described by Matheson (1967). from whose work the accompanying figure is taken. This information is based on a five-year average (1961-65); the original observations were published by the Meteorological Branch of the Ministry of Transport. The ice comes from three sources: (1) Labrador ice from the north, drifting in through the Strait of Belle Isle, (2) ice from the St. Lawrence River and Estuary, and (3) ice formed in the Gulf itself.

"Using the weekly ice summary charts, Forrester and Vandall (1968) divided the gulf into ten regions and estimated ice volumes and average ice thicknesses in each of the regions at two-weekly intervals through the six ice seasons of 1962 to 1967, and also through the six-year mean (1962 - 1967) ice season. For the mean ice season they found the greatest average ice thickness (24 cm) occurred in the region around Prince Edward Island early in March. Over the gulf as a whole the greatest average ice thickness (16 cm) occurred at the end of February for the mean ice season.

"It is essential to carry out heat budget studies in order to understand, and hence predict, the formation, growth, and break-up of the ice. Few complete studies of this character have been carried out in the Gulf of St. Lawrence; however, Lauzier and Graham (1958), Lauzier and Bartlett (1961). Coombs (1962) and Matheson (1967) have investigated the subject. Matheson (1967). from his study on the meteorological effect on ice in the Gulf of St. Lawrence, has shown that high heat



Five-year average ice concentrations, January to May (from Matheson, 1967).

losses during the season do not necessarily imply severe ice conditions. As pointed out by him 'computation of the heat fluxes revealed the very high heat gains or losses which may ensue if an airflow type is maintained over a long period. It is imperative that these high heat loss periods continue for at least three consecutive days in order to produce a significant effect on the ice cover" (El Sabh et al., 1969).

The McGill University ice drift study (mentioned previously) included the operation of a 'manned drifting station', air reconnaissance and the use of a drifting buoy, and showed that the ice fields take part in the tidal motion and that maximum response of the ice drift to changing wind stress is achieved in less than three hours.



Transmitter buoy mounted on a small ice flow, Gulf of St. Lawrence. Wind and water stress, ice study, McGill University.

Tides

On tides and tidal currents, Trites (1971) reports: "The semi-diurnal and diurnal tides from the North Atlantic Ocean are both propagated through Cabot Strait (Farquharson, 1962). There are two amphidromic points for the M_2 (lunar semi-diurnal) constituent - one near the Magdalen Islands and a second near the western end of Northumberland Strait. In most areas of the Gulf, the semi-diurnal constituent dominates. Tidal range increases rapidly towards the St. Lawrence River with a mean range of about 13 feet near Quebec city.

"Except in the St. Lawrence Estuary, Cabot, Belle Isle and Northumberland Straits, and other locally confined regions, tidal currents seldom exceed 0.5 knots. In Cabot Strait, tidal streams are typically of the order of a knot. In some areas, the phase of the tidal stream varies significantly with depth. Forrester (1970) has found evidence of internal tides in the St. Lawrence Estuary seaward of the Saguenay River entrance. It is possible that internal tides exist throughout much of the Gulf, but sufficient data are lacking at present to clarify the situation. If present, their behaviour is likely to vary substantially from season to season as the density structure undergoes marked variation in the upper part of the water column."

Circulation

Much remains still unknown about the currents in the Gulf, particularly the movement of the subsurface water and the deep currents. The surface currents are reasonably well known for the summer months, but the whole winter regime at all depths demands a great deal more investigation. Brief accounts of what is known, together with the history of the field work and the methods used, have been published by Trites (1971) and El-Sabh *et al. (1969)*.

The surface currents are influenced largely by the winds and by the inflow from the St. Lawrence River, which together result in a general anticlockwise pattern of surface movement. The dominant feature is the Gaspe Current, which varies considerably in strength, but which is normally strong and pressed against the Gaspe coast. Water from this current floods the Magdalen Shallows. The outflow round the northern tip of Cape Breton Island, in Cabot Strait, is partly balanced by an inflow round the southwest of Newfoundland which turns to the north up the Esquiman Channel. The Gaspe Current is coupled with west-flowing water along the North Shore, north of Anticosti, and also along the south coast of Anticosti. The pattern of flow through the Strait of Belle Isle is still uncertain: the inflow from the Labrador coast



Surface circulation in summer (from Trites 1971).

is clearly intermittent and small, the outflow rather more constant and mainly along the southern part of the Strait. These two currents, inward and outward, alternate in dominance in a pattern which appears to be related to the north-south atmospheric pressure gradient and the effect of the wind.

Both clockwise and anticlockwise gyres in the upper (mixed) layer have been observed in the Magdalen Shallows. These are some 20-30 km in diameter and appear to move in a general southeasterly and easterly flow north of Prince Edward Island (Blackford, 1965, 1967). The gyres may have significant biological effects, but much work remains to be done before either the physics or the biology of them are properly understood.

Subsurface currents are as yet imperfectly known. It is possible that the pattern of water exchange through Cabot Strait may be as variable as the much smaller exchange through the Strait of Belle Isle. In the Laurentian Channel there is evidence for the circulation to be as expected, namely a seaward current along its southern side and a landward (westward) motion along its northern side (Lauzier, 1967a). In the Gaspe Passage the deep water, in summer, has been observed to move westward, underlying and to the north of the much faster Gaspe Current flowing in the opposite direction.

The first and (so far) only attempt to study the winter circulation in the Gulf is that of El-Sabh and Johannessen (1972), based on observations made on board HMCS Labrador in March 1956 and 1957. and the CSS Baffin in February 1962. This study is also distinguished by the application of the Defant method of determining the reference layer for dynamic computations, within which layer the motion is taken as zero: the depth and thickness of this laver vary from locality to locality. According to the results of this method, the large anticlockwise gvre southeast of Anticosti Island, which is a consistent feature of the summer circulation, disappears in winter. Quoting from this paper: "On the contrary, a smaller clockwise gyre has been observed southeast of Anticosti Island. In general the gyres are associated with depressions in the zero reference laver." The surface flow through Cabot Strait in winter was found to be outward on both sides of the Strait, stronger on the Cape Breton side, which agrees with drift-bottle observations in winter; and with a strong inflow of surface water through the middle of the Strait which is diverted to the north and south and joins the outflowing current on both sides of it. an effect which might be caused by the prevailing northwest winds. The net volume transport through Cabot Strait was estimated to be 6000 m³/sec, which agrees well with the February and March estimates of net fresh water inflow to the Gulf given by Trites (1971).

Marine Climatic Change

Natural climatic changes are reflected in both the atmosphere and the hydrosphere; we are concerned here with the latter. Climatic changes in sea water have immensely important economic effects in terms of local productivity and the shift in the distribution patterns of economically important species. On the global scale, there is at present a general cooling trend, which reversed the well-documented warming between about 1915 and the 1940's. Lee (1967) has summarized the situation in the North Atlantic region, and Lauzier (1967b) has documented the decline in temperature, amounting to about 1°C, in the surface water of the Canadian eastern seaboard, including the Gulf of St. Lawrence, between about 1955 and 1965. The pattern of change, however, is not simple; surface temperatures in West Greenland, for instance, appear to have been rising during this same period (Hermann, 1967), and the deep water of the Gulf of St. Lawrence showed no cooling trend up to 1957 (Lauzier and Trites, 1958), although cooling became apparent in the core of the warm layer in Cabot Strait from 1958 to 1967 (Lauzier, 1967b). From 1967 on there is evidence of temperature increase (EI-Sabh pers. comm.).



CSS Dawson, iced-up after a winter cruise in the Gulf of St. Lawrence.

Fauna, Productivity, and Fisheries

Biogeographically, the Gulf of St. Lawrence is a remarkable transition zone between the Subarctic and the Subtropical. On one definition (Dunbar, *in press*) it falls within the marine Subarctic, the zone in which Arctic water (ultimately from the Arctic Ocean) and non-Arctic water are found together. Although as already mentioned above the amount of Labrador Current water in the Gulf is controversial, there is no doubt about the existence of Arctic and Subarctic species in the Gulf, and indeed water of Arctic origin penetrates farther south into the Bay of Fundy and the Gulf of Maine. As examples the typically Arctic copepods *Calanus glacialis, C. Hyperboreus,* and *Metridia longa,* are all common in the cold layer of the Gulf, as is also the Arctic Mysid *Boreomysis nobilis* (Maclellan, *pers. comm.*).

For most of our knowledge of the biogeographical position of the Gulf of St. Lawrence we are indebted to Dr. E. L. Bousfield of the National Museum (Bousfield, 1956, 1960, and Bousfield et a/., *in press*), who has established that the fauna consists in part of Arctic and Subarctic forms whose distribution ranges from the Arctic Ocean to the Gulf of Maine, and partly of temperate or Virginian forms, ranging in distribution from the southwestern part of the Gulf of St. Lawrence and western Nova Scotia to northern Florida and the Gulf of Mexico. General information on the fauna of the Gulf would not be appropriate here. Details of the seals, whales, and fishes are published elsewhere.

On present evidence, the Gulf is biologically the most productive Canadian marine region, and in fact it has several characteristics which should make it so. It is for the most part fairly shallow, which favors the ready return of the nutrients to the euphotic zone and encourages large phytoplankton and seaweed production; at the same time it possesses a deeper channel which supplies nutrient-rich water from the shelf outside the Gulf; it is an inland sea, which favors the retention of both nutrients and living crops within itself; and it is in part an estuary, with the advantage of the 'entrainment' effect of the fresh water runoff which brings deep water to the surface as described above.

The Canadian International Biological Program (IBP) study of primary and secondary production in the Gulf of St. Lawrence, organized in the Marine Sciences Centre, McGill University, was undertaken during three and a half open seasons from 1969 to 1972 (Steven, 1971; Bulleid and Steven, 1972). The results of this massive survey have still to be analyzed fully, but certain broad outlines are clear. Primary production is highest in the western part of the Gulf, especially in the Gaspe Passage, and falls off progressively to the east and southeast. The northeast Gulf is the lowest in production, although by no means negligible. The 'Gaspe Current production system' is the dominant feature in the pattern, and is driven apparently by upwelling of nutrient-rich deep water at the head of the Laurentian Channel in the estuary, off the mouth of the Saguenay river. The physical mechanism of this upwelling has not yet been established, but is probably a combination of entrainment by fresh water outflow, tidal forces, and the Coriolis effect. The overall pattern is shown in the figures. As the



Longitudinal profile, estuary to the continental shelf, drawn through maximum depths (from Brunei, 1970).



Approximate boundaries of the main areas of the primary production system as shown by the McGill University IBP 4-year study (from Steven 1971).

Gaspé Current moves east and southeast, the high phytoplankton crop gives way to high secondary (zooplankton) production in the Magdalen Shallows; the zooplankton supports the important fisheries of that area.

Chlorophyll concentrations in the Gaspe system were more recently measured by Platt (1972), using the fluorescence method, in June 1972. Platt's figures are somewhat higher than the McGill IBP measurements, but not incompatible with them; and moreover Platt demonstrated areas of especially high concentrations of chlorophyll which could be interpreted as gyres.

The measurement of secondary production (zooplanktonic herbivores) is considerably more difficult than the measurement of primary production, but from present knowledge of standing crops of zooplankton it is clear that the production levels are in keeping with the high primary productivity. Estimates of the production of two of the most important zooplanktonic groups, the copepods and the euphausiids, are being made at the time of writing.

A most interesting direct relation between variations in fresh water runoff and commercial catches of several fish and shellfish species has recently been demonstrated by Sutcliffe (1972). The number of years of lag, or 'slip' required to match the catch against the runoff, is approximately the age at which the species in question enters the commercial take. Fresh water runoff, in fact, by virtue of the entrainment effect, may be responsible for some 60% of variations in commercial catches.

The commercial exploitation of Gulf of St. Lawrence animal stocks accounts for more than 40% of the Canadian sea fisheries output. The information in Table 1 is taken from Dr. B. Muir's (BIO) reduction of International Commission for the Northwest Atlantic Fisheries (ICNAF) statistics.

Compared with ICNAF areas 2, 3 and 4 (southwest Labrador Sea, the Grand Banks region, and the Nova Scotian shelf and slope regions), the productivity as measured by fish catch for the Gulf was 4.0 metric tons per square kilometre, 3.0 metric tons for areas 2, 3 and 4 for 1970. For 1969 the corresponding figures were 3.7 and 3.2. The herring catch is probably on the decline, the mackerel and capelin on the increase, the remainder holding their own. Most of the fish production stays within the Gulf, so far as we know. Part of the herring stock moves out along the south shore of Newfoundland, some of the cod move to the region east of Cape Breton Island, and the mackerel are fully migratory, going

TABLE 1

Total 1970 Gulf of St. Lawrence fish catch including winter migrant herring and cod caught outside. Figures in brackets are the Canadian catch (metric tons). Included in the totals are those for fish taken outside the Gulf but of presumed Gulf origin.

Herring	313,889	(313,889)	
Cod	179,818	(104,277)	
Redfish	87,588	(79,732)	
Haddock	581	(575)	
Halibut	508	(489)	
American plaice	11,005	(10,999)	
Greenland halibut	1,112	(1,112)	
Winter flounder	2,204	(2,204)	
Witch flounder	4,418	(4,415)	
Flounder (non-specified)	3,047	(3,047)	
White hake	5,795	(5,780)	
Mackerel	5,888	(5,888)	
Alewife	2,518	(2,518)	
Smelt	1,754	(1,754)	
Sea scallop	10,221	(10,221)	
others (yellowtail, cusk,	4,284	(4,213)	
pollack, wolf fish, other			
ground-fish, salmon, capelin,			
eel, etc.)			_
TOTAL	635,886	(552,369)	metric

south during the winter. Foreign fishing activity within the Gulf increased in 1970, particularly in the cod fishery, and the area has now been declared an exclusive Canadian fishing zone, ready for unified management.

tons

There are several invertebrate species of considerable commercial significance in the Gulf, notably lobsters, oysters, other molluscs, and

shrimps; and certain of the seaweeds are also valuable economically. The lobster, in fact, to quote Wilder (1965) is one of Canada's most valuable marine resources. Southwest Nova Scotia and the southern part of the Gulf of St. Lawrence are the two Canadian areas of their greatest abundance. The fishery is operated close to shore, usually in water less than 50 metres deep. The total landed value of the lobster fishery in 1961 was \$17.9 million (compared with 15.4 for cod and 4.6 for haddock in the same year). The southern Gulf lobsters, although rather smaller than those of other areas, account for more than half the total Canadian landings.

An economic study of the Maritime oyster fishery has been published by Morse (1971). and Medcof (1961) produced an excellent general account of it. Oysters are produced throughout the southern part of the Gulf from Baie des Chaleurs to Cape Breton Island, the most important producer being Prince Edward Island. The annual value to the fishermen is of the order of half a million dollars, and according to Morse the potential of the industry is very much higher than this. There is very strong competition from the United States, whose output is much greater than the Canadian (Atlantic coast), and there has been a discouraging history of oyster disease and the effects of pollution by human sewage.

Pollution

"Quebec and the Atlantic Provinces constitute the last North American stronghold for Atlantic salmon and eastern brook trout" (Trites, 1970). The greatest producer of Atlantic salmon in the world is the Miramichi system in New Brunswick, and both salmon and trout populations were seriously threatened by the spraying of the woods with organochloride insecticides in the 1950's, in an effort to combat and control the spruce budworm. Organophosphate substances, such as Sumithion, were later substituted for the organochlorides, the former being less damaging to fish. The organochlorides, however, are highly stable compounds, and furthermore it is to be expected that the supply of them to the Gulf of St. Lawrence from the enormous drainage basin of the St. Lawrence River was, and perhaps still is, very large indeed, and we have very little information as yet on the extent of the damage done to other animal and plant species as, for instance, the sea birds. Nor do we know what quantities of pesticides (or of other pollutants, such as metals) reach the Gulf water by the atmospheric route. Of the pesticides sprayed from the air, probably only about half reaches the ground at the site of spraying; the rest becomes air-borne and may travel considerable distances.

The gannets on Bonaventure Island (located at the eastern end of the Gaspe Peninsula) are suffering from the thinning of their egg shells, one of the consequences of organochloride intake in the diet. Their diet consists very largely of small to medium-sized fish, including herring and mackerel. The limited information we have on the pesticide content of indigenous fishes in the Gulf indicates that the level is low (less than 0.1 ppm for the whole fish, and from 6 to 15 times as high for the viscera alone). The level in mackerel is considerably higher, up to 1.0 ppm for the whole fish, and in all probability the mackerel gain these levels outside the Gulf. Our knowledge of the whole matter of organochloride concentrations in the Gulf, however, as of most other pollutants, is still rudimentary.

There are approximately 50 pulp and paper mills whose effluent reaches the Gulf of St. Lawrence. The complaint about this effluent is that it is aesthetically displeasing, which is a serious effect with regard to tourism and the interests of riparian owners. At river mouths the effluent discourages salmon from migrating upstream and, if concentrated in a contained area, can impose abnormally high oxygen demands on the water.

Trites (1970) has estimated that some 200,000 lb of mercury are released annually into the St. Lawrence watershed, most of it coming from the Chloralkali industry. The threat is clearly to the River rather than to the Gulf. Quoting from Trite's report: "Lesser amounts of mercury may reach the Gulf from other sources, such as pulp and paper mills. As of 1968, five mills situated in the Gulf of St. Lawrence drainage basin were reported to be still using mercury compounds as slimicides, although the total annual usage was probably only of the order of 3000 lb of phenylmercury acetate (Fimreite, 1969)." And again: "In the Gulf of St. Lawrence, analyses have been undertaken on clams, herring, flounder, mussels, lobsters, crabs, oysters and shrimps. Preliminary results indicate that apart from a few samples taken nearby known mercury sources, levels have not exceeded the 0.5 ppm (wet weight) guideline of the Department of Health and Welfare (Bligh, pers. comm.). Relatively few analyses have been undertaken on the biota from the St. Lawrence Estuary seaward of the Saguenay. From the distribution of known mercury sources, it is likely that values in this area will be somewhat higher than in other parts of the Gulf "(Trites, 1970).

Petroleum residues (oil) in the Gulf have been studied by Levy and Walton (in press). The grounding of the Arrow in Chedabucto Bay in February 1970 had at least one positive result, namely the inauguration of general studies of the oil problem on our coast. Surveys in the Gulf were made in the summers of 1970 and 1971, the results of which are reported by Levy and Walton. The most interesting conclusion is that the concentrations of dissolved and dispersed residues are higher outside the Gulf than inside, and that there is a constant influx of oil with the water entering through Cabot Strait. In the deep water of the Gulf there is a progressive reduction of the concentration with distance from Cabot Strait, from 5-10 µg/l to less than 1µg/l. The authors point out that the dissolved oxygen values decrease in a similar pattern (see above), and that the biological degradation of the oil probably plays a part in the oxygen decline. Surface oil was found to be present at half the stations occupied, in concentrations less than 100µg/l, except in the vicinity of the Whale, a barge sunk in September 1970 on the Magdalen Shallows carrying a cargo of 4000 metric tons of fuel oil, where concentrations as high as 12,400 µg/l were recorded. The Whale sank intact, or almost so, and has been leaking persistently ever since.

Future Work, Future Management

This account of the state of our knowledge about the Gulf of St. Lawrence may give the general impression that we know quite a lot about it. A false impression, unfortunately; in fact, we are still quite ignorant of many of, the most vital points required to give us a real understanding of the mechanism of the Gulf as a whole and therefore to make management of its resources finally possible.

We talk much today of the ecosystem, of systems analysis and the systems approach to many sorts of scientific problems, an approach which is both appropriate and useful. Dickie (1971) has emphasized the need to discover what the limits of such systems are in the Gulf of St. Lawrence, and he has proposed to define a 'system' as a "set of units combined by nature or art to form an integral, organic or organized whole; an orderly working totality". By that definition, which is an excellent one, the whole world in all its complexity and its diversity of the physical, the biological, the historical and the human, is a system, which indeed it is; so that within that large system all we can hope to do is to identify subsystems, and these subsystems will be open and interconnected. In order to understand a mechanism such as the Gulf of St. Lawrence, it is necessary to break it down into units, or subsystems, and then to build models of them based on measurements in the field. It is this ecosystem research that we now have to do in order to manage
the resources of the Gulf satisfactorily, and it requires study of the physical units (bodies, populations), rate processes (photosynthesis rates, growth rates), and interrelations between them. To use a parallel from a smaller scale, in order to understand the working of a molecule it is necessary to know both the atoms and the bonds between them, and the one is as important as the other. This is the essence of interdisciplinary research.

The Gulf of St. Lawrence system, for our purposes of resource management, must obviously include the human society and its economic life, determined by the facts of the productivity, climate history and geographic position of the Gulf. But to treat that side of the system adequately would require an article at least double the length of this one, and an author with a different sort of training. It is necessary to end here, therefore, on a note of invitation.

Acknowledgements

I am indebted to many people at the Bedford Institute of Oceanography for help in finding source material and for quotable passages, and to three outside the Institute: Dr. E.L. Bousfield of the National Museum, and Mrs D.C. Maclellan and Mr. Mohammed El-Sabh, both of McGill University.

References

AUSTIN, F. W. G. 1866. On some of the fishes of the St. Lawrence. Trans. Lit Hist. Soc. Quebec, 4: 103 - 120.

BARNES, H. T. 1913. Report on the influence of icebergs, etc. . . . Can. Dept. Marine & Fish., Suppl. Ann. Rep., 1911-12. 33 PP.

BEAUVOIS, E. 1877. Les Colonies Européenes du Markland et de l'Escociland . . au IVe Siecle, etc.. . . Nancy: Crépin Leblond. 60 pp.

BLACKFORD, B. L. 1965. Some oceanographic observations in the southeastern Gulf of St. Lawrence - summer 1964. Fish. Res. Bd. Can. MS Rep. (Oceanogr. & Limnol.) No. 190.

BLACKFORD, B. L. 1967. Some oceanographic observations in the southern Gulf of St.- Lawrence - summer 1965. Fish. Res. Bd. Can. Tech. Rep. No. 25, (MS Rep.).

BOUSFIELD, E. L. 1956, Studies on the shore Crustacea collected in eastern Nova Scotia and Newfoundland, 1954. *Nat. Mus. Can Bull.*, 142: 127-152.

BOUSFIELD, E. L. 1960. Canadian Atlantic shells. Nat. Mus. Can.

BOUSFIELD, E. L., FILTEAU, G., D'NEILL, M., and GENTES, P. (in press) Recent studies on the hydrobiology of the middle St. Lawrence estuary. Nat. Canadien.

BRUNEL, P. 1971. Oceanographic studies in the St. Lawrence Estuary in 1970-72: A new interuniversity program. In: *Bedford Institute, Dartmouth, N.S., 2nd Gulf of St. Lawrence Workshop,* 1970: 131-145 (MS Rep.).

BULLEID, E. R., and STEVEN, D. M. 1972. Measurements of primary and secondary production in the Gulf of St. Lawrence. *McGill University, Marine Sciences Centre, MS Rep. No. 21.*

COOMBS, J. A. 1962. A preliminary investigation of the heat budget in the Gulf of St. Lawrence. Bedford Institute of Oceanography, Report BIO 62-1 (MS Rep.).

D'ANGLEJAN, B. 1970. Studies on the particulate suspended matter in the Gulf of St. Lawrence. McGill University, Marine Sciences Centre, MS Rep. No. 17.

O'ANGLEJAN, B., and DUNBAR, M.J. 1968. Some observations of oxygen, pH and total alkalinity in the Gulf of St. Lawrence, 1966, 1967, 1968. McGill University, Marine Sciences Centre, MS Rep. No. 7.

DAWSON, W. B. 1898. Survey of tides and currents in Canadian waters, 1896-97. Can. Dept. Mar. and Fish., Rep. Progr. 49 pp.

DICKIE, L. M. 1971. The Gulf as a biological production system. In: *Bedford Institute, Dartmouth, N.S., 2nd Golf of St. Lawrence Workshop, 1970: 88-110* (MS Rep.).

DUNBAR, M. J. 1971. The Gulf of St. Lawrence, past and future. In: *Bedford Institute, Dartmouth, N.S., 2nd Gulf of St. Lawrence Workshop, 1970:* 1-31 (MS Rep.).

DUNBAR, M. J. (in press) The nature and definition of the marine Subarctic. Trans. Royal Soc. Can.

EL-SABH, M. I., FORRESTER, W. D., and JOHANNESSEN, O. M. 1969. Bibliography and some aspects of physical oceanography in the Gulf of St. Lawrence. *McGill University, Marine Sciences Centre, MS Rep. No. 14.*

ELSABH, M. I., and JOHANNESSEN, O. M. 1972. Winter geostrophic circulation in the Gulf of St. Lawrence. J. Fish. Res. Bd. Can., 29: 595-598.

FARQUHARSON, W. I. 1962. *Tides, tidal streams and currents in the Gulf of St. Lawrence*. Can Dept. Mines and Tech. Surveys, Mar. Sci. Branch. 76 pp.

FIMREITE, N. 1969. Mercury uses in Canada and their possible hazards or sources of mercury contamination. *Can. Wildlife Serv. MS Rep. No. 17.*

FORRESTER, W. D. 1964. A quantitative temperature-salinity study of the Gulf of St. Lawrence. *Bedford Institute of Oceanography, Report BIO 64-11* (MS Rep.).

FORRESTER, W. D. 1967. Currents and geostrophic currents in the St. Lawrence estuary. *Bedford Institute of Oceanography, Report BIO* 67-5 (MS Rep.).

FORRESTER, W. D. 1970. Geostrophic approximation in the St. Lawrence Estuary. *Tellus, 22: 53-65.*

FORRESTER, W. D., and VANDALL, P. E., JR. 1968. ice volumes in the Gulf of St. Lawrence. *Bedford Institute, Report BI 68-7* (MS Rep.).

HERMANN, F. 1967. Temperature variations in the west Greenland area since 1950. In: International Commission for the Northwest Atlantic Fisheries (ICNAF) Red Book 1967, Part IV: 76-85.

HJORT, J. 1919. Canadian Fisheries Expedition, 1914-1915. Can. Dept. Naval Service, Ottawa. 594 pp.

INGRAM, R. G., JOHANNESSEN, O. M., and POUNDER, E. R. 1968. A pilot study of ice drift in the Gulf of St. Lawrence. *McGill University, Marine Sciences Centre, MS Rep. No. 5.*

KEEN, M. J. 1971. An outline of the development of the Gulf of St. Lawrence. Bedford Institute, Dartmouth, N. S. 2nd Gulf of St. Lawrence Workshop, 1970: 111-130 (MS Rep.).

KELLY, W. 1837. On the temperature of the surface water over the banks and near the shores of the Gulf of St. Lawrence. *Trans. Lit. Hist. Soc. Quebec, Ser. 1,* 3: 316-321.

KRANCK, K. 1971. Surficial geology of Northumberland Strait. *Marine Science Paper 5 / Geological Survey of Canada Paper 71-53.* Marine Sciences Branch, Department of the Environment, and Geological Survey of Canada, Department of Energy, Mines and Resources, Ottawa, Canada. 10 pp.

LAUZIER, L. M. 1967(a). Bottom residual drift on the continental shelf area of the Canadian Atlantic coast. J. Fish. Res. Bd. Can., 24: 1845-1859.

LAUZIER, L. M. 1967(b). Recent trends in temperature variations in ICNAF sub-area 4. In: International Commission for the Northwest Atlantic Fisheries (ICNAF) Red Book 1964, Parr IV: 24-32.

LAUZIER, L. M., and BAILEY, W. B. 1957. Features of the deeper waters of the Gulf of St. Lawrence. Bull. Fish. Res. Bd. Can., No. 111: 213-250.

LAUZIER, L. M., and BARTLETT, J. I. 1961. Heat budget studies, Gulf of St. Lawrence. In: Fish. Res. Bd. Can. St. Andrews, Ann. Rep. and Investigators Summaries, 1960-61: 217-219.

LAUZIER, L. M., and GRAHAM, R. G. 1958. Computation of ice potentials and heat budget in the Gulf of St. Lawrence. Fish. Res. Bd. Can. MS Rep. No. 11.

LAUZIER, L. M., and TRITES, R. W. 1958. The deep water in the Laurentian Channel. J. Fish. Res. Bd. Can., 15: 1247-1257.

LEE, A. 1967. Fluctuations in sea and air temperature in the ICNAF area since 1950. In: *International Commission for rhe Northwest Atlantic Fisheries (ICNAF) Red Book 1967, Parr IV: 3-5.*

LEVY, E. M., and WALTON, A. (in press) Dispersed and particulate petroleum residues in the Gulf of St. Lawrence. J. Fish. Res. Bd. Can.

LORING, D. (in press) Morphology and sediments of the Gulf of St. Lawrence. Bull. Fish. Res. Bd. Can.

MANN C. R., GRANT, A. B., and FOOTE, T. R. 1965. Atlas of oceanographic sections, Northwest Atlantic Ocean, Feb. 1962 - July 1964. Bedford Institute of Oceanography, Report BIO 65-16 (MS Rep.).

MATHESON, K. M. 1967. The meteorological effect on ice in the Gulf of St. Lawrence. McGill University, Marine Sciences Centre, MS Rep. No. 3.

MEDCOF, J. C. 1961. Oyster farming in the Maritimes. Bull. Fish. Res. Bd. Can. No. 131.

MORSE, N. H. 1971. An economic study of the oyster fishery of the Maritime Provinces. Bull. Fish. Res. Bd. Can. No. 175.

PLATT, T. 1972. The feasibility of mapping the chlorophyll distribution in the Gulf of St. Lawrence. *Fish. Res. Bd. Can. Tech. Rep. No.* 332 (MS Rep.).

SRIVASTAVA V. M. 1971. Fish of the Gulf of St. Lawrence; an unabridged bibliography. Fish. Res. Bd. Can. Tech. Rep. No. 261 (MS Rep.).

STEVEN, D. M. 1971. International Biological Programme study of the Gulf of St. Lawrence. In: Bedford Institute, Dartmouth, N.S.: 2nd Gulf of St Lawrence Workshop, 7970: 146-169 (MS Rep.).

SUTCLIFFE, W. H., JR. 1972. Some relations of land drainage, nutrients, particulate material and fish catch in two eastern Canadian bays. J. Fish. Res. Bd. Can., 29: 357-362.

TRITES, R. 1970. The Gulf of St. Lawrence from a pollution viewpoint. Paper presented at: FAO Technical Conference on marine pollution and its effects on living resources and fishing, Rome. Dec. 1970. 23 pp.

TRITES, R. 1971. The Gulf as a physical oceanographic system. In: *Bedford Institute, Dartmouth, N.S.: 2nd Gulf of St Lawrence Workshop, 1970: 32-63* (MS Rep.).

WALTON, A. 1971. An approach to chemical oceanography in the Gulf of St. Lawrence. In: Bedford Institute, Dartmouth, N.S.: 2nd Gulf of St. Lawrence Workshop, 1970: 64-87 (MS Rep.).

WHITEAVES, J. F. 1872. Report on a deep sea dredging expedition to the Gulf of St. Lawrence. In: Canada, Depr. Mar. and Fish., 4th Ann. Rep.

WILDER, D. G. 1965. Lobster conservation in Canada. In: International Council for he Exploration of the Sea (ICES) Rapp. et Proc.-Verb., 156: 21-29.

The Bedford Institute of Oceanography and Industry - Experience and Progress in the Past Decade

R. L. G. Gilbert, C. S. Mason, Atlantic Oceanographic Laboratory

Over the past ten years the Bedford Institute of Oceanography has developed close working relationships with Canadian industries, particularly with firms in the Halifax-Dartmouth region. As a result of growing recognition of the importance of the resources of the sea and the problems of marine pollution, this liaison is receiving careful attention. An opportunity to further increase industrial involvement at the Institute is presented by the new 'make or buy' policy of the Federal Government. This policy, which is based on recommendations contained in Volume 2 of the Lamontagne Report¹, states that 50% of government research will be carried out by contract with industry by 1980.

Institute contacts with industry cover a wide range of activities, and may usefully be divided into four broad categories:

- outside services providing support to projects carried out by Institute staff, e.g. equipment maintenance;

- contracted research, e.g. for the design and development of new equipment;

- transfer of new designs of equipment and new techniques from the Institute to world markets, using industry as the vital link and to mutual advantage;

- consulting services, drawing upon the broad base of expertise available at the Institute.

Services

When the Institute was founded there were insufficient support facilities in the area to meet all the requirements. This led to a build-up of in-house competence which naturally tended to grow to meet all the needs of the Institute. Only recently has the emphasis swung towards a greater use of external services.

Services such as illustrations and drafting, photography, and building maintenance can depend heavily on outside support. To ensure quality it is essential to have a small group of highly skilled staff employed at the Institute who are knowledgeable both of the research and survey programs concerned and of the technology involved in the service. In addition to quality control, in-house staff also administer the contracts and guide and instruct the user at the Institute how best to proceed to meet his requirement. This approach benefits the Institute by economically providing the level of service necessary to meet the demand, which can vary from month to month. It benefits the local area by encouraging the growth of support industry which is a material factor in attracting new industries.

Electronic and electro-mechanical equipment which is normally used in the laboratory rather than in the field can well be serviced by local industry. Currently most of the electronic test equipment as well as several types of highly specialized and unique apparatus are maintained under contract. The success attained in contracting out. many service requirements is leading to a gradual transfer of more of this work to industry.

It has traditionally been considered essential for the Institute to provide maintenance facilities and skilled personnel in the field programs and aboard ships. Yet these skilled staff are employed in the field for only a portion of each year and when at the home base are occupied with more routine technical services. We are attempting to broaden the involvement of industry by contracting for the services of skilled technologists required to support selected surveys in the field. It is possible that eventually only sufficient maintenance staff will be retained in-house to ensure quality and provide contract management. However, experience has shown that to monitor and control the quality of contracted work we must continue to employ a nucleus of highly skilled personnel who are familiar with the problems of working under the difficult conditions aboard ships and at remote land-based support stations.

An increase in the use of contracted services may also be observed in the Institute's ship charter program. Some of the more routine survey operations have been successfully transferred to charter vessels and in 1972 a complex hydrographic and geophysical charting program was highly successful using a chartered ship. The seasonal nature of requirements such as surveying makes the use of a charter advantageous as the vessel is 'off strength' immediately at the end of our requirement - thus we need not maintain an expensive facility in a standby condition. While we shall always require highly sophisticated research vessels on a year-round basis, probably provided in-house, recent experience has proven that some requirements can be successfully met by chartering commercial ships. We are transferring our seasonal vessel requirements to long term, five-year charters, which ensures continuity of program both to the Institute and to the supplier.

Contracted research and professional services

The first experience at the Institute with a completely funded research and development contract dates back to before the opening of the present building in 1962. The project, for the development of a comprehensive shipboard plotting system, was a complete disaster. The specifications were unrealistic and incomplete, and the contractor grossly underestimated the costs and was also inexperienced to the point of being incapable. The project was probably technologically impossible at that time. As a result several hundred thousand dollars and considerable ship-time were wasted. These events made it clear that in order to interpret and translate the needs of the user to the designer the Institute requires engineers on staff who are closely involved with the field programs. The requirements of the Institute for improved productivity can only be interpreted and translated into technological development if the real needs of the user can be communicated to the designer.

As a result of the above experience a different approach was used when the Institute attempted to acquire a new instrument by outside contract. This time detailed specifications for the completed and working item were provided. The first instrument produced using this approach was also a failure despite the fact that it was developed by a Canadian company which was a world expert on land-based instruments of similar type. At the heart of the problem was a failure of the Institute and the developer to fully recognize the requirements for extended periods of field trials before an instrument can be successfully completed.

Over the past ten years, experience has shown that the vast majority of oceanographic equipment, even apparently true and tried equipment, does not work when received at the Institute. In many cases the problems are minor and are relatively easily rectified after field testing, but it is sometimes necessary either to undertake considerable redesign or to reject the instrument as unsatisfactory. In recent years more recognition has been given to this, and a period of extensive trials, jointly carried out by the Institute and the developer, is now part of any program for the acquisition of new equipment. These trials in effect constitute a major subsidy to the company developing a new product for the world-wide market. Several non-Canadian firms have benefited from this type of indirect support, leading to a successful product subsequently manufactured out of Canada. Recognition of this has now led to a more determined drive to channel this type of development to Canadian, and preferably local, industries.

There remain several sources of delay in setting up a development contract with a local industry. The necessity of considering most seriously the lowest bidder for any contracted item does not always favour the selection of a young local firm against established foreign competition. It is not yet clear how or whether government make or buy' policy will tackle this problem and achieve the objective of developing Canadian industry in a competitive economy.

A second problem which we have not yet solved relates to the delays caused through contracting procedures within government agencies. This particularly affects the scientist who requires a new item of equipment to be developed as quickly as possible. Hopefully, as new procedures are developed and as contracting becomes more routine, less time will be lost in initiating new projects under government contract regulations.

Another problem relates to the delays involved in attempting to obtain services in the local area. Obtaining expertise locally is a difficult problem; at least twice we have delayed programs for about one year in attempts to obtain local support. In both cases the work had to be finished in-house and seriously delayed the successful completion of the scientific program. The inevitable reaction on the part of the user was a reluctance to go outside within the short-term range of any single program. As science-based industries expand in the local area much of this difficulty will disappear, but several more years at least will pass before we can expect an immediate local response to some difficult or unusual problem. We do not believe that the permanent solution lies in sending the work out of the region to central Canada (where many services are readily available which give a quick turn around) because of problems of communication and also the difficulties such services have in understanding the complexities of the marine environment (the latter increasing rapidly with the distance of the firm from the sea).

The Federal Government has announced its intention that 50% of government research will be carried out by contract with industry by 1980. If the capability to carry out this work is going to exist, industry will clearly be employing large numbers of research and development staff. It is likely that an appreciable proportion of this staff will be recruited from government laboratories - indeed the process has already begun at the Institute - but, during the next two or three years, most firms will not be financially in a position to hire full-time staff. Part-time staff may be hired, from universities or government laboratories, in order to handle the first contracts. Rules concerning the part-time employment of government staff by industry are not clearly laid down, but in recent years several Institute staff have been granted leave of absence without pay so that they can carry out consulting

work with a commercial enterprise. No doubt the introduction of the 'make or buy' policy will force the clarification of this issue, either in a formal or in an informal manner, as the demand for research and development staff grows.

The recent drive to transfer equipment originally designed and developed at the Institute to industry has led to a greater participation of non-Institute engineers in our field program (see 'Transfer of new equipment' below). In addition we have had industrial engineers participating in field programs to test marine equipment which they have developed but which is intended for non-Institute applications. While it may seem difficult to justify this direct subsidy to a local firm, it must be remembered that such projects develop a base of greater experience in ocean engineering within Canada and in particular in the Halifax-Dartmouth region. The 'make or buy' policy should enable us to increase this base and expand science-based industries in this area. already a major world centre for oceanographic research. There are already approximately 586 scientists, engineers and senior technical staff working in the marine sciences field in the Halifax-Dartmouth area²; thus, assuming a ratio of professional-to-support staff of 1:3, approximately 2000 people are directly employed. With such a large base on which to build, we hope that a significant number of new programs at the Institute will have a substantial proportion of outside participation.

Transfer of new equipment

As a result of the Institute's research and development programs, a number of new instruments have been developed in-house over the years and there has been a continuing program to transfer these developments to local industry. One of the problems associated with such transfers has been the very limited local capability for research and marketing. One of the first instruments developed at the Institute was, when first commercially available, the only one of its type in the world market. After completion of the development at the Institute and the successful licensing through Canadian Patents and Development Limited all work on the project ceased at the Institute. As a matter of policy no diversion of effort was made to continue engineering support to the licensed manufacturer on the assumption that continued subsidization would not help and might hinder commercial success. The manufacturer made design changes which prevented the instrument from giving correct results, and in addition after several years a newer and much improved version became available elsewhere. The failure of the locally built instruments reflected badly on the Institute and on the original developer, and resulted in a major financial loss to the manufacturer who had an unsaleable inventory on hand: As a result of this experience we now continue some support for an instrument marketed after Institute development. Test facilities in the field and at Institute laboratories are provided and the Institute endeavours to keep informed of any new innovations which might cause quick obsolescence.

Recently one of our engineers has assumed the responsibility for technological transfer and we are working much more closely with manufacturers of Institute-designed apparatus. A major bonus to the Institute from this program is that the transfer from a prototype unit to one which can be manufactured routinely from engineering drawings is much more successful. We aim never to build more than one of any piece of apparatus, thus ensuring development staff are not employed in routine production. The assistance from local industry in producing a marketable version frees our own staff from the type of work which, by its very nature, is not done well in a research facility.

During 1972 we have concentrated on supporting the manufacture of two new developments of the Bedford Institute of Oceanography, both licensed through Canadian Patents and Development Limited. The first of these is a porpoising towed body called Batfish which undulates continuously between the surface and 200 m depth while towed forward at a speed of up to 8 ms⁻¹. The body carries a number of sensors which make *in situ* measurements and transmit data to the ship for interpretation. Used to study density distributions in the upper mixed layer, it is currently being employed for studies in the Gulf of St.



Batfish



Shallow water rock core drill.

Lawrence and in the International Field Year for the Great Lakes. In July 1972, using the CFAV *Bluethroat*, a cruise was conducted on which the *Batfish* system was demonstrated to a number of non-Canadian purchasers. Development of the *Batfish* system is continuing and we anticipate that several new sensors will be commercially developed in 1973, with the Institute assisting in field trials. A newly developed shallow water rock core drill was also tested from the *Bluethroat* during the summer of 1972. This drill is designed for operation on the continental shelf and will retrieve a 2 cm diameter core of rock up to 6 m in length. A commercial user of this type of apparatus participated in one of the cruises. We now hope that further development of the drill by this user will result in improvements which will in turn benefit the Institute; in 1973 we hope to participate in a 'non-Institute' cruise during which these developments will first be tried.

Consulting services

As a result of the diversified program at the Institute, we have experts on staff from a variety of scientific and engineering disciplines. Thus the Institute is a source of expert knowledge and our staff are frequently involved in providing advice on a variety of local, national and international problems. We are consulted on many aspects of new industrial developments which relate to the sea. Our staff have been concerned with environmental impact studies for new oil, handling facilities at Lorneville, New Brunswick; Come By Chance, Newfoundland; and Canso, Nova Scotia. An extensive study of the wave climate of Halifax Harbour was initiated in support of container pier construction. Geologists, geophysicists and physical oceanographers have been consulted on a variety of topics (such as meteorology, wave climate, bottom sediments, and bathymetry) associated with offshore oil exploitation. Institute experts are involved with international problems such as deep-sea dumping, law of the sea, and marine transportation.

The Institute's role often goes beyond the provision of expert advice alone. It is sometimes necessary to conduct field studies on which to base an expert opinion. Thus the Halifax Harbour wave study involved the installation of several measuring stations and a program of complex data analyses before specific conclusions and recommendations could be made. More data on currents were required at Come By Chance, and a cruise was conducted to install strings of current meters at carefully selected critical points. The Institute played a major role in the environmental crises associated with the sinking of the tanker *Arrow* in Chedabucto Bay, Nova Scotia, and the 'red' herring phosphorus pollution incident in Placentia Bay, Newfoundland. The Institute is represented on the local Marine Applications Council. The Council is a group of industrial and research experts from the Atlantic region with a common goal of fostering development of Canada's maritime resources in a meaningful and well planned fashion. Another point of contact with industry has been in recent scientific and technical missions to Japan and the Federal Republic of Germany. These missions, which are sponsored by the Ministry of State for Science and Technology, serve a twofold purpose: the relationship between the Institute and Canadian industries is strengthened as a result of joint participation in a mission with a common goal; and the prime purpose of broadening Canadian international contacts is achieved.

A major program in which the Institute and industry participated jointly was a recent geophysical study in Baffin Bay. This joint industry-university-Institute program has been cited by A. E. Pallister, Vice-Chairman of the Science Council, as an example of fruitful scientific cooperation.

Conclusion

The Bedford Institute of Oceanography is involved with Canadian industry in many facets of its work. This symbiotic relationship will continue to develop, particularly as the government's 'make or buy' policy results in a more free and easy exchange of people and ideas between industries and government laboratories. We can look forward to an interesting and challenging future as Canadians (and in particular scientists and engineers in the Halifax-Dartmouth area) combine their talents to meet the expanding challenge of using and managing our marine environment.

References

- The Senate Special Committee on Science Policy. 1972. A Science Policy for Canada, Volume 2: Targets and Strategies for the Seventies. Hon. M. Lamontagne (Chairman). Information Canada, Ottawa. 608 pp.
- 2. Nova Scotia Dept. of Trade and Industry. 1973. The Ocean Science industry of Nova Scotia. Prepublication edition.

Marine Pollution Research

D. C. Gordon, Marine Ecology Laboratory; A. Walton, Atlantic Oceanographic Laboratory

Pollution is generally defined as the deleterious alterations occurring in the environment as a result of man's activities. Pollution is as old as man but few recognizable problems were apparent until the coming of the industrial revolution at the end of the nineteenth century. Since then both the extent and severity of pollution have been increasing steadily such that today even the oceans are showing signs of serious pollution.

Pollution has brought about the most obvious changes to the marine environment in coastal and estuarine areas. Many river estuaries in developed nations have lost forms of biological life and, in several instances, the chemical conditions have changed from oxidizing to reducing during the past few decades. In many cases these profound changes can be ascribed to the discharge of sewage (substantially untreated) to coastal waters. In the major industrial areas of the United Kingdom it has been estimated that 80% of all estuaries are in poor condition and in need of improvement, and 40% are considered to be grossly polluted. In the United States, in the case of the Hudson estuary, it is understood that the assimilative and recycling capacity of the water body for nutrients (e.g. phosphates, nitrates, silicates) is already being exceeded by a factor of 5 to 10.

Until recently there was little interest in marine pollution outside of coastal areas. Few people realized that problems existed or were even developing in the seas and oceans. However, numerous pollution studies have recently been stimulated at marine laboratories throughout the world by many alarming events and observations:

- the increasing frequency of oil spills and occurrence of tar lumps on the sea surface and beaches near major shipping routes;

- the reports of high concentrations of toxic metals in certain food fishes;

- the apparent widespread distribution of organochlorine pesticide residues in marine organisms from all depths and geographic regions of the sea.

Pollutants entering the marine environment can be divided into two distinct categories: 'natural' and 'man-made'. Natural pollutants are compounds which are products of natural processes; included in this category are: unrefined petroleum compounds, heavy metals such as mercury and cadmium, and nutrients such as nitrogen and phosphorus. Because of man's influence the flux of these compounds into the environment has accelerated. Studies of their behaviour are complicated by the need to distinguish between the natural background concentra-

tions, which can fluctuate quite significantly from time to time and place to place, and the amounts added as a result of man's activity. Failure to recognize and appreciate natural concentrations and fluctuations can introduce serious errors in interpreting results.

Man-made pollutants on the other hand are those that do not occur naturally but have been synthesized by man; such as, certain refined petroleum products, halogenated organic chemicals such as DDT and polychlorinated biphenyls (PCB's), plastics, detergents, pharmaceuticals, and radioactive elements. Since there is normally no natural background concentration the mere presence of these substances in the ocean indicates contamination. This broad group of pollutants is generally more persistent and perhaps more dangerous than natural pollutants since natural systems may not be capable of utilizing, degrading, and recycling them.

Marine pollution research involves many scientific disciplines, including meteorology, physical and chemical oceanography, geochemistry, physiology, and ecology. All must work together to tackle the problem of a suspected pollutant, deciding whether or not it is endangering the health of the ocean. This multidisciplinary approach requires both investigators with broad scientific backgrounds in oceanography and research teams composed of specialists with different scientific backgrounds.

All pollutants reaching the ocean can be classed as chemicals, with the exception of heat. When a new pollutant is recognized the first step in its investigation is the development of suitable analytical methods for detecting it in different reservoirs of the marine environment (in the air as aerosols, in seawater as suspended matter, in organisms ranging from plankton to whales, and in sediments). This is the task of analytical chemists. It is a generally difficult one because pollutant concentrations are extremely low, often in the parts per billion range. It is not surprising therefore that most analytical methods developed to date are for measuring pollutants in marine organisms where concentrations are usually greatest. For example, concentrations of organochlorine residues in seawater are only a few parts per trillion while in organisms they generally range from 1 to 10 parts per million. When analytical methods become used routinely in different laboratories it is imperative that interlaboratory calibration checks are frequently made to ensure that all analyses are comparable.

Once an analytical method has been developed in the laboratory, suitable sampling procedures must be devised; such sampling is generally done from ships. The problem is to avoid contamination of

the specimen during the sampling operation since all vessels constantly exude many of the same pollutants as those under investigation; for example: petroleum hydrocarbons originate from stacks, deck machinery, bearings and bilges; trace metals are present in rust and paint chips; and even chlorinated hydrocarbons, such as PCB's, are present in hydraulic fluids. These pollutants can quickly spread across the sea surface and easily contaminate samplers being lowered to deeper water.

Having developed accurate analytical and sampling procedures a survey can be conducted, in the marine area of interest, to determine the pollutant concentration and distribution in different environmental reservoirs. Again, care must be taken in the case of natural pollutants to distinguish true pollutant concentrations from natural background levels. This may require several years of observation in regions where seasonal changes are extreme, such as off eastern Canada. The whole issue of mercury contamination in pelagic fish was confused by failing to understand natural background concentrations. Recent evidence strongly indicates that high mercury concentrations occur naturally and are not the result of pollution.

When significant quantities of a pollutant are found in the marine environment it is necessary to determine where it originated. It is important to measure the rates at which a pollutant is introduced into the ocean and to understand the points and mode of entry. Pollutants generally enter the ocean from rivers, precipitation, atmospheric fallout, waste outfalls, ships, etc. Most pollutants enter the ocean in the northern hemisphere near the large population and industrial centres.

Once a pollutant enters the ocean, concern turns to its dispersal and transportation away from the injection point; both physical and chemical processes are important here, including the chemical form(s) and transformations of the substance.

There is increasing interest in the development of physical models which explain, and which can be employed to predict, mass movement of water in estuaries, coastal zones and the deep ocean. Although estuarine areas have recently received most attention by modellers the predictive capability of the ensuing models is apparently quite limited at this time. Significant difficulties appear to arise because of the large time variations occurring in such physical parameters as fresh-water inflow and wind-stress under natural conditions. In many estuaries the situation is further complicated by the variability caused by man, e.g. the modification of the fresh-water inflow of rivers - a good example of which is to be found in the St. Lawrence Estuary where the pattern of river inflow from the Quebec drainage area has changed substantially with the installation of hydro-electric schemes during the past decade.

Of particular interest in studies of the chemical factors affecting dispersal and transportation of pollutants is the role being played in the oceans by sea slicks or surface films. These less-soluble films - organic in nature - are suspected as being of significance in the transport of some of the more notorious organic pollutants such as DDT, other chlorinated hydrocarbons, and perhaps even the organometallic complexes of heavy metals. Petroleum products occurring in the oceans and originating from a number of sources, both natural and man-made, not only serve to increase the occurrence of such surface films but also constitute a route whereby pollutants can ultimately be transferred to the biota in the process of biodegradation.

When significant concentrations of a pollutant are detected in the environment it is necessary to determine what the hazard is. It is the role of the life scientists, principally physiologists and ecologists, to determine if the pollutant in question affects the ecological health of the oceans in the form(s) and at the concentration in which it is found.

In studying the interaction between pollutants and marine organisms two approaches are taken, (1) how do organisms affect pollutants, and (2) how do pollutants affect organisms. The first approach considers the transfer and alterations of a pollutant as it passes through biological systems. It is important to understand how pollutants are taken up by marine organisms and how they are subsequently altered and transferred. Numerous mathematical models have recently been developed which describe the dynamics of pollutant transfer in marine production systems. It now appears that pollutants such as mercury and organochlorine residues are not primarily concentrated through the food chain, as was earlier thought, but are taken up from the water around an organism at rates related to body size and metabolism. The second approach considers the effects a pollutant can cause on organisms that come into contact with it. Most work to date in this area has been done using acute toxicity experiments which have many shortcomings. More effort is now being expended to study the long-term, sub-lethal effects of pollutants on biological processes such as reproduction, growth, feeding, behaviour, and survival; this is being done at various organizational levels ranging from single organisms to entire communities.

In order to determine the real threat of a pollutant in the sea a multi-disciplinary study is obviously required. At the present, most of the work in this field is done by university and government scientists who find it increasingly difficult to keep up with the ever-expanding list of new compounds introduced into the ocean each year.

The Marine Ecology Laboratory, the Atlantic Oceanographic Laboratory, and the Atlantic Geoscience Centre, the three research laboratories at the Bedford Institute of Oceanography (BIO), are all involved, often jointly, to varying degrees in marine pollution research. Also located at the Bedford Institute of Oceanography are the laboratories of the Environmental Protection Service, the federal agency responsible for the abatement of pollution in both the marine and freshwater environments. Two principal geographic regions in which marine pollution research is being conducted by scientists at BIO are the Gulf of St. Lawrence and a section between Halifax and Bermuda.

In the Gulf of St. Lawrence there has been growing interest in understanding the various chemical, biological, physical and geological processes. This interest has led to the proposed Gulf of St. Lawrence Program, a multidisciplinary study of the Gulf spread over a period of several years. However, a considerable amount of marine pollution research has been in progress in this area for some time. Within the geosciences studies have been directed toward a better understanding of the influences of sedimentation processes on heavy metal pollutants. In addition, certain paleontological studies relating to population changes occasioned by industrial effluents are being performed. Physical and chemical studies have been focussed on: the distribution of suspended and floating petroleum residues and pulp and paper wastes; the concentration of pesticide residues and PCB's in different types of marine organisms and in sediment; and the determination of mercury in sediments. The occurrence and distribution of petroleum residues has



The distribution $(\mu g/I)$ of petroleum residues in dissolved and dispersed forms at the surface of the Gulf of St. Lawrence (July 12-August 8, 1971).



The distribution (mg/m^2) of particulate and 'fresh' petroleum residues floating on the surface of the Gulf of St. Lawrence (July 12 - August 8, 1971).

produced some interesting conclusions as may be seen from some of the data presented in the figures. It is clearly evident that at the time of the studies certain 'hot spots' were detectable. Leakage from the sunken barge *Whale* is undoubtedly responsible for one hot spot on the Magdalen Shallows. Other localized areas of high concentrations of dissolved and particulate petroleum residues are believed to be attributable to shipping activity. On the whole, however, the pattern of concentrations is more likely the result of oceanographic conditions prevailing in the region.

The Halifax-Bermuda section is of interest because it crosses a wide variety of marine environments: Halifax Harbour and Bedford Basin, the Scotian Shelf, slope water, the Gulf Stream and the Sargasso Sea. The concentration, distribution, and effects of various pollutants can therefore be compared under quite different conditions ranging from a busy harbour to the open sea far from land. This section is also of interest for marine pollution research because it lies just downwind of northeast North America, a region of concentrated industrial activity. To date along the section there have been studies of: the concentration and distribution of suspended and floating petroleum residues; the effect of observed petroleum residue concentrations on marine phytoplankton photosynthesis: the concentration and distribution of total mercury in seawater; and the concentration of pesticide residues and PCB's in marine zooplankton.

In Canada a comprehensive survey of the degree to which pollution is now affecting coastal areas is needed. Studies of some of these key areas have been, and still are, underway; such as, Bedford Basin in Nova Scotia, and the Strait of Georgia in British Columbia. However, an assemblage of knowledge for the country as a whole is an important task. From such a review a national policy could be developed for the continued development of the coastal area in keeping with environmental constraints.

As far as the high seas are concerned Canada undoubtedly has a commitment to pursue scientific endeavours leading to greater understanding of these areas. The fact that pollution knows no boundaries in the atmosphere is also evident in the oceans. Coastal waters and the further reaches of the oceans are inseparable as far as physical, chemical and biological transport mechanisms are concerned. In the past two years Canada has participated in discussions of marine pollution matters and will continue to do so in the future. As a consequence of the international deliberations on environmental concerns held in Stockholm in June 1972, Canada has recognized her obligations to cooperate with others in actions dedicated to the preservation and enhancement of the quality of the oceans. International agreement was reached in December 1972 to limit the practice of dumping of hazardous chemicals and other pollutants in the oceans. Although this agreement is in need of strengthening it does represent a considerable step forward. Within the next two years further international agreements are likely to be forthcoming. These will deal with pollution from ships' activities and the development of a comprehensive law of the sea regarding the many aspects of the usage of the oceans.

It is to be hoped that Canada will continue its role in environmental matters as a country dedicated to concern for the surroundings. In performing this role, however, Canada must be committed to the development of tidiness in-house, i.e., in inland waters and Coastal areas, in order to be able to speak forcibly in the international forum. In-house attitudes rest eventually on the desires of the people for a high quality of life as opposed to more immediate desires which may, in the long term, lead to irreparable environmental damage.

Further reading

Food and Agricultural Organization (FAO) of the United Nations. 1971. Global investigation of pollution in the marine environment. Report *of Joint Working* Parry. FAO, Rome. 18 pp.

Hood, D. W. (ed.) 1971. Impingement of man on the oceans. Wiley Interscience, New York. 738 pp.

International Council of Scientific Unions (ICSU). 1971. Global environmental monitoring. *Report of the Scientific Committee on Problems of the Environment (SCOPE)*. Tryckindustri AB, Solna, Sweden. 67 pp.

International Decade of Ocean Exploration (IDOE). 1972. Baseline studies of pollutants in the marine environment and research recommendations. *Proc. I.D.O.E. Baseline Conf., New* York, May 1972. 54 pp.

National Academy of Sciences. 1971. Chlorinated hydrocarbons in the marine environment. Report prepared by the Panel on Monitoring Persistent Pesticides in the Marine Environment of the Committee on Oceanography. National Academy of Sciences, Washington, D.C. 42 pp.

National Academy of Sciences. 1971. Marine environmental quality. Report of a special study held under the auspices of the Ocean Sciences Committee of the NAS-NRC Ocean Affairs Board. National Academy of Sciences, Washington, D.C. 107 pp.

National Academy of Sciences - National Academy of Engineering, 1970. Wastes management concepts for the coastal zone - requirements for research and investigation. *Report by the Committee on Oceanography and Committee on Ocean Engineering*. National Academy of Sciences, Washington, D.C. 126 pp.

Reed L. 1972. An ocean of waste, some proposals for clearing the seas around Britain. Oliver Burridge & Co., Crawley, Sussex. 72 pp.

Royal Commission on Environmental Pollution. 1972. Pollution in some British estuaries and coastal waters. *Third Report of the Royal Commission on Environmental Pollution*. HMSO, London. 128 pp.

Study of Critical Environmental Problems (SCEP). 1970. Man's impact on the global environment: assessment and recommendations for action. The MIT Press, Cambridge, Mass. 319 pp.

Taylor, G. R. 1970. The threat to life in the sea. Saturday Review Magazine, 1 August 1970: 40-42.

Baffin Bay - One Piece in the Jigsaw Puzzle of Global Tectonics

D. I. Ross, Atlantic Geoscience Centre

Baffin Bay is a small intercontinental sea separating Greenland from Arctic Canada. To the south it is separated from the Labrador Sea by the Davis Strait sill and to the north from the Arctic Ocean by Nares Strait. Additional access to the Arctic Ocean is provided by the Arctic Channels, notably Lancaster Sound.



Map of the Baffin Bay area showing in simplified form the geology and bathymetry.

The central basin of Baffin Bay reaches a depth of 2400 metres. To the east, the continental shelf of West Greenland is broad and deep, typically 400-600 metres. To the west the Baffin Island continental shelf is narrow and, for the most part, at depths of less than 200 metres. Numerous transverse troughs cut both continental shelves. There is a particularly prominent marginal channel in Melville Bay, approximately parallel to the northwestern Greenland continental margin; bathymetry data fail to reveal similar major features parallel to the Baffin Island shelf. To the south the bay shallows gently to 600 metres over the Davis Strait sill. Early magnetic data suggested this sill to be at least partly basaltic in nature, and possibly related geologically to the Tertiary basalts occurring around Disko Island and Cape Dyer, In the northwest there is a gradual shallowing into the southern portion of Smith Sound. The topography here is irregular but is generally shallower than 600 metres (Keen et *a*/., 1971).

The onshore geology surrounding the Bay is dominated by Precambrian crystalline rocks. These rocks are overlain in places by late Precambrian and lower Paleozoic sediments and on opposite sides of Davis Strait by Cretaceous and Tertiary sediments and volcanic rocks. These volcanic rocks are part of the Brito-Arctic province of Tertiary igneous rocks stretching from West Scotland to the eastern part of Baffin Island.

In 1970 seismic refraction measurements showed that Baffin Bay was not underlain by continental material as had been sometimes suggested. The crust was surprisingly thin, the crust-mantle interface being only 10 km below the sea surface. This meant that Baffin Bay was in fact a small ocean (Barrett *et al.*, 1971). Subsequent refraction measurements in the area (Keen and Barrett, *in press*) have shown an almost uniform thickness of 4 km of sediment across the central portion of the bay, as illustrated in the following figure. The sediment thickness increases to 6-7 km in the northern limit of the deep basin.



Crustal section across Baffin Bay from west to east as deduced from the seismic refraction lines C2, C3, etc., spaced approximately 50km apart across the deep central portion of the Bay (from Keen and Barrett 1972).

The results of the seismic measurements raise the question of the origin of Baffin Bay. From an examination of aeromagnetic profiles across the Labrador Sea, Hood and Godby (1964) suggested that the Labrador Sea was formed by sea floor spreading from a central Mid-Labrador Ridge. Le Pichon et al. (1971) identified a central ridge using seismic reflection techniques. In their reconstruction they suggested that the Labrador Sea ridge was offset from a similar spreading centre in Baffin Bay by a transform fault through Davis Strait (see figure). In present theories of plate tectonics, sea floor spreading is the only mechanism which satisfactorily explains the creation of oceanic crust. The geometry of the area imposes limitations on any such spreading and is therefore an important factor in deducing the history of evolution. Since the thickness of the crust changes from 10 km to 30-50 km across an ocean-continent boundary with a consequent major change in near-surface mass, surface ship gravity measurements provide a powerful tool in mapping the boundary. The extent of this transition zone as shown by the gradient of the gravity field across the boundary will depend on how the continental margin was formed and its subsequent history.

In the summer of 1971 the Marine Geophysics Division of the Bedford Institute of Oceanography carried out a major geophysical reconnaissance program in the Baffin Bay area. The main objectives of the cruise were:

- to study the variations in crustal structure across the bay in order to delineate any ancient spreading centre which might have been connected to the Mid-Labrador Sea ridge and which could explain the origin of the basin;

- to map the ocean-continental boundary as accurately as possible;

- to study some of the major features known to exist on the surrounding continental shelves which might throw some light on the history of separation of Greenland from Arctic Canada;

- to obtain information on the crustal structure of Davis Strait and to determine its importance in the evolution of the bay.

Although reconnaissance in nature the cruise proved very productive. Seismic refraction studies (Keen and Barrett, *in* press) indicated a remarkably uniform crustal section across the bay (see above figure) but failed to indicate the presence of a buried ridge, a feature normally associated with spreading centres found in major oceans. Of interest also was the suggestion that the depth of the crust-mantle interface increased significantly towards Greenland; this was further borne out by gravity measurements. A long reflection line through Davis Strait indicated that a considerable thickness of oceanic crustal material underlies the Strait similar to that observed beneath Iceland. The total crustal thickness in Davis Strait is 22 km - twice that of the deep bay to the north. Gravity measurements (Ross, *in* press) combined with seismic data from strategic lines have enabled the ocean-continental boundary to be well defined over most of Baffin Bay.



A very simplified diagram of a possible ridge, transform fault structure which may explain the opening of Baffin Bay. The centre of spreading is defined by the dashed line. Note that spreading associated with the Nansen Ridge in the Arctic Ocean subsequent to cessation of spreading on the Labrador Sea, Baffin Bay, Alpha Cordillera system has resulted in the displacement of the Alpha Cordillera west from the northern extension of Nares Strait along the Nansen fracture zone.

The transition zones off Baffin Island and Greenland are both narrow, consistent with the idea that they are primarily rifted margins. The northern margin at the mouth of Smith Sound is less clearly defined. Because of its striking linearity, Nares Strait has long been suggested as a major fault structure, and it has been considered by some (e.g. Wilson, 1965; Vogt and Ostenso, 1970; C. E. Keen et *a*/., 1972) to be a transform fault connecting the spreading centre through Baffin Bay

with one of the ridges which crosses the Arctic Ocean, such as the Alpha Cordillera; this is illustrated in the previous figure. Refraction measurements in Smith Sound indicated a continental crust although the total crustal section was not defined. The gravity data suggest a broad transition zone from the central oceanic area into a region of thin (~ 20 km) continental crust. Seismic reflection and magnetic data show several fault-bounded, sediment-filled troughs crossing the shelf in a northwest-southeast direction, and the reflection data also indicate cross-faulting within these features - the direction of these younger faults being approximately north-south. These troughs are aligned with similar Paleozoic troughs in the Thule-Dundas area and are assumed to be of a similar age. The cross-faulting within the troughs suggests tension stress in an east-west direction subsequent to their formation.

Following on from the early government and university work the petroleum industry commenced exploration in Baffin Bay and the adjacent continental shelves in 1971 (Pallister, 1972). The thick sediments suggested by magnetic data (Barrett and Manchester, 1969; Hood, 1968; C. E. Keen et al., 1972; M. J. Keen et al., 1972) were of considerable interest to the petroleum industry, particularly when the refraction results of 1970 showed velocities consistent with sediments of Mesozoic and Cenozoic ages which are in turn consistent with the possibility of oil deposits. As a result a greatly expanded exploration effort has occurred on the Canadian side of Baffin Bay during the last two years. It is important to recognize the complementary nature of the work carried out by industry on the one hand and government or university research agencies on the other. The research agencies are first and foremost involved in obtaining a regional framework within which the geology of the area can be explained. As part of this some geological structure will require detailed mapping in order to provide clues to the history of the area. The exploration industry is interested in looking in detail at potentially interesting sedimentary structures. The interpretation of data that they obtain in their localized surveys is very dependent on the regional framework. For example, the interpretation of seismic velocities in the range 5-7 km/s in Baffin Bay depends critically on whether the velocities are observed in oceanic or continental areas.

What then is the regional framework that has emerged? Baffin Bay is an ocean with a surprisingly thin crustal thickness and abnormally thick sedimentary cover. It is difficult to envisage how such an ocean could have been formed except by sea floor spreading in the not too distant geological past. No direct evidence exists for putting a date on the opening of Baffin Bay, i.e. the date when spreading was initiated. There is evidence that the initial rifting of Greenland and Canada occurred at least 100 million years ago, but such rifting might have predated active spreading by a considerable span of time. Accurate dating of the

commencemerit of spreading is important in reconstructing the history of the area. It is also important in considering the petroleum potential because it provides a date for the commencement of marine sedimentation in the area. The following figure shows the ocean-



Location of the ocean-continent boundary as deduced from gravity measurements and the results of the seismic refraction lines shown (i.e. B1, C1, etc.). Off central western Greenland the boundary is ill-defined because of lack of data.

continent margin as presently defined. The definition of the boundary is based primarily on gravity data plus the seismic refraction control shown; it is uncertain in the southeastern region where the nature of the outer Greenland shelf is not known. In the northwestern region the boundary defined from the gravity data lies some 100 km closer inshore than the topographic expression of the continental margin. Seismic data in this region are consistent with a considerably increased thickness of sediment (~ 7 km). This sediment appears to have been derived from the Arctic Archipelago and transported along the Arctic channels which formed part of the primary drainage system for the region.

On the continental shelves numerous sedimentary troughs are found. Lanacaster Sound is a deep, sediment-filled trough opening out into the northern part of the bay. On the Greenland side the Melville Bay trough appears to terminate just south of Cape York, and does not link up with similar smaller features observed in Smith Sound. Similar marginal troughs do not appear to occur on the Baffin Island continental shelf, although sparse data in some areas may result in small features being discovered. In the northern part of this shelf a shallow basement ridge parallels the shelf edge for perhaps 100 km. However, such features tend to be small isolated structures unlike the continuous trough and horst feature in Melville Bay. Presumably all are associated with the rifting of the two continents.

The relationship of the Tertiary basalts observed on opposite sides of Baffin Bay at Cape Dyer and Disko Island and their connection with the basalt pile observed in Davis Strait is still unclear. It is tempting to relate them to the commencement of sea floor spreading as have O'Nion and Clarke (1972). The age of the basalts (52 million years) may be consistent with a major change in spreading in the North Atlantic-Labrador Sea system (Le Pichon et a/., 1971). The offshore extent of the Disko Island basalts is now well documented (Park et al., 1971; M. J. Keen et a/., 1972; Ross and Henderson, in press). The southern limit of at least the shallow basalts is fairly clear but the possibility of a connection at depth with the Davis Strait complex cannot at this stage be ruled out. Grant (1972) has mapped the offshore extent of the Cape Dyer basalts and shown that they may be continuous with the shallow magnetic sources observed in the northern Davis Strait but more work is required before the nature and significance of Davis Strait can be fully understood.

In considering the evolution of the North Atlantic and Arctic Oceans a number of authors have discussed the opening of the Labrador Sea and Baffin Bay. In all these cases virtually no direct evidence has been given to explain the opening of Baffin Bay, and in fact in most cases little consideration has been made of the geological constraints in the area. From the information available prior to 1971, C. E. Keen *et al. (1972)* proposed a two-stage evolution of the bay. Essentially this model proposed some rotation of Greenland away from Canada about a point in the Arctic Islands plus a second phase of essentially 'strike-slip' motion along Nares Strait. Subsequent work in 1971 has provided no additional conclusive evidence for this model but rather has suggested a number of possible discrepancies. Primacy among these are:

- lack of evidence of a transform fault in the southern area of Nares Strait;

- present geometry of the oceanic basin is inconsistent with the proposed evolution of the basin;

- a remarkable uniformity of sediment thickness in an east-west direction across the basin;

- a crustal thickness which appears to increase across the basin towards the Greenland margin.

Two areas of further study are strongly suggested: (1) northern Baffin Bay continental shelf and Nares Strait area, and (2) Davis Strait and the Greenland shelf immediately north of Davis Strait. Both these areas have been proposed as sites of major faulting along which movement of the continents could have occurred and are critical areas for further investigation of discrepancies with present models. The resolution of these questions would go a long way to completing the picture of the tectonic framework of the Eastern Arctic.

References

BARRETT, D. L., KEEN, C. E., MANCHESTER, K. S., and ROSS, D. I. 1971. Baffin Bay - An Ocean. *Nature*, 229: 537-552.

BARRETT, D. L., and MANCHESTER, K. S. 1969. Crustal structure in the Baffin Bay and Davis Strait region from magnetometer surveys. (Abstr.) *Trans. Amer. Geophys. Union, 50:* 135.

GRANT, A. C. 1972. Geophysical investigations on the continental shelf off southern Baffin Bay. (Abstr.) Trans. Amer. Geophys. Union, 53: 407.

HOOD, P. J. 1968. Aeromagnetic investigations of Baffin Bay, the North Atlantic Ocean and the Ottawa area. Geol. Surv. Canada, Paper 68-1.

HOOD, P. J., and GODBY, E. A. 1964. Magnetic anomalies over the Mid-Labrador Sea Ridge. *Nature, 202: 1099.*

KEEN, C. E., and BARRETT, D. L. (*in press*) Seismic refraction studies in Baffin Bay: An example of a developing ocean basin. *Geophys. J. Roy. Astr. Soc.*

KEEN, C. E., BARRETT, D. L., MANCHESTER, K. S., and ROSS, D. I. 1972. Geophysical studies in Baffin Bay and some tectonic implications. *Can. J. Earth Sci.*, *9*: 239-256.

KEEN, M.J., LONCAREVIC. B. D., and EWING, G. N. 1971. Continental Margin of Eastern Canada: Georges Bank to Kane Basin (Feb. 1969). in: *The Sea, 4, Pt. II.* Ed. A. E. Maxwell. J. Wiley & Sons Inc.: 251-291.

KEEN, M. J., JOHNSON, J., and PARK, I. 1972. Geophysical and geological studies in eastern and northern Baffin Bay and Lancaster Sound. *Can. J. Earth Sci.*, 9: 689-707.

LE PICHON, X., HYNDMAN, R. D., and PAUTOT, G. 1971. Geophysical study of the opening of the Labrador Sea. J. Geophys. Res., 76: 4724-4743.

O'NION, R. K., and CLARKE, D. B. 1972. Comparative trace element geochemistry of Tertiary basalts from Baffin Bay. *Earth and Planet. Sci. Lett.*, 15: 436-446.

PALLISTER, A. E. 1972. International cooperative offshore exploration by government, university and industry. Baffin Bay - Canada, Greenland. In: *Proc. of 2nd International Ocean Development Conference.* Tokyo.

PARK, I., CLARKE, D. B., JOHNSON, J., and KEEN, M. J. 1971. Seaward extension of the West Greenland Tertiary volcanic province. *Earth and Planet. Sci. Lett.*, 10: 235-238.

ROSS, D. I. (in *press*) Free-air and simple Bouguer gravity maps of Baffin Bay and adjacent continental margins. *Marine Science Paper 12 / Geological Survey of Canada Paper*. Information Canada, Ottawa.

ROSS, D. I., and HENDERSON, G. (*in press*) New geophysical data on the continental shelf of central and northern West Greenland. Can. J. Earth Sci.

VOGT, P. R., and OSTENSO, N. A. 1970. Magnetic and gravity profiles across the Alpha Cordillera and their relation to Arctic sea-floor spreading. *J. Geophys. Res.*, 75: 4925-4937.

WILSON, J. T. 1965. Continental Drift. Scientific American, 208: 86-100.

(This page Blank in the original)

B

Atlantic Oceanographic Laboratory Marine Sciences Directorate Department of the Environment 1971/72

Director's Remarks

In the period of this review we have not had so major an expedition as the HUDSON 70 circumnavigation of the Americas, nor a crisis of the magnitude of the Arrow oil spill, which together loomed large in the affairs of the Laboratory in 1969 and 1970. Rather it has been characterized by less spectacular but steady progress across the broad front of our program: on physical and chemical properties and processes in ocean waters; on inshore and estuarine processes; on navigational and resource charting; and on the development of advanced oceanographic equipment which contributes indirectly to the development of the marine industry in Canada. Moreover, planning for the largest and most complex undertaking in the history of the Laboratory, the Gulf of St. Lawrence Project, has been underway in close cooperation with colleague laboratories in universities and government. This four-year, multidisciplinary study is discussed in the review of the Gulf of St. Lawrence by Dr. M. Dunbar (see Ocean Science Reviews 1971-1972, Part A of this Biennial Review).

In the latter part of the sixties our program took on a thrust towards research motivated by the emerging concern for the quality of the marine environment and for the prevention and abatement of pollution, although resource development and management remained as the major objectives. The pattern of sharpening focus on environmental questions has continued as we have come to appreciate the fundamental nature of the interdependence of resource development and quality of the environment. There is an increased sense of urgency abroad in the world of marine science about the monumental amount of effort that must be expended to advance the state of knowledge of the oceans. It is a prerequisite to bring knowledge to a level that will permit mankind's use of the oceans and their resources to be well managed, not only for present needs but those of the generations to come.

The parable of the courtier seems to be coming into its own on the global scale, even in respect of what was so recently thought of as the inexhaustible resources and capacity of the ocean to withstand the pressures of man. The courtier asked as a reward that he be given one grain of wheat on the first square of a chessboard, two on the second, four on the third and so on for sixty-four doublings. Little did his king realize that the last square would need many times the world's production of wheat for a year. It is important to note that each square needs more than all the previous squares together, i.e. 8 is larger than 1 + 2 + 4. Doubling times of less than twenty years are reported for many substances entering the sea through the action of man. Some are of a foreign and dangerous, or potentially dangerous, nature. While action has been taken to control in some degree the amount of such substances entering the environment, as for example DDT, there are many more over which no effective control exists. Moreover, it is

generally true that little or nothing is known about their fate in the sea. These concerns have been extensively documented in the scientific literature, in the reports of various international study groups such as GESAMP (Group of Experts on the Scientific Aspects of Marine Pollution), and in the documentation of the United Nations Conference on the Human Environment, Stockholm, 1972, to mention only a few. These concerns and the formal recognition of the need to do something about them are being expressed in such forums as the Convention on the Dumping of Waste at Sea, November 1972, the forthcoming Law of the Sea Conference, and the Intergovernmental Maritime Consultative Organization Conference of November 1973, which will have for consideration a protocol on the discharge of toxic substances from ships.

The Declaration on the Human Environment, approved by the 110 governments in attendance at Stockholm, is a milestone as the first international political consensus on ways of preserving and improving man's habitat. In its preamble the Declaration states that a point has been reached in history when "we must shape our actions throughout the world with a more prudent care for their environmental consequences". The defence and enhancement of the environment has become "an imperative goal for mankind". Such statements add up to the promulgation of a new ethic of social behaviour which may well go down in history as one of the most important milestones of our time.

Acceptance of this new ethic must come with the recognition that the earth is in a very real sense a space-ship, a closed system, entirely dependent upon what it carries to survive, the only exception being the absolutely vital supply of energy received from the sun. Mankind must learn how to live with and to manage the space-ship, Earth, to husband its large but not unlimited non-renewable resources, to nurture its renewable resources of air, water, food and all the vast array of other things we need or want, and to cope with the fact the population cannot continue to increase for the billions of those now aboard the ship and the several billion more who will be aboard by 2000 A.D. It is the great challenge of our time, if not the greatest ever faced by mankind.

For the oceanographer this great challenge is compounded by the relatively primitive state of knowledge about the oceans. The oceans are often thought of as the last great frontier on earth; the surface of the moon is much better mapped than the bottom of the ocean. Yet it is not an untouched frontier - man's influence is everywhere. Species of whales are in jeopardy; stocks of commercial fish are under pressure; polychlorinated biphenyls are found widespread through the marine ecosystem; petroleum is observable on the surface and in the water column almost everywhere over large ocean areas. To the degree the

frontier is not untouched, so must be the sense of urgency. There is so much to be done, not just in applied pollution research or monitoring, or surveillance, but throughout the whole spectrum of scientific endeavour related to the seas. Without theoretical and basic observational investigations into ocean dynamics, chemical processes and biological systems, the exploitation of marine resources and concomitant application of control measures are likely to prove at best inefficient, at worst ineffective. These then are the broad philosophical considerations that underlie and guide the program of the Laboratory.

It is appropriate to draw attention to the important role of the Hydrography Division in the Laboratory, particularly on the occasion of this our tenth anniversary. The Division is part of the Canadian Hydrographic Service which traces its beginnings back to 1883. The Service has been an element of the Marine Sciences Directorate for ten years but its entity as a Service has been preserved and indeed strengthened as it has gained new recognition for the progressive character of its program of surveys and the high quality of its output of navigational, natural resource and fishery charts, and of tides and currents tables, pilot books and other aids to navigation. The program of the Division, requiring as it does a heavy use of ship time and other support services, takes about 40% of the budget of the Laboratory. A description of the program will be found under the Hydrography section of the Review. It is readily apparent that the output of the Service not only serves the traditional role of aid to navigation but vital new roles in offshore resource development and in the preservation of the quality of the marine environment.

The HUDSON 70 Expedition continues to be a presence in the Institute although the ship returned to home base more than two years ago at this writing. This is particularly so for Dr. C. R. Mann who was principally responsible for organizing the Expedition and who was its Chief Scientist for the first four phases, a period of three months, and later rejoined the ship at Tuktoyaktuk for another month on the homeward leg to Dartmouth. As one follow-up he is preparing a volume comprising the collected scientific papers which continue to flow from the many scientists who participated in the Expedition. It is a special pleasure to record that the Nova Scotia Technical College on the occasion of its 1972 Spring Convocation awarded Dr. Mann the degree of Doctor of Engineering honoris causa for his work in studying the fundamentals of the physical processes occurring in the ocean, investigating the Gulf Stream system, heading a winter expedition to measure the flow of bottom water through the Denmark Strait, and organizing the HUDSON 70 Expedition that circumnavigated the Americas.

It is a matter of some pride and satisfaction to make note of the appointment, in January 1972, of Dr. B. D. Loncarevic, formerly Assistant Director (Research) of the Atlantic Oceanographic Laboratory, as Director of our new colleague organization in BIO, the Atlantic Geoscience Centre. His leadership bodes well not only for the Centre but for the Institute as a whole.

Late in 1971 Dr. W. M. Cameron stepped down to return to the laboratory bench. From its inception over ten years ago he headed the Marine Sciences Branch of the Department of Energy, Mines and Resources (now of the Department of the Environment), of which AOL is the Atlantic region component. It was during his directorship that this Laboratory and the Bedford Institute of Oceanography grew from an idea to its present size and status, thanks in large measure to his foresight, determination and leadership. Dr. Cameron was succeeded by Dr. A. E. Collin, who brings to his position not only youthful vigour and enthusiasm, but a breadth of relevant experience as naval officer, physical oceanographer, Arctic surveyor and latterly as Dominion Hydrographer.

Administrative Review

The personnel strength of the Laboratory has reached 552 man-years and a budget of \$10,742,000 during the period covered by this review.

At the end of 1972 the Atlantic Oceanographic Laboratory's Personnel Division became part of the Department of the Environment's new Regional Personnel Services. This unit serves the Maritime Region of the Department with its headquarters at the Institute. Mr. P. H. Sutherland, the Division Head, was appointed Regional Manager of the new service.

The Administrative Division continues to budget for and manage a number of common services for the Institute in general. These include security guards, safety programs, housekeeping services, power, telephone, telex, mail, and (in part) stores. In addition, arrangements are in effect for the provision of central registry, finance and purchasing services for the Atlantic Geoscience Centre.

Wm. L. Ford
ATLANTIC OCEANOGRAPHIC LABORATORY

DIRECTOR W. L. Ford

RESEARCH

CHEMICAL OCEANOGRAPHY A. Walton

COASTAL OCEANOGRAPHY R. W. Trites

OCEAN CIRCULATION C. R. Mann

METROLOGY C. S. Mason

PROGRAM ANALYSIS AND PROJECT COORDINATION C. D. Maunsell

HYDROGRAPHIC SURVEYS

REGIONAL HYDROGRAPHER R. C. Melanson

SUPPORT

ADMINISTRATION S. H. Scott

PERSONNEL P. H. Sutherland

PUBLIC RELATIONS C. E. Murray **TECHNICAL SERVICES**

CHIEF R. L. G.Gilbert

COMPUTING M. T. Darwood

DRAFTING AND ILLUSTRATIONS J. R.Lord

ENGINEERING SERVICES S. B. MacPhee

PHOTOGRAPHY N. E. Fenerty

SCIENTIFIC INFORMATION SERVICES AND LIBRARY H. B. Nicholls

SHIPS E.S.Smith

Research, Survey and Senior Support Staff

Wm. L. Ford - Director

M. J. Dunbar* - Scientific Leader and Coordinator, Gulf of St. Lawrence Project

Chemical Oceanography

A. Walton - Division Head

J. M. Bewers A. R. Coote

- I. W. Duedall
- E. M. Levy
- D. H. Loring

I. D. Macaulay¹ G. J. Pearson R. Pocklington¹ B. Sundby⁴

F. C. Tan'

Coastal Oceanography

- R. W. Trites⁶ Division Head
- C. R. Butler'
- D. D. Dobson
- T. R. Foote
- W. D. Forrester
- E. M.Hassan⁶
- R. Heath^{4,2}
- F. Jordan
- F. K. Keyte²

- K. Kranck'
- D. Krauel⁶
- D. J. Lawrence
- R. H. Loucks
- H. J. A. Neu
- G. H. Seibert⁴
- S. H. Sharaf El Din²
- P. E. Vandall

Metrology

- C. S. Mason Division Head
- E. G. Banke E. A. Bendell² A. S. Bennett J. J. Betlem J. Brooke W. C. Cooke J.-G. Dessureault
- F.W. Dobson
- G. A. Fowler

- P. A. Gouldthorpe²
- P. F. Kingston
- D. L. McKeown
- S. D. Smith
- M. Stepanczak
- J. P. Thorburn
- M. R. Thorpe^{4,2}
- D. E. Wells³

Ocean Circulation

C. R. Mann - Division Head

R. A. Clarke J. A. Elliott D. M. Garner' J. R. N. Lazier G. T. Needler N. S. Oakey

- C. Quon
- R. F. Reiniger
- C. K. Ross
- H. Sandstrom

Program Analysis and Project Coordination

C. D. Maunsell - Division Head

W. B. Bailey

Hydrography

R. C. Melanson - Regional Hydrographer

A. L. Adams	S. T. Grant ¹	
R. C. Amero	M. A. Hemphill	
R. G. Burke	D. D. LeLievre	
T. M. Calderwood ²	R. F. Macnab ⁸	
R. M. Cameron	J. M. R. Pilote	
E. J. Comeau	L. D. Quick ²	
P. L. Corkum ²	J. R. Robson ¹	
G. R. Douglas	J. G. Shreenan	
S. S. Dunbrack	T. B. Smith	
R. M. Eaton	N. H. J. Stuifbergen ¹	
G. N. Ewing ²	M. G. Swim	
L. A. Foster ¹	R. K. Williams	
V. J. Gaudet	G. M. Yeaton	

Administrative Services

S. H. Scott - Administration Officer

B. V. Anderson V. W. Hilchey

Personnel

- P. H. Sutherland Division Head
- M. D. Dalzell L. C. Rosenthal1

Public Relations

C. E. Murray'

Technical Services

R. L. G. Gilbert' -Chief

Ships

- E. S. Smith¹ Division Head
- S. Baggs P. M. Brick D. W. Butler A. Holler F.W. Mauger

G. Smith J. W. C. Taylor W. Thorne M. J. A. Wagner

Engineering Services

S. B. MacPhee - Division Head

V. D. Conrad' D. F. Dinn W. W. Goodwin P. F. Green R. G. Mills² A. D. Parsons C. R. Peck H. Scott¹ W. F. Shearman H. B. Sutherland R. N. Vine R. D. Wardrope

Computing Services

R. C. Richards² M. T. Darwood¹

V. N. Beck G. Collins J. G. Cuthbert¹ K. J. Hutton' B. J. MacDougallD. M. PorteousP. S. Trites

Scientific information Services and Library

H. B. Nicholls¹

C. S. Allan N. C. Sabowitz¹

Drafting and Illustrations

J. R. Lord

Photography

N. E. Fenerty

¹ Joined AOL

- ² Left AOL
- ³ Away on educational leave
- ⁴ Postdoctoral Fellow
- ⁶ FRB (MEL) staff
- ⁸ GSC (AGC) staff

^{*} Dr. M. J. Dunbar on secondment from McGill University, Montreal.

Chemical Oceanography



As an introduction to the more detailed descriptions of projects being carried out by the scientific staff of the Chemical Oceanography Division, it is of interest to note some of the major external factors which have proved to be most influential in the development of our programs. Perhaps the most significant was the creation of the Department of the Environment within the Federal Government in April 1971. This event reflected not only the developing awareness of environmental *savoir faire* on the part of the people of the nation but also international recognition of the fact that many current environmental issues have world-wide implications. Development of our knowledge and ability to deal with these issues will depend, to a substantial extent, on our recognition of these features, not only in chemical oceanography but in all aspects of oceanographic studies.

Our programs range from projects of a national nature; for example, development of baseline chemical oceanographic information in the Gulf of St. Lawrence and other coastal areas; to the broader aspects of the subject in the open oceans, such as, nutrient studies in the North Atlantic and oil pollution contamination of the high seas. From time to time our expertise has been sought in the international forum, recently at pre- and post-Stockholm deliberations regarding ocean-dumping and general matters concerning marine pollution from ships and other sources. This involvement has tended to grow substantially during the past year.

Although the subject of 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 Studies. Some of these areas of study have been initiated since the time of the last Biennial Review and others have changed emphasis in keeping with overall Departmental objectives; I suspect that this situation of 'constant change' has now become a 'permanent feature' of oceanography as the subject assumes a more significant place in national and international science in this part of the twentieth century.

In the coming years it is anticipated that we will be pre-occupied with environmental issues of the marine environment, both national and international. Programs will undoubtedly be developed to enable us to maintain and expand our chemical knowledge of both coastal and high seas, recognizing simultaneously the interdisciplinary demands placed upon us by the medium which we are endeavouring to understand.

A. Walton

Inorganic Chemistry

Anthropogenic activities or discharges to the environment have both long- and short-term effects on the behaviour and distribution of chemical species in the hydrosphere. These effects may manifest themselves in water, sediments and/or biota. The present objectives of the Inorganic Chemical Oceanography program are to study the distribution and geochemical behaviour of major and trace elements in the water column. This work is aimed at identifying transport and exchange processes and providing a framework within which to estimate the impact of man-made injections of material to the environment.

An area which has been under intensive study in these respects in the preceding two years has been the Gulf of St. Lawrence which receives a very significant proportion of run-off water from the Canadian Shield and also receives the water from the St. Lawrence River watershed. The watershed of the river, in particular, receives a major amount of industrial and municipal waste water from the eastern U.S.A. and Canada. We have given priority in two cruises, in 1971 and 1972, to the establishment of basic chemical characteristics of Gulf water and to discover and give rational interpretation to the behaviour of inorganic species.

The first program, a short one, yielded element mass ratios to chlorinity for the major elements $(Kg_x/Kg_{cl})_{water}$: Li⁺, 9.25 x 10⁻⁶; F⁻, 6.8x 10⁻⁵; Ca⁺⁺, 2.09 x 10⁻²; Sr⁺⁺, 4.07 x 10⁻⁴, These results, obtained by atomic absorption spectrophotometry, indicate that on the whole the saline water within the Gulf is not significantly different chemically from North Atlantic water.

Substantial preparations were made for our 1972 cruise to the same region, recognizing that contamination problems are very common to trace element programs. Laboratory and shipboard handling and filtration operations were critically examined and all containers underwent thorough cleaning before use. Care was taken to ensure that duplicate samples were available from regions of particular interest.

Work is now being performed on the determination of Co, Cu, Fe, Pb, Ni and Zn in these 1972 samples using atomic absorption spectrophotometry. The substantial quantity of data generated has necessitated development of a processing and storage program. The data will be used to assess the degree of conservatism of these species; should any non-conservative behaviour be noted, the causative mechanism will be given closer examination.



Atomic absorption spectrophotometer.

I. D. Macaulay, J. M. Bewers

The spatial and temporal distributions of suspended particulate matter in Bedford Basin, Nova Scotia are being examined and correlated with oceanographic parameters, such as currents, tides, run-off, and wind velocities. This information is being used to gain further insight into the processes of sedimentation and sediment transport.

Chemical and mineralogical analyses of particulate matter are being carried out together with studies of spatial variations in particulate concentration in the Gulf of St. Lawrence where much is known about the sediments but comparatively little about matter suspended in the water column.

B. Sundby

In 1962 R. Greenhalgh and J. P. Riley (University of Liverpool) (*Nature, 97:* 371-372) reported significant increases in fluoride concentration with depth in the China Sea, the North and South Atlantic, and the Mediterranean Sea. Prior to this work, fluoride had been considered to be a conservative ion whose distribution was fairly uniform with location and depth in the major oceans. Initially, some stations near the Mid-Atlantic Ridge in the North Atlantic were sampled and the ratio of fluoride to chloride was found to be constant at 6.82 x 10^{-5} . One hundred and thirty-four samples from 48 stations

in the South Atlantic and Pacific Oceans, collected during the HUDSON 70 Expedition, were also analyzed and gave mean fluoride chloride ratios of 6.59 x 10⁻⁵ and 6.66 x 10⁻⁵ for the two oceans respectively. One station on the Reykanes Ridge was found to exhibit structured fluoride concentration with depth but this has subsequently been attributed to sampling contamination. More recently, a series of samples was obtained from two stations, previously reported as anomalous, in the Labrador Sea. These samples were subsequently analyzed by ourselves, Dr. D. R. Kester (University of Rhode Island), and Dr. T. B. Warner (Naval Research Laboratories, Washington, D.C.) as part of an intercalibration experiment. The intercalibration study was very successful but the existence of anomalies at these stations was not confirmed.

J. M. Bewers

The exchange of material between the oceans and atmosphere is a subject of increasing interest to the environmental scientist. It is strongly suspected that many pollutants are introduced to the oceans primarily by way of the atmosphere and that, conversely, many materials present in continental rain and snow are derived from the oceans. This subject, sea/air chemistry, is directly linked with meteorology, hydrology, and aerosol chemistry.

Much controversy presently surrounds the nature and magnitude of the mechanisms responsible for sea to air transport of chemical species. There exists convincing evidence that some species (e.g., phosphate ion) are transported from the sea to the atmosphere several hundred times more efficiently than chloride or sodium. However, for some other components, such as fluoride, the data are both conflicting and much less convincing. In an effort to shed more light upon these processes, a simple model of the circulation of sea-salts has been developed and used to derive theoretical relative efficiencies for the sea/air transport process for the halides: chloride, fluoride, bromide, and iodide. Simultaneously, it was possible to predict the halide content of meteoric water and to compare this with experimental data. The theoretical values of these parameters for bromide, iodide and chloride were found to be in good agreement with experiment, although the model provided further support for the contention that bromide is a significant atmospheric pollutant in urban areas. The derived values for fluoride, however, indicated a very high sea/air transport efficiency for this element, as well as suggesting that some of the experimental precipitation data for fluoride are unrealistically high. Resolution of the differences between the theoretical and experimental values would require that either many of the samples of rainwater were contaminated by dry fallout or that the continents are a primary sink for oceanic

fluoride. In view of much of the recent environmental data on this element, it appears realistic to suggest that fluoride is conserved within a simple hydrologic cycle and that it has the highest sea/air transport efficiency of any of the halides.

J. M. Bewers

The reliability of neutron activation analysis for trace element analysis of environmental samples is dependent upon resolution which increases both with the degree of radiochemical separation of the sample and improved gamma-ray detection systems. Radiochemical procedures are directed towards removing interferences in the gamma-ray spectrum of the sample. Although improvements in detector resolution have reduced the need for extensive post-irradiation chemistry, modern detectors still have finite resolution and interferences can occur. As an aid to purely instrumental analysis and to assist the radiochemist in optimizing his procedures, a manual of gamma-ray interferences encountered in thermal neutron activation analysis has been prepared from the existing 'Isotope Catalogue for Instrumental Activation Analysis'. This manual may be used to predict interferences in specific samples and thus assist in the design of appropriate radiochemical separations. Alternatively, the constituents of multiple gamma-ray peaks may be predicted by laboratories not having access to large computers and peak-fitting routines.

J. M. Bewers, G. J. Pearson

Organic Chemistry

The marine environment is the Earth's largest reservoir of free organic material and dissolved organic compounds particularly play an important role in biological, geochemical and physical processes in the oceans. For these reasons a study of organic matter in the marine and sedimentary environments is an essential part of oceanographic research. Organic compounds found in the sea and in marine sediments are produced both by plants and animals, the amounts and nature of the organic matter depending upon its source. Plant-derived material consists predominantly of cellulose and lignins, in which the amount of nitrogen is small and the ratio of carbon to nitrogen (C/N) in sediments derived from this material usually exceeds 10. Animal remains are characterized by larger amounts of fats and proteins; nitrogen in this material is considerably higher and the C/N ratio ranges from 6 to 12.

Samples of seawater and marine sediments from stations in the **Gulf of St. Lawrence** have been analyzed for organic carbon and nitrogen. Organic carbon values were found to be high in areas where there is an input of effluent from forest industries (Corner Brook, Newfoundland, and Bagotville and Chicoutimi, Quebec) but generally low in the St. Lawrence estuary. The C/N ratios found in these regions were high and similarly indicative of large proportions of land-derived organic matter. Sediments from the Nova Scotian Shelf, Cabot Strait, Esquiman Channel, Bay of Chaleur, and estuary of the St. Lawrence showed low C/N ratios typical of sediments containing high proportions of marine-derived material. Concentrations of organic carbon in sediments around the *Whale* barge wreck in the Magdalen Shallows indicate that these have not been unduly contaminated by oil (the *Whale* sank in September 1970 carrying a cargo of 4000 metric tons of fuel oil).

Particulate carbon concentrations were found to be high in water from the Humber Estuary, the Esquiman Channel and the Strait of Belle Isle. High C/N ratios reveal that the particulate organic matter in the first two water bodies is predominantly plant-derived but in the Strait of Belle Isle the C/N ratios are characteristic of material of marine origin. Since the Strait of Belle Isle is not an environment of appreciable sedimentation, there have been no previous indications of high organic content in the waters of the area.

Complementary to the quantitative studies of carbon, hydrogen, and nitrogen in organic material a method for the determination of lignin in sediments and particulate matter has been developed. Alkaline nitrobenzene oxidation is used to produce identifiable derivatives from lignin which can be separated by gas liquid chromatography. Results to date show that lignin constitutes a substantial proportion (1 - 14%) of the organic matter in sediments of the Gulf of St. Lawrence. The greatest amounts of lignin were found in samples with both high organic carbon content and high C/N ratios (Corner Brook, Upper Saguenay River). This is further evidence of the effects of effluent from forest industries.

R. Pocklington

Data from a standard oceanographic station (Panulirus) near Bermuda have been subjected to statistical analysis to deduce temporal variability at this station. The results indicate that the greatest variability occurs in the surface water where diurnal and seasonal effects penetrate; at greater depths the extent of seasonal changes shows a secondary maximum at 600-800 metres. This indicates that the assumption which underlies the use of standard depths for oceanographic work, namely, that variability decreases uniformly with depth, is invalid. Evidence was also found for a consistent cooling trend in the top 400 metres which, taken with other evidence from the North Atlantic, may indicate a continuing cooling trend in the North Atlantic.



Five-year running means of temperature show that the important 18° isotherm has risen 75 metres over 15 years at the Panulirus station, southeast of Bermuda. This implies considerable cooling of nearsurface water in the northwestern Sargasso Sea which, together with other evidence from the North Atlantic Ocean, may indicate a continuing cooling trend in this area.

R. Pocklington

Physical Chemistry

During 1971-72 two cruises to the **Gulf of St. Lawrence** were carried out to provide information concerning the distribution of temperature, salinity, dissolved oxygen, total carbon dioxide, both carbonate and total alkalinity, calcium and magnesium throughout the Gulf and estuary; to gain knowledge of the chemical interactions between these species; and to establish baseline data against which temporal changes can be evaluated.

Dissolved oxygen concentrations, determined by the Carpenter-Winkler method, were generally greater than 8 ml/l at the maximum in the photosynthetic layer, decreasing to approximately 6.5 ml/l at the surface and much lower values near the bottom. Oxygen concentrations in the deep waters decreased from greater than 5 ml/l as they entered the Gulf through Cabot Strait to less than 3 ml/l at the extremities of the Esquiman Channel and the Laurentian Trough. Both the highest (8.8 ml/l) and the lowest (2.5 ml/l) concentrations were observed near the extremity of the Laurentian Trough in a region of suspected upwelling.



Dissolved oxygen concentrations in the Gulf of St. Lawrence from Cabot Strait (station 1) to the Saguenay (station 52).

Total and carbonate alkalinity were measured by a differential electrometric titration method and the data processed by a computerized Gran procedure. Of the 245 successful determinations made on the second cruise the average pK was 5.869 with a coefficient of variation of 0.2%.

Differential titrimetric methods, with spectrophotometric detection of the end points, for the determination of calcium and magnesium in seawater have been perfected, and ratios of calcium and magnesium to chloride concentrations may be determined with a precision of better than 0.3%. The average values for the Mg⁺⁺/Cl⁻ and Ca⁺⁺/Cl⁻ ratios in the Gulf of St. Lawrence are 0.0668 and 0.0213 respectively, lending considerable support to the concept of the constancy of the relationships between the concentrations of the major ions in seawater. Geographical variations in the relationships between calcium, magnesium and chloride concentrations were observed in the Gulf of St. Lawrence only in those regions where the solution of 'sea salt' was perturbed by inflowing waters having 'abnormal' calcium and magnesium ratios.

E. M. Levy

About two years ago a study was undertaken to learn how the structure of the water in seawater is altered due to the presence of sea salt. The approach taken was to determine the effect of the various sea salts on the compressibility of seawater. The compressibility of a solution is sensitive to molecular structure and, therefore, if ions are capable of interacting with the water matrix, the compressibility technique should be useful in studying ion-water interactions. Such interactions are of fundamental importance to marine chemistry in that all physicochemical properties of seawater are dependent upon the molecular structure of the seawater.

A specially designed high pressure differential densimeter was constructed to measure differences in compressibilities ($\Delta\beta$) Compressibility experiments were then conducted in the following manner. An initial series of experiments was carried out to determine $\Delta\beta$ between sea salt solutions and the reference water (in this case distilled water). The second series of experiments consisted of runs in which the reference solution was seawater. The $\Delta\beta$ measurements for the distilled water runs provided the basis for a comparison of the water in seawater with distilled water. The $\Delta\beta$ values in these two series of runs were determined at nominal concentrations of 0.13 molal and 0.26 molal at temperatures of 2°C and 15°C.

The A/3 values have been correlated with other solution properties used to determine the extent of structure breaking.



Differences in compressibilities as a function of ionic radius for structure-making and structure-breaking anions and cations.

One of the important factors in the propensity of ions to cause structure breaking is shown in the work of Padova (1963. *J. Chem. Phys.,* 39: 1552-1557) who calculated the intrinsic 'effective' radii (r_e) of ions in aqueous solutions. The first figure shows plotted as a function of r_e for the series NaF, NaCI, and NaI. The $\Delta\beta$ values correlate with r_e. According to Padova, Cl and l are structure breakers because the r_e of ions in solution is greater than the minimum radius

necessary to cause complete dielectric saturation of the local water structures. The second figure shows a similar plot for the cation series LiCl, NaCl, KCl, and CsCl. Here there is no obvious correlation between the $\Delta\beta$ for the solutions and the r_e for the cations. The third figure shows another plot of $\Delta\beta$ versus r_e for the series of alkaline-earth chlorides MgCl₂, CaCl₂ and BaCl₂. Here there exists a good correlation between $\Delta\beta$ and r_e . It is particularly interesting that for the halide salts the slope of $\Delta\beta$ versus r_e is positive but for the halide salts the slope is negative. Both F⁻ and Mg⁺⁺ are usually considered strong structure makers, yet they appear to affect $\Delta\beta$ in relatively opposite ways. The same analogy can be applied to I and Ba⁺⁺ which are generally classed as structure breakers. (However, Ba⁺⁺, according to Padova, is a structure maker.) Such inverse effects, as shown in these figures, give added support to the belief that anions alter water structure in a very different way than do cations.

These interpretations are particularly relevant to seawater chemistry because seawater contains several different anions and cations (i.e., CI^{-} , SO_{4}^{--} , Na^{+} , Mg^{++} , Ca^{++} , K^{+}), each of which affects the structure of water in seawater in a different way.

I. W. Duedall

As a consequence of the sinking of the tanker *Arrow* in Chedabucto Bay during February 1970, a program was initiated to establish present levels of pollution of the North Atlantic by petroleum residues both as suspended and 'dissolved' material dispersed throughout the water column and as tarry lumps and other forms which float on the surface.

In the early stages, analytical methods were developed to identify the source of oils spilled in the marine environment and to measure quantitatively the total material distributed throughout the water column. More recently, procedures have been devised to study the distribution of petroleum residues in the form of tar lumps.

In order to assess the impact of the *Arrow* incident on concentrations of petroleum residues in the Chedabucto Bay area and adjacent open ocean areas, a series of measurements was made in the region in May 1970. At this time the concentrations of dissolved and dispersed petroleum in the outer reaches of the Bay were 0-90 ppb, whereas the 'background levels' in the open Atlantic, some 200 miles from the source, were 2-13 ppb. As the effects of the *Arrow* spill subsided 'background concentrations' decreased and by the following January they had dropped to about 2 ppb. This provides some insight into the impact of a spill, such as the *Arrow*, on the marine environment and the rate at which 'normal' conditions are restored.

To investigate a coastal area which had not been affected by the *Arrow* spill, the concentrations of dissolved and dispersed petroleum residues in the Gulf of St. Lawrence were measured during the summer of 1970. 'Backgrounds' of 1-6 ppb were observed in all areas and at all depths sampled.

To establish a more detailed picture of the overall distribution of petroleum residues in the Gulf, to define the major sources, and to determine temporal variations, a much more extensive study was carried out in 1971. Concentrations ranging from 0 to more than 15 ppb were observed. This work indicated that a major source of petroleum residues in the Gulf of St. Lawrence is the Atlantic water, which enters and leaves the region through Cabot Strait, and that the distribution of petroleum residues within the Gulf are closely related to the passage of water through the system. In addition, there was definite evidence of comparatively smaller inputs from shipping and other human activities.

Further information on the distribution and temporal variations in the distribution of petroleum residues in the Gulf of St. Lawrence will be available when samples collected in the spring of 1972 are analyzed. E. M. Levy

The distribution of petroleum residues in the form of tarry particles floating on the surface of the oceans has been measured over a broad expanse of the western North Atlantic from the Caribbean to the high Arctic, from Canada to the Azores, and in the Mediterranean. Gravimetric analyses of the material collected reveal concentrations ranging from 0 in certain areas to more than 10 mg/m² in the more heavily 'polluted' regions. These data are being analyzed in terms of surface circulation of the North Atlantic and of human activities in the area.



Tar lump supporting goose barnacles; collected from the western North Atlantic Ocean.

E. M. Levy

Nutrient Chemistry

In order to determine the response of the ocean as a whole to any of the stresses now being imposed on it by our industrial societies, a more extensive and detailed knowledge of the ocean circulation processes is required. A number of techniques are being used to further our understanding, including the use of the nutrients, silicate, phosphate, nitrate, and oxygen, to trace the movement of water masses which are formed under different conditions.

The HUDSON 70 Expedition presented an opportunity to measure these non-conservative constituents in the regions of deep water formation and to follow the changes in their distribution away from the Antarctic convergence in the Atlantic and Pacific Oceans. The silicate data obtained for the South Atlantic, together with previous AOL and historical data, have been used by Mann, Coote and Garner to describe the meridional distribution of silicate in the basins of the western Atlantic Ocean. The silicate maximum co-exists with the intermediate oxygen minimum at a potential density of about 27.6 throughout most of the South Atlantic. At about 20°S this occurs at a depth of 1200 metres and it can be traced southward to a maximum depth of 1600 metres where it rises toward the surface near the Antarctic convergence. Similarly, the maxima for nitrate and phosphate can be traced back in slightly shallower water with lower potential density. We argue that advection is the dominant process which determines the meridional distribution of nutrients and that in situ regeneration at depth plays an insignificant role in determining the meridional distribution of nutrients in the South Atlantic. Menzell and Ryther (1968. Deep-Sea Res., 15: 327-337) came to a similar conclusion concerning in situ regeneration based on the distribution of oxygen and organic carbon.

The oxygen distribution along 30°W in the South Atlantic has been examined in some detail and found to contain the same features described by Deacon (1933. Discovery Reports, 7: 171) using his Discovery data. Our values are 0.3 ml/l to 0.5 ml/l higher but if allowance is made for a systematic error, said by Gordon (1967. Antarctic Map Folio, Ser. 6) to exist in the Discovery oxygen data, it would appear that the concentration of oxygen in the South Atlantic has remained constant over the last forty years.

In the Pacific Ocean the CSS *Hudson* made a meridional transect at 150°W where the observed distribution of oxygen is similar to that described by Reid (1965. Intermediate Waters of the Pacific Ocean). However, at about 10°N latitude there was evidence of the easterly flowing bottom current described by Edmond *et a*/. (1971. *Deep-Sea Res., 18*: 127-131).

In a continuing study of the mixing of water masses in the North Atlantic, nutrient data have been obtained from the area off the southeast Tail of the Grand Bank. A. R. Coote

Simultaneously with other chemical measurements, nutrient surveys have been carried out in the Gulf of St. Lawrence in 1971 and 1972. In addition, a station near to the mouth of the Saguenay, in a region thought to be one of upwelling, was sampled over a 30-hour period in both years.

A. R. Coote

Stable Isotope Chemistry

Stable carbon (C^{13}/C^{12}), oxygen ($0^{18}/0^{16}$) and hydrogen (H/D) isotope ratios have been used to study a variety of oceanographic problems. Among these are mixing and circulation of water masses, paleotemperatures and thermal structure of past oceans, sources of organic matter in marine sediments, stability and chemical nature of dissolved organic and particulate organic matter in water column, air-sea exchange rate, paleoecological problems, and natural versus man-made organic carbon pollution in marine environments. In 1972 a stable isotope studies section was formed in the Chemical Oceano-graphy Division to investigate some aspects of these problems.

The carbon isotope ratios of natural carbon reservoirs exhibit characteristic ranges. As a result of man's activities, however, the carbon isotopic composition in marine areas is being altered, particularly in the coastal regions. These activities include:

(a) Combustion of fossil fuels - producing CO_2 enriched in C^{12} relative to natural atmospheric and oceanic bicarbonate.

(b) Release of petrochemicals and petroleum products accidentally or intentionally into the environment - providing an input of organic matter enriched in C^{12} relative to contemporary organic matter.

(c) Discharge of pulp mill and sewage effluents.

Bedford Basin, Nova Scotia, which is currently receiving effluents from oil refinery and sewage plants, is a strategically important and particularly suitable region for investigation by the C¹³/C¹² approach. Currently the carbon isotope ratios of dissolved organic carbon (DOC), particulate organic carbon (POC), total dissolved inorganic carbonates (IOC), plankton and total carbon in sediments of the Bedford Basin, its inlet and outlet, are being investigated to:

(a) provide baseline data to monitor pollution, i.e. to establish the range of C^{13}/C^{12} ratios for POC, DOC and IOC;

(b) estimate the contribution of organic carbon to various carbon reservoirs in the area;

(c) understand the sources of organic matter in sediment;

(d) understand the chemical nature and stability of DOC and POC;

(e) understand the carbon isotope fractionation behaviour in plankton materials.

Samples from relatively unpolluted bays in Nova Scotia and other Canadian coastal zones are being analyzed for comparative purposes.

F. C. Tan

Because of the differences in vapor pressure of H_2O^{16} and H_2O^{18} the oxygen isotopic composition of the hydrosphere varies with the evaporation-condensation processes taking place. The O^{18}/O^{16} ratio of water vapor is about 8‰ lower than its equilibrium liquid at 20°C. As a result, O^{18} is concentrated in ocean waters in comparison with continental waters. Continental waters, however, are more variable in oxygen isotope composition than ocean waters. Variations up to 50‰ in O^{18} content at progressively higher altitudes and higher latitudes have been reported.

Projects currently underway include investigations of the oxygen isotope composition of water samples from the Bedford Basin and related inlets and outlets, as well as lakes, and precipitation in the Dartmouth-Halifax area, in order to establish baseline data for hydrological studies and to investigate the mixing and circulation of water in Bedford Basin.

F. C. Tan

A Nuclide Analysis Associates 6-inch, 60-degree sector isotope ratio mass spectrometer, capable of determining the stable isotope ratios of hydrogen, carbon, nitrogen, oxygen, and sulfur, was installed in July 1972. The performance of the instrument is being closely tested and monitored by analyzing carbon and oxygen standards of known isotopic composition. Preliminary experiments indicate a precision of 0.01% is achieved for C^{13}/C^{12} and O^{18}/O^{16} ratios.



Isotope ratio mass spectrometer.

High vacuum systems have been constructed for the analysis of C^{13}/C^{12} and O^{18}/O^{16} ratios in a variety of organic and inorganic substances.

F. C. Tan

Data Processing

The Chemical Oceanography Division uses a variety of analytical instrumentation including: gas chromatographs, CHN analyzer, UV spectrophotometer, Technicon AutoAnalyzer, atomic absorption spectrophotometer, and isotope ratio mass spectrometer, all of which are capable of rapid and reliable analyses. With such instrumentation the limiting factor to our experimental work is shifting from the analytical procedures to the sampling, sample preparation, and data reduction methods. A system has been introduced therefore to automate data handling procedures. This was accomplished in several stages:

(i) analytical equipment was interfaced to computer-compatible devices (manual, as in keyboard operations or punched cards, or automatic, as in punched paper tape or magnetic tape); (ii) instrumental data were then reduced to standard units of the parameter being measured;

(iii) a data bank was established to store and permit the retrieval of data generated in the various sections of the Chemical Oceanography Division.

At present, steps (i) and (ii) are essentially complete since some form of interfacing is available for each of the major instruments and programs for the reduction of generated data to meaningful chemical data have been written. These were developed for use in batch mode on the in-house CDC 3150 computer or to run interactively on the Dalhousie University CDC 6400 computer via a Datapoint 3300 terminal and audio coupler. Many Small routines for calibrating and plotting have also been developed for the Division's HP 9100A programmable calculator.

Establishment of the data bank and program development for data interpretation will continue concurrently, with emphasis placed on the latter. Both vertical and horizontal section plots of the analytical results of the Division's cruises are a priority need and programs will be developed for this purpose in the near future.

G. J. Pearson

Coastal Oceanography



The Coastal Oceanography Division, which is jointly supported and manned by AOL and MEL, is engaged in studies to describe and understand physical processes in the coastal region of the eastern Canadian seaboard. Activities of the Division can be grouped roughly into two parts, based on geographic scales. The estuaries, coastal embayments, etc., constitute one group, and the gulfs, and open coastal areas extending out over the continental shelf, the other.

Our inshore studies have arisen, in large measure, as the result of specific questions or problems such as pollution or potential pollution threats in Canso-Chedabucto Bay and Pictou, both in Nova Scotia; Long Harbour, Conception Bay, Come By Chance, Placentia Bay, and St. Georges Bay, all in Newfoundland; and Saint John and Lorneville, both in New Brunswick. Others have arisen in relation to coastal engineering problems, e.g. the Halifax Harbour wave study and the Petite Passage current study (both in Nova Scotia), while still others have had a multiple purpose, such as the studies in St. Margaret's Bay, Halifax Inlet, Bedford Basin, and Petpeswick Inlet (all in Nova Scotia). Usually the problem has been cast in a time-frame that has permitted very little time for field work but at the same time required information, assessment and forecasts which could not be provided from existing knowledge. There has been and still is an urgent need to improve our fundamental knowledge about the dynamics, circulation, flushing and exchange processes for the near-shore, estuarine and coastal embayment areas, so that the specific parameters that must be obtained for any specific area can be more accurately defined. In our Division, we have attempted to move in this direction by first attempting to classify the inlets and estuaries, etc., into a relatively small number of basic types, and then selecting representative types to study in detail with the hope that we will learn enough about each type to permit extrapolation into others where relatively few data exist. This, however, is proving difficult to develop quickly, since, with the available staff, 'fire fighting' activities consume much of the available effort.

Our offshore coastal studies of the gulfs and continental shelf areas have covered, in most cases, only a small fraction of the Canadian Atlantic seaboard. One significant departure from this is a Wave Climate Study, using principally wave data provided through the Maritime Forces Weather Centre by weather ships, weather stations, Canadian and U.S. government ships, navies of NATO countries and merchant ships. This material is of value in a number of practical needs but is of special interest to the offshore petroleum industry. On an area basis, our largest single effort has been directed towards the Gulf of St. Lawrence. In view of the immense importance of this area in terms of fisheries, navigation, waste assimilation, potential mineral resources, and recreation, it is expected that our research effort will be continued and expanded.

As the Division is jointly sponsored by AOL and MEL, only a portion of our activities are reported in this section. Additional reports appear in the MEL Review, Part C of this Biennial Review.

R. W. Trites

Gulf of St. Lawrence

Observations from current meters moored in 1968 and 1969 at locations along the channel of the St. Lawrence estuary between the Saguenay River and Matane have been analyzed and used to describe the internal tides in the estuary. At each current meter location the portion of the tidal streams attributed to internal tides was obtained by subtracting the tidal streams necessary to support the observed surface tides from the actual tidal streams detected by the current meters. The tidal streams associated with the surface tides had previously been calculated from tide gauge observations and the principle of continuity. The tidal streams thus measured for the internal tides fitted very well with the hypothesis of a progressive semidiurnal internal tide propagating seaward along the estuary. This internal tide is believed to be generated by the interaction of the surface tide with the shoaling bottom topography at the inland end of the Laurentian Channel. The axial tidal streams experienced at the surface of the estuary are at least as much the result of the internal tide as of the surface tide: the cross-channel tidal streams are almost entirely the result of the internal tide. Further measurements and studies are planned for 1973 to investigate the generating mechanism and to determine the role this might play as a mixing process near the entrance of the Saguenay River.

W. D. Forrester

Analysis conducted by M.I. El Sabh at McGill University in cooperation with W. D. Forrester of Coastal Oceanography has demonstrated the high accuracy that can be obtained in transport calculations employing geostrophic currents in sections across the St. Lawrence estuary and Cabot Strait. To achieve this, however, it is necessary to calculate the geostrophic currents from the average of several observed density sections, to eliminate the effect of short-term fluctuations. It is also necessary to impose the condition that the calculated current field



Lowering a string of current meters from CSS Dawson.

provides the correct known transport of one material, to adjust for the uncertainty in selection of a reference surface. In this study, the imposed condition was that of zero net salt transport and the accuracy was checked by calculating the net transport of water. The transport of water agreed consistently to within 20% of that expected from estimates of run-off plus precipitation minus evaporation.

W. D. Forrester

Oceanographic observations in the Gulf of St. Lawrence during the winter are not numerous (total observations at CODC (Canadian Oceanographic Data Centre) for March are <100 and for August 1000). This is particularly true in conditions of maximum ice coverage. Forrester managed to make observations during the winter of 1969, but that year turned out to be an exceptionally light ice year. A cruise was therefore planned for February-March, 1972, on board the CSS Baffin. The year in this instance turned out to be an exceptionally heavy ice year, not allowing the ship to proceed very far into the Gulf. The ship was also plagued by mechanical troubles and the cruise was terminated prematurely. However, the Cabot Strait section stations were occupied over one tidal period for each station, in addition to a few stations inside the Gulf proper. Subsequently a limited number of stations were occupied on an opportunity basis from the icebreaker CCGS John A. MacDonald until the break-up and melting of the Gulf ice. All the observations are being analyzed now, and another cruise is planned for the same period in 1973.

E. M. Hassan

It is becoming increasingly recognized that fresh water regulation, as implemented in the St. Lawrence system since the turn of the century for power production and navigation improvement, has caused significant modifications to the ecosystem of the region. The effect is not limited to the estuary and Gulf of St. Lawrence, and may extend throughout the fresh water influence of the St. Lawrence on the water of the Atlantic.

The most obvious changes introduced by altering the seasonal run-off involve the water structure (i.e. the temperature, salinity, density), the general circulation, upwelling, mixing, and flushing of both the embayment and contiguous water masses in the Gulf of St. Lawrence. Such changes are bound to create climatic modifications which in turn influence the formation of the ice in the winter and its melting in the spring. Recent studies by W. H. Sutcliffe (MEL) reveal that fluctuations of certain fish species, and hence the biological balance, are correlated with variations in fresh water run-off.

In order to evaluate the magnitude of this man-made interference, the run-off from the St. Lawrence system was analyzed for the period from 1964 to 1970. This disclosed that on the average the ratio between the winter run-off and the spring run-off has been modified as follows:

	Ottawa River	St. Lawrence River	St. Lawrence River
	Above Montreal	Above Montreal	at Pointe des Monts
Natural	1:6	1:1.7	1:3.4
Regulated	1:2.65	1:1.27	1:1.82

During this seven-year period, the fresh water inflow of the sector extending down to Pointe des Monts was artificially increased in February by an average of 3600 m^3 /s with a maximum of 4200 m^3 /s in 1967, and decreased in May by an average of 7800 m^3 /s in 1970. More than two-thirds of this regulation occurs in the Province of Quebec while the remainder occurs in Ontario. The variation in the regulation in 1970 for four points along the system is shown in the accompanying graph.



Run-off and regulation for the St. Lawrence system, 1970.

From these results, it can readily be seen that at Pointe des Monts, which is at the entrance to the Gulf of St. Lawrence, nearly half of the seasonal variation in discharge occurs as a result of water regulation. As has been argued (Neu, AOL Report 1970 - 9), these changes must have had a profound impact not only on the physics of the water and the dynamics of the Gulf and the adjacent waters but most probably on the entire ecosystem of a large part of the Atlantic region.

Of great concern is the fact that the scope of these regulations is increasing rather than decreasing. At the present several additional power schemes along the system are in the design stage. The ultimate aim of power interests is to achieve optimum power production by increasing winter discharges to the point where they may even exceed the spring flow. Obviously this deserves immediate and comprehensive consideration before any further man-made modification is implemented.

H. J. A. Neu

Estuaries and Coastal Embayments

During the past two years the scope of our work has continually broadened due in part to participation in multidisciplinary task forces on Halifax Inlet waste dispersion, national water needs, and planning for coastal zone management (Prince Edward Island). As a result, much of the research work carried out in the laboratory and in the field is now seen to have many applications for planning and management; new research topics which contribute to the planning activity are being initiated. Intelligent management of estuaries is a difficult task, owing to the complex, webbed, and interactive nature of estuarine usage. Ideally, a thorough knowledge and understanding of the physical. chemical, biological, and geological characteristics are required if an estuary is to be utilized to the maximum benefit of mankind. In practice, however, management decisions are frequently made with only fragmentary knowledge about the way in which the system functions and with an incomplete assessment of the options available. The flow diagram in the figure (from the Prince Edward Island Task



A schematic illustrating the development of planning for water management in a coastal system. The various aspects of the system are considered in sequence and the sequence is repeated at increasingly refined levels. Thus one spirals in on the goal of an acceptable management plan.

Force Report) suggests a systems approach encompassing, in concept, all relevant features of man-estuary interaction. To proceed one satisfies each demand in the circuit in a gross way, then raises the level of sophistication and completes another circuit and so on until it can be judged that the functioning and planning options in the real system have been adequately understood. The attractiveness of this spiral approach is that it can be comprehensive, that the cross-couplings of the webbed real-life system can be reduced to forward feeds treated continuously and iteratively, and that all elements around the circuit can be matched with respect to their level of sophistication. Our direct contribution is in the area of simulation modelling and research.

The model of Hansen and Rattray (1966. Limnol. and Ocean., 11: 319-326) for a two-layer, steady-state estuary flow has guided much of our work. In particular, this has led us to emphasize the difference between advective and diffusive exchanges of water quality parameters, e.g. that advective exchange is likely to be much more variable than diffusive exchange because the river and wind driving forces are more variable than the tidal driving force. We have perceived these modes in the exchange of nutrients in Petpeswick Inlet (in collaboration with W. H. Sutcliffe, MEL) and in the exchange of mercury and other elements in LaHave estuary, Nova Scotia, (in collaboration with D. E. Buckley, AGC). In Halifax Narrows analysis is in progress on a suite of current meter records spanning one year. These data are being used to calibrate the Hansen-Rattray model for the Narrows. In the laboratory, two models have been developed for Halifax Inlet. One is a simple one-dimensional gravitational wave-seiche model for determining the natural frequencies of oscillation and the other is a modification of a statistical model for predicting the frequency of intermittent replenishment of the deep water in Bedford Basin.

The latter work involved the use of Markov-Monte-Carlo (Gringorten, 1968. *Tellus 20:* 461-472) statistics and further applications have been developed. One example is a technique whereby estimates of lateral plume dispersion have been made using current meter data instead of distribution and concentration of conservative properties. The advantage is that temporal coverage is more easily obtained than through the use of dye and thus the two techniques are complementary. Another application of Markov-Monte-Carlo statistics is the estimation of extreme currents expected once in three years from current meter records of a few months. These extremes should be of use to those planning marine operations such as supertanker docking and oil drilling. Estimates of extreme currents are being prepared, using available data, for the Scotian Shelf, Strait of Canso, and Come By Chance Bay.



Dispersion scales vs time, St. Margaret's Bay, Nova Scotia, August 1967. The solid and dashed lines connect points based on current meter data in the minor (cross plume) direction at 6 m depth for two confidence levels. The symbols represent dye patch equivalent widths based on total areas at various times after release.

A new graphical method for presentation of current meter data has been devised to assist those planning marine operations. It shows the percentage occurrence of various current speeds in each of 12 direction segments. From this presentation, one can assess the current regime with respect to most frequent direction, direction of strongest rate, and distribution of speeds within a given direction segment. In addition the predicted extreme currents are displayed for each direction segment.



The statistical distribution of water currents from a current meter moored on the Scotian Shelf (Emerald Basin, $43^{\circ}46$ 'N. $63^{\circ}00'$ W). The individual plots show frequency of occurrence of various speeds in each of the twelve direction segments. Directions are relative to the true north arrow. On each plot, the small arrows mark the highest observed speed in each direction, while the numbers represent the estimates of the extreme currents expected to occur only once in three summers.

R. H. Loucks, D. J. Lawrence

At the request of an interagency task force, formed to study the environmental impact of the proposed Lorneville Superport, the meteorological and hydrodynamic conditions and forces which affect the area concerned were investigated. Lorneville is located 15 km southwest of Saint John, New Brunswick, about midway along the north shore of the Bay of Fundy. The region is completely open to the Bay of Fundy with a steep rocky coast and water depths in excess of 40 metres at a distance of less than 1 km from shore. The deep-water superport complex is intended to serve as a receiving, trans-shipping and unloading facility which will also be linked to a tank farm on shore for storage and industrial use.

The environmental conditions, which have a bearing on the design and operation of the superport, were analyzed. They are, compared with many other coastal regions, extremely severe. In winter, temperatures can drop to -26°C. Visibility is frequently restricted by fog, rain or snow (visibility range 0 to 1 km 30 days annually). Storms of gale magnitude (in the winter from cyclonic and in the summer from tropical disturbances) often reach strengths in excess of 35 m/s (70 mph) and waves, associated with these weather fields, may achieve heights of 9 metres annually and 14 metres in a hundred-year period. On top of these are the ever present tides with maximum ranges of 8.8 metres, and periodically alternating tidal currents reaching values of 1 to 1.2 m/s in the outward direction and about half that in the inward direction.

As is apparent from this brief review, the nature of the forces acting on the area is generally of such severity that, in order to minimize environmental consequences, careful consideration should be given to the type of superport chosen, its design, and also its operation. It is the opinion of the author that a flexible type of facility, which is capable of adjusting with the vessel to the forces of nature, is safer and is therefore, from an environmental viewpoint, preferable to a fixed one.

The movement of oil and the subsequent contamination of the coastline and inlets from oil spills depend on many factors. These include the place of release, duration of spill, time of accident with respect to tide, prevailing currents and meteorological conditions. A spill at Lorneville during Low Water or shortly thereafter would advance into the Bay of Saint John and spread over most of its area as shown in the figure. Oil released during the other tide stages would primarily be carried seaward, contaminating the coast and inlets of New Brunswick and Maine. Depending on the season and wind conditions, part of it would cross the Bay of Fundy and foul the coast of Nova Scotia.



Expected excursion of oil spilled at start of rising tide, Lorneville.

It must be recognized that in the case of a major oil disaster, there is hardly any coastal section between the Atlantic coast of Nova Scotia and Cape Cod which would not be threatened by oil pollution.

H. J. A. Neu

In order to assess the effects of a paper mill being constructed at Stephenville, Newfoundland (on the ocean environment), an oceanographic study of St. George's Bay was carried out during November 1970 and May 1971. Results indicate that the wind is the dominant factor in water movement, with tide and fresh water influence being secondary. A weak counterclockwise circulation is easily masked. Findings are limited since the observations do not cover all seasons.

E. M. Hassan

A program to study the gross composition and transport of suspended particulate matter in coastal waters was initiated with a study of Petpeswick Inlet, carried out in cooperation with the Marine Ecology Laboratory. Particulate matter was sampled along the length of the tidal inlet and over several tidal cycles. Analysis of particulate size spectra, using a Coulter Counter, as well as chemical determinations of organic parameters showed the general pattern of particulate matter distribution and movement.

In Petpeswick Inlet the concentration of organic particulate matter was found to fluctuate with the same period as seiche-like variations in the current speeds. Published records of similar measurements in other inlets are being examined to determine if this is a general characteristic of coastal inlets.

Much of the inorganic fraction of particulate matter in coastal areas consists of fine monomineralic grains flocculated into larger particles. In order to obtain information on the size and density of these particles, a requisite for dynamic transport studies, considerable time was expended on studies of the composition and formation of flocs. The settling rate and constituent grain size of flocs in natural samples were measured. Suspensions of natural and artificial particle distributions were flocculated in the laboratory and the resulting particle spectra determined. From the results the development of a general theory for the flocculation of sediment in sea water has been attempted.

As an aid to comparison with future samples a file of typical particle spectra has been started with spectra from Chedabucto Bay, Northumberland Strait, and Petpeswick Inlet. Common features in the general shape and size characteristics of these spectra enable a rough differentiation between inorganic and organic particles, living plankton, and particulate pollutants. The goal of this 'finger printing' of particulate matter is to be able to predict the natural particle distribution in any Maritime area and recognize the addition of particulates arising from waste discharge or as the result of other environmental changes.

K. Kranck

Wave Climate and Extreme Sea State

In recent years oil exploration has greatly increased on the Continental Shelf of the Canadian Atlantic coast. This exploration is faced with difficult technological problems unique to the aquatic environment, specifically the sea state. As in other coastal areas, available wave information from wave gauges was inadequate for designing oil rigs, marine structures, developing safety standards, and planning offshore operations. A solution therefore had to be found to provide information on the seasonal occurrence and distribution of extreme wave heights along the seaboard.
The only data base available was that provided by synoptic wave charts issued by the Maritime Forces Weather Centre. From isolines of significant wave heights and from plotted wave periods and wave directions, the wave climate was derived for 1970. The results are reported in AOL Report 1971-10, 'Wave Climate of the Canadian Atlantic Coast and .Continental Shelf - 1970'. They demonstrated clearly that the sea state along the coast was highly non-uniform with respect to time and space. During the winter, the monthly energy level was approximately five times greater than during the summer. Energy concentration on the Grand Banks and along the coast of Labrador was three to four times that over the Scotian Shelf. The reason for this lies in the seasonal variation of the direction and strength of the wind and cyclonic disturbances. In 1970 extreme wave heights varied along the coast from 9 metres in the Gulf of Maine to about 13 metres on the Scotian Shelf and reached a maximum of 19 metres on the Grand Banks.

In designing oil rigs the 'lifetime' or 'design-wave' is usually the 100-year wave. Statistical methods were applied to obtain this extreme value. As shown on the graph, this wave varies from 16 metres in the



^{&#}x27;Design-wave' (100-year wave) distribution along the Canadian Atlantic coast.

Gulf of Maine at the U.S.-Canada border to 30 metres at the outer region of the Grand Banks. Along the coasts of eastern Newfoundland and Labrador the 'design wave' is quite constant and almost of the same magnitude as over the Grand Banks.

From these results, the conclusion must be drawn that if a drilling rig is built for a 'design wave' of, say, 20 metres, it may withstand successfully all sea conditions on the Scotian Shelf, but will probably fail over the Grand Banks or off the Labrador coast.

H. J. A. Neu

James Bay

Because of the expected development of the James Bay area in Quebec and the proposed major changes in river flow conditions, the Division has capitalized on the occasion of the Canadian Hydrographic Service (Central Region) carrying out a survey program in the northeastern part of the Bay area during the summer of 1972, and has obtained oceanographic observations at a section across the mouth of James Bay and at a few other stations in the northeastern area. Although limited in time and space, these observations represent a significant contribution to the acquisition of a meaningful data base which will prove useful in the future should the planned hydro-electric development become a reality.

E. M. Hassan

Support Activities

Although a large measure of technical support for the division's activities is provided by other divisions within the Institute, a portion of the specialized needs, particularly current measurements and moorings, are provided by the division itself. Such field and equipment support is provided for Coastal Oceanography as well as for other divisions within the Institute. In addition, several universities, including Dalhousie, McGill, and Memorial, were supported in a limited way on various projects. Over 200 instruments were moored and recovered in the Gulf of St. Lawrence, Halifax Harbour, St. Margaret's Bay, Petpeswick Inlet, St. George's Bay, Come By Chance, and off the Grand Banks, to depths of 4000 metres,

Data reduction service for current meters, temperature and depth recorders, thermometers, and a salinity-temperature-depth system is

provided for institute users by a Data Analysis group. This includes having the record interpreted or translated, digitized, processed by computer, edited and plotted. Feedback from research scientists is used to continuously improve and streamline this process. Raw data, printouts and magnetic tapes of oceanographic data are filed. If the format or nature of the information is suitable, it is also forwarded to the Canadian Oceanographic Data Centre in Ottawa for storage and redistribution to interested parties. A report containing an inventory of current meter records from 1958-1970 was published in February 1971. This volume will be updated and republished soon to include data for 1971 and 1972.

C. R. Butler

Metrology



The Metrology Division is concerned with research, design, and development of new and unique oceanographic equipment directly related to the overall program of the Institute.

We aim to carry this out in close collaboration with other research scientists at the Institute, Dalhousie University, Halifax, Nova Scotia Technical College, etc., and to coordinate developments with industry by involving industry in the design and construction stages of any equipment acquisition. 'In addition, design and development contracts are arranged when feasible and the Division is developing a program to assist industry in the *in* situ testing of any new equipment. However, there is need to do much more than acquire a specific piece of hardware. An increasing emphasis in our program is to develop new techniques in using available equipment (for example, acoustic positioning, *Batfish*) and, in conjunction with AOL's standards laboratory, to develop calibration techniques to ensure measurements are tied into international standards (STD calibration).

The thrust to transfer new technology to industry has continued and the 'Batfish' and 'Rockdrill' are now manufactured under license. We have succeeded in contracting more of our strict 'hardware' requirements to local industry and anticipate this trend will continue with a corresponding change in emphasis of our in-house program. We hope that some of the new development work on both Batfish and drills will be carried out jointly with Canadian industry both locally and beyond the bounds of the Maritimes.

The division also includes a section responsible for experimental studies of the physical interactions at the air-sea interface. The main objective of this section continues to be the development of equipment and techniques for the measurement of wind stress under conditions of strong wind and unrestricted fetch. Despite a major setback caused by the collapse of the stable tower in December 1970, this program will be pursued as one of the long term objectives of the Institute.

The Metrology program is continually evolving - one project, the development of a new shallow water drill, has been outstandingly successful. Another project - the Radio Controlled Launch - has been cancelled outright because changing hydrographic survey requirements rendered the remote vehicle obsolete.

One highlight of 1971 was the suggestion award won by Mr. W. M. Proctor of the electronic design section who developed a technique for producing printed circuit boards. A description of the technique is given by Mr. Proctor at the end of this report (Support Facilities).



Presentation of a suggestion award to W. Proctor for his development of a technique for producing printed circuit boards.

The program of the division is divided into project areas and the following detailed descriptions highlight the work done in each area over the past two years.

C. S. Mason

Application of Underwater Sound

A requirement to obtain rock samples from specific points in a survey area - such as the Mid-Atlantic Ridge at 45° N - led to the development of an acoustic positioning system. A successful system to precisely position the Metrology Rock Core Drill has been developed and is now being used for several applications where a precise relative positioning system is desirable. The system is capable of defining the position of an instrument in the deep ocean to an accuracy of ± 20 metres relative to acoustic bench-marks placed on the bottom. To accomplish this, an American Machine and Foundry acoustic positioning system was purchased consisting of a receiver, acoustic transponders, and beacon pingers. In addition, the Electronic Design Section of Metrology has developed a suitable clock and cycling electronics to control the system, an interface for a PDP-8 computer, a punch paper tape data logger, and various items of test equipment.

The acoustic transponders are each mounted in a flotation collar developed by Metrology and shown in the figure. The moored instruments can be recovered at the end of an experiment by transmitting an appropriately coded acoustic signal to activate an



Acoustic transponder mounted in a flotation collar as used for a deep sea acoustic positioning beacon.

anchor release mechanism. Each mooring package is fitted with a flashing light and radio beacon for location purposes when it returns to the surface. The acoustic beacon pinger is mounted on the instrument whose position is required. The beacon internal clock is synchronized to a shipboard clock before the instrument is lowered from the ship.

The ship interrogates all transponders at time T_0 on a common frequency f_c (refer to survey technique figure). Each transponder replies at a different frequency f_A , f_B . The shipboard receiver measures the travel time of the acoustic pulse and converts it to the equivalent slant range from the ship to each transponder. At time $T_0 + t/2$, the beacon pinger emits a signal, f,, which is received at the ship and which also triggers the transponders which again reply at frequencies f_A and



Illustration of deep sea survey technique using bottom mounted acoustic survey beacons.

 $f_{B}.$ In this case the receiver measures the slant range summation from the beacon to each transponder to the ship as well as the slant range from the beacon directly to the ship. If three transponders are used, the position of the instrument to which the beacon is attached is then uniquely defined by this assemblage of slant ranges providing the relative positions of the transponders are known.

Two survey methods to define the relative positions of the transponders have been explored. The baseline crossing and cloverleaf technique has been compared with a best fit solution to a number of simultaneous slant range measurements to all the acoustic transponders from a number of different points within the working area. The latter method is as effective as the former in terms of accuracy while requiring less ship time. A description of these survey techniques along with experimental results obtained during a cruise to the Antigua area during January and February, 1971, is being submitted for publication.

During July and August, 1971, this system was used to determine the relative positions of core samples obtained using the hydrostatic rock core drill in the median valley of the Mid-Atlantic Ridge. The system

was also used in the same area to position a deep sea camera over a period of several hours.

During this cruise, the very rugged topography of the median valley prevented direct transmission from the pinger to the transponders. In such circumstances, it was necessary to rely upon a surface reflected signal to the transponders with a resultant decrease in positioning accuracy.

During November 1971, the same system was utilized to accurately position a ship during extended Batfish tows on the edge of the Scotian Shelf. The beacon pinger was also attached to a Guildline STD during some of the vertical casts on that cruise to confirm that the acoustic positioning system correctly defined the depth of an instrument package. In addition to these experiments, simultaneous hyperbolic Decca and acoustic positioning fixes of ship position were obtained over two separate night/day periods to study the repeatability and variability of Decca.

In May 1972, two transponders and one pinger were moored in coastal waters at a depth of 500 metres. Experiments were performed to: test the accuracy of the iterative solution of the transponder positions; determine the accuracy of determination of instrument position represented by the beacon pinger moored on the bottom; study the system capabilities in shallow water; and obtain further measurements of hyperbolic Decca variability. Preparation of papers is presently underway describing the method of positioning instruments acoustically and presenting information on the variability of hyperbolic Decca position fixing at sea.

D. L. McKeown, B. B. Hartling

An oblique echo-sounder produces a record of the sea bottom topography in a strip 350-450 metres wide on either side of a ship's track. Designed specifically for use in Canadian Continental Shelf waters where there are marked temperature structures, a system has been developed and used operationally for bottom mapping prior to -drilling. The oblique echo-sounder project suffered a major set-back in February 1971 when the towed body (*Moby Fish*) and transducers were lost at sea. This occurred during a survey of the anchorage for the Air-Sea stable tower at the mouth of Halifax Harbour when the towing cable fouled a buoy line marking one of the tower anchors. Initial attempts at recovery utilizing underwater television and divers ended in failure. A request was made to the Canadian Armed Forces for the use of their submersible SDL-1 to aid in recovery attempts. This unit was finally made available in September 1972 and the towed body was

Recovery of the towed body *Moby 1* using the Canadian Armed Forces Submersible SDL-1.



 a) Claw of submersible fastening to towed body on sea bed. (Canadian Force: Photograph)



b) Submersible and towed body immediately after recovery. (Canadian Forces Photograph)

successfully recovered. The fiberglass towed body was severely damaged but repairs are underway. Both transducers were flooded and are being returned to the manufacturer for possible rejuvenation. The pitch and roll transducer assembly was corroded beyond repair although the oil-filled transducer attitude motor was unharmed. Much credit is due the officers and men associated with the SDL-1 for their effective search and recovery operation.

A replacement towed body and a single transducer have been acquired and, based on experience gained with the first towed body, minor alterations were made to the Moby *Fish* (the towed body). As a result of field trials pitch was reduced to $\pm 0.9^{\circ}$ and roll to $\pm 0.4^{\circ}$. The towing noise of the body is -49 db which is remarkably low. This excellent towed body was designed by Defence Research Establishment Atlantic as part of their variable depth sonar development.

Initial towing trials in Bedford Basin from the launch *Phoenix* permitted the testing and adjustment of the side-scan equipment. Extensive trials were then conducted aboard CFAV *Bluethroat* in the summer of 1972 and the performance of the new instrument compared with a similar survey made in 1965 by Chesterman (Dept. of Physics, Univ. of Hong Kong). Bottom samples were obtained from sites suggested by AGC geologists who assisted in the examination of the records. The Nova Scotia Research Foundation's offshore acoustic range was also occupied although bad weather precluded complete coverage. By the end of the summer an operational system was available.

A unique feature of the AOL oblique sounder is the ability to vary the 'vertical' axis of the beam to cope with various thermocline effects. A line was established between two buoys in Bedford Basin and the fish was towed over this area with various beam angles. With the axis of the vertical beam at 0° (horizontal) very little information was obtained beyond 200 metres and a significant gap in the record existed between the main and side lobes. At 7.5° below the horizontal the whole area from directly below the ship out to a range of 200 metres was covered. Although full BOO metres coverage could not be achieved, it was possible to adjust the beam angle for optimum bottom coverage. The beam angle to the horizontal can be adjusted from 0° to 10°.

In September 1972 the oblique sounder was tested in the Gulf of St. Lawrence with D. H. Loring of MEL and off the Labrador coast with I. M. Harris of AGC. The first portion of the cruise was especially useful to the Metrology Division as the surficial geology of the Gulf is well known so that much can be learned about the interpretation of side-scan records in subsequent studies of cruise data. Also, during this portion of the cruise there was an opportunity to contrast the AOL system with a unit hired from the Institut Français du Petrole. The deep thermocline was a constant problem in the Gulf and the AOL unit suffered from a flooded transducer but useful information was obtained concerning surficial geology and the two side-scan systems produced comparable records. The barge *Irving Whale* sunken off P.E.I. was also located and examined with the oblique sonar.

The main purpose of oblique sonar surveys in the Labrador area was to locate possible rock outcrops suitable for sampling with the electric rock core drill. The drilling sites located initially through brief side-scan surveys were found to be glacial till rather than rock outcrops. A more extensive side-scan and reflection seismic survey revealed that the whole area was probably covered with 5 to 7 metres of glacial till. This was confirmed by the drilling operation. During this survey many excellent records of bottom gouging by icebergs, such as those shown in the figure, were obtained.



Side-scan record from the Labrador sea area, illustrating gouging of the sea floor by icebergs.

Plans for future applications of the system are being formulated through discussions with interested users. It is hoped that the system will be expanded to meet the original design goal of looking to both sides of the ship's track and of being operationally useful for hydrographic surveying.

P. G. Jollymore, D. L. McKeown

For many years it has been the practice of oceanographers to measure the velocity of surface currents by means of floats containing either a radio transmitter or radar reflector for positioning purposes; unfortunately, the movement of the drogue is a function of both water currents and wind, because of protuberance above the water surface. The Swallow Float, an acoustic drogue, is used to track deep ocean currents. The acoustic source is contained in a pressure case designed such that the drogue sinks until it reaches a depth where the water density is such that it is neutrally buoyant. It is then tracked acoustically as it moves about under the influence of currents. Work has started on the basis of our acoustic positioning experience to combine the relevant characteristics of these devices into a unit for use in tracking surface currents in inlets. Some equipment has been purchased and we hope to commence field trials under the new project in the summer of 1973.

D. L. McKeown, P. G. Jollymore

An underwater package capable of switching on or off up to four separate devices via an acoustic link has been designed and built. This unit has undergone tests in Bedford Basin and just recently during a cruise on the CSS Dawson (Cruise 72-024). The results of these tests have been most promising and to date no problems have been encountered. The system has been designed to work in a high noise environment with a signal-to-noise ratio of up to 1 being tolerated. A commercial acoustic interrogator is used as the signal source. With the present transmitting and receiving system, a range of up to two miles may be used with reliability. Initial application will be for remote control of the hydrostatic rock core drill.

P. G. Jollymore

Radio-Controlled Launch

During the past two years major changes have occurred in the radio-controlled launch program. The original gasoline engine was replaced with a diesel engine to increase safety and reliability. The remainder of the system has not been substantially altered in the past two years. The prototype launch was tested in February 1971 during a cruise to the Antigua area and again in July 1971 during a cruise to the Mid-Atlantic Ridge. The control system, echo sounder telemetry system, and the launch performance telemetry system were extensively tested and found to perform satisfactorily under all conditions. On the other hand, the present hull and engine combination proved unsatis-

factory in open sea conditions although the entire system worked well in Bedford Basin.



The radio-controlled launch underway.

In the spring of 1972, the radio-controlled launch concept was re-evaluated. It was felt that the next major step would have to be a study of hull forms and power plants along with field trials of the existing prototype launch under a realistic survey program. However, the launches were originally intended as a survey system for rapidly and economically obtaining bathymetric information on a hydrographic program such as the Labrador Shelf survey. With the rapid evolution of multidisciplinary hydrographic surveys, incorporating gravity, magnetic, and shallow seismic data along with bathymetry, the launch concept became obsolete. Thus changing requirements have led to the cessation of the radio-controlled launch project. A report on the program was presented in Brighton at Oceanology International 72. Technical manuals for the system have been drafted and presently discussions are being held with interested parties concerning the eventual disposition of the prototype launch.

D. L. McKeown, E. A. Bendell, P. D'Entremont

Oceanographic Sensors for Data Logging

The Batfish porpoising towed body continues to be the major project under this heading. Mechanical development of the towed body has continued, resulting in improvements in the launching and recovery methods and consequently in the reliability achieved at sea. Hermes Electronics Ltd., Dartmouth, are now licensed to produce two models; the standard version, capable of porpoising dives to 200 metres while being towed at 6 m/sec (12 knots) and a larger-winged version capable of 400-metre dives at 4 m/sec (8 knots). A launching sled has been designed which enables routine launching of *Batfish* and the faired towing cable under adverse sea conditions.



Batfish launching sled aboard CFAV Bluethroat

The low drag cable fairing used with *Batfish* cannot be handled on a standard oceanographic winch because its minimum bending radius is 45 cm and it cannot be wound over itself. We have built a special winch which is light and compact to meet this requirement. The winch drum is 1.15 metres in diameter and 1.23 metres wide. One layer of cable

wound with the fairing tail up contains 300 metres of cable. When the drum is full, a second drum formed of four segments is installed over the first drum and a second layer of cable can be stored to make a total capacity of 600 metres.

Both the large- and small-winged *Batfish* have been used with the Guildline Instruments salinity-temperature-depth apparatus (STD) for tows of 24 hours duration. Contoured sections are shown in the illustration. These contours are plotted manually through points computed and plotted automatically by the PDP-8 computer, which is also used for data acquisition.



Typical contoured sections of temperature vs depth, measured with the *Batfish* towed body.

Batfishes have now been towed from a variety of ships and in various places, including the Scotian Shelf, the Gulf of St. Lawrence, and as far offshore as the Gulf Stream off southeastern Newfoundland. The Gulf of St. Lawrence cruise, August 1972, on the CFAV *Bluethroat* (336 tons), with a scientific party relatively unfamiliar with the *Batfish*, may be taken as marking the point at which the *Batfish* became a useful scientific tool rather than a research project in itself.

Precision calibration has continued to be an integral part of the program. In addition to the precise temperature calibration that was set UP for the Digibridge temperature recorder (Bennett, A.S., 1972, *Deep-Sea* Res., 79: 157-163). facilities for salinity calibration have been expanded. A calibration bath has been built which is similar to that in use at the National Research Council Applied Physics Laboratory in Ottawa but differs in design details, especially in dimensions and construction materials. Detailed study of the discrepancies between calibrations carried out at the Bedford Institute of Oceanography and by Dr. T. M. Dauphinee in Ottawa culminated in an experiment in



Salinity - temperature - depth calibration bath.

which the Ottawa apparatus was brought to BIO and used side by side with our bath. This led to improved understanding of the precautions and method needed to achieve accurate salinity calibrations and to improve quality control of the salinity sensors which should be reflected in more accurate and more reliable salinity measurements at sea.

Development of an improved version of the Guildline-NRC STD is continuing. Engineers from Guildline have visited AOL and also participated in a cruise on the *CSS Dawson*. They are now producing a re-engineered version, made up from modular units, which we hope to test at sea early in 1973.

Dr. T. M. Dauphinee, National Research Council, is continuing to develop new and improved sensors for the STD in collaboration with Guildline and AOL. We hope to test new high speed sensors for salinity and temperature early in 1973.

The development of the Digibridge recording thermometer has been completed. Six units were moored during a *CSS Hudson* cruise. Unfortunately the five units which were recovered had failed after six to eight days operation. The failure was caused by a combination of design errors in the battery pack and electronic control circuits which have since been eliminated. A license to manufacture the instrument has been granted to Hermes Electronics Ltd. by Canadian Patents and Development Limited.

A. S. Bennett, M. Stepanczak, J. P. Thorburn, J. J. Betlem, J.-G. Dessureault, T. M. Dauphinee (NRC)

Eddy Flux Measurements Over the Sea

An ongoing project is the study of wind stress, heat exchange, and evaporation under open-sea conditions and at high wind speeds. Design studies have been carried out by the Systems Engineering group of Engineering Services for re-installation of a stable platform near the approaches to Halifax Harbour in 1973-74.

A series of measurements has been carried out in Lake Ontario as a contribution to the International Field Year for the Great Lakes (IFYGL) at a fixed mast installed by the Canada Centre for Inland Waters (CCIW) and at a 'Bedford Buoy' (large spar buoy) installed by Atmospheric Environment Service (AES). A sonic anemometer, a thrust anemometer, a micro-thermistor, and a Lyman-Alpha (ultraviolet) humidiometer were used to sense and record turbulent fluctuations of wind, temperature, and humidity. The principal results are: (1) parameterization of the fluxes for use in IFYGL budgeting and modelling projects (presented by Smith and Banke at the 3rd National Oceanographic Symposium, Burlington, 1972), and (2) comparison of sensors with those operated by other groups participating in IFYGL and, in particular, an evaluation of thrust anemometer performance.

S. D. Smith, E. G. Banke

Wind Stress Measurements Over Ice

Turbulence measurements have been made in the atmospheric boundary layer over ice in the Arctic Ocean, with 'AIDJEX' (Arctic Ice Dynamics Joint Experiment); in the Beaufort Sea, supported logistically by the Polar Continental Shelf Project; and with the Defence Research Board of Canada in Robeson Channel.

Turbulent flux data for winds, temperature, and humidity were collected. A total of 137 forty-five minute data tapes are now on hand, for various ice surfaces from smooth to rough. To relate turbulence measurements to ice contours, survey lines were run upwind and downwind from the various probe locations. Spectra of winds and surface elevations are being compared to determine the relationship between wind stress and surface type. Participation in the above experiments has resulted in values for bulk transfer coefficients of sensible heat flux, $C_T = 1.2 \times 10^{-3}$, and of evaporation, $C_0 = 0.55 \times 10^{-3}$, over Arctic ice. The mean drag coefficient over ice is approximately $C_{10} = 1.6 \times 10^{-3}$ with a range from 1.0 to 3.7 x 10^{-3} . Verbal presentations of results have been made by Banke and Smith (at the 2nd Canadian Conference on Micrometeorology, 1971, and at the Sea Ice Conference, Iceland, 1971); and by Smith and Banke, and Thorpe, Smith and Banke, (both at the fall AGU meeting, San Francisco, 1972).

See also Banke, E., and Smith, S. D. 1971. *J. Geophys. Res.*, 76: 7368-7374; and Smith, S. D. 1972. *J. Geophys.* Res., 77: 3886-3901.

E. Banke, S. D. Smith, M. R. Thorpe, C. S. Mason

Iceberg Towing

In a joint project with Memorial University, Newfoundland, iceberg towing was conducted by a launch in 1971 and by the *CSS Dawson* in July 1972 in order to measure towing forces and derive drag coefficients for a small number of 'growlers' or small icebergs



Towing a growler, CSS Dawson, July, 1972. (Memorial University of Newfoundland Photograph)

(presented by Banke and Smith at the Canadian Seminar on Icebergs, CFB Halifax, 1971). A computer model is being developed in an attempt to predict the motion of icebergs under the influence of winds and water currents.

E. Banke, S. D. Smith, J. Gorman

Wave Follower Program

Research into the mechanisms by which the wind makes waves grow lies at the centre of the Air-Sea Interaction problem. The fluxes of momentum, heat, and water vapour are in some sense controlled by the same processes which make waves grow. The latest work shows that most of the wind-wave interaction in the air takes place below the wave crests, i.e. in the troughs of the waves. To study the interaction experimentally, it is necessary to put sensors there. We propose to move the sensors vertically on a servo-controlled platform, keeping them at a fixed height above the waves. The most interesting variables to measure are the wave height, turbulent fluctuations in air pressure, and the mean and turbulent components of horizontal wind speed. The air pressure is thought to be the principal mechanism of energy transfer from the wind to the waves; a study of variations of the wind speed with height and with horizontal distance along the waves (parallel with the wind direction) will give insights into the validity of many of the presently fashionable theories of wave generation.

In August 1971 approval was given to begin work on a wave follower. The instrument chosen is a servo-controlled hydraulic system designed by M. Peep and R. Flower at Chesapeake Bay Institute, Johns Hopkins University, under the guidance of Dr. Blair Kinsman. Extensive discussions were held initially with Peep and Flower, and their assistance has proved invaluable.



The newly constructed AOL wave follower for Air-Sea Interaction studies.

Redesign and construction of the servo-electronics and of the mechanical and hydraulic system were carried out in late 1971. In the spring of 1972 laboratory tests were begun on its performance. Simultaneously work was begun on a tower for mounting it, which enables the device to be raised and lowered with the tides. In October 1972 the wave follower was first put into salt water, and tests are underway alongside the BIO dock. To date all required specifications have been met or surpassed.

In May 1971 an invitation was received to take part in JONSWAP II (Joint North Sea Wave Project), an international experiment to be held off the North Sea coast of Germany in August-September 1973. It is an attempt to make as complete a study as possible of a field of waves growing under the influence of an offshore wind. For the first time simultaneous measurements will be made of wave growth and of the flux of momentum downwards into the waves. The latter is to be accomplished with the use of the wave follower which will be instrumented to give measurements of the fluxes of turbulent energy and momentum from the wind to the wave field: fixed turbulence sensors will measure the fluxes of momentum, heat, and water vapour from air to sea. These measurements will give a more accurate determination of the ratio of total downwards momentum flux to that going into the growing wave field alone. It will also be possible to estimate the spectrum of energy dissipation. The results of this experiment will be useful in obtaining a better understanding of the processes that occur at the air-sea surface.

F. W. Dobson, D. R. Harvey, D. F. Knox, P. F. Kingston

Rock Core Drills

The development of a new type of rock core drill for use from a conventional oceanographic ship has continued. The aim to recover 30 to 60 cm long cores of vertically oriented rock samples has been achieved for operational depths from shallow water to ocean depths of 3600 metres. Within this project new methods are being investigated to increase the degrees of control and reliability of power. The long range goal is to enable the scientist to deploy a bottom sampling device with directional control into a previously surveyed area. The accuracy of navigational positioning will be dependent on the progress of the acoustic work described elsewhere (see Metrology: acoustic positioning). Ultimately the framework of the unit should be able to carry other sampling aids, such as a surveying camera, side echo sounder, grab samplers, temperature probes, etc., so that a total survey of the area under investigation can be performed.

Early in 1971 tests of a hydrostatic drill for drilling in water depths of up to 3600 metres (deep ocean operation) were conducted (Cruise 71-002). The purpose of the cruise was to check the function of mechanisms used on the drill designed for 1800 metres depth with changes in the motor size and the reservoir. Theoretically, the motor size could be reduced because of the greater pressure available and conversely the strength of the reservoirs had to be increased. There was also a demand for an increased cycle time of the drill which was achieved by increasing the volume of the reservoirs. The tests on that cruise indicated that most of the mechanisms of the drill would function at greater depths; however, further modifications to the motor were required.

In June 1971 a drilling program with the University of Dalhousie was conducted in the Median Valley of the Mid-Atlantic Ridge using the modified drill together with spherical steel vessels acting as reservoirs. The smaller motors failed after several tests and in consequence the motors used previously for 1800 metres depth had to be installed in spite of the possible problems of expected case distortion. The experiment was successful and, for the first time in oceanographic history, hard cores were obtained from the pillow lava bottom of the median valley. The two photographs below the gradual descent of the drill barrel as the unit operates. A total of six basalt cores were



A series of Bottom photographs of hydrostatic drill operate in the median valley of the Mid-Atlantic Ridge, July 1971.

obtained ranging in length from 10 cm to 32 cm. However, difficulties were experienced in using the present assemblies in the rugged terrain because of .the steep short slopes of the pillow lava; considerable damage to the drills occurred on several stations. In summary, the present drill design is now proven for water depths from 600 to 3600 metres with a cycle time of 20 minutes. Further work is required on the frame and certain mechanical details to assure continuous work in rough terrain.

As part of the overall drill project objective of extending the useful range of small, bottom-operating, rock core drills, work has continued on a unit for shallow water. Because depths are limited, it is possible to supply power to the drill from a surface ship to drive an electric motor.



Shallow-water electric rock core drill with 20 foot barrel.

Initial trials were conducted on an electro-hydraulic system in which it was possible to control remotely the various drilling parameters. This equipment achieved a measure of success at sea but, because the electric-hydraulic conversion is relatively inefficient and the hydraulic control system was complex, alternate means of driving the drill were investigated. The work on drive systems resulted in a prototype that offers several advantages for underwater operations. It is relatively simple, robust, and compact, can theoretically drive a drill barrel of any reasonable length (at present up to 9 metres), and powers the barrel at the bottom of the rig which is ideal from the point of view of rig stability. The system applies rotation and download from the electric motor directly to the drill barrel by a mechanical linkage. Torque limitation, extension rate and drill rpm can be adjusted prior to use to suit the power and/or download available on the drill frame. The drill unit is shown in the photograph.

Extensive trials on land were conducted with the rig followed by forty-five experimental drilling stations run at sea from the CFAV *Bluethroat* Thirty-one lowerings of an operational nature were made on two geological cruises to the Gulf of St. Lawrence and the Strait of Belle Isle where 17.7 metres of rock core were recovered.

The results obtained on field operation indicate that the shallow range rock drill is an operational exploration tool. Through Canadian Patents and Development Limited, the license to Hermes Electronics Ltd. for drill manufacture has been extended to include the shallow drill which will soon be commercially available.

J. Brooke, G. A. Fowler, P. F. Kingston, W. C. Cooke

New Devices for Water Sampling

Water sampling devices to provide a continuous flow to a shipboard fluorometer have been built for Coastal Oceanography and MEL. These units use a deep well pump suspended on a towing cable which contains the water hose and electrical conductors to supply power to the pump and carry instrument signals from a depth-temperature sensing unit mounted at the pump intake. Because of high power requirements to drive water at high speed from depth to the sensing unit, the towing cable length has been limited to 30 metres. An *in situ* fluorometer hose has recently been purchased and will be fitted into the *Batfish* (Metrology's porpoising towed body). This project is being carried out jointly with Hermes Electronics Ltd. and hopefully a new sensor for a *Batfish* will also be commercially available.

A second type of sampler is under development for Chemical Oceanography for use with an auto analyzer. This equipment injects air bubbles into a water sampling tube at depth. The air bubbles perform a dual function in providing some upward drive to the water column while segmenting the samples and wiping the tube walls after the passage of each short sample of water. It is hoped that this equipment will be able to work down to 150 metres depth and provide samples from several depths at the same time. Operation before the 1973 season is anticipated.

G. A. Fowler, A. E. Johnson, W. J. Whiteway

Liaison with Local Industry

As a result of the research and development program at the Institute, a number of new and unique instruments have been produced. Further production of these devices is essential not only to satisfy the continuing requirements of the Institute but also to manufacture the equipment for a worldwide market. Significant improvements and new innovations will also result from the fresh look that local industries can bring into continuing Institute projects. Responsibility for liaison with local industries in the Halifax-Dartmouth area has been assigned to one of the Metrology design engineers. Working through Canadian Patents and Development Limited licenses have been granted for manufacture of *Batfish*, Digibridge, and Hydrostatic and Electric Underwater Drills, and applications for several other devices are underway. The manufacture is being drawn into the earlier design stages of other new equipment (see above: New Devices for Water Sampling, Oceanographic Sensors for Data Logging).

A major project in 1972 was a demonstration of the *Batfish* system jointly with Hermes Electronics Ltd., Dartmouth, and the Department of Industry, Trade and Commerce. The system was installed on CFAV *Bluethroat* and over a two-week period potential users from the U.S.A., Italy, Germany, and France were able to see the system in operation under realistic field conditions.

J.-G. Dessureault, C. S. Mason

Support Facilities

The instrument development shop has continued to spend approximately 50% of available time on projects within the division, with the remainder divided more or less equally between AOL, MEL and AGC. Division of the shop into two sections has continued. The precision workshop is used only by qualified technicians primarily from Metrology Division. The technicians' workshop is used by all Institute staff openly.

P. F. Kingston

The primary responsibility of the standards laboratory is to provide reference standard facilities for all significant units of measurement of importance to operations within BIO. Where feasible, standards are traceable to the National Research Council or the National Bureau of Standards. Primary reference standards are kept in the BIO standards laboratory room and secondary standards are available for use in the Institute or the field. In 1971 a dead weight tester was installed for calibrating pressure gauges. The temperature calibration facility is now operating routinely and the large constant temperature bath is used to calibrate Digibridge recording thermometers and other equipment. The STD calibration program now includes *in* situ calibrations as well as the in-house laboratory calibrations.

J. J. Betlem

To enable easy and routine testing of new equipment at sea, we have been developing a program in which, at specified periods throughout the summer, ship time is available for periods from one day to two weeks. In 1972, CFAV *Bluethroat* was used for four 2-week long periods. Approximately 60% of the available ship time was spent on Metrology projects with the remainder going to local industry and projects in AOL, MEL and AGC.

A portable laboratory has been acquired as a support facility for this project. The laboratory consists of a modified cargo container fitted with air conditioning, electrical distribution panels, and clean and dry work areas. In 1972, the laboratory was used for six cruises with a utilization of approximately 1800 hours.

W. J. Whiteway, C. S. Mason

As part of a long term project to improve handling facilities in our research fleet, a portable marine hydraulic hoist was purchased for AOL Ships Division and has been fitted to the CSS *Hudson*. This hydraulic hoist appears to be superior to others that have been previously purchased and experience in 1972 has justified the routine use of this type of equipment.

J. Brooke

The only feasible way of interconnecting modern electronic integrated circuits is through the use of printed circuit (PC) boards. It was found that it was not possible to obtain PC boards from local manufacturers on short notice so an inexpensive in-house method was devised to meet urgent requirements. Starting with a full scale taped master a negative is

produced by using a water developed film. Copper clad board is photosensitized and through contact printing the circuit is transferred onto the copper clad board. The board is then etched in ferric chloride. A silver dip plating is then applied to protect the copper foil. This complete procedure requires approximately four hours to produce a printed circuit board that is ready for drilling and component installation. This system of producing PC boards has been used extensively during the past two years where the time element has been an important factor. The development of this system resulted in W. M. Proctor, a member of the Electronic Design Section, receiving a Suggestion Award.

W. M. Proctor

Ocean Circulation



During the past two years the Ocean Circulation Division has continued to develop and expand its program aimed at understanding some of the physical processes that occur in the body of the ocean. As has previously been the case, a large portion of the division's work has been directed towards understanding the Gulf Stream System off the Tail of the Grand Bank. To this end the ability to moor current meters in the Stream has been developed and was used in an international, three-ship experiment carried out in the area in the spring of 1972. Using the same techniques the division will participate in the ICES (International Council for the Exploration of the Sea) '73 Overflow Expedition at which time the deep water flow between Iceland and Greenland will be measured. We can look forward to carrying out more large scale experiments using our mooring technology, but in the future the emphasis may easily shift more in the direction of experiments designed to investigate particular facets of ocean dynamics rather than the more or less descriptive operations of the past.

The Division has recently become involved in instrument development and experiments directed towards measurements of microstructure. This has taken two directions. Firstly, a probe has been developed which can measure velocity, temperature, and salinity microstructure and which will be used to examine the extent and nature of small scale 'turbulent' patches in the oceans. Secondly, experiments are being carried out in lakes for the purpose of looking at the contribution of low frequency internal waves to the step-like structure often observed in the density profiles of both lakes and oceans.

In conjunction with the experimental programs described above, theoretical investigations are being conducted in large-scale low-frequency motions, large-scale oceanic models, internal waves, and basic stratified-rotating flows. Although in the past, deep sea oceanography has suffered from the lack of relevance of idealized theories and models in interpreting the usually sparse measurements, we can look forward to decreasing the gap between these two approaches toward gaining real understanding of ocean dynamics.

G. T. Needler

North Atlantic

The Gulf Stream flows northward along the United States eastern seaboard then eastward across the North American Basin along 40°N as an intense narrow current characterized by a rather sharp thermal front between the warm waters of the Sargasso Sea and the colder waters

inshore. Off the Tail of the Grand Bank of Newfoundland the Stream encounters shoalling water over the Southeast Newfoundland Ridge which causes the Stream to spread out or branch. Farther to the east, the North Atlantic Current transports warm water northward along the eastern edge of the Grand Banks and then eastward across the Atlantic at about 50°N. It is not known, however, what portion of the water or salt or momentum, transported to the region off the Grand Banks by the Gulf Stream, is carried out of the region by the North Atlantic Current and how much is dissipated and returned to the Gulf Stream gyre.

During the 1960's, the Bedford Institute of Oceanography sent several cruises to investigate this area, observing the density field by classical hydrographic stations. However, by the middle 1960's it was apparent that the partition of the Gulf Stream transports in this complex region could only be resolved by direct measurements of the velocity field. Cruises on the Dawson in this area in both 1970 and 1971 were undertaken by Ocean Circulation and these resulted in the development of reliable current meter moorings which could be moored beneath the Gulf Stream for periods of up to 75 days and measure currents at several levels up to 2000 meters from the ocean floor. The 1970 data obtained from test moorings under the Gulf Stream near 50°W coupled with a series of three sections along the mooring sections gave valuable information concerning the time and spatial scales that might be expected in this region. The 1971 data, although not yet fully analyzed, complement the information obtained in 1970 by giving shorter horizontal spacings and longer time series.

These 1970-1971 data indicate that at 50°W the Gulf Stream and associated eddies extend to the bottom, the velocity at the bottom being about 20% of the surface velocity, and the current directions at the bottom and at 500 metres depth being within 20° of each other. Also the currents observed during 1970 appear to be aligned along the depth contours implying topographic control of the Stream and its eddies. Using the current meter data and the hydrographic sections collected in 1970 it was possible to estimate the absolute transport of the Gulf Stream. Previous estimates of absolute transports of the Stream farther upstream suggested that the transport increases exponentially with distance downstream of Cape Hatteras (Knauss, J. A., 1969. Deep-Sea Res., supplement to 16: 117-124). Our estimate at 50°W suggests that little increase occurs between 60°W and 50°W. The data collected in the area in 1972 will provide a better transport estimate. If the no growth in transport result is confirmed, the fluxes into and out of the Stream will have to be examined to determine why east of 60°W they come into dynamic balance.

A major cooperative effort between April 12 and July 15, 1972, saw the *Hudson*, the *Chain* (Woods Hole Oceanographic Institution) and the *Cirolana* (Lowestoft, U.K.) working in the area to the south and east of the Grand Banks. In order to obtain estimates of the total transports for the Gulf Stream upstream of the Southeast Newfoundland Ridge and for the North Atlantic Current downstream, the *Chain* set a section containing 12 near-bottom current meter moorings along 49°40'W from 37°N to 41°30'N; the *Hudson* set a further two moorings along 49°40'W, immediately to the north of the Woods Hole moorings, and eight moorings in a section across the North Atlantic Current from 43°N, 47°30'W to 41°6'N, 42°30'W; and the *Cirolana* set three moorings across Flemish Pass. The *Chain* and the *Hudson* then occupied



Location of current meter moorings to the south and east of the Grand Banks, April 12 - July 15, 1972.

a grid of stations between and along the two current meter lines while Cirolana ran two oceanographic sections to the north of the main Hudson mooring line. Each ship ran bottle stations, observing temperature, salinity, oxygen content, and silicate concentrations at a number of depths at each station, standardizing their analysis against common standards. The Hudson also took measurements of nutrients, nitrates, and phosphates. The temperature and salinity data allow one to calculate the density field which in turn can be used to calculate the pressure field. The pressure field can then be combined with the current meter data to obtain the velocity field through each oceanographic section or line of stations. The temperature and salinity as well as the silicate and oxygen concentrations can then be used to identify certain types of water and by using the velocity field one can calculate the flux of these types of water into and out of the region. Using this technique it is hoped that accurate estimates of the partition of the Gulf Stream transports in this region can be obtained.

Even with three ships operating it is impossible, using bottle stations, to survey the entire area of interest quickly enough that the structure does not change significantly over the sampling time and on a fine enough scale to include all the scales of interest. In order to observe these finer scales the *Hudson*, using XBT's (expendable bathythermographs), spent several weeks running a large number of lines back and forth over the Southeast Newfoundland Ridge, the region in which the branching is suspected to occur. A detailed picture of the temperature field in the upper 700 metres was obtained. Following this operation moorings were recovered and the *Hudson* returned to Halifax where preliminary processing of the data is still in progress.

(See also the essay, "The Gulf Stream off the Tail of the Bank", in Ocean Science Reviews 1971-1972, Part A of this Biennial Review.)

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

Using the data from HUDSON 70 as well as from several previous cruises, mostly by AOL, meridional sections of silicate, salinity and potential temperature have been constructed for the western basins of the Atlantic Ocean. The major silicate maxima and minima have been traced back along surfaces of constant potential density to source water masses which are either rich or poor in silicate content, Small scale features in the silicate distribution near the bottom over the Southeast Newfoundland Ridge are related to features in the salinity distribution which leads us to conclude that even at intermediate depths, advection is the dominant process determining the silicate distribution in the western basins. This is consistent with the findings of Menzel and

Ryther (1968. *Deep-sea Res. 15:* 327-337) who studied organic carbon and oxygen distributions. As far north as the Newfoundland Basin the silicate content of the near bottom water is dominated by the flux of high silicate Antarctic Bottom Water. Similarly, the intermediate silicate maximum associated with the Gulf Stream System may be traced back to the Antarctic through Antarctic Intermediate Water.

C. R. Mann, A. R. Coote

The dense water, from the Norwegian Sea, that flows across the Greenland/Scotland ridge, mixes with the North Atlantic water to form North Atlantic Deep Water. It is now known that this flow is the major contribution to the existing deep water in the North Atlantic. Previous investigations have shown that the overflow of dense water occurs intermittently at four locations along the ridge. However, these investigations have been unable to determine the causes or spatial and temporal scales of the fluctuations of the overflow. Recent improvements in self-recording moored instruments now make it feasible to investigate these problems.

The International Council for the Exploration of the Sea (ICES) is sponsoring a cooperative investigation of the Greenland/Scotland overflow during the late summer of 1973. Seven member countries have committed 13 ships to investigate the oceanography of the ridge system from Greenland to Scotland. It is expected that 47 moorings of current and temperature sensors will be operating for the period of the experiment. In addition, moored and shore-based stations will monitor meteorological parameters and sea level fluctuations. During the time the moored instruments are operating, shipborne measurements will be taken of physical, chemical and biological characteristics across and along the ridge.

The Atlantic Oceanographic Laboratory will undertake to investigate the overflow in the Greenland to Iceland area. This forms a continuation of the work done in 1967 in Denmark Strait and the Irminger Sea. During that experiment we found that the overflow had current speeds up to 1.5 ms⁻¹. The moorings, at that time, were unable to withstand the drag exerted by the fast currents. Since then, much effort has gone into the design of a mooring to withstand high current speeds. Using the *CSS Hudson*, four moorings of temperature and current sensors will be placed north of the sill and five moorings south of the sill. In addition a meteorological buoy and deep-sea tide gauge will be installed in Denmark Strait. The moorings will be in place from mid-August to mid-September and during that time several sections of temperature, salinity, and chemical parameters will be measured across the channel to determine their spatial and temporal variability. A program of oceanic microstructure measurements will also be undertaken in the overflow.

C. K. Ross, C. R. Mann

Currents in Drake Passage

During the HUDSON 70 expedition four buoys were moored at four equally spaced positions; each buoy carried three current meters, one at 150-metre depth, one at 1500-metre depth, and one 120-metres from the bottom. The depth of water at all four positions was about 3500 metres. The records from the current meters have been examined with a view to describing the currents in the Passage during the time the current meters were in position (31 January to 15 February, 1970). The records show that at 120 metres depth there was a strong current near Cape Horn flowing from west to east with a mean speed of about 2/3 knot. Another easterly flowing current was recorded near Antarctica, in the southern part of the Passage, with a mean speed of about 1/3 knot. Currents in the middle of the Passage were weak and variable. The currents at a depth of 1500 metres were also weak and variable. At the bottom of the Passage the currents were directed to the west, from the Atlantic to the Pacific, with mean speeds up to 1/6 knot. This description of the currents differs considerably from the concepts of the currents in the Passage based on dynamical calculations. Most observers have considered that the flow was directed west to east at all depths which makes a large difference in the estimate of volume transport. In the past these estimates have ranged as high as 237 Sverdrups to the east, and as low as 0 Sverdrups. An estimate based on our current meter records gives a mean transport of 15 Sverdrups to the west. It is evident from the records that the currents were slowly changing so that this number is unlikely to represent a long term mean; it is, however, the best estimate currently available.

Theoretical Studies

In recent years several models for the main oceanic thermocline have been published. These models for the most part have suggested that diffusion is not of primary importance in maintaining the density field. At the same time, however, one must recognize the fact that features such as the Salt Tongue, arising from the Mediterranean outflow, disappear in one crossing of the ocean. With this in mind a model for the Mediterranean tongue has been devised in order to estimate the magnitude of the diffusion of salt in the tongue and whether it is mainly along or across density surfaces. While the results are at present somewhat inconclusive, it appears that the diffusion coefficients are just small enough to be consistent with basically advective thermocline models.

One great limitation of thermocline models has been that, while they can to some extent satisfy surface and deep boundary conditions over the ocean's interior, they have not been matched to side boundary conditions, whether at a physical boundary or at the boundary of a region of different dynamics. Recently an effort has been made to satisfy boundary conditions on a sloping side boundary using those thermocline solutions for which the density is a function of potential vorticity. It has been found that fitting the eastern boundary conditions leads to reasonable interior density fields. In addition, inclusion of topography, such as a ridge, leads to strong violation of the Sverdrup relationship in the interior, as is consistent with the observed Gulf Stream transports as well as with recent results from numerical models. It is hoped to use these solutions to provide a model for an enclosed basin. While such a model will not be realistic dynamically for the entire basin, it should enable better understanding of the thermocline solutions now being used for the interior.

G. T. Needler, R. A. Heath

The analysis of low frequency oscillations in a spherical shell has been continued with the cooperation of Dr. P. LeBlond of the University of British Columbia. The intention is to resolve the relative effects of stratification and shell thickness on suppressing the horizontal component of rotation in low frequency motions. The oceanic case for which the Varsala frequency is somewhat larger than the local inertial frequency has been solved for mid-latitudes and a paper produced (1973. *Geophys. Fluid Dynamics).* However, the weak stratification problem remains intractable and it is intended to continue work in this direction as well as on inertial and trapped equatorial waves which are somewhat related.

G. T. Needler

Work has been continuing on various aspects of the problem of interaction of internal waves with bottom topography. Within the framework of two-dimensional theory, the method of characteristics allows one to formally express solutions in terms of non-uniform eigenfunctions which are constructed so as to fit the variable depth boundary conditions. However, the mathematical formalism in general
provides little immediate insight into a physically specified situation. What remains is essentially a problem of translation between the sets of non-uniform functions and normal modes, when the latter exist. Since both are infinite sets, the evaluation of normal mode coefficients involves inversion of matrices of infinite size, which means that in practice only solutions of truncated systems can be attempted. To circumvent the difficulty of direct matrix inversion, a technique of successive approximations has been devised to deal with incident, transmitted and reflected modes which are needed to describe the encounter of waves with a region of variable depth. The technique is based on the assumption that the simple 'geometrical optics' approach of the characteristic theory yields a good approximation to the desired solution. The solution may then be improved in successive steps by alternate use of the radiation condition for normal modes to eliminate unwanted modes and the characteristic theory to rigorously represent the improvement. The method is equivalent to an inversion of the infinite matrix by an iterative procedure.

The technique has been evaluated for several special but diverse cases of internal wave propagation. The effect of varying the radius of curvature of a reflecting surface upon plane wave reflection and diffraction was studied and a report prepared for the 'Liege Fourth Colloquium on Ocean Hydrodynamics' in March, 1972. This and other cases studied indicate that unless the topography changes very abruptly, the 'geometrical optics' solution is a good approximation of the actual solution. Even for relatively rough topography, seldom are more than one or two additional iterations required to attain desired accuracy. One may therefore, with some confidence, attack actual problems in the ocean in order to test the analytical method.

The behaviour of the semi-diurnal tide in certain regions of the ocean may be investigated within the framework of the above procedure. Although the barotropic component of the tide is usually considered separately from the internal tide, it can be treated within the mathematical formalism of the characteristic theory. Since the nature of the barotropic tide is altered very little by the presence of the internal tide, it is convenient to consider it as known and evaluate the internal tide, which arises from the interaction of the barotropic tide with bottom topography. Although numerical experiments are useful for the purpose of estimating the response of certain types of topography, the real test of the theory must be performed in the field.

A promising site for comparison of theory and measurements is found in the St. Lawrence estuary just downstream from the mouth of the Saguenay River, at the head of the narrow but relatively deep

Laurentian Channel. The tidal flow must adjust itself to a change of depth from about 100 metres to more than 300 metres over a distance of approximately 20 km. The fairly gradual slope of the bottom becomes critical for the semi-diurnal tide about half-way down and one expects that tidal streams are amplified there. This certainly increases vertical current shear and may lead to unstable conditions in the water column and increased mixing. Biologists have for some time speculated about a 'nutrient pump' in about the same area of the estuary. Internal tides have been detected downstream from the site, but no measurements exist in the immediate area. The relatively small extent of the slope area permits monitoring of the tidal currents there with sufficient spatial resolution to make a detailed comparison between theory and measurements possible. Plans are now evolving to deploy an array of moored current meters in the slope area for a survey of the tidal currents. The experiment is a cooperative venture between Coastal Oceanography and Ocean Circulation.

H. Sandstrom

A general study has been completed on diffusively induced convection in a contained stratified fluid; this is related to considerations of oceanic boundary layer mixing as studied by Wunsch (1970, Deep-Sea Res. 77: 293-301) and Phillips (1970, Deep-Sea Res. 77: 435-443.). The problem is modelled on a tilted square cavity. Two opposite sides are maintained at different temperatures and the remaining two are insulated. When the maximum temperature differential is small, the solution can be obtained by use of regular perturbation techniques, and the results are expressed in power series in A, the Rayleigh number. Weak motion exists throughout the cavity. When the temperature differential is large, corresponding to large A, boundary layer flows dominate. To solve the problem of large A, one must resort to techniques of singular perturbation. When the heated walls are almost horizontal, flow consists of boundary layers of thickness $e^{1/4}(=A^{-1/4})$ near the insulated walls. This boundary layer is adequate to meet all boundary conditions in an infinite medium as studied by Wunsch and Phillips in 1970. However, in a confined medium, additional boundary layers of thickness e^{1/6} are required near the insulated walls. These additional boundary layers serve as source and sink for the e^{1/4} - layer. Hence the matching of these two different boundary layers at the corners is necessary for completeness. When the heated walls are vertical. the flow consists of double Stewartson boundary layers of thicknesses e11/6 and e11/8 respectively near the insulated walls, but no boundary layer exists near the heated walls except the end points of the double boundary layers where additional e^{1/4} layers are required to match the main layers onto the end boundaries. There is no equivalent

case in an infinite medium. These analyses have been extensively supplemented by numerical studies at arbitrary tilt, and extremely low Prandtl number at which the system is completely non-linear. Some of these results are perhaps also applicable to convection in the earth's interior.

Some preliminary numerical experiments have been done on the penetrative convection of 4°C fresh water. Dr. Oakey is supervising the construction of a convection tank for an experiment on a rotating table.

C. Quon

Microstructure Studies

In recent years the routine use of the STD (salinity-temperature-depth recorder) has emphasized to physical oceanographers the presence of a great amount of detail in the structure of an oceanic water column. Instead of the smoothly varying curve that has been traditionally shown in a vertical plot of temperature or salinity, a profile is in most cases much more complex. The water column is often composed of a large number of layers, with a thickness of a few centimetres to a few metres and of nearly constant T and S, separated by regions of sharper gradients. Spatial studies have shown these layers to be continuous over a distance of about 1000 times the thickness. There are two currently favoured theories for the formation of this structure: (1) a horizontal interleaving of two water types, and (2) the result of breaking internal waves. A third possible source for some types of layering is a double diffusion process; that is, a convectively driven vertical mixing that results from the difference in diffusivity of temperature and salinity; however, this process is likely to occur only in restricted areas of the ocean. Some of the questions which arise from the presence of the microstructure are: (1) Does the mixing or dissipation of large scale structures such as the Gulf Stream give rise to this microstructure and if so is this by shear instability or by the breaking of internal waves? (2) What role does the microstructure play with respect to being a sink for internal wave energy, along with subsequent vertical mixing? or (3) If the structure is largely a result of horizontal interleaving, how does it contribute to or affect the vertical mixing? and (4) How does one evaluate a vertical eddy coefficient?

In an attempt to answer some of these questions a new program of oceanic microstructure studies has been started. The basic aims of the program are (1) to parameterize the microstructure in the ocean with a number which can be used to compare spatially and temporally where

and when mixing occurs, and (2) to look in detail at the microstructure in relation to larger scale phenomena in an attempt to determine which mechanisms are most important in its generation and dissipation.

To accomplish these tasks an instrument, the Oceanic Turbulence Probe, has been built and tested. The instrument is operated in a manner similar to a salinity-temperature-depth recorder. It is lowered from a ship at a speed of 1 to 2 m/s to a maximum depth of 2500 metres and gives a vertical section of the parameters of interest. During descent the large scale features of conductivity, temperature and depth are measured accurately. In addition 'micro' probes, mounted well ahead of the main structure and away from instrument generated disturbances, monitor small scale fluctuations in temperature, conductance, and velocity. A thermistor, 0.025 cm in diameter, with a time constant of 13 ms, measures temperature; conductance is monitored using a double-point contact probe; and velocity fluctuations are detected with a hot film anemometer. The motions of the body are measured using a three-axis accelerometer package. A standard FM telemetry link is used to send the data via a multiconductor cable to the shipboard recording equipment. The data are recorded on magnetic tape and an analogue display is presented on two 6-channel, high-frequency recorders.

The system has been used during a cruise in the region of the Gulf Stream south of Halifax to obtain microstructure information under a wide variety of conditions. The data will be used to obtain a distribution of the microstructure along the section and to show whether the measurements necessary to develop a microstructure index can be obtained from a simplified, more readily used instrument. An indirect method using the rms levels and mean gradients will give an estimate of the vertical mixing present along the section.



Oceanic turbulence probe.

J. A. Elliott, N. S. Oakey

In October 1971 a study of the small scale structure in the vertical temperature profiles in fresh water lakes was started. This study was prompted by a brief set of measurements taken in a lake in Wales in which it was observed that some of the structure migrates through the water column with time; that is, a specific bump or wiggle in the temperature profile can be traced through a series of profiles and, as time passes, the piece of structure (bump or wiggle) will change in both temperature and depth. This observation is intriguing for it leads to the postulate that these structures are caused by long period internal waves in which the particle motion is nearly horizontal and in which there is a phase change down the water column. Structure similar to that observed in lakes is ubiquitous in the ocean and much effort is being expended to discover the formation processes since it is generally believed that such structure is a manifestation of processes that are important in the vertical transport of heat and salt in the ocean. The present study is being pursued under the assumption that stratified lakes are ideal locations to investigate those processes which depend on density variations alone; such processes are the same in lakes and ocean.



Investigation of vertical temperature profiles in a freshwater lake, Waverley, Nova Scotia, 1972.

To investigate the phenomena further an instrument was designed to repeatedly obtain vertical temperature profiles from a raft. During the summer of 1972 this instrument was placed on a raft moored 250 metres from the shore in 18 metres of water at Lake William near Waverley, Nova Scotia. An Aanderaa thermistor chain was also hung from the raft to measure temperatures at 11 depths every 5 minutes. Although much of the summer was used in getting the instruments to work, enough results were obtained to confirm the earlier observations that the structure is related to internal wave motion. Making use of this summer's experience, more detailed and definitive results will be obtained in early 1973.

J. Lazier

Instrument Development

For the purpose of providing prototype instruments for new studies and for evaluating existing specialized oceanographic equipment the Ocean Circulation Division maintains an instrumentation group. The members of this group also provide technical assistance needed for carrying out oceanographic field programs.

In the second category, acoustic releases used in mooring experiments are re-armed, reconditioned, and thoroughly tested before each deployment. Since most of our mooring sites are in deep water these acoustic releases must function correctly if the mooring is to be recovered.

Other instruments, such as the Bathysonde conductivity-temperaturedepth recorder, are routinely calibrated and maintained. During the past two years the Bathysonde has been interfaced with a PDP-8/L computer. Bathysonde data can now be stored in digital form and temperature, pressure and salinity calculated. These can be scaled and plotted on an XYY recorder through a digital-to-analogue interface. The system of bathysonde, computer, and multiple water sampler has been tested extensively at sea during two cruises.

Much effort during the last year and a half has been directed towards the development of an instrument, with associated calibration facilities, to measure turbulence levels in the ocean. The instrument itself is described above (see Microstructure Studies). One calibration facility is a temperature plume tank to determine the frequency response of thermistor and conductance probes. This 2.5-metre long tank contains heated plumes of water arranged along the major axis. A probe's response to the plumes can be measured as it traverses the length of the tank at low and high speeds. From these results the time constant can be calculated.

An annular tank has been designed and constructed for studies of the motion of fresh water near the 4°C density maximum, in a rotating

annulus. The tank has a 30 cm outside diameter with the facility of changing in 5-cm increments both the inner diameter of the annulus and the depth, from 10 cm to 25 cm. A cooled base and heated upper surface provide a vertical temperature gradient.

N. S. Oakey

Hydrography



Canada's Atlantic Seaboard, the Gulf of St. Lawrence (east of Pointe des Monts), Hudson Bay, and the eastern Arctic form the sizable region of concern of the AOL Hydrography Division. This Division, which is part of the Canadian Hydrographic Service, has the responsibility of charting all navigable waters to satisfy the requirements of the mariner. In addition, in close cooperation with the Atlantic Geoscience Centre, it is involved in multidisciplinary surveys of the Continental Margin for the production of natural resource maps. Three auxiliary Sections are maintained within the Division: Development, which develops instrumentation and techniques to expeditiously collect and process hydrographic field data; Navigation, which evaluates present and new means of positioning and is the authoritative voice of the Institute on navigational requirements; and Tidal, a new section, which directs the tide, tidal current, and water levels work carried out by the Division.



The most prominent staff change in the past two years was the promotion of Mr. G. N. Ewing from Assistant Regional Hydrographer to Dominion Hydrographer. Mr. G. R. Douglas is the new Assistant Regional Hydrographer.

Mr. G. N. Ewing

The Hydrographic Acquisition and Processing System (HAAPS), developed at the Institute over the past few years, is now being used in the field and is operating exceptionally well. HAAPS is an automated data collection system, used on the small survey launches, coupled with a small computer-plotter system, on board the ship or on shoe. A plot of water depths corrected for tidal fluctuations and sound velocity variations can be produced within one hour after the end of the work day.

A number of changes have been introduced into the multidisciplinary (hydrographic-geophysical) surveys. Hydrography has taken over the full responsibility for such surveys, with the exception of seismics, which remain the responsibility of the Atlantic Geoscience Centre.

In 1971, the Arctic program, undertaken from Ministry of Transport icebreakers, was quite successful. However, in 1972 the severe ice

conditions and the necessity for the icebreakers to be assigned to escort duties resulted in a lack of progress in the priority areas. AOL has no control over the movements of these icebreakers which can be used by hydrographers only as opportunity permits.

R. C. Melanson

Hydrographic Charting

The Charting Section surveys navigable waters within the Atlantic Region for the production of navigational charts and related publications. In early 1972, the Section was given the additional responsibility of surveying the continental margin for the production of natural resource charts. Surveys are conducted by both ship-borne and shore-based establishments (or parties); normally seven such establishments are placed in the field yearly. The field season usually commences in May and terminates in October. The remainder of the year, except for special projects, is spent in processing all data to final form. The field data are processed as completed field manuscripts and then submitted to the Compilation Section of the Canadian Hydrographic Service, Ottawa, where the resultant charts are drawn and published. The main charting effort continues to be concentrated in and about the Atlantic Provinces; however, increasing priority is being placed on the eastern Arctic.

The departmental ships from which surveys are conducted are the CSS *Baffin*, the CSS *Kapuskasing*, the CSS *Maxwell*, and, occasionally, the CSS *Hudson*. Surveys in the Arctic are undertaken primarily from Canadian Coast Guard Ships of the Ministry of Transport (MOT). In 1972, two vessels, the MV *Minna* (2354 tons gross) and the MV *Christmas Seal* (149 tons gross) were chartered for approximately $3\frac{1}{2}$ months to carry out multidisciplinary surveys on the continental shelf, and chart revisory and navigational range surveys along the south coast of Newfoundland, respectively. Shore-based parties are generally supported by three 10-metre survey launches and two land vehicles. Hydrographers also participate in oceanographic cruises to collect bathymetry and navigational data for the General Bathymetric Chart of the Oceans (GEBCO).

During 1971, P. L. Corkum's party, aboard the CSS Kapuskasing, completed work in Northumberland Strait and then sailed to Notre Dame Bay, Newfoundland, to continue systematic charting of the east coast of this province. Hi-Fix was used for the majority of positioning by the HAAPS-equipped vessel and launches. During the cruise two wharves were surveyed at Holyrood, Newfoundland, to satisfy the

requests of industry.

In 1972, the *Kapuskasing's* final season on hydrographic surveys, a large portion of St. Mary's Bay, Newfoundland, was charted with E. J. Comeau as hydrographer-in-charge. This survey, supported by the positioning systems Hi-Fix and Hydrodist, was to complete the relatively unsurveyed portion between two existing navigational charts. In addition, a tidal current survey, in cooperation with Coastal Oceanography, was carried out in Come By Chance, Newfoundland, as an aid to navigation in docking supertankers at the wharf of the new oil refinery. Three other smaller projects consisted of: a shoal examination at the entrance to Come By Chance; a wharf and approach survey in Witless Bay to satisfy a Ministry of Transport request; and a survey of Logy Bay, Newfoundland, to assist Memorial University in the placement of sea floor research stations. The *Kapuskasing*, after serving on hydrographic surveys since 1949, has been returned to the Department of Defence for re-assignment.

The CSS Baffin was also involved in coastal charting during 1972; from May 2 until September 4 this was conducted under party chief G. M. Yeaton and from September 5 until October 27 under D. D. LeLievre. A detailed survey of the Virgin Rocks was finished, completing that portion of the Grand Banks. Positioning was controlled by Hi-Fix and a Range Positioning System. Following that project a systematic search



1971 areas of hydrographic survey operations in the Atlantic provinces.

was made for a wreck and shoal off the east coast of the Avalon Peninsula. The vessel then moved to the Labrador coast to continue detailed charting in the Hopedale area to satisfy an urgent requirement by the Newfoundland Ship Owners Association. This was also intended as the final evaluation of HAAPS which was fitted to the vessel and three launches, with positional input from Hi-Fix and Mini-Fix. Towards the latter part of September, because of deteriorating weather conditions, the vessel was re-assigned to survey the harbour of Sept Isles, Quebec, a high priority project because of the large volume of shipping now using this Gulf of St. Lawrence port. In addition, a number of smaller jobs were performed including the establishment of electrical centres at Bonavista and St. Anthony, Newfoundland, for future offshore surveys, and positioning the Loran A antennae at Bonavista and Battle Harbour, Newfoundland, to satisfy a Ministry of Transport request.

A number of small, high priority charting projects at widely spaced geographical locations were assigned to the establishment on board the CSS *Maxwell*. In 1971 the party was under M. G. Swim. Many of the projects undertaken resulted from requests made by the Ministry of Transport: a channel survey at the entrance to the Bras d'Or Lakes; a



1972 areas of hydrographic survey operations in the Atlantic provinces.

shoal examination in the Great Bras d'Or Lake; a shoal examination at the Canso Harbour entrance; a harbour survey at Newport Point, Quebec, for the establishment of aids to navigation; surveys of White Bear Arm, Windy Tickle, and the Rattle, Labrador, also for the establishment of aids to navigation; a channel survey at Stephenville, Newfoundland. In addition, 27 navigational charts along the Labrador coast were brought up-to-date through field revision; outstanding shoals were examined in Alexis Bay and River, Labrador; Camp Island Cove, Labrador, was surveyed to complete a blank space on the existing chart; an electrical centre for future surveys was established at Cape St. Louis, Labrador; and a number of navigational ranges along the Labrador coast and in Nova Scotia were positioned.

Under party chief, J. M. R. Pilote, the major project of CSS Maxwell for 1972 was the route survey of the inside passages along the Labrador coast between Hopedale and Nain. The necessity for such a survey resulted from an urgent requirement by the Newfoundland Ship Owners Association. This was a cooperative program to some extent with the Baffin and worked out exceptionally well. In addition, this establishment carried out a survey of Forchu Harbour, Nova Scotia, to aid the Ministry of Transport in placing aids to navigation; positioned newly established navigational aids in Jordan Bay; performed a shoal examination of Cheticamp, Nova Scotia; carried out a check survey in Yarmouth Harbour, Nova Scotia, to verify or disprove a report that silting was occurring: did a post-dredging survey in Liverpool for chart revision; conducted a detailed survey of Back Bay, New Brunswick, to satisfy the requirement of shipping; surveyed a channel and wharf at Port aux Choix, Newfoundland, to aid the local fishing industry; and established an electrical centre at the western extremity of Anticosti Island, Quebec, to aid future surveys.

The MV *Christmas Seal,* a charter vessel, under V. J. Gaudet as hydrographer-in-charge, carried out chart revisory and navigational range surveys along the south coast of Newfoundland for a three-month period in 1972. A survey was conducted of the inner portion of Great St. Lawrence Harbour, Newfoundland, to satisfy a request of industry; three sets of navigational ranges were positioned in Nova Scotia; a reported shoal in Bras d'Or Lake was examined; the Loran A antennae at Port aux Basques were positioned to satisfy a Ministry of Transport request.

During the 1971 field season G. M. Yeaton's shore party (No. 1) continued charting the coastal waters of Nova Scotia in the Tusket Island-Yarmouth area. This project, supported by Mini-Fix and a Range Positioning system, is a continuing one to satisfy coastal navigation requirements. Even though this is one of the most difficult areas along the Atlantic seaboard, a considerable amount of new charting was accomplished.

The Arctic program makes use of Ministry of Transport icebreakers. In 1971 the CCGS Labrador, with R. K. Williams, hydrographer-in-charge, was assigned to charting a portion of the Northwest Passage, specifically Viscount Melville Sound, in order to have modern navigational charts available should the Passage develop into a major resource transportation route. Positional control was from a 12f Decca chain established by the AOL Engineering Services Division. Because of the tremendous amount of time required for the establishment of such a system in the Arctic and the fact that the survey was to be continued in future years the chain, with the exception of electronic components, was left intact at the termination of the season's activity. Ice conditions were exceptionally good for this type of operation; therefore an appreciable amount of new charting was accomplished.

The CCGS John A. MacDonald carried a small team of hydrographers, under J. M. R. Pilote, to perform charting on an opportunity basis during the 1971 field period. This survey team enjoyed a very successful season and a number of blank areas on existing charts will be filled in from its efforts. Prior to going to the high Arctic a survey was



1971 areas of hydrographic survey operations in the Arctic. carried out in Hudson Strait off the entrance to Deception Bay to satisfy a mining company request. In the Arctic Archipelago additional bathymetry was obtained in Tanquary Fiord, d'Iberville Fiord, Norwegian Bay, Massey Sound, Hessel Sound, Wellington and Maury Channels. In addition to satisfying, to some extent, navigational charting, the profiles obtained will be used in assessing areas for pipeline crossings.



1972 areas of hydrographic survey operations in the Arctic.

In 1972, the CCGS *Labrador*, this time with hydrographer-in-charge A. L. Adams, was again assigned to the Northwest Passage survey; unfortunately ice conditions were very severe, so the vessel spent the season on escort duty, therefore necessitating the cancellation of the Viscount Melville Sound project. Quite a lot of new bathymetry was collected along the escort track; however none of the priority projects could be worked upon and have been rescheduled for 1973.

The CCGS *Louis St Laurent* also carried a team of hydrographers in 1972 to collect chart information on an opportunity basis. As with *Labrador*, this vessel was also hindered from working on priority areas because of heavy ice conditions and escort duties. However, new bathymetry along the ship's track will help fill in some blank areas on the existing charts.

The multidisciplinary, hydrographic-geophysical charting was continued through 1971 and 1972. In 1971 the CSS *Baffin* was again used to survey the continental margin in the Grand Banks-Flemish Cap area. T. B. Smith was the party chief. As in past years, positioning was done by Lambda (Low AMBiguity DeccA); however, for part of the cruise this system was complemented by Loran C which is a low frequency, long range aid to navigation. The feasibility of incorporating seismic reflection, by air gun, into the off shore systematic surveys was assessed for a three-week trial period. Seismics proved to be quite compatible to the measurements of the other parameters, so future surveys will incorporate this discipline whenever possible.

The first attempt at performing systematic offshore surveying using a vessel other than *Baffin* was made in 1972 under the direction of D. D. LeLievre when the MV *Minna* was chartered for a 3½ month period. She gave a commendable performance and proved to be more economical than the *Baffin* for such an operation. Lambda, supplemented by Satellite Navigation for part of the season, was used for positional control.



MV Minna at the Bedford Institute.

At the conclusion of the *Minna's* operation the CSS *Hudson*, with R. Macnab as hydrographer-in-charge, was assigned to the offshore program. The *Hudson's* program differed somewhat from that of *Minna's* because it was expanded to include more scientific input and the area of survey was changed in order to obtain data in areas of immediate geological interest. Deep and shallow seismic reflections were recorded, and a close evaluation was made of the LaCoste and Romberg gravimeter, equipped with an inertial platform. This cruise was a cooperative one involving the Atlantic Oceanographic Laboratory, the Atlantic Geoscience Centre, and the Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa.

In addition to the above surveys many smaller projects were undertaken by hydrographers operating directly from the Institute. Such projects resulted from requests by other government departments, industry, and divisions within the Institute, and included shoal examinations, pre- and post-dredging surveys, cross-section profiles of shipping channels, and considerations for new waterfront construction.

T. B. Smith, R. C. Melanson

Hydrographic Development

The Hydrographic Development Section at AOL, together with other groups of the Marine Sciences Directorate, 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 cooperation 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. Some of the activities that are carried out in conjunction with this goal are: evaluation of new equipment, software development, circuit design and fabrication, and training.

A fundamental role of hydrography is the measurement of two parameters, depth and position. The hydrographic Development Section has been active in the development of a semi-automated survey system to measure these parameters. Known as HAAPS, the Hydrographic Acquisition and Processing System employs a ship or shore based computer facility to process and plot bathymetric survey data recorded by data loggers on the survey vehicles. The logging units automatically record time, depth, position, and administrative data on magnetic tape. The tapes are then processed by a computer to select and plot the shallows and deeps required to delineate the bottom topography.



A HAAPS data logger, radar and depth sounder installed in a 7.6 metre Bertram launch.

Over the past two years considerable effort has gone into refinements aimed at improving the reliability of the data loggers and increasing the capability of the software. Special circuits have been designed to check for bad depth data, to monitor and detect faults in the recording process, and to ensure that the proper number of characters are written on magnetic tape for each record. On the software side, stringent checks on the validity and quality of the data read from magnetic tape have been incorporated. In addition, the depth selection and plotting algorithm has been modified to require less storage and to speed processing.

A HAAPS system, consisting of three data loggers and an 8K PDP-8/L computer facility, was used during the 1971 Notre Dame Bay survey off the northern coast of Newfoundland. A fourth data logger was acquired for the 1972 survey season and the system was used on the Labrador coast survey carried out by the CSS *Baffin*.

The possibility of using small computers for the contouring of bathymetric survey data is of considerable interest. Shoal areas, which frequently require further investigation, are more readily spotted from contoured data. Also, contouring serves as a visual check on the validity and consistency of the bathymetric data. Manual methods of contouring are tedious and time consuming; consequently plans are being made to use a small computer (Hewlett Packard 2100A with disk storage). A software contouring package developed by the Arcon Corporation of Wakefield, Massachusetts, is being purchased.

The increasing frequency of range, revisionary, and other miscellaneous surveys operating from mobile shore parties or small ships brought about a requirement for a compact and portable computer facility. Studies were carried out which culminated in the purchase of two Hewlett Packard 9100B programmable calculators and 9120 printers. An extensive set of survey programs for geodetic, chart projection, levelling, and tellurometer corrections have been written. The programmable calculators have proven to be a valuable survey tool.

A BO'SUN Multi-Beam Sonar System has been rented for evaluation as a potential tool for hydrographic survey work. The BO'SUN system is a measurement rather than a search sonar. Slant range data is recorded digitally on magnetic tape. Software is available to edit, process and plot the data in the form of a contoured bathymetric chart. One advantage over conventional side scan sonar is that the need for interpretation of analog records is virtually eliminated.



BO'SUN multibeam sonar system being towed by CSS Maxwell.

A variety of smaller projects have been completed. Metric converters for the semi-automatic chart scalers have been designed and built as part of the phasing in of the metric system for charts. Several test and calibration boxes for various components of the HAAPS data loggers have been produced by the section and have proven to be of great benefit in the field. In addition, a number of programs have been written for miscellaneous field requirements.

R. G. Burke

Navigation

The Navigation Section was formed in 1970 to perform missionoriented research and development in navigation, and to advise and assist those who have problems in positioning at sea.

The Section's first major project has been to evaluate the new distance-measuring ('rho-rho') version of Loran C (a long-range radio-navigation aid), and then to introduce it as a regular oceanic navigation method for the Institute's work. The evaluation was made by comparing rho-rho Loran C against a two-range Decca survey chain using the CSS Baffin in May 1971. The results, published in the Canadian Surveyor (Eaton, R. M., and Grant, S. T., 1972.26; 125-135) showed effective operation at ranges of over 2000 km, with a distance-measuring accuracy of about 200 metres. In the spring of 1972 the Institute bought a rho-rho Loran C navigation system, and the techniques are being developed for using it as a regular oceanic survey tool. This has involved integrating its operation with satellite navigation; writing computer programs for the instantaneous processing of ranges into geographic position and assessing fix accuracy; developing operational procedures; and training users. Rho-rho Loran C was used as the prime navigation system for the CSS Hudson's joint Hydrography-Geophysics cruise off the Labrador coast in October 1972.

Satellite navigation has become standard equipment for all cruises beyond the range of the Decca Navigator. Improved computer programs from the manufacturers have made it possible to turn over its operation to the ship's officers, relieving the scientific staff of this task. In 1972, the Navigation Section ran courses in satellite navigation for ships' officers; these courses were also attended by members of the Ministry of Transport and the Department of Defence and they will be repeated in 1973 to meet a strong demand from the marine community. The Section also collaborated with Mobil Oil (Canada) Ltd., Dabbs Control Surveys Ltd., and Shell (Canada) Ltd. in a satellite positioning experiment on Sable Island, and tested the Shell (Canada) Ltd. method of Decca lane identification on the joint hydrographic-geophysical survey in 1972; lack of time made this second test inconclusive and it will be continued in 1973.

Other activities include investigations leading to fitting and testing a Doppler sonar speed log on the CSS Dawson; keeping both a watching and a participating interest in Omega (a very long-range radiopositioning system), inertial navigation, acoustic navigation using seabed transponders, and Doppler sonar navigation; and the Section's very important function of advising and assisting all sections of BIO and the local marine community in problems of precise navigation.

R. M. Eaton

Tidal

The Tidal Section was formed at the Bedford Institute of Oceanography in March 1972 to direct the tide, tidal current, and water levels work carried out by the Canadian Hydrographic Service in the Atlantic Region.

Since its formation, the Section has supplied tide gauges to hydrographic field parties and other users in the Institute, and at St. Andrews, New Brunswick; Ellerslie, Prince Edward Island; Memorial University, Newfoundland; and the Nova Scotia Agricultural College. The data from these gauges are digitized and forwarded to Tides and Water Levels, Marine Sciences Directorate, Ottawa, for inclusion in water level reports as well as becoming part of the national inventory of tidal information. As part of a ground water study by the Inland Waters Branch, Department of the Environment, a tide gauge was installed at Sambro, Nova Scotia, using a new stilling well of PVC pipe.

Considerable work has been done in the tidal current field since the Section's inception. The data resulting from hydrographic tidal current measurements were forwarded to the Canadian Hydrographic Service, Ottawa, for inclusion in *Sailing Directions* (coastal pilot books). In addition, a new concept (the vector plot principle) in the display of current information was submitted to the Dominion Hydrographer for consideration. The 1974 current predictions for the tide and current tables were compiled, edited, and forwarded to Tides and Water Levels, Ottawa. The analysis of current measurements taken in January and August, 1972, as an aid to navigation at the superport associated with the new oil refinery at Come By Chance, Newfoundland, is well underway and a report is being written. Future work will involve the utilization of telemetered tidal information from bottom-mounted tide gauges together with co-tidal charts for the reduction of hydrographic sounding data.

L. A. Foster

Technical Services

The formation of the Department of the Environment in 1971 resulted in the division of the old Atlantic Oceanographic Laboratory into two units - the new Atlantic Oceanographic Laboratory (of the Department of the Environment) and the Atlantic Geoscience Centre (of the Department of Energy, Mines and Resources). Discussions which had been taking place during previous years on the future shape of the Bedford Institute of Oceanography were brought to a sharp focus by this split. Services provided to the scientists, such as Ship support, or Engineering support, were required by both units, but even if it had been desired to split the support activities the permanent division of the fleet between the two units would have posed severe problems.

It was decided to initiate the concept of Institute-wide support facilities, which would equitably provide services to all research and survey units at the Institute, but in terms of organization would form part of the Atlantic Oceanographic Laboratory of the Department of the Environment. AOL would thus become the 'Lead Agency' in this regard, and would justify funding for support activities for the three existing laboratories (AOL, MEL, and AGC) - and also for any other laboratories which might move into the Institute in the future. The elements included in Technical Services include Ships; Engineering Services (including building and grounds operations); Computing Services; Scientific Information Services and Library; Drafting and Illustrations; and Photography.

Technical Support Services exist in order to provide support to the Research and Survey activities at the Bedford Institute of Oceanography, regardless of which laboratory is involved. There is no inclusive mandate for the activities of Technical Services - not all the ships serving the Institute are programmed or operated by Technical Services; engineering activities are located both in Technical Services and in all three laboratories; drafting activities are found in many areas of the Institute. It is, nevertheless, the ambition of Technical Services to concentrate most, if not all, of the activities in which it is involved, by assimilating other activities. This process should not, and will not, be accomplished by force majeure, but by clearly demonstrating to the users that services are provided more effectively and economically by Technical Services than by the users' own facilities. Therefore, the attitudes of management within Technical Services are similar to those of a private industry, and consciousness of costs, efficiency, and effectiveness pervades the whole organization. One result of the drive towards higher efficiency is that an appreciable amount of the service provided will be subcontracted, as is the case in any industry. Since the workload fluctuates substantially through the year, if staff levels are set to enable the peak loads to be met then for much of the year there will be insufficient workload, and costs will soar. Staff levels should be such

as to meet the minimum workload, and peak demands met by subcontract. The institute should stimulate the local economy by spin-off activities, and this objective adds to the drive towards subcontracting. Experience has shown that there is an appreciable demand in the local area for the support activities which are required by users at the Institute, and that it is possible to help an entrepreneur to establish appropriate commercial facilities by giving a firm contract for such work, on a year-by-year basis. Such contracts form a base upon which a firm can be established, and business is attracted from other users to develop a full-fledged independent operation. These two reasons underlie the drive which exists throughout Technical Services to increase the proportion of the workload which is met by contracts with Industry. At present, about 15% of the work of Technical Services is carried out by contract, our aim is to increase this to 50% in ten years' time, testing each year to ensure that the aim is still realistic and valid.

Specific steps which have been taken, within Technical Services, as a result of the broad philosophy outlined above, are outlined in the descriptions of the activities of each section. The initial results which have been achieved are encouraging, and give good promise for much more extensive developments in future years.

R. L. G. Gilbert

Ships



The Ships Division at AOL consists of the administration section (shore staff) and the research and survey fleet. The shore staff is engaged in the administration required to operate the fleet of ships and launches on a daily as well as long term basis and the fleet is utilized in support of the research and survey activities carried out by BIO and by universities and other research organizations.

Administration Section

The overall aim of the section is to operate the fleet effectively, arrange for necessary charter vessels, and coordinate the programming of the ships and launches. In order to accomplish this a high degree of cooperation with scientists, hydrographers and support sections is required. Considerable effort is being expended in preparing realistic operating budgets and keeping costs at reasonable levels. Studies are under way dealing with:

(a) The costs and effectiveness of charter vessels versus ships owned by the Department of the Environment;

(b) Provisioning of ships, which is presently being handled through the Canadian Armed Forces Ration Depot, Halifax, on a trial basis;

(c) Policy for replacement of hydrographic survey launches;

(d) Effectiveness of Sewage Treatment Plants - a plant is now installed onboard the CSS Hudson.

In addition a management consultant was engaged to review the administration section and a professional catering consultant is studying the catering services on the departmental vessels.

Research and survey fleet

The operations during the last two years are indicated in the following table:

Name	No. of	Cruises	Days A Home	way from e Port	Nautio Stea	cal Miles
	1971	1972	1971	1972	1971	1972
CSS Acadia	-	-	-	-	-	-
CSS Baffin	1	2	236*	199	31,961	13,261
CSS Dawson	9	13	139	181	21,953	29,692
CSS Hudson	4	4	224*	130	29,996	24,249
CSS Kapuskasing	1	2	160	126	10,136	10,164
CSS Maxwell	1	2	166	172	5,981	5,493
CFAV Sackville	11	11	125	130	17,386	16,721
CFAV Bluethroat	2	4	9	54	278	2,555
MV <i>Minna†</i>	-	1	-	90	-	14,331
MV Christmas Seal†	-	1	-	85	-	2,000

* includes refit and drydock at Saint John, N.B. † charter vessels



The CSS *Acadia* is a steam-driven, coal-burning ship. She was retired from service as a hydrographic survey vessel in 1969. Since then the vessel has been tied up alongside the BIO wharf and kept open to the public during the summer months. Guided tours were conducted at regular intervals and the vessel continues to be a popular tourist attraction.



The CSS Baffin is a diesel-driven ship designed primarily for hydrographic survey work in Arctic waters. The vessel is icestrengthened, has a cruising range of 14,000 miles and 45 days endurance, carries five hydrographic survey launches and is also equipped with geophysical recording instruments. The *Baffin* is utilized for offshore hydrographic charting and geophysical studies and for survey work in coastal and Arctic waters.



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 12,000 miles and 60 days endurance. The vessel is equipped with a bowthruster and controllable pitch propellers and is particularly well suited for placing and retrieving moored buoys and instruments.



The CSS *Hudson* is a diesel-electric driven ship designed as a combined oceanographic research and hydrographic survey vessel. She is primarily utilized for multidisciplinary offshore oceanographic surveys ranging from tropical to Arctic waters. The vessel is ice-strengthened, has a cruising range of 15,000 miles with 60 days endurance, and is equipped with bowthruster and scientific laboratory facilities and recording instruments.



The CSS *Kapuskasing* is a steam-driven ship, designed as an Algerine class minesweeper and converted for hydrographic survey work. She has a cruising range of 3500 miles and 12 days endurance, and carries four hydrographic survey launches. She is mainly utilized for hydrographic survey work in coastal areas. The *Kapuskasing* is now being retired from service with the Department of the Environment and returned to the Department of National Defence (DND). The future of the vessel will

depend on the outcome of a 'Wear and Waste' test which is being carried out by DND.

Short History. The CSS Kapuskasing was built by the Port Arthur Shipbuilding Co., Port Arthur, now Thunder Bay, Ontario, and after outfitting and trials was commissioned into the Royal Canadian Navy on 17 August 1944. Until the end of the war she was engaged in convoy escort duties, lending support to both small Coastal convoys and to larger mid-ocean convoys during the coastal stages of their passages between Newfoundland, Sydney, Halifax, and New York. The Navy 'paid off' the *Kapuskasing* on 27 March 1946. In the spring of 1949 she was handed over to the then Department of Mines and Technical Surveys on a loan basis and converted to an hydrographic survey ship at the Halifax Shipyard.



The CSS *Maxwell* is a diesel-driven ship and was designed for hydrographic survey work in near-shore and coastal waters. She has a cruising range of 2000 miles and 14 days endurance and carries two survey launches. The *Maxwell* is mainly utilized for hydrographic charting along the coasts of the Atlantic provinces.



The CFAV *Sackville* is a steam-driven ship designed as a corvette and converted for oceanographic research work. She has a cruising range of 3500 miles and 14 days endurance. The vessel is manned by DND and programmed by AOL. The *Sackville* is used for oceanographic studies primarily in coastal regions.

Ship		Length	Displacement	Built
CSS	Acadia	182 feet	1350 tons	1913
CSS	Baffin	285 feet	4420 tons	1956
CSS	Dawson	212 feet	1997 tons	1967
CSS	Hudson	293 feet	4793 tons	1963
CSS	Kapuskasing	222 feet	1250 tons	1943
CSS	Maxwell	115 feet	275 tons	1961
CFA\	/ Sackville	205 feet	1250 tons	1941

To satisfy requirements that could not be met by the ships operated by AOL the Department chartered several ships from private shipping companies. Several projects were carried out in Fisheries Research Board vessels and a Canadian Armed Forces Auxiliary Vessel, the CFAV *Bluethroat* Launches and other small craft were utilized for local surveys and research work. Through the courtesy of the Ministry of Transport, icebreakers were made available for hydrographic survey' work in the Arctic.

Engineering Services



The prime responsibility of the Engineering Services Division is to provide support for the scientific and survey programs at the Bedford Institute of Oceanography. This consists of engineering support in design, specification and construction; technical support, mainly in the electronics field; and fabrication and maintenance support for heavy mechanical equipment. Support is provided to AOL, MEL and AGC on an equal priority basis. In instances when Engineering Services Division do not have the personnel or resources available, it acts as a contract agency and prepares specifications to have the work completed by commercial contractors.

Engineering Services Division is divided into four sections: Marine Electronics, Systems Engineering, Depot Workshops, and Buildings and Grounds.

Marine Electronics with a total of 30 technicians and technologists is the largest section. It is responsible for repair, maintenance, modifications, design changes, and overhaul of electronic equipment installed in the ships and launches as well as of much of the electronic equipment used in the engineering design and research laboratories.

Systems Engineering consists of engineers and technologists who develop new mechanical, electro-mechanical and electronic equipment for use by the scientific and survey staff. They also provide engineering consultation to personnel at the Institute and at local universities.

Depot Workshops, which are the Institute's main workshops, carry out fabrication of mechanical and electro-mechanical prototype equipment designed at the Institute. The workshops have a staff of tradesmen skilled in welding, machining, engine repair, carpentry and electrical work. This group carries out the overhauls on survey launches as well as on much of the heavy mechanical equipment used during oceanographic and hydrographic cruises.

Buildings and Grounds have for the past year been part of Engineering Services; prior to this the section was part of Administration. It is involved in maintaining and operating the heating plant and carrying out maintenance procedures throughout the buildings and grounds of the Institute.

S. B. MacPhee

Marine Electronics

During the period covered by this review the organization of the Marine Electronics Section has expanded with the addition of an Electronic Stores group to the other five major groups: Communications, Computer-Microwave, Electronic Positioning, Sonar, and Test Equipment. These groups are responsible for the repair and calibration of the major portion of the electronic equipment used within the Institute, on the ships, and in the field. Although the number of staff has not increased over the past two years, the equipments for which electronic technicians are held responsible, in their support role, have increased in number and complexity. To keep pace with the technological advances taking place throughout the electronics field, stress has been placed on training personnel in an effort to accommodate the technician's dual role of a specialist while in the Institute shop environment and a generalist while on board ship or in the field.

A great deal of information exchange took place between Marine Electronics Section personnel and staff of other Sections within Engineering Services in the development of a lightweight diesel driven power unit required to operate for long unattended periods in remote or isolated areas and in the development of an up-to-date, standard electrical distribution system for the launches. Both projects have increased the efficiency of field operations. The Section as a whole expended considerable effort in support of university cruises in departmental ships over the past two seasons; this support being by way of installation and check-out of computers, satellite navigation receivers, and sonar systems.

A proposal for a navigation centre in CSS *Hudson* required active coordination with the Head of the Navigation Group in the Hydrography Division. Preliminary investigations have been completed, recommendations forwarded, and two electronic systems relocated within the ship to allow users an opportunity to evaluate the concept from an operational point of view.

C. R. Peck

The Communications Group is responsible for the installation, maintenance and repair of approximately 500 units of general and specialized communications equipment installed in departmental ships and launches, at the Institute, and in the field. Modification of existing equipment to tailor its capability to a precise, special requirement of the user is still one of the more interesting responsibilities accepted by this group.



Loran C equipment.

New personnel coming to the Institute as well as those employees who have not had experience in operating radio transceivers are trained in the proper techniques by the communications group. Arrangements are then made with the local inspector of the Department of Communications for examinations and subsequent issue of certificates in the proficiency of radio. The relevant requirements of the Radio Act and the standards of the Radio Regulations of the Canada Shipping Act, including radio licenses, renewals, and applications for licensing of all departmental radio facilities, are all attended to by this group.

W. F. Shearman

The Computer-Microwave Group has had its area of responsibility enlarged with the addition of a PDP-11 and HP 2100 computers to the existing family of PDP-8's, together with the usual peripheral punches, readers, tape transports, plotters, teletypes, etc. This group of technicians is also responsible for the installation, maintenance and repair of 'X' and 'S' band radar systems, 'X' band radar transponders, the Radar Range Positioning System (RPS), tellurometer equipments, satellite navigation receiving systems (SatNav), the Bedford Institute of Oceanography Data Logging Systems (BIODAL), and underwater TV systems. Technicians in this group are continually up-dating equipment and systems to meet the expanding requirements of users; examples of this are the additional 4K memories installed in PDP-8 computers to extend their operating capabilities.

Technicians from this group assisted the Department of Survey Engineering, University of New Brunswick (UNB), with technical support of two Doppler Satellite Navigation Receiving Systems. UNB was involved in a project with the Surveys and Mapping Branch of the Department of Energy, Mines and Resources; the maintenance and repairs were carried out by technicians from the Computer-Microwave Group.

A. D. Parsons

The Electronic Positioning Systems Group provides the technical support for the operation of the precise electronic positioning systems utilized by hydrographic and scientific personnel. These systems are quite distinct from conventional electronic aids to navigation; included are low, medium, and ultra-high frequency phase comparison systems (Decca 12f, 12f Lambda, Hi-Fix and Mini-Fix, and Tellurometer Hydrodist). The systems are normally in the field during the March to November period as positioning support for multidisciplinary surveys encompassing bathymetric, geophysical and geological data collection. It is during this survey season that personnel from the other groups within the Marine Electronics Section are appointed to these field assignments in order to provide as much experienced technical assistance as possible. During the 1971 and 1972 survey seasons, additional electronic technicians were hired on a casual basis to assist in operating and maintaining this equipment.

The results from the evaluation of the 12f positioning system carried out in the Gulf of St. Lawrence in October 1969 provided data on accuracy parameters which has been useful in the operation of that system. The fitting of Loran C and SatNav in our survey ships has instigated investigation into utilizing these systems to provide information which can be used to pick up positioning 'lane' counts when atmospherics or weather create a loss of lock in the Decca 12f Lambda system during surveys.


Mini-Fix electronic positioning system.

Considerable effort was expended in establishing a Decca 12f chain in the Viscount Melville Sound area during the 1971 season with CCGS *Labrador* as the mobile operating base. Using helicopter support, a hyperbolic configuration was established and approximately two weeks' operating time realized within the very short navigation period available in the Arctic. A full survey season was expected for the 1972 season and the three stations were winterized completely; the 150 foot transmitting masts were left standing with the view of cutting down on the required activation time. Unfortunately ice conditions and other circumstances led to the cancellation of this survey about mid-August 1972.

During a hydrographic survey on the Labrador Coast in 1972 accurate positioning was provided by Decca, Hi-Fix, Mini-Fix, and Motorola RPS. The CSS *Baffin* employed the Hi-Fix chain in the range-range mode while the ship's launches and helicopter utilized the Mini-Fix chain in the hyperbolic mode. Such a configuration caused one serious consequence: while the ship surveyed using Hi-Fix control, with the master transmitter operational in the ship, it was impossible to effect repairs to Mini-Fix receivers either in the ship's electronics workshop or in the launches because of the close proximity of the two frequencies involved and the high electromagnetic field caused by the Hi-Fix transmitter. Under similar circumstances in the future, simultaneous use of both these systems indicates a requirement that for this type of survey, both chains should be operated in the hyperbolic mode (for which the master transmitters are at shore stations).

The Radar Positioning System (RPS), a technical responsibility of the Computer/Microwave Group, was installed in the CSS *Maxwell* which operated in conjunction with the *Baffin* between Nain and Hopedale on the Labrador coast in 1972. Later in the season the system was transferred to the *Baffin* and used in the Sept Isles, Quebec, area. The success of this short range system has proven its adaptability to the rugged, isolated survey areas.

H. B. Sutherland

The Sonar Group installs, maintains and repairs some of the most modern and accurate depth recording instruments available. The area of responsibility has expanded in the recent past to include an electro-magnetic log fitted in the *CSS Hudson*. At present, the group is involved with the fitting and evaluation of a Doppler log system in the *CSS Dawson*. One other recently added responsibility has been the maintenance and support of acoustic releases used by other Divisions in the Institute as well as universities.

The conversion from the older Kelvin Hughes sounders to the more modern Edo/ASM sounder continued during this review period, the program being approximately 90% complete. As a result of requests from the Department of National Defence this group provided portable echo sounder installations for use in emergencies or when proceeding into doubtful anchorage areas in sub-Arctic and Arctic waters. Our inventory of these solid-state portable echo sounders - Raytheon DE719 - has doubled during the review period and a total of six are now held. A program has also commenced to evaluate available dry paper recorders to replace the Alpine moist paper Precision Echo Sounders in use for the past six years. The charter vessel *Minna*, used for the multidisciplinary survey off the east coast of Newfoundland in 1972, experienced some growing pains during the installation and early operational periods. Nevertheless, the arrangement of equipments and the layout of working areas did provide valuable background for use in future when a similar survey is undertaken. One problem that arose was focused upon the a.c. power supply. This problem was accentuated by the fact that the vessel's main supply is d.c. and a high degree of voltage and frequency regulation was essential for operating computer peripherals, digitizers, and other electronic equipment.

W. W. Goodwin

The Test Equipment Group is responsible for the repair and calibration of the electronic test equipment held at the Institute, and the entering of data on all equipment into a computer inventory control system. The facilities in the lab are employed by the technicians to calibrate and repair the test equipment as well as being used to monitor the repair and calibration work completed by contract. To accomplish the calibration of accurate high resolution test equipment, the lab is capable of measuring d.c. voltages to 0.0024%. frequencies to better than 2 parts in 10^9 , resistance to 0.02% and a.c. voltages to 0.02%. In instances where greater accuracies are required, the facilities of the Standards Lab, a part of the Metrology Division, are available to the personnel concerned (the Standards Lab holds standards traceable to the National Research Council).

R. E. Delong

Electronic Stores are also controlled by the Marine Electronics Section. These stores stock electronic components, wire, hardware and auxiliary components for the construction of prototype equipment. Over the past two years the requirements of maintaining a current, up-to-date supply of components has been emphasized. Quarterly meetings are held with users from development and design groups to review and revise the inventory, and obsolete items are not re-ordered.

R. J. Vandal

Systems Engineering

Systems Engineering provides electrical, electronic, mechanical, and electromechanical engineering support for the research and survey programs conducted by AOL, MEL, and AGC. The projects undertaken, although generally of less than six months duration, involve considerable engineering investigation and design. Where practical, portions of the fabrication and assembly work required to complete a project are carried out by outside contract under the group's supervision. The program for the group is decided jointly by the heads of Engineering Services, Metrology, and Systems Engineering. During the reporting period many projects were undertaken. Some of the more significant ones will be discussed in the following paragraphs.

D. F. Dinn

An optical beam attenuance meter (nephelometer) has been designed and two prototypes produced; the first for MEL, the second for AGC.



Optical beam attenuance meter.

The instrument is used to measure the attenuation of light, at various wave lengths, in water. From these measurements the attenuance coefficient is obtained. The coefficient can be applied in determining underwater visibility, relative plankton density, and the amount of particulate matter in the water column. Both units have undergone

extensive field testing and evaluation in Bedford Basin, the LaHave estuary, and the Bay of Chaleur. The instrument generally meets its design goals, particularly that of maintaining accuracy over extended periods of use despite lamp aging and rough handling. During the CSS *Dawson's* July 1972 cruise to the LaHave estuary a correlation coefficient of 0.88 was obtained between the measured attenuance coefficient, cx, and the concentration of suspended particulate matter as determined by filtration of water samples taken at the same location over a 12-hour time interval. Initial laboratory tests indicate that the attenuance versus wavelength curve, obtained using the instrument, can be useful in determining whether suspended material in the water is mineral or organic. Hermes Electronics Ltd. of Dartmouth are currently in liaison with the Institute with the intent of developing the attenuance meter as an oceanographic product.

E. Larsen

Performance tests on the Askania Gravimeter used by AGC required a method of subjecting' the device to precisely known fluctuations. Attempts to purchase a suitable sine-lift device from Askania, a German company, were unsuccessful as the company was no longer manufacturing the device. Finally the design drawings for the sine-lift were purchased from Askania. Systems Engineering then coordinated the manufacture of the parts by a local machine shop, and assembled the device. The sine-lift is used to periodically calibrate the gravimeters.

R. N. Vine

To receive low level seismic reflection signals utilizing a towed hydrophone array, it is desirable to reduce the noise generated by the array moving through the water. To achieve this reduction a winch was designed to pay out the array at ship's speed during the period of signal arrival, thus holding the array relatively stationary in the water. The cable and array are then recovered for the next air-gun shot. After a feasibility study was completed a winch was built to alternately pay out and retrieve the hydrophone array. Production drawings were completed and a report (Vine, AOL Report 71-6) written on the winch.

R. N. Vine

Work on Coastal Oceanography's inshore wave studies project was terminated with the completion of the project in early 1972. The mini-tower, an aluminum spar buoy used to hold pressure sensors, a wave staff, and a radio telemetry system, was designed by Systems Engineering and fabricated in the Depot Workshops. Engineering support in relocating the tower and maintaining the telemetry system and shore based receiving stations was given during the complete project. A report (MacPhee, Report Series / BI-R-72-1) was prepared on this system.

S. B. MacPhee

Work in support of the Air-Sea Interaction Group of Metrology Division has continued. The design of the Mark IV stable platform and an analysis of its failure in December 1970 have been documented (Mills, Report Series / BI-R-72-4). In addition a preliminary report on a new platform with a more reliable mooring scheme has been prepared in anticipation of the requirements of the Air-Sea Interaction Group in 1974. It is anticipated that the new platform will be held in place by six 40-ton concrete anchors and 2.5-cm diameter steel guy wires. In addition, the instrument platform will be some 3 metres lower than in the previous structure, with the idea that the maximum wave loading will be reached earlier and will be less severe.

R. G. Mills

Modifications to the Air-Sea Interaction telemetry system were completed enabling sonic anemometers to be used on a large spar buoy in Lake Ontario during the fall of 1972. Included in the modification was a d.c. to a.c. inverter to power the sonic anemometer and a special rotor for its three-component probe. If the results of the evaluation are satisfactory, an attempt may be made to install the sonic anemometer on the Air-Sea Interaction stable platform when it is next installed (see above).

D. F. Dinn

A simple, direct-reading, flow meter for measuring flow rates between 1.0 and 30 cm/sec in small tidal channels was designed and constructed for MEL. The device utilized a 50-cm diameter disc as a drag form coupled to a cantilevered strain-gauged deflection sensor. The unit is self-contained, lightweight, and battery-powered with a battery life in excess of 200 hours. The present application for the flow meter is in Petpeswick Inlet where a study of the food budget and productivity of mussel beds is in progress.



Direct-reading flow meter.

E. Larsen

Two 20-step programmers suitable for controlling an air-gun firing circuit or keying an echo sounder were designed and built. The units will be used by AGC in seismic profiling work. In conjunction with this project an interface unit has been built which will enable an EPC or similar recorder to operate in conjunction with a Kelvin Hughes



Interface unit for MS-26B echo sounder.

MS-26B echo sounder. Only the transmission unit and transducers are required from the MS-26B system since an integral part of the interface unit is a tuned amplifier for processing the received echo. The new interface unit will enable a much better recorder to be used while retaining the desirable qualities of the MS-26B system.

G. E. Awalt

Two audible warning units were developed for AGC around a commercially available digital clock. The units produce an audible tone at two independently selectable times in a one-hour period and are intended for use at shore stations and on ships not having a Bedford Institute of Oceanography Data Logging System (BIODAL). One of the units features an internal rechargeable battery pack with a float charger, giving it a capability of providing uninterrupted operation during main power failures lasting less than two hours.

G. E. Awalt

A preheater and stabilizer for hollow cathode lamps of the type used in the Perkin Elmer 403 Spectrophotometer was produced for Chemical



Preheater for hollow cathode lamps.

Oceanography. The unit enables the characteristics of up to three lamps to be stabilized by running them at prescribed currents for periods of 30 minutes or longer. In addition, the unit greatly increases the speed at which analyses for multiple trace metals can be conducted, since up to four different lamps (including one in the spectrophotometer) can be held ready for immediate use. Increased lamp life is a byproduct of stabilization.

D. F. Dinn

A tank was designed and constructed for Ocean Circulation to enable flow measuring devices, such as Pitot tubes, to be accurately calibrated. Even at very low heads (low flow rates) the tank was required to produce symmetrical streamlines at the point where the water exited to the device being calibrated. The streamlines would not normally be symmetrical if the height of water above the outlet was not much larger than the diameter of the outlet. This problem was resolved by creating a partial vacuum above the tank thus requiring a much higher water column for a given pressure at the outlet.

R. N. Vine

A free-floating platform was designed and fabricated to enable Ocean Circulation to quantitatively study the wind-induced drift of surface waters. The platform takes the form of a slender, heavily damped, tower with a wind vane above the surface to keep the unit correctly oriented with respect to the wind direction. Below the surface the platform supports an automatic camera and five dye injectors, spaced out vertically, which inject a small quantity of dye into the water at timed intervals. The resulting photographs show the relative motion of the water at the different levels at which the dye was injected; from this the surface wind shear can be estimated.

R. N. Vine

Systems Engineering were highly involved with the procurement and evaluation of a deep-sea depth digitizer system which would automatically record bathymetry via a Bedford Institute of Oceanography Data Logging System (BIODAL). Two units were purchased and a number of trials were performed on the CSS *Hudson* and the charter ship *Minna*. As a result of the trials numerous improvements were incorporated into the system. Generally it is felt that without a significant signal-to-noise ratio improvement in the sounding system presently used on BIO ships, depth digitizing would require considerable operator input to ensure useful records. The technology required to carry out this improvement is currently available.

S. B. MacPhee, G. E. Awalt

Trials were conducted on five rewired launches immediately prior to the 1972 survey field season. These vessels had been wired in accordance with a standardized electrical system specification developed by Systems Engineering in 1971. A special electrical system was designed for the twin engine launch, *Tudlik*, to facilitate parallel alternator operation. Specifications and electrical diagrams were prepared for the rewiring of this launch and trials conducted on the electrical system upon completion of the work.

P. F. Green

A general purpose winch controller for winches with d.c. motors under 5 hp rating has been developed to assist Coastal Oceanography. The prototype unit has been successfully used in trials to operate a 5 hp winch used in STD work.

P. F. Green

Depot Workshops

The past two years have shown a general rise in the amount of work done by the Depot Workshops. This was implemented by the

employment of additional personnel, the expansion of various units within the workshops, the purchase of new equipment, and the addition of transport to the list of services.

One innovation has been the introduction of a job cost accounting system. This was done to get a greater appreciation of the cost of projects, to assess workloads on the various shops, and to obtain information for financial allocations to the laboratories within the institute.

On the operational side, much work over and above the usual routine maintenance was carried out. Work was done on the fabrication of an aluminum tower for wave studies, steel towers for air-sea interaction studies, and on the fabrication of components for rock core drills. A Batfish recovery sled was constructed, winches were fabricated, nets for collecting plankton samples were constructed, and a small diesel powered generator was developed for supplying power for long periods in remote locations. Launches were overhauled in compliance with new



Power unit for use in remote locations



Launches under repair in boat shed.

electrical wiring standards and four new hydrographic launches were fitted out with additional equipment for hydrographic surveys. The Transport unit was responsible for moving electronic positioning equipment to several remote areas of Newfoundland. Depot mechanics were called out on several occasions to service this equipment. Work was done on all ships operating out of the Institute including the charter vessels MV *Minna* and MV *Carina*, the auxiliary vessels CNAV *Sackville*, CNAV *Bluethroat*, *CCGS Labrador*, and *CCGS Narwhal*. The *CSS Hudson* was fitted with a 12-ton crane, computers, and various other electronic equipment for the geoscience cruise to the northwest Atlantic and Baffin Bay.

Other work included overhaul of the two mobile cranes, additions to the electrical systems to meet the needs of several departments in the Institute, and the carrying out of a general clean-up throughout the equipment storage areas.

R. D. Wardrope

Buildings and Grounds

During the period covered by the report, in addition to the normal building maintenance, heating plant maintenance, and watchkeeping duties, many alterations and additions were implemented to accommodate new programs and new employees. Considerable effort was expended in the development of a 2.5-acre outside storage area; this area is being used for the systematic storage of heavy oceanographic and survey equipment.

To alleviate the over-crowding problem in the main building, several laboratories were relocated to the Depot building. Coastal Oceanography and Engineering Services already have labs in the Depot building, and it is anticipated that the technical labs of AGC will be relocated in the Depot in 1973.

J. F. Greig

Computing Services



At the Bedford Institute of Oceanography computing requirements arise from the programs of all three laboratories and span most classes of applications normally associated with scientific data collection, analysis, and research. Traditionally, processing, reduction, and analysis of data collected at sea have generated the major portion of the workload but a significant amount of numerical modelling and other types of computationally bound jobs have been done also. A medium scale in-house computing facility has been built up to serve the needs of well over 100 active users.

The staff of the Computing Services section provides operations, data preparation, systems software support, and educational, applications programming and consulting services to these users. In addition approximately 20% of staff effort is allocated to the shipboard computing field. The costs of equipment rental, operations and support staff are distributed in proportion to use of the main computing facility at a nominal rate of \$100 per hour. This rate is thought to be realistic and currently economically competitive for the users. In past years the user had a very restricted set of options in selecting his computing resources but now that communications facilities are permitting a wider choice of machines to be used by remote job entry it is expected that certain classes of jobs may be done cheaper elsewhere.

Regardless of the location of hardware, the non-operational support role of the section is considered highly desirable because it provides a continuing centre of specialized knowledge which users, the majority of whom have computing as a secondary interest, may draw upon to assist in developing efficient and economical programs. In the future this knowledge will become more useful because users will not have the facts and time required to select the best computing resource for their applications.

The staff size and physical configuration of the main computing facility, a Control Data Corp. 3150, have not changed significantly since the introduction of a closed-shop mode of operation early in the review period. The workload, after building up to a level requiring routine two-shift operation early in the period, appears to have reached a plateau.

The Computing Centre's capabilities were enhanced by introducing routine operation of the CDC 3150 communications facilities to remotely enter jobs into outside large computers, in particular Dalhousie University's CDC 6400 in Halifax. The centre also has attempted to stimulate interest amongst BIO staff in the use of local time-sharing services where appropriate and this effort appears to have

been successful. The amount of money spent on outside computer use is expected to be close to 15% of the section's budget during fiscal 72/73. Use of this diversity of sources of computer power has given us an appreciation of the range of costs of each class of computing in different machines.

A significant contract for programming a system for processing of oceanic data has been let to a Montreal company and the results are awaited with interest. It is evident from this project that a considerable amount of in-house effort must go into preparing specifications for and monitoring a contract of this type.

At present the section is embarking on a study of BIO computing requirements and the most economical means of meeting them. Many



Map of the world plotted using Institute computers.

options are open to us in selecting computing resources. One extreme would be to provide all classes of computing in-house and the other to use the best outside supplier for each class of job. The cost and reliability of long distance data communications will significantly influence our choices in this regard. At the present time the cost of communication outweighs the gains in unit computing cost available through the economies of scale of large computers in the large metropolitan centres.

In the field of shipboard computing BIO has embarked on a program of installing a new generation of mini-computers aboard its major vessels. In keeping with the potential magnitude of capital investment a small computer evaluation cruise was conducted on the CSS Hudson in November 1971. As a result of this cruise an HP 2100A computer was selected and purchased for permanent installation on the Hudson. The capabilities of this machine, which is a miniature general purpose computer, far exceed those of the earlier generation of PDP-8 computers used in past years. When used for compiling and executing FORTRAN programs the machine is compatible with larger computers hence allowing most staff members with some familiarity with FORTRAN programming to use the machine after a short familiarization course. The ease of use of the machine derives from the operating system programs supplied by the manufacturer. Detailed knowledge of these programs will not normally be available on board ship, or even within BIO, therefore there is some risk that an error in a user's application program could indirectly disable the system by causing changes in the portion of the machine reserved for manufacturer's programs. In such an event recovery action may be taken at the expense of temporarily losing user files. Some users, accustomed to the dedicated nature of current shipboard machines to one user at a time, may find problems of this kind difficult to accept but they are the price of having a powerful shared computing resource. To take full advantage of all the capabilities of these machines, particularly in an on-line data acquisition mode, a considerable body of special knowledge must be built up. Also, there are a number of technical and operational reasons why it may be found desirable to assign a shipboard operator to multiple user systems; for example, user file integrity must be maintained with a protection system which is fallible and, if the machine is eventually used in all its possible modes, no one user will have an appreciation of the overall use of the systems.

M. T. Darwood

Scientific Information Services and Library



Scientific Information Services and Library (SISL) was formed in 1967. At that time the original library function was expanded and additional responsibility was assumed in connection with the selective transfer of scientific and technical information to and from the Bedford Institute of Oceanography. Of the present services, the library and information retrieval are concerned with *information-in*,. the remaining services are concerned with *information-out*.

The Bedford Institute Library is for the use of all staff at the Institute. It does not, as a matter of policy, attempt to collect everything in the field of oceanography, but rather to service the specific interests of the Institute. As such its holdings are comparatively small. For example, current journals number fewer than 500; the importance of each journal to the Institute, however, has been checked in two recent user surveys. Regional cooperation plays an important part in the operation of the library. During 1972 the Institute made arrangements with several local libraries whereby it could quickly and economically obtain copies of items that it did not hold: this was achieved by eliminating formal interlibrary loan procedures. A systems analysis of existing library operations is presently under way. One outcome of this has been the decision to develop a mechanized serials control system. This will provide users with an accurate and current file of the library's journal and other serial holdings, including the location of each item in the stacks (the first part of the system is now in use). It will also enable library staff to maintain and control the collection more effectively than under the present manual system. It is planned to introduce a pilot scheme for the keyword-in-context (KWIC) indexing of documents and reports which could eventually eliminate the need to catalogue this class of material.

Information retrieval services fall under one of two categories, retrospective searching and selective dissemination of information. In the past SISL has played a rather passive role with regard to retrospective searching; it has supplied the tools for the job but has left the actual searching to the individual. In 1972 a group of university students with scientific backgrounds was formed to carry out literature searches during the summer months. About 30 searches were requested by Institute staff; this new service was well received. Some small use has also been made of external services for retrospective searching: for example, the Canadian Index to Geoscience Data. In the selective dissemination of information the Institute has relied almost entirely on the CAN/SDI service operated by Canada's National Science Library in Ottawa. This is a service whereby scientists are regularly notified of recent papers in their particular field of interest. The National Science Library regularly receives the magnetic tapes of such services as Chemical Abstracts and Biological Abstracts; these are scanned by computer and compared with several hundred individual user-profiles. About 50 scientists at the Institute have such profiles in the system reflecting their particular interests. These scientists are mailed output every week, two weeks, or month, depending on the tapes searched. SISL staff advise on the preparation of user-profiles, liaise with the National Science Library, and monitor the relevancy of the output.

The flow of information through SISL is two-way. In addition to making external information available to the staff of the Institute it is the responsibility of SISL to ensure that the information generated by the Institute is made available to others in Canada and the rest of the world. Outside requests for technical information are dealt with by compiling lists of references to relevant papers and reports by Institute staff: copies of the actual items are often supplied. Short literature searches may be undertaken, and the inquirer is often put in touch with the appropriate expert at the Institute. SISL staff review papers and reports produced by Institute staff. They take steps to ensure that the quality of the Institute's publications is kept at a high standard. recognizing that poor presentation can hamper the appreciation of good research work. The major papers are designated Bedford Institute of Oceanography Contributions and are allocated an appropriate Contribution Number. The Institute's Contributions for 1971/72 are listed according to laboratory in this review (see Appendices B-1, C-1, D-1 at ends of AOL, MEL, and AGC sections respectively). A separate document is available listing all publications and reports by Institute staff. The actual operation of sending out information in the form of reports and documents is handled by the library; material is sent out to some 900 different addresses throughout the world. For this purpose a special computer program was developed to control the mailing list and print out the addresses. Two publications produced by SISL are worthy of special mention: one is the annual volume of Collected Contributions, which brings together the major research publications of the Institute; the other is this Biennial Review and its sister volume, Ocean Science Reviews.

H. B. Nicholls

Drafting and Illustrations



The Drafting and Illustrations Unit is a facility available to all departments and sections established within the confines of the Bedford Institute of Oceanography. It is not feasible, because of staffing limitations, for all production to be done within the Unit; therefore our function is becoming more and more oriented toward quality control rather than entirely production. It is essential that staff familiar with the technical side of presenting scientific data be available to ensure that the illustrations used by the scientists have the maximum possible legibility and clarity of presentation. It is also much easier to deal with the varying demands of the various sections if these requirements can be brought together under one facility where the low output phase of one section may be complemented by the peak demands of another.

We are responsible for the preparation of scientific data for slides and other visual aids, and for publication in various journals. We have also been involved in the making of displays and preparation of drawings for models.

In progressing towards a more comprehensive facility, we have acquired and developed such useful techniques as phototypesetting, silkscreening, diazo whiteprinting, various media for colour work, Scotchcal (an image-on-metal process) suitable for instrument panels, etc., and are now in the process of setting up a master system of sketches. These sketches are the base of many drawings prepared for publication; only the data need be added as the basic shoreline, place names, latitudes and longitudes, etc., already exist. This system, though it can never be complete, has and will save a tremendous amount of time by eliminating much duplication of effort in drawing base maps.

In a further effort to meet the increasing demands of the Institute, we have, over the past year, been attempting to establish an outside facility to aid our in-shop production. Though the system is not yet fully established, it will become a more efficient operation as the outside contracting firms become more fully acquainted with Institute standards.

J. R. Lord

Photography



The primary role of this unit is to provide photographic service and support to the scientific and technical operations of the Institute. The majority of this work is performed at the institute proper, but many assignments are for cruise and field work, ranging from deep ocean-bottom recording to aerial operations. At the Institute, the unit's operations include cartographic reproductions, with a giant cartographic camera, processing of all sizes of films, colour slide production, provision of studio facilities, and motion picture production. All these functions are primarily utilized in support of Institute research as recording media but the facilities and the products themselves are also used in other ways, such as for public information, displays, publications, etc.

The cartographic reproduction facility, established early in 1970, is now working full time producing field sheets, maps, charts, and diagrams. Chart re-scaling and field sheet reproduction are providing the hydrographers with a quick, personally directed service and avoiding the long delays and confusion created previously by having such work done by hand or in Ottawa by the Surveys and Mapping Branch of the Department of Energy, Mines and Resources. The extra advantage achieved by this facility is precise, high quality production of all line work for printed publications.

As a central photo production unit, our files automatically become a film, print, and slide source for all sections. This service has increased and broadened as our stocks of pictures increase.

With the addition of a Public Information Officer to the Institute staff we have found our material in demand on a much larger scale. Gradually our Institute is becoming known nationally and internationally and requests for pictures of the scientific research are being requested by various public and scientific media throughout the western world.

This seemingly insatiable demand has led to the release of some of our motion picture work and has focused the interest of film producers, TV producers, and book publishers on us to meet the demand of an 'environment conscious' public. Our film taken in the Arctic, entitled "Hudson '70 - The Arctic Voyage", produced by Crawley Films of Ottawa, with the approval of the National Film Board, has received many favourable comments wherever it has been shown. To date, it has not been officially 'released', as it is awaiting national TV distribution details.



Nature's Negative It's not a fingerprint nor a cross section of a tree. It's a fish scale from a salmon which defied all normal methods of being photographed to resolve its detail. The solution was to use the scale itself as a 'negative' in the enlarger and project it to a high contrast film from which prints have been made up to 4 X 5 feet. The original is about ¼ inch wide.

During the summer of 1971, our unit was requested to provide a test series of aerial photographs of local harbours and harbour approaches for the Canadian Hydrographic Service's *Sailing Directions* With the cooperation of the Ministry of Transport helicopter group, Halifax Harbour, Chester, and Mahone Bay were covered and the photographs forwarded to the Hydrographic Service in Ottawa. This initial submission was answered with a request to proceed and to provide the same coverage of 15 harbours in Nova Scotia from Yarmouth to Sydney. By the fall, these were completed and forwarded. In April 1972, we received an additional request to provide the same coverage of approximately 35 more ports. These included ports in Nova Scotia, New Brunswick, Prince Edward Island, the Gaspe, north shore of the St. Lawrence, Newfoundland, Magdalen Islands, and Sable Island. To date, most of these are completed, but a few of the more distant are still to be photographed.

The summer of '72 saw the start of the development of a free running ocean bottom camera vehicle. This is the result of a proposal by the photo unit made in 1969 on the concept of an independent, free-floating submersible vehicle to house a rapid sequence-framing camera, to provide continuous strip photos or motion pictures of the bottom. The instrument machine shop of the Metrology Division started work on the unit in late spring and an initial unit was assembled to test its behaviour underwater. The first tests were made in July at Lake William in Nova Scotia. The vehicle's performance was filmed in underwater motion pictures by scuba divers. The tests were successful, but the visibility was poor. The next tests were made at Thrumcap Shoals at the mouth of Halifax Harbour. Motion pictures, taken at 40 feet in clear water, showed the vehicle performing successfully although underpowered. Plans were then made and a target date of mid-September set to produce a sea-going unit capable of 180 metres depth. Time would not permit development of the required camera unit and related lighting equipment, so the vehicle was designed to carry an existing Edgerton camera and light source. Shallow water tests were made on this unit at Thrumcap and in St. Margaret's Bay. The underwater motion picture film showed the unit performing perfectly on the bottom. The CineSea, as the vehicle had now been named, was taken to sea on the CSS Dawson in mid-September for its first open water trials. The only means of knowing how it performed was by the results its camera brought back. Unfortunately, the camera ceased to function shortly after reaching bottom. The vehicle apparently was successful, as it did return to the surface as scheduled. It is believed the camera failure was due to a combination of low temperature and pressure, as the units were housed in light aluminum pressure cases that previously had not been tested in deep water. The results to date are encouraging and plans are being made to improve the unit for further deep water work in the coming year.

N. E. Fenerty

Appendix B-1 Major Publications and Reports by AOL Staff, 1971/72

Bedford Institute of Oceanography Contributions

Publications indicated by an asterisk are joint papers with MEL and/or AGC; they are repeated in the corresponding lists for MEL and/or AGC.

BANKE, E. G., and SMITH, S. D. 1971. Wind stress over ice and over water in the Beaufort Sea. J. Geophys. Res., 76: 7368-7374 (BIO Contribution 255).

BENNETT, A. S. 1972. The calibration of thermistors over the temperature range 0-30°C. *Deep-Sea Res. 19:* 157-163 (BIO Contribution 273).

BEWERS, J. M. 1972. The global circulation of the halogens in nature. In: Proc. 24th Int. Geological Congress, Montreal, 1972, 10: 273-281 (BIO Contribution 270).

BEWERS, J. M., and PEARSON, G. J. 1972. The behaviour of particulate material in the treatment lagoons of a bleached kraft pulp mill. *Water, Air and Soil Pollution, 1:* 347-358 (BIO Contribution 319).

COOTE, A. R., BEWERS, J. M., and PEARSON, G. J. 1971. Graphite irradiation capsules for thermal neutron activation analysis. *Radiochem. Radioanal. Letters*, 6: 265-274 (BIO Contribution 228).

COOTE, A. R., DUEDALL, I. W., and HILTZ, R. S. 1971. Automatic analysis at sea. In: Advances in automated analysis, 2, Industrial Analysis. Proceedings of Technicon International Congress on Automation in Analytical Chemistry, New York, November 1970. Thurman Associates: 347-351 (BIO Contribution 217)*'

DOBSON, F. W. 1971. Measurement of atmospheric pressure on wind-generated sea waves. J. Fluid Mech., 48, Pt. 1: 91-127 (BIO Contribution 230).

DOBSON, F. W. 1971. The damping of a group of sea waves. *Boundary-Layer Meteorology, 1:* 399-410 (BIO Contribution 226).

DUEDALL, I. W. 1972. The partial molal volume of calcium carbonate in sea water. Geochim. Cosmochim. Acta, 36: 729-734 (BIO Contribution 314).*

DUEDALL, I. W., and BUCKLEY, D. E. 1971. Calcium carbonate monohydrate in seawater. *Nature*, 234: 39-40 (BIO Contribution 263).*

DUEDALL, I. W., and COOTE, A. R. 1972. Oxygen distribution in the South Atlantic. J. Geophys. Res., 77: 496-498 (BIO Contribution 267).*

DUEDALL, I. W., and COOTE, A. R. 1972. Oxygen distribution in the Pacific Ocean. J. Geophys. Res., 77: 2201-2203 (BIO Contribution 287).*

DUEDALL, I. W., COOTE, A. R., KNOX, D. F., and CONNOLLY, G. F. 1971. A dispenser for Winkler's dissolved oxygen reagents. J. Fish. Res. Bd. Can., 28: 1815-1816 (BIO Contribution 275).*

EATON, R. M., and GRANT, S. T. 1972. Rho-Rho Loran-C for offshore surveys. *The Can. Surveyor*, 26: 125-135 (BIO Contribution 291).

FORRESTER, W. D. 1971. Distribution of suspended oil particles following the grounding of the tanker Arrow. *J. Marine Res.*, 29: 151-170 (BIO Contribution 232).

FORRESTER, W. D. 1972. Tidal transports and streams in the St. Lawrence River and Estuary. Int. Hydrographic Rev., 49: 97-108 (BIO Contribution 259).

GARNER, D. M. 1972. Flow through the Charlie-Gibbs fracture zone, Mid-Atlantic Ridge. *Can. J. Earth Sci.*, 9: 116-121 (BIO Contribution 260).

JOLLYMORE, P. G. 1971. A portable digital sounding system for Arctic use. Int. Hydrographic Rev., 48: 35-42 (BIO Contribution 223).

KRAKIWSKY, E. J., WELLS, D. E., and KIRKHAM, P. 1972. Geodetic control from Doppler satellite observations. *The Can. Surveyor, 26: 146-162* (BIO Contribution 292).

LEVY, E. M. 1971. The presence of petroleum residues off the east coast of Nova Scotia, in the Gulf of St. Lawrence, and the St. Lawrence River. *Wafer Res.*, *5*: 723-733 (BIO Contribution 246).

LEVY, E. M. 1972. The identification of petroleum products in the marine environment by absorption spectrophotometry. *Water Res.*, 6: 57-69 (BIO Contribution 265).

MANN, C. R. 1971/72. A review of the branching of the Gulf Stream system. *Proceedings of the Royal Society of Edinburgh (B), 72:* 341-349 (BIO Contribution 296).

NEEDLER, G. T. 1971. Thermocline models with arbitrary barotropic flow. Deep-Sea Res., 18: 895-903 (BIO Contribution 247).

NEU, H. 1972. Extreme wave height distribution along the Canadian Atlantic coast. *Ocean Industry*, 7: 45-49 (BIO Contribution 325).

PAGDEN, I. M. H., PEARSON, G. J., and BEWERS, J. M. 1971. An isotope catalogue for instrumental activation analysis, I, II, and III. J. Radioanal. Chem., 8: 127-188, 373-479.9: 101-189 (BIO Contribution 238).

PLATT, T., CONOVER, R. J., LOUCKS, R. H., MANN, K. H., PEER, D. L., PRAKASH, A., and SAMEOTO, D. D. 1970. Study of a eutrophicated marine basin. FAO Technical conference on marine pollution and its effects on living resources and fishing, Rome, Italy, Paper FIR: MP/70/E-30. 10 pp (BIO Contribution 219)."

POCKLINGTON, R. Secular changes in the ocean off Bermuda. J. Geophys. Res., 77: 6604-6607 (BIO Contribution 324).

QUON, C. 1972. High Rayleigh number convection in an enclosure -a numerical study. *The Physics of Fluids, 15: 12-19* (BIO Contribution 253).

SHEARER, J. M., MACNAB, R. F., PELLETIER, B. R., and SMITH, T. B. 1971. Submarine pingos in the Beaufort Sea. *Science*, *174:* 816-818 (BIO Contribution 257).*

SMITH, S. D. 1972. Wind stress and turbulence over a flat ice floe. ./. Geophys. Res., 77: 3886-3901 (BIO Contribution 305).

THOMSON, J., and WALTON, A. 1971/72. Natural radioactive decay series elements in the oceans and sediments. *Proceedings of the Royal Society of Edinburgh*, 72/73: 167-182 (BIO Contribution 308).

Bedford Institute of Oceanography Report Series

This series of technical reports was introduced on 1 January 1972 to replace the original AOL series. In the following list reports issued during 1971 are numbered according to the AOL series (AOL Report 71-). Reports issued during 1972 are numbered according to the Bedford Institute of Oceanography Report Series (BI-R-72-).

Reports indicated by an asterisk are joint reports with MEL and/or AGC; they are repeated in the corresponding lists for MEL and/or AGC.

AGES, A. 1971. Oil reconnaissance in the Magdalen Islands - 1970. AOL Report 71-8.

BANERJI, R. K., SCHAFER, C. T., and **VINE, R. N.** 1971. Environmental relationships and distribution of planktonic foraminifera in the equatorial and northern Pacific waters. *AOL Report* 71-7.*

BEWERS, J. M. 1971. Fluoride in the South Atlantic and Pacific Oceans. AOL Report 71-4.

BRUNAVS, P., and WELLS, D. E. 1971. Accurate phase lag measurements over seawater using Decca Lambda. AOL Report 71-2.

EASTON, A. K. 1972. Tides of Hudson Strait. BI-R-72-6.

LEVY, E. M., and WALTON, A. 1971. An evaluation of two Neuston samplers. AOL Report 71-9.

LOUCKS, R. H., LAWRENCE, D. J., and FORBES, S. R. 1972. The effect of a sinusoid perturbation on the extremes of a Markov process. *BI-R-72-8*.

LOUCKS, R. H., and SADLER, H. E. 1971. Exchange processes between Petpeswick Inlet and continental shelf waters. AOL Report 71-5.

MACPHEE, S. B. 1972. A system for measuring vertical pressure profiles of ocean waves. BI-R-72-1.

MILLS, R. G. 1972. Design and installation of the Atlantic Oceanographic Laboratory stable platform. *BI-R-72-4.*

NEU, H. J. A. 1971. Review of the layout of the container pier in Halifax Harbour. AOL Report 71-1.

NEU, H. J. A. 1971. Wave climate of the Canadian Atlantic coast and continental shelf - 1970. AOL Report 71-10.

OAKEY, N. S. 1972. A deep sea wave recorder intercomparison. BI-R-72-9.

POCKLINGTON, R. 1972. Variability in the ocean off Bermuda. BI-R-72-3.

SEIBERT, G. H. 1972. Physical oceanographic study of St. George's Bay, Newfoundland. *BI-R-72-2*.

THORBURN, J. P. and DINN, D. F. 1971. On-line analog-to-digital hardware at the B.I. Computing Centre. AOL Report 71-3.

VINE, R. N. 1971. Design of a seismic hydrophone winch. AOL Report 71-6.

Appendix B-2 Affiliations

During the years 1971-72 some staff members of the Atlantic Oceanographic Laboratory were affiliated in various ways with the academic community.

At Dalhousie University, Halifax, Dr. C. Ft. Mann is an Associate Professor in the Physics Department. Drs. G. T. Needler and H. Sandstrom are Research Associates in the Institute of Oceanography. In addition, Dr. Sandstrom gave a course in dynamical oceanography and is the supervisor of a Ph.D. candidate in oceanography. Dr. W. Forrester is an Associate Professor in the Institute of Oceanography and gave a series of lectures on physical oceanography. Dr. F. W. Dobson gave a series of lectures on fluid mechanics.

At the Nova Scotia Technical College, Halifax, D. F. Dinn gave courses in electronic design. Dr. A. S. Bennett is associated with the college as associate supervisor and member of guiding committee for a Ph.D. student. H. J. A. Neu gave a series of lectures on the principles of waves.

Dr. W. Forrester is supervisor of a Ph.D. candidate at the Marine Sciences Centre, McGill University, Montreal. Dr. R. Pocklington is a member of the Corporation of the Bermuda Biological Station for Research.

C

Marine Ecology Laboratory Fisheries Research Board of Canada Department of the Environment 1971/72

Director's Remarks

The program of the laboratory is directed to the study of processes underlying marine production, with special reference to fisheries. Study is focussed on four principal objectives:

Prediction of potential fish production and catch in various water masses.

Development of knowledge necessary to management for increased catch or increased efficiency of natural harvesting.

Assessing levels of pollutants and their effects on natural production.

Development of methods and technologies for beneficial manipulation of environments applicable to marine culture or environmental quality control.

The laboratory was established at the Bedford Institute of Oceanography in 1965, to encourage development of knowledge of the dependence of fishery resources and their food-chains on changes in the physical environment. As a result, there has been a considerable interaction of biological with physical and chemical studies, both within the Institute and with other marine science oriented laboratories in the Halifax-Dartmouth area, especially the Institute of Oceanography and Department of Biology at Dalhousie University.

For its initial program the laboratory examined the biological and physical dynamics of a 'model' natural system in St. Margaret's Bay. Over the past two years, the knowledge gained in this field program, supplemented by laboratory and theoretical studies, has been the basis for comparative programs in other coastal inlets, such as Bedford Basin-Halifax Harbour, and Petpeswick Inlet, and more broadly to larger systems such as the Gulf of St. Lawrence and the Continental Shelf and adjacent offshore waters. The aim has continued to be a description and exploration of phenomena observed in systems of various size scales which would have useful application to fishery exploitation and management or to environmental quality manipulation and control.

In the course of this work several hypotheses have been developed which appear to have important practical consequences. Investigation and testing of these hypotheses is therefore the basis of the on-going program. For example, it has been found that in coastal inlets, the nitrogen and other mineral 'fertilizers' of the biological system are primarily supplied by vertical mixing of the water column under the influence of forces generated by winds, tides, and fresh-water outflow. This fertilizer is taken up both by the phytoplankton and by attached large algae, the latter being responsible for a much larger share of the primary production than had heretofore been suspected. The dynamics of this intense coastal production are under active study in various types of coastal systems. In the Gulf of St. Lawrence, where river outflow appears to be a dominant mixing force, the rate of river outflow is strongly correlated with commercial catches several years later, when the stocks which were produced in the area of river influence grow to commercial size and age. Results indicate that two-thirds of the variation in catch can be attributed to changes in the suitability of the environment for the survival of the fish larvae.

The situation is more complicated in smaller coastal inlets when tidal and meteorological forces predominate. In some of them, the nutrient intake by the primary producers is extensively utilized by zooplankton in the inlet, so that 'export' to the sea is at various higher trophic levels, and available further offshore to larvae and juvenile stages of the fish populations which occur there. In the smaller and shallower inlets with marshy borders, the most significant export may be nitrogenous compounds in either dissolved particulate or detrital form. The combination of studies indicates that events in the coastal zone have an important influence on production in traditional fishing areas, and may be used to predict general trends in the catches. Of particular interest are indications that variability of coastal physical parameters, within the scale of effects which are subject to manipulation or control by man, have significant effects on natural production, including fish production.

The laboratory has undertaken the development of techniques which may be useful for making shorter term predictions of fish catch and environmental quality. Our acoustic fish-counting system now appears to give reliable estimates of abundance of commercial groundfishes such as cod, haddock, and redfish. Methods of survey for practical inventory have also been worked out and are ready for an assessment of their economic efficiency in fishing and fish management. An analogous acoustic system has been developed and given preliminary testing for smaller organisms such as euphausiids, shrimps, and juvenile and small fishes. A fluorometric continuous survey instrument and data acquisition system has also been developed for measuring phytoplankton production. Its usefulness for assessing effects of eutrophication has been demonstrated in the field.

The environmental quality program has emphasized studies of the levels and nature of petroleum and chlorinated hydrocarbons in various important coastal inlets and at sea; all of which are areas of rapidly growing activities related to oil exploration and transportation. New methods of sampling and analysis have been developed where necessary. Field collections and survey methods have received the cooperation of the oil exploration companies. Other studies have been concerned with local problems or potential problems of heavy-metal contamination, and both these and the hydrocarbon investigations have been extended to measurements of the tolerance of marine plants and animals to the foreign substances identified.

During the past year, special efforts have been made to cooperate with the Cape Breton Development Corporation and other laboratories of the region in setting up commercial scale aquaculture systems for oysters, mussels, Irish moss and salmonid fishes. In addition, smaller scale studies of various aspects of the aquaculture potential for oysters and mussels, commensurate with the present limited laboratory resources, have been developed.

More detail on these programs is supplied in the following pages.

Administrative Review

Since the last Biennial Review the manpower and financial resources of the laboratory together with the physical support requirements have continued to expand at a modest rate. The total staff has increased from 68 in 1970 to 78 at the end of 1972 and the operating budget from one million dollars to over one million, three hundred thousand dollars. We also continue to enjoy associations with an increasing number of visiting fellows, graduates, students and other research colleagues who have been actively involved with our programs during the two years.

During the period, expansions and improvements have been made to our water laboratory at the Bedford Institute of Oceanography, to our permanent substation at Ellerslie, Prince Edward Island, and to our field station at St. Margaret's Bay, Nova Scotia, about 25 miles from the main laboratory in the Institute.

The Atlantic Oceanographic Laboratory at the Bedford Institute of Oceanography has continued to support our requirements for oceanographic ships and the Fisheries Research Board's vessels and charters have continued to provide the Marine Ecology Laboratory with its fishery research vessel requirements, including two small vessels which have operated from Dartmouth and other local inshore waters. Late in 1972 an internal re-organization within the laboratory was introduced to simplify the management of the research programs which are now identified in four main groups under senior scientists and the staff list contained in the review reflects these changes.

L. M. Dickie

MARINE ECOLOGY LABORATORY

DIRECTOR L.M. Dickie

RESEARCH

ASSISTANT DIRECTOR, RESEARCH B.S. Muir

BIOLOGICAL OCEANOGRAPHY T. Platt

ENVIRONMENTAL OCEANOGRAPHY R.W. Trites

ENVIRONMENTAL QUALITY D. C. Gordon Jr.

FISHERIES OCEANOGRAPHY B.S. Muir

SUPPORT

ASSISTANT DIRECTOR, ADMINISTRATION M. Blaxland
Research, Survey and Senior Support Staff

Director and Administration

L. M. Dickie	- Director
B. S. Muir M. Blaxland	 Assistant Director (Research) Assistant Director (Administration) and Executive Assistant to Director
R. C. Edmonds ¹	
H. S. Glover	- Manager, Biological Substation, Ellerslie, Prince Edward Island
K. A. Overton	

Biological Oceanography

K. H. Mann² - Senior Biologist T. C. Platt - Scientist-in-Charge

P. C. Beamish R.J. Conover K. L. Denman¹ S. R. Durvasula¹ K. R. Freeman M. Hodgson R. Anitra Laycock^{1,4} J. C. MacKinnon^{2,7} J.-L. Martin^{1,5} P. Mayzaud^{1,5}

R. J. Miller^{2,4}
M. A. Paranjape
D. L. Peer
S. Poulet⁵
A. Prakash
D. D. Sameoto
R. W. Sheldon
J. C. Smith
W. H. Sutcliffe, Jr.
J. R. Wheeler^{1,4}

Environmental Oceanography

R. W. Trites - Senior Oceanographer

I.	W.	Duedall ²	D.	Η.	Loring
Ε.	М.	H. Hassan	Ρ.	Ε.	Vandall ¹
D.	Ρ.	Krauel			

Environmental Quality

D. C. Gordon - Scientist-in-Charge

R. F. AddisonS. R. Kerr²Jacqueline Dale¹Georgina A. Phillips¹Donna C. Darrow¹N.J. Prouse¹G. L. Fletcher²W. P. VassB. T. Hargrave¹D. M. Ware¹G. C. H. Harding¹D. E. WillisP. D. Keizer'M. E. Zinck

Fisheries Oceanography

B. S. Muir - Scientist-in-Charge

- Vivien M. Brawn (Srivastava)² R. G. Dowd R. E. Drinnan
- T. C. Lambert
- K. T. MacKay^{2,7}
- S. Paulowich

- ¹ Joined MEL
- ² Left MEL
- ⁴ Postdoctoral Fellow
- ⁵ Research Fellow, France-Canada Cultural Agreement
- 7 Graduate Student

Biological Oceanography



Phytoplankton Productivity and Nutrient Measurements in Coastal Inlets

The program of study of *in situ* primary production and phytoplankton nutrients in the coastal inlets of Nova Scotia was continued in 1971-72. Twelve-month series of weekly measurements of a wide variety of parameters relevant to primary production were completed and published for Bedford Basin (four stations) and Petpeswick Inlet (one station). These studies, which complement similar work done earlier in St. Margaret's Bay, extend our knowledge of the ecological dynamics of type-inlets on our coast. The exploratory phase of our studies of primary production in coastal inlets is now considered to be completed. In the future, emphasis will be placed on experiments (in the field) involving small-scale manipulation of the environment.



Map showing the location of Bedford Basin, Petpeswick Inlet, and St. Margaret's Bay.

In Bedford Basin, annual production by phytoplankton was estimated to be 200 g C rn^{-2} yr⁻¹ which may be compared with 190 g Cm⁻² yr⁻¹ estimated for St. Margaret's Bay. Production during the spring bloom contributed relatively less to the annual production than was the case in St. Margaret's Bay.

An intensive experiment was carried out to attempt to find the balance in the 24-hour chlorophyll budget for the Basin in terms of production, grazing and loss by tidal exchange. The experiment was successful. It indicated that 58% of the daily phytoplankton production (11% of the total standing stock) was lost by exchange with the sea while 34% was consumed by grazing of zooplankton. Of the chlorophyll lost by export, 35% was exchanged via the mean flow and 65% by fluctuations in the flow. This experiment illustrated the difficulty of providing verification data for any continuous model of primary production in such a coastal embayment.

For Petpeswick Inlet, annual production by phytoplankton was estimated to be 140 g Cm^{-2} yr⁻¹. No evidence was found for the occurrence of a spring bloom of phytoplankton. Maximum production occurred during the fall months. This inlet differs from those studied previously by our group in that it is covered by ice for four months during the winter and also in that hydrogen sulfide is produced in the bottom waters there during winter.



Phytoplankton (500x)

Comparative studies made simultaneously in different inlets revealed that fluctuation in phytoplankton nutrients followed strikingly similar patterns. It is concluded that, except during the spring bloom, nutrient levels on the coast of Nova Scotia are controlled more by water exchanged with the continental shelf than by biological processes within the inlets. Flushing of the inlets is most extensive in late summer and autumn. Major water replacements occur at least once every year on this coast and the flushing takes place on a broad front rather than affecting isolated inlets.

A detailed comparative account of the dynamics of phytoplankton nutrients in the coastal inlets of Nova Scotia is in preparation. Studies on the relationships between carbon and caloric content of phytoplankton have provided sound theoretical and empirical reasons for expressing caloric content in terms of grams of carbon rather than grams dry weight. The possible range of variation of the former measure is considerably narrower than that of the latter, a matter of importance in generalized food chain calculations. This work provides a rationale for the prediction of caloric content from carbon content of phytoplankton, simplifying both operationally and conceptually the work involved in studies of ecological energetics.

T. Platt

Studies on Spatial Distribution of Phytoplankton

Studies on the nature and significance of heterogeneity of phytoplankton distributions in nearshore environments have been continued.

Using the continuous-flow fluorometer system, developed at MEL, for automated chlorophyll sampling, a study was made of the short-term fluctuations in local phytoplankton abundance at a station on the Bradelle Bank, Gulf of St. Lawrence. Spectral analysis of the data revealed that the distribution of the variance of phytoplankton abundance in the mixed layer follows a minus-five-thirds power relationship over a range of length scales from 10 to 1000 metres. This result is consistent with (but does not necessarily prove) the hypothesis that local concentration of phytoplankton is controlled largely by turbulence. Regardless of the physical mechanism involved, it is significant progress to learn that the power spectrum of phytoplankton abundance has a regular shape. This observation will be useful in theoretical calculations of food-chain dynamics.

The continuous fluorometer system has also been used successfully in a study of the feasibility of mapping the chlorophyll and temperature distribution of the Gulf of St. Lawrence. Maps of chlorophyll and temperature distribution at 5 metres depth were produced for the Gaspe coast from CFAV *Sackville* in June 1972. Surveying speed was 6 knots, and survey lines were spaced 3 miles apart. The results are collected in FRB Technical Report No. 332.

An intensive study of the spatial distribution of biomass and productivity of phytoplankton in Bedford Basin was made during the summer of 1972. Six stations were used and the experimental design, which involved ten replicate biomass measures and six replicate productivity measures for each station, allowed calculation of the productivity : biomass (P:B) ratio, and its standard error, for each of the six stations on each of ten sampling days. Preliminary analysis of the results indicates that the assumption of equal P/B for different stations at the same depth on the same day is not tenable.



Contours of Chlorophyll distribution (mg m $^{-3}$) in the Gulf of St. Lawrence.

T. Platt

Humic Compounds and Coastal Fertility

Studies on the influence of humic compounds on primary productivity of coastal waters were continued and extended to include humic compounds derived from decomposed littoral brown algae (phaeophyta) and from mangrove leachates. The results obtained so far have shown that humic and fulvic acids whether derived from terrestrial sources or from littoral algal vegetation exert a positive influence on the growth of marine phytoplankton. The almost identical growth responses obtained with humic compounds derived from different sources suggest common features in the molecular structure of the various humic additives. Available evidence suggests that the comparatively large amounts of allochthonous as well as autochthonous humus introduced in the coastal environment may play a significant ecological role in biological conditioning of coastal waters in favour of high phytoplankton production.

A. Prakash

Dialysis Culture of Marine Planktonic Algae

The dialysis culture system was originally designed to grow bacterial populations, but in spite of the successes in cultivating a variety of micro-organisms, the technique has not heretofore been effectively exploited for growing planktonic algae. The dialysis culture system employs exchange dialysis of nutrients and diffusible metabolites through a semipermeable membrane to obtain extraordinarily high concentrations of metabolically active cells. During the past year we have used the system successfully to culture several species of marine diatoms and dinoflagellates under laboratory and field conditions. A variety of dialysis systems have been used and particular attention given to growth characteristics and other metabolic attributes of the planktonic algae. This work was carried out in collaboration with Dr. Arne Jensen during my sabbatical year (May '71 - April '72) at the Institute of Marine Biokjemi, Trondheim, Norway. Some of the results have been submitted for publication.

In several features, a dialysis culture system is superior to a continuous or chemostat culture system and appears to be a promising tool for monitoring biological growth potential as well as effects of pollutants, and other growth promoting or growth inhibiting substances in natural waters. In addition, this system appears ideal for studying autoinhibition, species succession, extracellular products and several other problems in algal physiology. Some of these aspects are currently being investigated.

A. Prakash

Pollution-Induced Eutrophication and Aquaculture

Eutrophication in coastal embayments through urban drainage has usually been looked upon as something vicious and undesirable. Yet this increased pollution-induced fertility of coastal waters provides an excellent opportunity to correct eutrophication by channelling it into some sort of aquaculture. Our earlier studies on Bedford Basin, which receives substantial amounts of domestic wastes from the Halifax-Dartmouth metropolitan area, had indicated it to be a highly eutrophic ecosystem, differing markedly from adjacent coastal embayments not only in its high nutrient load but also in quantitative and qualitative development of its phytoplankton community. A study to examine the aquaculture potential of sewage-enriched and unenriched bodies of water was initiated and Bedford Basin and St. Margaret's Bay were selected for this purpose. Comparative growth studies on blue mussel (Mytilus edulis) were carried out in these two bays. Preliminary results



Monitoring mussel growth in Bedford Basin.

indicate that *Mytilus edulis* responds very favourably to suspension culture in eutrophic waters and is able to attain marketable size in about two seasons. From the available evidence the potential for commercial exploitation of this species using hanging culture technique in our coastal waters appears promising. Further studies on various aspects of mussel culture are in progress.

K. R. Freeman, A. Prakash

Productivity of Seaweeds and Marsh Grasses

It is usual in marine ecology to think of food chains as consisting of plant material which is eaten by a grazing animal, this in turn being consumed by a predator, such as a fish. This model may be substantially true for the open ocean, but in coastal waters, where many fish of commercial importance spend a critical part of their life history, food chains tend to have a different character. A very large share of the inshore plant production is by large plants, such as seaweeds and marsh grasses, which tend to decay and break up before entering the food chains. Such systems are known as detrital food chains. Large seaweeds, such as kelp *(Laminaria),* are major contributors to detrital food chains.

In the past two years, data on growth and productivity of *Laminaria* populations have been subjected to more rigorous analysis. The growth rates in 1969/70 were in many cases higher than in the previous year, and consideration of the relative proportions of young and old plants in the populations has led to an upward revision of estimates of the rate at which the seaweed biomass is turned over. The final estimate of productivity of the seaweed zone in St. Margaret's Bay is 1750 g Cm⁻² or 603 gCm⁻² averaged over the whole bay. It is thought that not more than 10% of this production enters the grazing food chain. The remainder enters the water column as dissolved or particulate organic matter. The details of the process whereby this material is assimilated into planktonic or benthic animal populations is under investigation.

Increase in size of the blades of the kelps occurs very rapidly in winter, when temperature and light input are very low. Much of this blade material is broken off and carried away in suspension at times of high wind. As a result, the kelps supply organic material to the food chains of the bay at a time when production of the phytoplankton is minimal.

Available evidence suggests that this production mechanism is important in Arctic waters, where the period of low temperature and low light intensity is correspondingly longer. Work has begun on a study of the contribution of marsh grass (*Spartina*) and sea grass (*Zostera*) to the productivity of Petpeswick Inlet. This site was selected as being typical of the kind of estuary in which sediments accumulate and salt marshes develop. The productivity of these plants was estimated by extensive sampling at the end of the summer growing season, and by observation of marked plants to determine the amount of material contributed to the detritus food chain in the course of the growing season. The estimated average productivity of the marsh grass is about 290 g Cm⁻², one of the highest figures for marsh grass recorded north of Georgia. There is evidence in the literature that *Spartina* marshes are extremely active in nitrogen fixation at the level of the roots. This aspect may be at least as important an influence on the productivity of the inlet as the contribution of organic matter to the detritus food chains.

There are extensive beds of mussels (*Mytilus*) in the creeks of the salt marshes. They depend on the salt marsh productivity for their food supply. A study of their ecology is reported elsewhere.

K. H. Mann

Bacterial Decomposition of Seaweeds

Investigation has shown that only a small percentage of the very high annual production of seaweed in St. Margaret's Bay is utilized directly by the major herbivore. The possibility that bacteria may play an important ecological role in a detrital energy channel beginning in the seaweed zone was thus considered and a study of the bacterial decomposition of *Laminaria longicruris* initiated in February 1972.

Growth of *Laminaria* in the site selected (Shad Bay, Nova Scotia) has been observed to be seasonal. Plants grew to a maximum size in early summer. Decomposing tissue was noted in increasing amounts on the ends of the fronds as the year progressed and by October many plants were completely senescent.

The bacterial flora was found to alter both quantitatively and qualitatively with the physiological condition of the plant. Senescent tissues were consistently found to have upwards of a hundred times as many bacteria per unit area as the healthy frond. Onset of senescence was found to be accompanied by rapid increases in the proteolytic component of the flora. A discrete group of organisms capable of metabolizing characteristic *Laminaria* substrates was regularly isolated from the decomposing tissue.

A. Laycock

Aquatic Macrophytes as Sources of Particulate and Dissolved Organic Matter

Aquatic macrophytes, sea grasses and seaweeds are major contributors to the primary productivity of coastal waters. Quantification of the processes of decomposition in these plants is not readily achievable in the field and laboratory experiments are currently being conducted on *Laminaria longicruris* and *Spartina alterniflora*. Among the parameters being measured are particulate and dissolved carbon, carbohydrate, and protein; nitrate, nitrite and ammonia; ATP; and numbers and functional groups of bacteria.

Results to date indicate that young *Laminaria* plants can be very rapidly decomposed by bacteria present on the plant surface, when conditions become unfavourable for growth. After two weeks in the dark at 10 C only 2.5% of the original plant tissue remained intact and more than half of the carbon had been mineralized. The nitrogen budget for the system is being investigated.

Results are not available as yet on the decomposition of *Spartina* and older *Laminaria* plants but it is obvious that it is taking place at a much slower rate than that described for the young seaweed.

A. Laycock, W. H. Sutcliffe, Jr.

Particulate Transport and Nutrient Chemical Balances in Petpeswick Inlet

Studies were concerned mainly with relations between the transport of water and of the particulate and dissolved material in it. Water transport studies were made by Dr. R. H. Loucks (AOL) and are described in detail elsewhere in this review. Tidal effects were by far the most important factor in transport.

The particle spectra of water from the inlet and from the sea were quite characteristic and easily recognized and distinguished. The form varied seasonally and the variation was much greater in the inlet than in the sea. By means of the spectra the penetration of seawater into the inlet on the flood tide could be followed. As the flood tide penetrated to the head of the inlet it apparently stimulated phytoplankton growth in the inner basin. Much of the resulting particulate material was carried from this basin on the ebb tide. But it did not leave the inlet, nor did it return to the head of the inlet on the next flood tide. We conclude that, in general, particles produced in the inner basin were either consumed or broken down in the outer part of the inlet. At the mouth of the inlet the dissolved and particulate material was measured over a tidal cycle on five occasions during the summer of 1971. Dr. Loucks' computer programs were used to calculate net transport. We found that there was no consistent export or import either of particulate material or of dissolved carbon. Dissolved nitrogen, on the other hand, was exported on four of the five sampling periods. More than one metric ton of nitrogen was leaving the inlet each day. This could not be accounted for by influx from streams or other outside sources. It seems to be associated with the extensive *Spartina* marshes and attempts are now being made to test this hypothesis. A hot combustion method for measuring dissolved carbon and nitrogen has been developed in collaboration with Dr. D. C. Gordon.

K. Kranck (AOL), R. W. Sheldon, W. H. Sutcliffe, Jr.

Preliminary Studies of Some Coastal Processes

A year-round study of the living and nonliving suspended particulate material of St. Margaret's Bay, together with considerations of the nitrogen budget, led to some tentative conclusions about the role of land drainage in the supply of nutrients for primary production. In this case fresh water was thought to be important in mixing rather than a direct source of nitrogen. Tests of this hypothesis in the Gulf of St. Lawrence showed significant positive correlations between the discharge of the St. Lawrence River and total landings of several commercial species when times of landing were lagged appropriate to age at average commercial size for the species in question.

W. H. Sutcliffe, Jr.

Standing Stocks and Production Rates of Particles in the Ocean

There is considerable geographic variation in the standing stock of oceanic particles. In temperate regions seasonal variation is also considerable but in the tropics this is much less. The shape of the size frequency distributions of particles in the size range 1 to 100 microns varies predictably both geographically and with depth, and the concentration of particles (in volume/volume of water) is roughly constant over a size range from about 1 to 10^6 microns, i.e. from bacteria to whales. It can be inferred that the rate of particle production is size-dependent and that in temperate regions relatively large particles (within the 1 to 100 micron range) are produced slowly

from high standing stocks while in the tropics relatively small particles are produced rapidly from low standing stocks.

R. W. Sheldon

Laboratory Models of Planktonic Food Chains

Part 1. The Thecosome-Gymnosome Food Chain

Although many remarkable adaptations for food-getting are known within the planktonic community most planktonic animals appear to be feeding generalists. Extreme specialization of a predator for a specific prey seems to be relatively rare. Within the molluscan class Pteropoda, there are several exceptions. In them, a gymnosome feeds apparently on a specific genus or perhaps even species of thecosome. One such linear food chain link involves the common 'sea butterfly' *Clione limacina* and its thecosome prey *Spiratella ('Limacina') retroversa* and *S. helicina*. This situation provides an excellent opportunity for studying energetics of a simplified predator-prey system.

Clione seizes its prey by means of six buccal cones which also manipulate the shell into position so that a set of hooks can be ejected from specialized hook sacs into the flesh of the prey before it can withdraw completely into its own shell. After a period of some minutes the prey is withdrawn completely from its shell, which is then discarded, and the prey ingested. By counting and measuring the numbers of discarded shells, we can determine the amount of *Spiratella* eaten and by measuring the anaesthetized *Clione* at regular intervals we can determine their rate of growth.

In laboratory situations, when given all the Spiratella they could eat, Clione grew rapidly for a period, growth rates of 25% per day being not uncommon. Then they slowed down or ceased to grow altogether for a period, often followed by another spurt of rapid growth. In nature growth seems to be a much more gradual matter. Small individuals of both prey and predator appear in the late summer or early fall, increase in size gradually, reaching maximum dimensions in late spring. Our studies of feeding habits show that Clione strongly selected for, and grew best when able to get, larger prey. Statistical analysis of factors affecting feeding rate made it clear that the most important control was not the number of prey but the size of prey, regardless of other environmental conditions. Apparently the oscillations in growth pattern observed in the laboratory resulted from the unintentional imposition of a growth asymptote by the size of prey available in nature at the time of initial experiments. Once larger prey appeared the asymptote was penetrated and another period of rapid growth made possible.

If one plots log of growth efficiency, K, against either size of *Clione* or the amount of ration consumed there is no significant negative slope of the regression (or K-line) such as has been found in fishes when they are fed a uniform-sized prey of pelletized food source. Our results suggest that this derives from the fact that the *Clione* continually selected larger food particles as they grew. Increased food particle size is also known to enhance growth efficiency in fishes. It appears that in nature size-selection is a generally important factor in predator production efficiency and size.

Part 2. Neritic Copepods Feeding on Natural Particulate Matter

The model-T Coulter counter has enabled the rapid quantitative classification of natural particulate matter into size frequency spectra in terms of relative concentration. It has enabled us to investigate quantitatively the food preferences of important copepod species in terms of size when feeding on this natural particulate matter. Particulate matter in the upper waters of Bedford Basin at most times of the year has a pronounced bimodal size frequency distribution with major peaks at roughly 10 microns mean spherical diameter and another around 30 to 50 microns. During major bloom periods in spring and fall the principal increase is shown in the peak of larger-sized particles. Feeding studies with dominant copepod species Pseudocalanus minutus, Temora longicornis, Acartia clausi and Eurytemora herdmani show that all graze preferentially on and derive the larger fractions of their nutrition from these larger portions of the size frequency spectrum, regardless of the season and despite the fact that the species of algae representing these peaks vary markedly from spring to fall. Only when the peak at the large size has been grazed to a low level or is missing for some other reason do these species show significant grazing on the smaller-sized particles.

On the other hand, in deeper waters of Bedford Basin and in the waters of Halifax Harbour the 30-50 micron peak is often relatively small. The same species of copepods in those waters generally select from a different portion of the food spectrum.

It has been suggested that feeding rate in copepods approaches some asymptote as the concentration increases. Such curves have been variously simulated with exponential and hyperbolic functions. It has also been postulated that there is some 'threshold' concentration of particles necessary to initiate feeding. Using data from feeding studies with natural particulate matter, but sometimes artificially concentrated or diluted, we have been attempting to verify the existence of an asymptote and a threshold level for different parts of the size-frequency spectrum. In addition we have been testing various published models of copepod feeding with our data. To date it seems clear that the asymptote may be approached rarely under bloom conditions for those portions of the food size spectrum which are not heavily exploited, but is never reached, at least in Bedford Basin, for other portions. Moreover, thresholds apparently do operate to induce a switch from one sized food source to another.

Thus it appears that the relative size of food particles has a significant role in the efficient operation of food chains for planktonic organisms as well. It may be that it is sometimes ecologically more efficient to insert an additional trophic step in some types of production systems to avoid too large a size discrepancy between prey and predator.

R. J. Conover, S. A. Poulet

Biochemistry and Physiological Ecology of Zooplankton Nutrition

Previous studies on respiration and nitrogen excretion carried out on several species of starved Mediterranean zooplankton showed different patterns of behaviour which seemed to be a function mainly of the rate of the biomass turn-over of the species studied. Analysis of the O/N atomic ratio obtained under such nutritional conditions showed them to be relatively low compared with those obtained by other authors; an hypothesis was formulated that alterations in the pattern of amino-acid metabolism (such as gluconeogenesis) occurred.

To test this assumption experiments on the existence and the activity of Glucose-6-phosphatase (key enzyme for the gluconeogenesis pathway) on two major species of copepods (Calanus finmarchicus and Acartia clausi) are being performed. The low level of activity (1 /15th of the activity of mammalian liver) recorded for Calanus even after one week of starvation supported the argument that regulation of the carbohydrate level is unnecessary in the short term (~ two weeks). Glucose-6-phosphatase from Acartia shows a slightly higher activity, though of the same order of magnitude. Experiments to study the variations of this activity with the duration of starvation are under way. Further studies on the grazing, and the respiration and the nitrogen excretion, together with a survey of the variations of the content of the main biochemical fractions will lead to a better knowledge of the physiological basis of the nutritional pattern of these two species. Attempts are being made to relate the CHN elementary spectrum to the biochemical composition of the plankton in an effort to improve our understanding of the assimilation efficiency and the energy transfer at this ecological level.

P. Mayzaud

St. Margaret's Bay Zooplankton and Ichthyoplankton

Variability in zooplankton samples taken on two fixed stations in St. Margaret's Bay was studied over a time period of 26 hours. Preliminary results showed a periodic change in the biomass and numbers of copepods of five different species that correlated with the tidal cycle. This same periodicity was not present in the number of fish larvae, cladocera or *Sagitta elegans* eggs. These components of the samples appeared to vary randomly with time. The biomass and numbers of *Sagitta elegans* showed a regular fluctuation that was 180 degrees out of phase with the cycle of copepod numbers. The analysis of data is still in progress and will be completed by the end of 1972.

D. D. Sameoto

Gulf of St. Lawrence Euphausiid Study

In June of 1972 a study was started using high frequency sonar (120 kHz) with the ultimate purpose of determining the biomass and production of the three major species of euphausiids in the Gulf; also to find areas of concentration of the animals and determine if the densities are sufficiently high to warrant commercial exploitation.

Preliminary results showed that high concentrations of the euphausiids *Thysanoessa inermis* and *T. rashii* and *Meganyctiphanes norvegica* occurred along the south shore of the Gaspe from Cap des Rosiers to Gros-Morne and between Pointe Ste. Anne and Les Mechins and near Pointe des Monts. Lighter concentrations were found in the centre of the Gaspe Passage near the western tip of Anticosti Island and the Gaspe Peninsula.

The layers of euphausiids rose to the surface during the hours of darkness and were concentrated in the top 20 metres of water during the early hours of the morning. Samples taken in the scattering layers confirmed they were euphausiids. It was possible to make rough estimates of the densities of the animals in the layers from the zooplankton samples. The maximum density found from the samples was 0.72 grams wet weight per cubic metre. This sample was not taken in the most dense scattering layer, therefore the densities in other layers may be much greater than this value.

The fact that the euphausiids concentrated near the surface during the night opens up the possibility of harvesting them commercially. The results of the preliminary study are reported in FRB Technical Report No. 350. This work will continue during 1973.

The Food Chain Leading to Lobsters

Lobsters feed on a wide range of invertebrates, taking whatever is available in greatest abundance. In the seaweed zone of St. Margaret's Bay, the most abundant invertebrate food is the sea urchin, Strongylocentrotus. It occurs throughout the zone, from the intertidal to a depth of about 20 metres, but is unevenly distributed. In the areas of high density large seaweeds are absent and experiments and observations show that the seaweeds are removed by the grazing of the sea urchins. When the sea urchins are removed the seaweeds recolonize the area. There is strong circumstantial evidence for the view that lobster predation is a key factor controlling the abundance of the sea urchins, so that overfishing of lobster stocks leads to a population explosion of the sea urchins, and overgrazing of the seaweed beds. Thus, overfishing of lobsters may lead, through a two-step interaction, to removal of the basic plant growth on which the whole production system depends. In St. Margaret's Bay this effect is confined to a mosaic of patches; if the effect were more widespread serious degradation of coastal production processes could occur.



Lobster feeding on sea urchins.



Sea urchins grazing on seaweed.

Calculations have been made of the total food resources available to lobsters in the seaweed zone of St. Margaret's Bay. It appears that the invertebrate production exceeds the food requirements of an average lobster population by a factor of 10. The excess is presumably removed by crabs, sculpin, etc. It is possible that a scheme for exclusion of competitors and increase in density of lobster populations could lead to intensive, controlled lobster production.

K. H. Mann

Energetics of Sea Urchins

An energy budget was constructed for a population of the sea urchin, *Strongylocentrotus droebachiensis*, in the nearshore area of St. Margaret's Bay, Nova Scotia. Of the six age classes identified ages 1+ and 2+ accounted for about one-half the population energy flow. Population production efficiencies were: production/assimilation = 0.28, production/consumption = 0.04 to 0.13, and production/ biomass = 0.80. Although *Strongylocentrotus* was the dominant herbivore in the seaweed bed it utilized only 1 to 7% of seaweed production. As with other populations of sea urchins, however, it had a proportionately greater influence on seaweed biomass, and also presumably production, by clearing seaweed from large areas of substrate and maintaining it clear. Loss of dissolved organic matter, the only term in the energy budget not measured, was estimated by

subtracting the other terms in the energy budget from consumption. In laboratory animals this ranged from 40-80% of absorption (consumption-faeces). A critical review of energy budgets for six other species of marine benthic grazers also revealed larger amounts of energy unaccounted for that might be attributed to loss of dissolved organic matter. It was demonstrated that *Strongylocentrotus* respiration could have been approximated from the respiration rate at a single temperature, the annual temperature in the sea urchin habitat, and a single Q_{10} of 2.05 derived from a respiration temperature curve representing 14 species of marine poikilotherms.

R. J. Miller

Uptake and Metabolism of Metals by Decapoda

In the decapoda (crustacea) certain metals are considered to be essential for the life process: Ca, Mg, Sr are used in the elaboration of the exoskeleton; Cu is an important component of the respiratory pigment haemocyanin; Fe is a component of most of the molecules involved in the respiratory chain (the cytochromes); Zn is a component of carbonic anhydrase which plays an important role in calcification.

Using the method of atomic absorption spectrophotometry a study was made of the occurrence and changes in distribution of these metals in various organs and tissues during the moult cycle of *Cancer irroratus* and *Carcinus maenas*, collected at Terence Bay, Nova Scotia. Such studies are of importance not only because they enhance our knowledge of the basic metabolism of these metals in crustacea, but also in view of the current interest in the occurrence and dynamics of metals in the marine environment.

Mg, Ca and Sr are concentrated essentially in the carapace. This concentration, which takes place during the post-moult stages, seems to occur after mobilization of the metals in the hepatopancreas and their transport by the haemolymph. The concentration, which is only weak at the beginning of the intermoult, increases abruptly at the intermoult stage. Cu is accumulated in special cells of the hepatopancreas. Zn is present in large quantity in the muscles.

Fe is present in trace quantities only in the haemolymph, but sometimes occurs at levels greater than 1000 ppm (fresh weight) in the gills. The concentration takes place during the intermoult, and the iron is released from the animal along with the old gill during the moult. Like Cu. Fe is accumulated also in special cells of the hepatopancreas.



Iron in a transversal section of the gill of *Cancer irroratus* (decapoda). fe = iron; lb = Branchial lamellae; rb = Branchial raphe.

These findings are of considerable significance since they represent the first observation of such concentrations of Fe in certain tissues of decapoda. The role played by these accumulations of Fe, in the metabolism of the animals, is under investigation.

J.-L. Martin

Studies on the Benthos - Distribution

To design a sampling pattern which will be most efficient in obtaining ecological information it is necessary to know something about the spatial distribution of the organisms under study. Random grab samples from an anchored vessel have shown that marine benthic organisms have a contagious (patchy) distribution. It is also known that the degree of contagiousness of an organism has an effect on its availability as food to a predator.

A program is underway to measure such small scale variation in benthic organisms. For this purpose lines of continuous adjacent benthic samples have been taken using SCUBA. A preliminary survey of 45 continuous samples indicated a need for more data so, during October 1971, a line of 130 adjacent samples was taken. From these, 45 different species of benthic invertebrates were sorted from which seven species of Amphipoda, five species of mollusks and six species of polychaetes provided sufficient data for patch size and distribution measurements. These data will also be used in productivity studies of the dominant species.

D. Peer

Environmental Oceanography



Staff of MEL engaged in physical oceanographic studies, together with a rather larger complement of similarly occupied staff of AOL, form the Coastal Oceanography Division of the Institute. The portion of this Division's activities particularly relevant to the AOL responsibilities are reported elsewhere in this review. The summaries contained herein are those that are especially pertinent to the MEL objectives and responsibilities.

R. W. Trites

Coastal Embayments

The importance of estuaries and coastal embayments to the production of renewable living resources both in the nearshore area as well as over much of the Continental Shelf is becoming increasingly recognized. Since physical environmental conditions play a vital role in determining the productive capacity in the sea, it is mandatory to achieve a working understanding of these processes and the factors involved.

From the recent field programs in St. Margaret's Bay, Halifax Inlet, and Chedabucto Bay, it has been possible to develop a better understanding of the dynamics of the coastal zone of the Atlantic coast of Nova Scotia. The observed circulation, induced by changing atmospheric conditions, has been analyzed. In summer and fall when the bays have essentially a two-layered vertical density distribution, quasi-periodic changes in wind and atmospheric disturbances produce a quasi-periodic flow which is out of phase between layers. Correlation between the observed flow and atmospheric parameters together with results from a simple one-dimensional two-layered model indicate that the observed flow is produced primarily by direct wind forcing rather than by a response to forcing at the entrance of the bays.

The energy associated with the classical two-layered estuarine circulation has been analyzed. This energy has then been compared to the energy available from external sources, e.g. tides, wind, solar heating. It is hoped that this type of approach will provide useful information for the classification of estuaries.

R. A. Heath, R. W. Trites

Diffusion Studies

During a recent period of absence from MEL, a detailed study of turbulent diffusion was undertaken under divers conditions and at various locations in the Irish Sea. A fluorescent tracer dye was employed to observe the diffusion rates in a plume formed by a continuous fixed-point source in the near surface layers. Although a high degree of variability was present in the observed concentration distributions, a computer analysis was devised which extracted lateral and vertical eddy diffusivities as functions of the diffusion time for each release. These diffusion rates were representative of the mean conditions during each experiment and variations in the diffusivities proved to be significantly correlated with the prevailing environmental conditions. Of particular importance to the diffusion rates in the surface layer were the wind speed and the mean current speed. The vertical eddy diffusivity in the surface layer appeared to be proportional to a nondimensional function involving the wind speed, the vertical water column stability and the vertical current shear.



On-board fluorometer used in diffusion studies.

The experience gained in this study will be used to critically review some of the earlier dye dispersion studies performed in the Margaree and Pictou areas. It is hoped that further quantitative evidence of the dependence of the diffusion rates on the measurable environmental parameters will be found. The acquisition of an in *situ* fluorometer will permit the fluorescent tracer technique to be extended to subsurface releases. Initially the method will be used to follow the trajectory of deep water masses but it is anticipated that the observations will produce data on the diffusion rates as a function of the depth.

D. Krauel

Mesoscale Inhomogeneities

In 1964 a program was initiated to investigate the oceanographic variability in the southern Gulf of St. Lawrence. The discovery of an intense 'gyre' approximately 20 km in diameter, which traversed the survey area over a ten-day period, stimulated a series of cruises in 1965, 1968, 1969 and 1970. Although gyres have been detected on a number of these cruises, frequently they have been recognized only after the cruise has been completed and data analyzed. Improved measurement and analysis tools were required if their frequency of occurrence, stability, and duration were to be established.

In July 1972, the newly developed *Batfish* was used operationally in the area between Cape Breton Island and Prince Edward Island to acquire detailed spatial temperature-salinity data. This instrument, which is towed from the ship and undulates continuously over a controllable depth range, was fitted with STD sensors. Thus, the technical capability of acquiring the needed data has been achieved. The instrument stood up to expectation, but the absence of a computer onboard capable of processing and presenting the data sufficiently rapidly meant that full utilization of the *Batfish* results as an aid to follow what appears as gyres was not attained. From preliminary analysis of the data at BIO, at least one gyre was encountered. It is expected that computer programs will be available shortly to allow the gyre phenomenon to be more thoroughly investigated.

E. M. Hassan, R. W. Trites

The surface circulation in the Gulf of St. Lawrence is the result of a number of driving forces. The relevant importance of the wind-driven currents compared with the thermohaline circulation remains largely unknown. Development of a numerical model using wind stress as the forcing function is currently under development.

E. M. Hassan

Remote Sensing

Studies are presently underway to evaluate remote sensing techniques (aerial photography, radiometry, scanning, etc.) with regards to the measurement of oceanographic parameters in the coastal regions. Aerial photography (multispectral) and infrared imagery obtained from the Canada Centre for Remote Sensing and gathered over the St. Lawrence Estuary are forming a basis for initial studies. It is hoped that these may be used to accurately map the distribution of temperature and currents on the sea surface for this region.

P. E. Vandall, Jr.

Geochemistry of the Major Elements in Marine Sediments from the Gulf of St. Lawrence

Major element analyses have been made on glacial marine sediments (240) from the Gulf of St. Lawrence. The total major element data indicate that Si, Al, Ti, K, Na, Mg, Ca and to a lesser extent Fe and Mn have entered the depositional basin structurally combined in detrital silicate and carbonate minerals. Within the Gulf, Si varies between 21.0 and 42.3%, Al between 1.7 and 9%. Ti between 0.07 and 0.76%. K between 0.54 and 3.15%, Na between 0.56 and 2.8%, Mg between 0.14 and 3.52%, Fe between 0.61 and 5.72%. Ca between 0.20 and 25.2%, and Mn between 0.07 and 0.27% with sediment texture and location. These textural and regional variations in major element concentrations are mainly determined by the nature, abundance, grain size, and provenance of the host minerals of these elements.

Chemical partition of the major elements into their detrital and nondetrital contributions reveals that most of the major elements accumulate at the same rate as detrital sedimentary material and that small but significant quantities of some elements enter in true solution and are incorporated into the sediments in a variety of ways such as precipitation, sorption onto suspended matter, and extraction by living organisms in response to present physico-chemical conditions in the Gulf.

D. H. Loring

Distribution of *Clostridium botulinurn* Type E in Marine Sediments from the Gulf of St. Lawrence

Analysis of 390 sediment samples from the estuary of the St. Lawrence River and the Gulf showed C. *botulinurn* type E to be present in high incidence in some areas while it appeared to be absent from others. In the St. Lawrence estuary C. *botulinurn* was found in fine-grained sediments from the lower estuary but not from the upper estuary. In the Laurentian trough a few scattered samples contained C. *botulinurn*. In the southern Gulf the highest incidence was found in fine-grained sediments from the Chaleur Bay trough, the Shediac trough, and in Northumberland Strait. The distribution of C. *botulinurn* was found to be closely related to the present sedimentary environments in the Gulf. It appears to be supplied in suspension along other fine-grained detrital material from the adjacent land areas and is deposited in response to the present current and circulation patterns in the Gulf.

R. A. Laycock, D. H. Loring

Fisheries Oceanography and Population Studies



Fish of the Gulf of St. Lawrence

An unabridged bibliography of fish of the Gulf of St. Lawrence was compiled containing over 800 published and manuscript references. The listing and species index is available as FRB Technical Report No. 261. The information is accessible on computer tapes for special listing and for updating.

V. M. Srivastava

Larval and Postlarval Studies

Rearing Larval Marine Fish. Facilities were designed and built to enable marine fish with either pelagic or demersal eggs to be hatched and their early larval stages reared under controlled temperature and light conditions. Cultures of phytoplankton, oyster larvae and brine shrimp were maintained; the two latter cultures together with wild zooplankton being used as live food for the larval fish. Barnacles, horse mussels and blue mussels were collected but these wild stocks matured too late to provide young at the time required for food for the larval fish. Ripe herring gonads were brought in from the Magdalen Islands and the eggs artifically fertilized in the hatchery. The fertilized eggs, adhering to ground glass plates, were kept in running, filtered seawater in darkness until the herring larvae hatched. The larvae were then reared for four weeks under a 12-hour dark and light cycle. They provided material from which mean length, dry weight and stage of development could be determined at known ages. The study demonstrated the feasibility of rearing marine fish larvae under our laboratory conditions and techniques and enabled us to specify our requirements for food cultures, equipment, and staff if we were to embark on a program of rearing for various production and environmental quality study applications.

V. M. Srivastava

Feeding Ecology of Postlarval Fish. One critical state in the development of young fish occurs when the food supply in the yolk sac is completely absorbed; thereafter both growth and survival become dependent to a great extent on the availability of suitable planktonic food.

To clarify some of these relations a study was undertaken to (1) determine the influence of food size on the foraging success of postlarval fish, and (2) to correlate their ability to handle various sized

particles with the abundance and size composition of zooplankton in the Gulf of St. Lawrence. To date, feeding experiments have provided information on the acceptable range of food size; and, for purposes of field comparisons, the size composition of Gulf zooplankton were monitored at weekly intervals throughout the summer of 1972.

The analysis has yet to be completed, but nonetheless it is clear that the capture success of young fish decreases rapidly with increasing food size. For example, the strike success (number of prey captured per number of attacks) of 2 cm winter flounder averaged about 90% throughout the 100-micron prey size range, 30% in the 351-micron range, and fell to 0% in the 1000-micron range. From this and related information on foraging it should be possible to estimate the feeding potential available to planktophages, such as young flounder, from the dynamics of natural plankton populations.

D. M. Ware, C. Newcombe

Energetics of American Plaice

Laboratory Feeding Studies. Ultimate prediction of the growth of fish in nature requires information on the size of the daily ration and the expenditure of energy for metabolism under different environmental conditions. To acquire some of these statistics for a species of commercial importance, individual American plaice were allowed to feed *ad libitum* in a controlled environment offering constant food densities. The resulting feeding rates and activity of 14 animals were monitored continuously for 30 to 50 days. After each experiment an energy budget was constructed to identify the portion of the ration allocated to growth, activity, standard metabolism and SDA (Specific Dynamic Action (cost of food processing)). In order to balance the budget SDA was calculated by difference, and over the range in food concentrations examined accounted for 35% of the ration.

Under poor feeding conditions (0.28 gm food m⁻²) plaice restricted their activity to periods of darkness, swam a distance of approximately 0.1 km (at a cost of about 0.34 kilocalories), and consumed a ration equivalent to 0.0003% of the body weight (0.39 kilocalories). With increasing food concentrations swimming was distributed more evenly throughout the day, and the ration increased until it reached an asymptote of 2.2% of the body weight. Over all food levels, the expenditure of energy for activity was found to be slightly less than proportional to the daily food intake.

Maintenance for animals averaging 180 gm wet weight required 1 kilocalorie per day at 6°C. But beyond this point both growth and growth efficiency (gross) climbed to respective maxima of 0.88 kilocalories per day and 0.28 at the highest rations recorded (3.1 kilocalories). These observations illustrate that whenever the cost of total metabolism is proportional to rations, as might be the case for relatively quiescent species, growth rates can be limited simply by the rate of food processing.

D. M. Ware

St. Margaret's Bay Population. The seasonal pattern of production processes in the American plaice population of St. Margaret's Bay was analyzed with a computer model of the population's energy transfer and conversion processes. Estimates were derived for seasonal and annual energy flows of the population in its present unexploited state and in states that might be attained as a result of fishing.

Net annual production of the Bay population is approximately 2.3 kcal m^{-2} . The production/biomass ratio for the population, including larvae, is 0.4 and the ecological efficiency (production/ingestion) is 17%. When larvae, whose annual production amounts to 0.5 kcal m^{-2} , are excluded the above ration and efficiency figures become 0.3 and 12% respectively. Larvae and 0+ fish together account for 20% of population ingestion and 34% of net production while their biomass amounts to 4% of the total. Gonad production constitutes 8.5% of total population production and 13% of production by fish aged 1 and up.

Production by the population during summer months (i.e. gross production) is approximately twice the annual net production. Winter metabolic requirements amount to 49% of gross production; the quantity remaining is divided between net body production (44%) and gonad production (7%). Summer metabolism accounts for 80% of total annual metabolism and winter metabolism for 20%; aside from the fact that the summer feeding period is 1.4 times the overwintering period, the main factor contributing to the relatively high summer metabolism is the heat released during food processing.

Fishing yields were studied using the model for equilibrium states assuming that population response mechanisms have a capacity to maintain ingestion at its pre-exploitation value. For an intensive fishing situation a yield of 0.3 kcal m^{-2} is estimated if no population response occurs whereas yields of 0.6 and 1.1 kcal m^{-2} are predicted when growth rate and density increases, respectively, take place.

J. C. MacKinnon

Mackerel Biology Study

The bulk of the northern population of Atlantic mackerel enters the Gulf of St. Lawrence in late spring or early summer. Spawning takes place immediately over large areas of the southwestern shallows, larger fish spawning earliest. Pelagic eggs and larvae drift with the current. Young juveniles are found inshore in abundance, during August, where they feed on larger plankton and small fish. During July, August and September adults predominately filter feed on small plankton (less than 500 microns); at most other times of the year they are predominately particulate feeders using larger individual prey organisms (greater than 2 mm).

B. S. Muir

Growth and Productivity. Estimates of abundance and growth rates for the Northern population of the Atlantic mackerel, *Scomber scombrus*, have been used to derive yearly production estimates. These estimates suggest that while the biomass has remained relatively constant, the productivity and P/B ratio have fluctuated an order of magnitude. This fluctuation is a result of unequal recruitment and the domination of the stock by two year classes.

K. T. MacKay

Filter Feeding. The effective pore size of the gill raker filter in Atlantic mackerel is of the order of 200 X 400 microns. Analysis of stomach contents from the Gulf of St. Lawrence in July and August showed that the fraction between 850 and 500 microns made up between 12 and 49%. the 300 micron fraction between 12 and 32% and the 150 micron fraction between 5 and 31%. In the laboratory, mackerel increase swimming speed and rate of turning in the presence of patches of plankton and plankton odor and the lowest concentration at which they filter feed is about three times the average concentration in the Gulf of St. Lawrence. A 350-gram mackerel can filter 1500 litres or more of water per hour but at average concentrations it would require about 15 hours of filtering to obtain a daily ration. These observations lead to the conclusion that mackerel can detect and remain in local concentrations of zooplankton in a patchy natural environment.

B. S. Muir, C. P. Newcombe



Atlantic mackerel filter feeding on zooplankton in laboratory tanks.

Feeding Model. A theoretical model has been developed to deal with a schooling fish searching for patches of prey. The model is being applied to mackerel feeding in the Gulf of St. Lawrence and used to test the hypothesis that small scale patchiness of prey influences the growth and feeding of the predator plus the size and shape of predator aggregations.

K. T. MacKay

Metabolism and Digestion. Mackerel must swim continuously for hydrostatic equilibrium and for respiration; for a 325-gram mackerel the basal swimming speed at 13-14°C is about 25 cm s⁻¹. Oxygen consumption for a non-fed fish (325 grams) under these conditions is 44 mg O_2 hr⁻¹ (150 cal hr⁻¹)

Following a meal of 40 grams of frozen mackerel flesh (12% of the body weight) oxygen consumption increased and the elevation lasted for 80 hours (13-14 C). The total increase, over 80 hours, amounts to 338 calories per gram of food. This represents a loss of energy (termed calorigenic effect or SDA) of 27% of the food intake. Mackerel exhibit a very high assimilation efficiency; when fed fresh whole silversides, they retained 98.8% of the calories and lost only 1.2% in the faeces.

Under these conditions, gross growth efficiency would be 34%. However, routine metabolism will certainly be higher than the 44 mg O_2 hr⁻¹ measured above so the gross efficiency under natural conditions would be less.

T. C. Lambert, B. S. Muir

Hydrodynamics. The minimum swimming speeds observed for Atlantic mackerel in laboratory tanks are consistent with those calculated using hydrodynamic lift principles and are slower than for most other scombroids at a comparable size. Adaptations which minimize the speed required for hydrostatic equilibrium would be, energy conserving. Of the several variables affecting minimum swimming speed, fat content is the most important and has important implications for over-wintering when food is scarce; a 5% difference in total fat content will result in a 20% difference in energy utilization. Analysis of drag components for a 317-gram fish suggests that at a cruising speed of 35 cm s⁻¹ swimming accounts for about 17% of the total metabolism. Theoretical analysis of drag at different speeds suggests that the cost of swimming increases as the square of the swimming speed as proposed by other workers.

K. T. MacKay

Southern Fish Species in St. Margaret's Bay and Prospect Bay

Continued monitoring of captures of rarely reported southern species in the St. Margaret's Bay and Prospect Bay areas since 1968 has shown the regular occurrence of southern strays from August to October, the period of maximum surface temperatures. The most notable records are: the blackwing flying fish, *Hirundichthys rondeleti*, a tropical species previously reported only from the Florida Keys; the bulleye, *Cookeolus boops*, and bigeye, *Priacanthus arenatus*, both previously reported no further north than Cape May, New Jersey; and the great amberjack, *Seriola dumerili*, not previously reported north of Cape Cod. The monitoring has shown also a regular incursion of white mullet larvae into Prospect Bay during the summer where they remain until the onset of cold weather. The Atlantic menhaden, *Brevoortia tyrannus*, which was first reported in 1968 has increased in numbers and commercial sized catches have been reported since 1970.

K. T. MacKay

Metabolism and Enzyme Activity in Fishes

Studies on the relationships between various environmental and biological parameters and the regulation of a number of physiological factors in certain fishes have been continued for the duration of the period covered by this report.

Blood Studies. The effects of change of season on the levels of a number of hematological parameters in the American plaice (*Hippoglossoides platessoides*) of St. Margaret's Bay have been followed for three years. Hematocrit, concentration of serum proteins and hemoglobin, cell number, mean cell volume and surface area, hemoglobin/cell and hemoglobin/cell surface area all show increases beginning about May, reaching maximum levels in late July thence declining to winter levels. Photoperiod appears to be the most significant environmental parameter in this regard.

The relationship between fish size and various blood parameters have also been determined. All parameters studied exhibit a direct relation to fish weight.

Males have higher values of all parameters than do females of the same size.

Ration, growth and metabolism have all been shown to be directly
related to those blood parameters studied in Tilapia, sculpins, and winter flounder.

Comparative studies have also been carried out on the blood of a number of local marine fishes.

Enzyme Studies. Seasonal variations have been observed in the activities of enzymes involved in the regulation of glycolysis and gluconeogenesis in the American plaice. Pyruvate kinase, a glycolytic control enzyme, exhibits low activity in the winter followed by increasing activity in the summer. Glucose-6-phosphatase, a gluconeogenic control enzyme, shows the reverse seasonal cycle. Data on lactic dehydrogenase, a bifunctional enzyme, are not yet complete.

Glucose-6-phosphatase and pyruvate kinase both are reciprocally related to the logarithm of the weight of the fish.

Rations, growth, and metabolism are directly related to pyruvate kinase activities in Tilapia liver but reciprocally related to glucose-6-phosphatase activities.

A limited comparative study on the relative levels of pyruvate kinase and lactate dehydrogenase in heart, liver, and skeletal muscle of several species is incomplete but indicates some interesting variations in the functional relationships of these tissues in different fish.

J. C. Smith

Marine Mammal Energetics

Cetacean Metabolism. Attempts to estimate the energy budget of large whales are frustrated by the impracticalities of working on live specimens, their little understood heat exchange systems, and their size which is unequalled by terrestrial mammals. Suggested metabolic rates have ranged from one higher than human to one less than a sloth.

An approach which shows encouraging results is a comparison of oil yields (from commercial fisheries), for whales of similar sizes, before and after known periods of intensive feeding. The oil gain is the energy store for whales migrating from the Antarctic/Arctic area of high seasonal production to the thermally conservative tropics.

Using this energy 'ration', supplemented with the known reduced feeding in warmer waters, estimates can be made of standard metabolism. With this as a base, and considering the variation in body size between populations, an estimate of their impact on zooplankton and commercial fishing can be made.

Hydrodynamic Model. A plastic replica of a baleen (filter feeding) whale's head and feeding apparatus has been constructed and will be tank-tested with the following objectives in mind: (1) to study the feeding mechanism of baleen whales and its similarity to filter-feeding fish, and (2) to study an evolved, large scale, filtering mechanism with the possibility of applying some of its principles to man-made plankton sampling devices.

P. F. Brodie

Marine Bio-Acoustics

Active sonar has become increasingly useful for studies of the biological content 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 echolocation, where 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.

Cetacean Bio-Acoustics. In consideration of zooplankton echolocation it was noted that the large baleen whales must locate and consume tons of zooplankton each day. In May 1969 hypotheses were developed regarding the existence and nature of echolocation sonar from these whales. Obviously, if the signals existed their properties might be useful to aid in the design of man-made sonar. Of particular interest would be the variation of sonar signals between whales that preferred different zooplankton prey species.

Sonar from the baleen whales has now been recorded a number of times; acoustic characteristics are very different from the well known dolphin and porpoise sonar. Variation between species is strong. The study of this biological sonar has progressed in three independent ways: (a) recordings at sea, (b) transmitter studies, and (c) receiver (ear) studies.

Successful recordings were made on a three-month cruise in the Gulf of St. Lawrence during the summer of 1972. Three species, Fin, Humpback and Minke were encountered. The use of a sailing vessel was found to be advantageous.



Humpback whale encountered in the Gulf of St. Lawrence during the summer of 1972.



Humpback whale encountered in the Gulf of St. Lawrence during the summer of 1972.

The exact location of the acoustic transmitter is unknown but the physiology of the upper jaw of Fin, Humpback and Sei whales has been studied in an attempt to understand acoustic focussing mechanisms of the animals. It has become apparent that in baleen whales acoustic transmission is very unlike that of dolphins and porpoises; these whales may have evolved an extremely highly focussed sonar beam, hence the considerable difficulty in recording the sound pulses at sea.

Acoustic receivers, the middle ear bones, have been studied in the laboratory. The acoustics of these bones show relationships to the acoustic parameters of the recorded sonar. Physiological studies have been carried out in cooperation with E. D. Mitchell of the Fisheries Research Board, Arctic Biological Station, Ste. Anne de Bellevue, Quebec, and D. D. Prentiss of the Nova Scotia Research Foundation, Dartmouth, Nova Scotia.

P. Beamish

Acoustic Echo Counting System for Demersal Fishes

To date, the computerized Echo Counting System has been developed and tested for reliability on Cod, Haddock, and Redfish with satisfactory results on both the Scotian Shelf and Gulf of St. Lawrence.



Acoustic fish counting system. Retrieval of 4% foot deadweight towed body containing 50 kHz downward-looking transducer and acoustic baffles.



Acoustic fish counting system. On-board data processing.

A Honeywell 316 computer containing high speed multiply and divide, teletype, high speed paper tape reader and punch, 8 K-word memory and special interface between the echo sounder and computer has been obtained to eventually phase out the hardwired data acquisition counting system.

Programs have been developed for use with this computer in a real-time mode to process the raw count data to a density per unit volume (1000 m³) in four size groups. The processed data are presented on a teletype in table form at the time interval specified with time of day, depth of water, densities in four size ranges and two layers. Parameters such as layer thickness and distance from bottom, beam angles and time intervals are entered by the operator at the beginning of a sequence of runs. An additional program, used during fishing operations, estimates the total numbers, total weights, average density and percent of each size group for the tow.

A PEC read-write magnetic tape recorder has been added to the system to store every echo from the transducer to the bottom for every transmission. This will be the beginning of a data bank for acoustic surveys carried out on both the Gulf of St. Lawrence and Scotian Shelf areas.

Using the computerized counting system six cruises were carried out during the last two years, two during 1971 and four during 1972. During March 1971 the *E. E. Prince*, equipped with the counting



Fisheries Research Board vessel E. E. Prince.

system, joined 15 National Sea Products ships to compare our estimates with commercial vessels. Estimates within \pm 10-25% of the actual catches of the vessels were obtained.

During 1972 surveys were conducted during March on the Scotian Shelf, July and September in the Gulf of St. Lawrence, and November on the Scotian Shelf. The July and November cruises were conducted to establish preliminary requirements and test theories of optimal survey patterns being developed by the Nova Scotia Research Foundation, under contract. Ten by ten mile detail surveys were carried out in three areas in the Gulf, Chaleur Bay, Orphan Bank, and Gaspe with four diagonal runs in zig-zag fashion, following. It appears the latter is sufficient to survey the ten by ten miles (100 square miles) with a 25% confidence limit. A large area, 40 by 80 nautical miles (3200 square nautical miles), was tested during November using the same zig-zag format. This run format was found suitable for operational surveys because of the ease of navigation. Confidence limits similar to the previous experiments on small areas were obtained. A good estimate of mean densities and 'fishability' of the stocks can be obtained from an area this size with 30 hours of surveying.

R. G. Dowd

High Frequency Acoustic Survey System

Following the basic design philosophy used in developing MEL's acoustic system for counting groundfish, a multichannel, high-frequency, acoustic system for biomass studies of smaller organisms such as euphausiids, shrimp, and small pelagic fish is under development. The system is expected to be capable of giving quantitative information in addition to mapping the distribution of the organisms under study. Parts of the system have been successfully tested on euphausiids in the St. Lawrence estuary and on small pelagic fish in Great Central Lake, Vancouver Island.

S. Paulowich

Bellows Differential Compressimeter

An apparatus has been designed and constructed to measure directly, to 900 bars, the difference between the isothermal compressibilities of two seawater solutions whose compositions differ with respect to the concentration of one of the major salts. The instrument is being used to determine how specific sea salts affect the seawater compressibility. This information will be used to study hydration of ions in seawater. A knowledge of hydration is of fundamental importance in developing any theory for the structure of seawater.

This apparatus consists of three main parts: a pair of closely matched stainless steel bellows which are mounted independently of each other in the same pressure vessel, two electromechanical transducers for sensing the axial compression of the bellows, and a specially designed detector.

In operation one bellows is filled with a reference solution (seawater of salinity 35‰) and the other is filled with a test solution which is the same as the reference solution but it has been doped with an additional amount of any one of the major sea salts. As hydrostatic pressure is applied the bellows compress differentially owing to the difference in their compositions. This differential displacement of the two bellows is measured and the output voltage of the detector is directly related to the difference between the isothermal compressibilities of the test and reference solutions.

I. W. Duedall, S. Paulowich

Continuous Flow Fluorometer

A field test was carried out (June 1972) in the St. Lawrence estuary to study the feasibility of mapping in detail the chlorophyll distribution over a broad geological area by a shipborne technique. For this test a number of modifications were made to the existing system, the major ones being that the pump fairing and depressor were improved allowing operation with the ship working at its maximum cruising speed (11 knots), a new pressure transducer was installed in the pump fairing for continuous depth monitoring and recording, and the data acquisition system was expanded to accept digitized Decca Navigator coordinates.

S. Paulowich

Food Chains and Fish Production

Studies of food-chains in the sea have been undertaken in the course of efforts to predict the potential fisheries yields and to compare them with present yields. Over the past ten years attempts at such prediction have become an increasingly popular exercise. The total range of the resulting estimates for the world's fisheries is high, although most of them cluster about a rather smaller range. However, this apparent agreement tends to obscure small but important differences in the basic data employed.

In attempting to examine the productivity of particular areas, such as the ICNAF area, meaningful or useful estimates require somewhat greater precision than has been tolerated in global estimates. For this reason, basic concepts of trophic efficiencies have been re-examined in the light of recent experimental data and theoretical developments. The results suggest that we have sufficient knowledge of the major mechanisms responsible for observed values of production efficiency to establish criteria useful in describing the natural biological production systems for purposes of prediction.

Recent data on productivity and food relations of North Atlantic fishes have been reviewed. Ironically, many of the heavily fished regions of the Northwest Atlantic are still relatively poorly studied. However, existing data on fisheries together with knowledge of trophic production systems makes possible an evaluation of the usefulness of various kinds of research programs for increasing the quality of yield predictions in the ICNAF region. Of particular importance are critical tests of alternative hypotheses concerning the effects of changes in basic types of fishing effort on sustained yield. Preliminary consideration suggests that 'maximum sustained' yield needs redefinition as a bio-economic criterion of optimum operation.

L. M. Dickie

The European Oyster - Ostrea edulis

Stocks of these oysters held overwinter under natural conditions at the Ellerslie Laboratory suffered a total mortality in the spring run-off. Foundation breeding stocks held in the hatchery supplied with water pumped from greater depths showed good survival. Stocks held on the outer coast of Nova Scotia in an area subject to low salinities in the spring also showed high mortalities.

In the summer of 1971, juveniles for field planting studies were reared in the Ellerslie Hatchery from surviving brood stocks. Again larval and spat survival and growth were good. A light natural spatfall was observed at Ellerslie.



Two-year old European oysters (Ostrea edulis), hatchery reared from quarantined 1969 importation, and grown under natural conditions at the Ellerslie Laboratory on Prince Edward Island.

Exceptional run-off and unusually low salinities in early 1972 caused extensive mortalities in these animals and the bulk of them was moved to the Dartmouth Laboratory and returned to Ellerslie after salinities had stabilized in the spring. An estimated 30% survived, whereas all oysters left at Ellerslie died. Throughout 1972 growth has been excellent and these oysters will be held at a number of sites in the Maritimes in the winter of 1972-73, for assessment of their commercial potential.

R. E. Drinnan

Aquaculture Research and Development - Cape Breton, Nova Scotia

In response to a request from the Cape Breton Development Corporation (DEVCO) and as a complement to their program of development of renewable resource based industries in Cape Breton, a research and development program in marine aquaculture was prepared and has been underway since June 1972. The aim of this is threefold:

(a) To provide a knowledge of the physical, chemical and biological dynamics of the system as a basis for assessing its potential for responsible multispecies aquacultural development, and possible long term effects of other human activities on such an industry;

(b) To carry out research on selected species and associated fauna and flora and to develop and assess relevant technology;

(c) To provide technical advice to participants in the industry and DEVCO technical personnel in a variety of aquacultural and related fields: marketing, processing, etc.

The 1972 program, necessarily limited by time for planning and preparation, included: a network of stations for physical hydrographic parameters; monitoring stations for relevant biological parameters (growth and mortality of molluscan species in suspension, seasonal fouling, growth and survival of salmonid fishes in cages, and growth of Irish moss, a commercial seaweed); a survey of heavy metal distribution in the marine system and tributaries; studies on acclimation to seawater and food conversion of salmonid fishes; compilation of available data on the Cape Breton area; and bibliographic compilations on species of potential interest.

The study has involved a number of federal, provincial, university and private agencies with basic funding supplied by DEVCO and overall planning and coordination by FRB staff.

Results to date include: from hydrographic data and biological monitoring, a far greater geographic area suitable for aquaculture of temperate species than suggested by previous work; fouling identified as a major factor in suspended molluscan culture; promising survival and growth rates in caged salmonids; a successful commercial scale oyster seed production operation by DEVCO technical staff and industry groups; and confirmation of promising potential of the area for year-round holding of high quality oysters for marketing. It is hoped to extend the scope of the program in 1973 to fill some of the obvious gaps and follow up promising leads. Projects presently under consideration include: a survey of the field distribution of known salmonid diseases; a study of natural fish populations and food relationships; extension of biological monitoring to include planktonic productivity parameters; extension of work on marine algae to include other commercially important species and field productivity and distribution observations; and engineering input to the design of commercially applicable cultural support structure.

R. E. Drinnan

Environmental Quality



Analysis of Hydrocarbons in Seawater

Considerable effort has been expended to develop accurate and practical methods for analyzing both dissolved and suspended hydrocarbons in seawater. This project is complicated by the very low concentrations to be measured and the necessity to distinguish between naturally-occurring hydrocarbons and polluting petroleum hydrocarbons. The preferred method for measuring total oil in seawater at this time involves liquid extraction with methylene chloride, removal of methylene chloride by vacuum distillation, taking up of residue in hexane, and analysis of the hexane solution by fluorescence spectrophotometry. The use of ion exchange resins to concentrate oil from seawater, in place of liquid extraction, is presently being evaluated. Procedures have also been developed to separate aliphatic and aromatic hydrocarbons by liquid chromatography, and to determine the principle normal alkanes and some of their isomers by gas chromatography.

P. Keizer

Concentration of Oil in Marine Waters off Eastern Canada

The following surveys have been conducted to determine the concentration of oil in seawater at the following areas off Eastern Canada, with emphasis on understanding regional, temporal and depth variations:

1. Chedabucto Bay: Observations were made in Chedabucto Bay in April 1971, 14 months after the *Arrow* disaster. Concentrations averaged 1.5 μ g l⁻¹, only slightly above natural background, indicating that most if not all of the oil originating from the *Arrow* had been removed from the water column.

2. Halifax Harbour: Observations were made in Halifax Harbour between 10 June and 20 August, 1971. Average oil concentrations ranged from 1.9 to 71.7 μ g Γ^1 at the surface and from 0.8 to 2.8 μ g Γ^1 at 5 metres. The highest concentrations were found in the central portion of the Harbour, especially on the Dartmouth side.

3. Bedford Basin: Observations were made in Bedford Basin during June, July and August, 1972. Concentrations at the surface ranged from 0.4 to 63.6 μ g Γ^1 , and at 10-15 metres they ranged from 0.2 to 30.2 μ g Γ^1 . Oil concentrations, in the seawater just off Bedford Institute of Oceanography, were an order of magnitude higher in the summer of 1972 than in 1971.

4. Halifax-Bermuda Section: Cruises along this section were made in October 1971, and March, July and November 1972. The highest oil concentrations, up to 10 μ g l¹, are found over the Scotian Shelf and in slope water. Concentrations in the Sargasso Sea rarely exceed 3 μ g l¹. No oil is discernible below about 100 metres. There appear to be significant temporal changes in concentration which cannot be explained at this time.

5. Bermuda Hydrostation: Samples were collected every two weeks at an oceanic station 16 miles southeast of Bermuda by staff from the Bermuda Biological Station and sent to us for analysis. There appear to be significant temporal variations in oil concentration, ranging from 1 to 10 μ g Γ^1 . At the moment, these variations cannot be explained. Oil concentrations are definitely higher around Bermuda than in the part of the northwestern Sargasso Sea traversed by our section.

6. Continental Shelf: A sampling program in cooperation with the Eastern Petroleum Operators Association (EPOA) has just been initiated. Member oil companies of EPOA are collecting water samples near all oil exploration platforms operating off eastern Canada and near Sable Island, and sending them to us for analysis. This project will provide information against which the future consequences of petroleum exploitation can be measured.

7. Come By Chance: Water samples have been collected in Come By Chance Bay, Newfoundland, once a month between December 1971 and December 1972 by the Environmental Protection Service (EPS) and sent to us for analysis. The purpose of this project is to obtain data against which the future effects of the refinery, now under construction, can be measured. The concentrations are very low, generally less than 1 μ g Γ^1 , and appear to reflect natural background, which does not appear to change seasonally.

D. Gordon, P. Keizer, J. Dale

Miscibility of Oil in Seawater

Laboratory experiments are being conducted to study the passage of different types of petroleum products (crude, No. 2 fuel, and No. 6 fuel oils) into seawater with the purpose of determining what types, forms, and concentrations of hydrocarbons might be encountered by marine organisms living in a water column contaminated by oil. Analytical observations have been made on both the filterable and filter-passing fractions using fluorescence spectrophotometry, gas chromatography,

elemental analysis, and Coulter counting. Preliminary results indicate that (a) oil concentrations up to 350 μ g l⁻¹ can occur in seawater, (b) most oil entering seawater is in a particulate form, (c) the concentrations of oil appearing in seawater are inversely related to temperature, and (d) most oil particles are smaller than 10 microns.

D. Gordon, P. Keizer, N. Prouse

The Effect of Various Oils on Marine Phytoplankton Photosynthesis

Procedures have been devised to assess the effect of oil-contaminated seawater on the photosynthetic rate of natural populations of marine phytoplankton, as measured using the radiocarbon method. The results from Bedford Basin indicate that low concentrations of refined oils significantly inhibit photosynthesis, while low concentrations of crude oil appear to have a stimulatory effect. This stimulatory effect of crude oil has also been observed in samples collected on the Scotian Shelf. In deep ocean water, however, low concentrations of crude oil inhibit planktonic photosynthesis.

D. Gordon, N. Prouse

The Concentration of Total Mercury in Seawater

The concentration of total mercury in seawater has been measured along the Halifax to Bermuda section. All analytical work has been done on board ship. Concentrations are very uniform with both distance from the coast and depth, averaging 0.2 μ g Γ^1 . Geochemical calculations indicate that most of this mercury is natural in origin and suggest that the high mercury concentrations observed in pelagic fish do not represent pollution.

D. Gordon, D. Buckley (AGC)

Distribution of Dissolved and Particulate Organic Matter in Seawater

A great quantity of pollutants entering marine waters are organic in nature. Before we can study their effects and rates of accumulation, it is imperative that we understand the distribution and expected variation of naturally occurring organic matter in the sea. With this purpose in mind, the concentrations of both dissolved and particulate organic carbon and nitrogen are being measured four times a year at five stations along the Halifax-Bermuda section. A part of this project has been the development of a new method for measuring dissolved organic carbon and nitrogen. Seawater is acidified with phosphoric acid, frozen and freeze-dried, and the resultant salt is analyzed in a commercial elemental analyzer. Plans are underway to begin a sampling program that will enable us to construct a carbon budget for Bedford Basin.

D. Gordon, N. Prouse

Pesticide Studies

Investigation of the factors governing transfer and accumulation of pesticides and related contaminants in aquatic ecosystems continues. The program objective is to provide predictive understanding of the relevant processes, in the form of useful mathematical models of contaminant behaviour in natural systems. Several studies related to this general objective are, listed below:

1. A review of the literature pertaining to pesticide accumulation by aquatic invertebrates has been prepared in the form of a book chapter now in press. The study has identified the relevant transfer processes, and provides a simple compartmental model of residue accumulation that serves as a basis for further development.

S. R. Kerr, W. P. Vass

2. Notwithstanding the substantial advances made in the areas of the toxicity and sublethal properties of compounds such as DDT, we still lack a vital understanding of the major processes controlling the uptake and clearance rates of pesticides from aquatic organisms. To this end, studies were undertaken to determine if the clearance of labelled DDT-C¹⁴ by the common intertidal gastropod, *Littorina littorea*, was coupled directly with metabolism.

As expected the loss of DDT by ten blocks of different sized snails held at two temperatures (5,16°C) was directly proportional to the internal pesticide load. At constant temperature, clearance rates (b) were inversely related to body size, and approximately 65% of the variation in b can be attributed solely to the parallel decline in metabolic rate per unit weight of the larger snails.



DDT uptake tests on snails.

Related studies are now in process to distinguish whether the uptake of DDT by snails exposed to different temperatures and concentrations of radioisotope is more closely related to metabolism or external surface area. Once this process has been modelled adequately, we plan to expand the analysis to include uptake of pesticides from contaminated food.

D. M. Ware, S. R. Kerr

3. Further elaboration of mathematical models of pesticide transfer has been done, and the results are now being prepared for publication. The transfer and accumulation processes have proven to be exceedingly complex, depending in part upon the affinity of the contaminants for various living and non-living substrates, and upon various physiological properties of the affected organisms.

S. R. Kerr

In addition, assistance with pesticide regulation was provided to the Environmental Protection Service, in the form of a two-month secondment of a scientist, together with additional part-time assistance. This contribution ended in 1971 with the preparation of a confidential report recommending Department of the Environment practices for pesticide regulation.

S. R. Kerr

Organochlorine Residues in Seals

Blubber samples from harp seals taken near the Saguenay River in the Gulf of St. Lawrence were analyzed for DDT metabolites, PCB, dieldrin. The concentration of total DDT and metabolites (ZDDT) ranged from 3.1-22.6 ppm, PCB (as Aroclor^(R), 1254) from 2.4-22.2 ppm, and dieldrin from 0.1-0.3 ppm of blubber. Residue levels tended to be higher in older animals.

R. F. Addison, S. R. Kerr

DDT Transport and Metabolism

The transport and disposition of DDT in the skate (*Raja radiata*) has been studied. Following intravenous administration, DDT was deposited in fatty tissue, principally liver. Metabolic clearance rate from blood was approximately 150-200 ml/hr. Metabolism of DDT was not detected, even over prolonged periods. After five weeks, approximately 80% of the administered dose could be recovered from the fish, indicating that excretion from the animal was slow.

R. F. Addison, D. C. Darrow



Extracting test specimen from anaesthetized skate during studies of DDT transport and metabolism.

PCB Studies

Polychlorinated biphenyls (PCB) and terphenyls have wide industrial applications, on account of their chemical stability. This stability also accounts for their persistence in the environment and since 1970 a study of the distribution and biological significance of these materials has been under way in this laboratory.

The major components of Aroclor^(R) 1221, a polychlorinated biphenyl mixture, have been tentatively identified as the following (weight % composition of each component is given in parentheses): Biphenyl (12.7). 2-chlorobiphenyl (28.4), 4-chlorobiphenyl (18.7), 2,2'-dichlorobiphenyl (12.5), 2,4'-dichlorobiphenyl (13.6). and 4,4'-dichlorobiphenyl (6.2).

Studies on the ability of marine organisms to metabolize and transport PCB components are underway. Trout and skate can metabolize biphenyl to its 4-hydroxy derivative; small amounts of 2-hydroxybiphenyl are also formed. In the course of this work, a procedure for the analysis of 4-hydroxybiphenyl by electron capture gas chromatography of its chloroacetate has been developed.

The transport of 2-, 3-, and 4-chlorobiphenyl in the skate has been studied. Following intravenous administration, the 2- and 4-isomers are deposited in fatty tissue (liver) but the 3-isomer appears to be either preferentially metabolized or excreted.

An analytical procedure for Aroclor 5460, a chlorinated terphenyl, was developed. Cod fed Aroclor 5460 deposited this material in various tissues. Absorptive and excretory efficiency seemed poor. Some selectivity in adsorption, deposition or excretion of Aroclor 5460 was observed.

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

Gulf Plankton Studies: PCB Contamination

Throughout June to September, 1972, surface plankton samples (# 20 net) were taken weekly at a station approximately six miles northeast of Alberton, Prince Edward Island (Gulf of St. Lawrence). The objectives of this study were twofold: (1) to identify the degree of DDT and PCB contamination of plankters ranging from 73 to 2000 microns in diameter, and (2) to assess the temporal variation in organochlorine levels.

Little can be said at this time regarding the second objective, since all the samples have not been analyzed. Nevertheless in view of the data now available there is evidence of an inverse relation between particle size and PCB (matched to Aroclor 1254) tissue concentrations. On a wet weight basis, small plankters (73 to 102 microns diameter) contained in the order of 7 ppm PCB, whereas larger plankters (760 to 1050 microns) contained about 0.10 to 0.08 ppm. Although some of our observed concentrations appear to be higher than other reported values, analyses of the sampling gear and collection vessel (paint and bilge) virtually ruled out the possibility of inadvertent contamination during collection.

To date we have encountered only trace amounts of DDT and its derivatives.

D. M. Ware, R. F. Addison

Phosphorus Studies

Involvement of FRB laboratories in the analytical program arising from the elemental phosphorus (P_{el}) pollution problem in Long Harbour, Newfoundland, terminated in spring of 1971. By this time, P_{el} levels in water from various sampling points in Long Harbour were generally below detectable limits (less than 1 ppb). This was in contrast to the situation in mid-1969 (at the beginning of the program) when P_{el} concentrations of up to several hundred ppb were observed in some locations. Analysis of bottom deposits from a heavily polluted area in Long Harbour showed that P_{el} concentrations had not been appreciably reduced during the previous 18 months, but as most of the soft overburden from this part of the harbour bottom had been removed during dredging operations, the total amount of residual P_{el} was probably much reduced. P_{el} was not found in two samples of herring taken from Long Harbour and adjacent areas in May 1971 and reputed to have been poisoned by P_{el} .

Laboratory studies showed that aqueous suspensions of P_{el} oxidized to phosphate. No intermediate oxidation states of P (hypophosphite or phosphite) were detected by thin layer or gas-liquid chromatographic procedures.

R. F. Addison

Hydroxamic Acids

Derivatives of n-alkyl hydroxamic acids (RCONHOH) have been proposed as ore flotation agents. These compounds have been shown to be acutely toxic to trout and salmon fry. In a study of variation of toxicity with chain length ($R = CH_3$ to $C_{17}H_{35}$), maximum toxicity was observed in intermediate chain length compounds ($R=C_8H_{17}$, C_9H_{19}).

R. F. Addison

Mine Waste Water Surveys

Waste waters from the northeastern New Brunswick mining industry were examined for residues of xanthate, dithiophosphate, and isopropylethylthionocarbamate process reagents. Xanthates were not detected in waste waters, and dithiophosphate and isopropylethylthion-ocarbamate were detected only in some samples, and then only at low concentrations (*ca.* 1 ppm).

A new method for the estimation of isopropylethylthionocarbamate by electron capture gas chromatography was developed.

R. F. Addison

Pelagic and Benthic Carbon Budgets

Organic enrichment of aquatic ecosystems, whether as sewage or toxic chemicals, alters pathways of energy flow through both pelagic and bottom communities. The effects may be temporary and reversible or long-lasting, depending upon the material, its rate of addition, and the subsequent biological and physical processes of removal.

Carbon pathways and rates of exchange may be used to describe the fate of organic matter added to various aquatic systems. Processes of organic matter addition are being compared with losses from the water column at the mud-water interface in an attempt to construct an annual carbon budget for Bedford Basin. Results from this enclosed coastal estuary influenced by urban development will be compared with a similar study in St. Margaret's Bay, a relatively unenriched estuary with open exchange to the ocean. Both areas have been studied intensively from a physical, chemical and biological point of view during the last few years. The present study integrates and builds on much of this previous work.



Carbon flow through aquatic pelagic and benthic communities.

Preliminary results indicate that, in deep-water systems with stratification in the surface layers, over 65% of the carbon supply is respired by pelagic communities. The proportion of the remaining carbon supply which reaches the sediment surface is inversely related to depth. In open ocean environments, over 90% of the carbon produced by primary production is lost, presumably as CO_2 , in the upper 250 metres. Pelagic communities thus appear to serve as effective barriers to the loss of carbon to the sediment surface.

Measurement of total organic matter, carbon, nitrogen and organochloride residues are being made in samples of sedimenting detritus and surface sediment from Bedford Basin in an attempt to quantify the vertical partitioning and pathways of decomposition of organic matter in the water column.

B. Hargrave

Substrate-Surface Area Interactions

Measurements of oxygen consumption by mud-sediment suspensions, sand grains, pebbles and rock surfaces have been compared on the basis

of organic content and surface area. The method offers a simple and standardized procedure for indexing microbial community respiratory processes and provides a dynamic measure of bacterial activity.

There is a positive correlation between organic content and oxygen uptake, but all surfaces consume oxygen at remarkably similar rates when expressed on a surface area basis. The adsorption and subsequent fate of a simple organic compound (glucose) and an organo-chloride pesticide (DDT) are being followed using oxygen uptake and radiochemical methods. Mud, detritus particles, and rocks are being used to test the idea that metabolism of adsorbed material may be controlled by surface dependent reactions.

B. Hargrave, G. Phillips

Sublethal Effects of Pollutants

Behavioral traits, such as crawling, and physiological indices, such as respiration, may be sensitive measures of sublethal effects of pollutants on organisms. Crawling and respiration rates of the snail *Littorina littorea* are increased in the presence of Bunker C oil and decreased with brief exposure to a low toxicity dispersant (Corexit 8666) in sea water at 20 C. The addition of the dispersant to an oil-sea water mixture also decreases crawling and respiration.

B. Hargrave, C. Newcombe

Appendix C-1 Major Publications and Reports by MEL Staff, 1971/72

Bedford Institute of Oceanography Contributions

Publications indicated by an asterisk are joint papers with AOL and/or AGC; they are repeated in the corresponding lists for AOL and/or AGC.

ACKMAN, R. G., HINGLEY, J., and MACKAY, K. T. 1972. Dimethyl sulfide as an odor component in Nova Scotia fall mackerel. J. Fish. Res. Bd. Can., 29: 1085-1088 (BIO Contribution 332).

ADDISON, R. F., FLETCHER, G. L., and DOANE, J. 1972. Analysis of a chlorinated terphenyl (Aroclor 5460) and its deposition in tissues of cod (*Gadus morhua*). Bull. Env. Contam. Toxicol., 8: 52-60 (BIO Contribution 318).

ADDISON, R. F., ZINCK, M. E., and ACKMAN, R. G. 1972. Residues of organochlorine pesticides and polychlorinated biphenyls in some commercially produced Canadian marine oils. J. Fish. Res. Bd. Can., 29: 349-355 (BIO Contribution 288).

BEAMISH, P. C. 1971. Quantitative measurements of acoustic scattering from zooplanktonic organisms. *Deep-Sea Res., 18:* 811-822 (BIO Contribution 312).

BEAMISH, P. C., and **MITCHELL, E.** 1971. Ultrasonic sounds recorded in the presence of a blue whale *Balaenoptera musculus*. *Deep-Sea Res., 18: 803-809* (BIO Contribution 235).

CONOVER, R. J. 1971. Some relations between zooplankton and bunker C oil in Chedabucto Bay following the wreck of the tanker Arrow. *J. Fish. Res. Bd, Can.,* 28: 1327-1330 (BIO Contribution 256).

CONOVER, R. J., and **LALLI, C. M.** 1972. Feeding and growth in *Clione limacina*, a pteropod mollusc. *J. Exp. Marine Biol. Ecol, 9*: 279-302 (BIO Contribution 345).

COOTE, A. R., DUEDALL, I. W., and HILTZ, R. S. 1971. Automatic analysis at sea. In: Advances in automated analysis 2, Industrial Analysis. Proceedings of Technicon International Congress on Automation in Analytical Chemistry, New York, November 1970. Thurman Associates: 347-351 (BIO Contribution 217).*

DICKIE, L. M. 1972. Food chains and fish production. In: International Commission for the Northwest Atlantic Fisheries Special Publication No. 8. Proceedings of a Symposium on Environmental Conditions in the Northwest Atlantic, 1960-1969, Dartmouth, Nova Scotia, Canada, 1971: 201-221 (BIO Contribution 285).

DICKIE L. M. 1972. On relations between fishing and long-term yield. In: *Economic aspects of fish production. Proceedings of International Symposium on Fisheries Economics,* Paris, France, 1971. OECD, Paris: 105-125 (BIO Contribution 336).

DUEDALL, I. W. 1972. The partial molal volume of calcium carbonate in sea water. *Geochim. Cosmochim. Acta,* 36: 729-734 (BIO Contribution 314)*.

DUEDALL, I. W., and BUCKLEY, D. E. 1971. Calcium carbonate monohydrate in seawater. *Nature*, 234: 39-40 (BIO Contribution 263).*

DUEDALL, I. W., and COOTE, A. R. 1972. Oxygen distribution in the South Atlantic. J. Geophys. Res., 77: 496-498 (BIO Contribution 267).*

DUEDALL, I. W., and COOTE, A. R. 1972. Oxygen distribution in the Pacific Ocean. J. Geophys. Res., 77: 2201-2203 (BIO Contribution 287).*

DUEDALL, I. W., COOTE, A. R., KNOX, D. F., and CONNOLLY, G. F. 1971. A dispenser for Winkler's dissolved oxygen reagents. *J. Fish. Res. Bd Can., 28:* 1815-1816 (BIO Contribution 275).*

FLETCHER, G. L., and ADDISON, R. F. 1972. Some aspects of the chemistry and acute toxicity of the iron ore flotation agent dimethyl ammonium alkyl hydroxamate and some related compounds to brook trout. *Bull. Env. Contam. Toxicol.*, 7: 147-159 (BIO Contribution 337). GORDON, D. C., JR., and MICHALIK, P. A. 1971. Concentration of bunker C fuel oil in the waters of Chedabucto Bay, April 1971. J. Fish. Res. Bd. Can., 28: 1912-1914 (BIO Contribution 277).

HOBBIE, J. E., HOLM-HANSEN, O.. PACKARD, T. T., POMEROY. L. R.. SHELDON R. W., THOMAS, J.P., and WIEBE, W. J. 1972. A study distribution of the activity of microorganisms in ocean water. *Limnol. Oceanogr.*, 17: 544-655 (BIO Contribution 338).

HUGHES, R. N., and THOMAS, M. L. H. 1971. Classification and ordination of benthic samples from Bedeque Bay, an estuary in Prince Edward Island, Canada. *Marine Biol.*, 10: 227-235 (BIO Contribution 264).

HUGHES, R. N., and THOMAS, M. L. H. 1971. The classification and ordination of shallow-water benthic samples from Prince Edward Island, Canada. J. Exp. Marine Biol. Ecol., 7: 1-39 (BIO Contribution 229).

HUGHES, R. N., PEER, D. L., and MANN, K. H. 1972. Use of multivariate analysis to identify functional components of the benthos in St. Margaret's Bay, Nova Scotia. *Limnol. Oceanogr.*, 17: 111-121 (BIO Contribution 295).

KERR, S. R. 1971. Analysis of laboratory experiments on growth efficiency of fishes. J. Fish. Res. Bd, Can., 28: 801-808 (BIO Contribution 241).

KERR, S. R. 1971. Prediction of fish growth efficiency in nature. J. Fish. Res. Bd. Can., 28: 809-814 (BIO Contribution 242).

KERR, S. R. 1971. A simulation model of lake trout growth. J. Fish. Res. Bd. Can., 28: 815-819 (BIO Contribution 243).

LAYCOCK, R. A., and LORING, D. H. 1972. Distribution of *Clostridium* botulinum type E in the Gulf of St. Lawrence in relation to the physical environment. *Can. J. Microbiol.*, 78: 763-773 (BIO Contribution 313).

MACKAY, K. T. 1972. Further records of the stromateoid fish *Centrolophos niger* from the Northwestern Atlantic with comments on body proportions and behavior. *Copeia:* 185-187 (BIO Contribution 282).

MANN, K. H. 1971. Relation between stipe length, environment, and the taxonomic characters of *Laminaria*. J. Fish. Res. Bd. Can., 28: 778-780 (BIO Contribution 237).

MANN, K. H. 1972. Case history: The River Thames. In: River Ecology and Man, Proceedings of an International Symposium on River Ecology and the Impact of Man. Eds. R. T. Oglesby, C. A. Carlson and J. A. McCann. Academic Press, New York: 215-232 (BIO Contribution 251).

MANN, K. H. 1972. Ecological energetics of the seaweed zone in a marine bay on the Atlantic Coast of Canada. I. Zonation and biomass of seaweeds. *Marine Biol.*, 12: 1-10 (BIO Contribution 249).

MANN, K. H. 1972. Ecological energetics of the seaweed zone in a marine bay on the Atlantic Coast of Canada. II. Productivity of the seaweeds. *Mar. Biol., 14:* 199-209 (BIO Contribution 294).

MANN, K. H. 1972. The analysis of aquatic ecosystems. In: Essays in *Hydrobiology*. Eds. R. B. Clark and R. J. Wooton. University Press, Exeter, England: 1-14 (BIO Contribution 339).

MANN, K. H., and BREEN, P. A. 1972. The relation between lobster abundance, sea urchins, and kelp beds. J. Fish. Res. Bd. Can., 29: 603-609 (BIO Contribution 290).

MILLER, R. J., MANN, K. H., and SCARRATT, D. J. 1971. Production potential of a seaweed-lobster community in Eastern Canada. J. Fish. Res. Bd. Can., 28: 1733-1738 (BIO Contribution 272).

MUIR, B. S., and BROWN, C. E. 1971. Effects of blood pathway on the blood-pressure drop in fish gills, with special reference to tunas. *J. Fish. Res. Bd. Can.*, 28: 947-955 (BIO Contribution 250).

MUIR, B. S., and NIIMI, A. J. 1972. Oxygen consumption of the euryhaline fish aholehole (*Kuhlia sandvicensis*) with reference to salinity, swimming and food consumption. J. Fish. Res. Bd. Can., 29: 67-77 (BIO Contribution 340).

PEER, D. L. 1972. Effects of kraft mill effluent on a marine benthic community. *Water, Air and Soil Pollution, 1:* 359-364 (BIO Contribution 321).

PLATT, T., CONOVER, R. J., LOUCKS, R. H., MANN, K. H., PEER, D. L., PRAKASH, A., and SAMEOTO, D. D. 1970. Study of a eutrophicated marine basin. FAO Technical conference on marine pollution and its effects on living resources and fishing, Rome, Italy, Paper FIR: MP/70/E-30: 10 pp. (BIO Contribution 219)^{*}.

PLATT, T., and **CONOVER, R. J.** 1971. Variability and its effect on the 24h chlorophyll budget of a small marine basin. *Marine Biol., 10: 52-65* (BIO Contribution 231).

PLATT, T. 1972. Local phytoplankton abundance and turbulence. *Deep-Sea Res.*, 79: 183-187 (BIO Contribution 274).

PLATT, T., PRAKASH, A., and IRWIN, B. 1972. Phytoplankton nutrients and flushing of inlets on the coast of Nova Scotia. *Naturaliste can., 99: 253-261* (BIO Contribution 347).

PRAKASH, A. 1971. Terrigenous organic matter and coastal phytoplankton fertility. In: *Fertility of the Sea, 2. Proceedings of an International Symposium on the Fertility of the Sea,* Sao Paulo, Brazil, December 1969. Ed. J. D. Costlow. Gordon & Breach: 351-368 (BIO Contribution 244).

RASHID, M. A., and **PRAKASH, A.** 1972. Chemical characteristics of humic compounds isolated from some decomposed marine algae. *J. Fish. Res. Bd. Can.*, 29: 55-60 (BIO Contribution 280)*

SAMEOTO, D. D. 1971. Life history, ecological production, and an empirical mathematical model of the population of *Sagitta elegans* in St. Margaret's Bay, Nova Scotia. J. Fish. Res. Bd. Can., 28: 971-985 (BIO Contribution 245).

SAMEOTO, D. D. 1972. Distribution of herring (*Clupea harengus*) larvae along the southern coast of Nova Scotia with observations on their growth and condition factor. *J. Fish. Res. Bd. Can.*, 29: 507-515 (BIO Contribution 311).

SAMEOTO, D. D. 1972. Yearly respiration rate and estimated energy budget for Sagitta elegans. J. Fish. Res. Bd. Can., 29: 987-996 (BIO Contribution 323).

SHELDON, R. W. 1972. Size separation of marine seston by membrane and glass fibre filters. *Limnol. Oceanogr.* 17: 494-498 (BIO Contribution 333).

SHELDON, R. W., and KERR, S. R. 1972. The population density of monsters in Loch Ness. *Limnol. Oceanogr.*, 17: 796-798 (BIO Contribution 326).

SHELDON, R. W., PRAKASH, A., and SUTCLIFFE, W. H., JR. 1972. The size distribution of suspended particulate matter in the ocean. *Limnol. Oceanogr.*, 77: 327-340 (BIO Contribution 334).

SUTCLIFFE, W. H., JR., SHELDON, R. W., PRAKASH, A., and GORDON, D. C., JR. 1971. Relations between wind speed, Langmuir circulation and particle concentration in the ocean. *Deep-Sea Res.*, 18: 639-643 (BIO Contribution 234).

SUTCLIFFE, W. H., JR. 1972 Some relations of land drainage, nutrients, particulate material, and fish catch in two Eastern Canadian Bays. J. Fish. Res. Bd. Can., 29: 357-362 (BIO Contribution 289).

SWIFT, D. J. P., SCHUBEL, J. R., and SHELDON, R. W. 1972. Size analysis of fine-grained suspended sediments: a review. J. Sed. Petrology, 42: 122-134 (BIO Contribution 320).

THOMAS, M. L. H., and JELLEY, E. 1972. Benthos trapped leaving the bottom in Bideford River, Prince Edward Island. *J. Fish. Res. Bd. Can., 29:* 1234-1237 (BIO Contribution 341).

WARE, D. M. 1971. Predation by rainbow trout (Salmo gairdneri): the effect of experience. J. Fish. Res. Bd. Can., 28: 1847-1852 (BIO Contribution 335).

WARE, D. M. 1972. Predation by rainbow trout (Salmogairdneri): the influence of hunger, prey density, and prey size. J. Fish. Res. Bd. Can., 29: 1193-1201 (BIO Contribution 331).

WILLIS, D. E., and ADDISON, R. F. 1972. Identification and estimation of the major components of a commercial polychlorinated biphenyl mixture, Aroclor 1221. *J. Fish.* Res. *Bd. Can., 29: 592-595* (BIO Contribution 298).

Fisheries Research Board of Canada Technical Reports

ADDISON, R. F., SCHNARE, L. D., and GORDON, D. C., JR. 1972. Analysis of northeastern New Brunswick mine wastes for xanthate, isopropylethylthionocarbamate (DOW: Z-200), and dithiophosphate (Cyanamid: Sodium Aerofloat). *FRB Tech. Rep, No.* 293.

ADDISON, R. F., ZINCK, M. E., ACKMAN, R. G., CHAMUT, P., and JAMIESON, A. 1972. Results of the elemental phosphorus monitoring program, Long Harbour, Newfoundland. (July 1970 - April 1971). FRB Tech. Rep. No. 303.

FREEMAN K. 1972. The spatial and seasonal distribution of coliforms in Bedford Basin. FRB Tech. Rep, No. 352.

KEYTE, F. K., and TRITES, R. W. 1971. Circulation patterns in Gulf of St. Lawrence: June 1968 and September 1969. FRB Tech. Rep. No. 277.

MICHALIK, PAULA A., and GORDON, D. C., JR. 1971. Concentration and distribution of oil pollutants in Halifax Harbour, 10 June to 20 August 1971. *FRB Tech. Rep. No. 284.*

PLATT, T. 1972. The feasibility of mapping the chlorophyll distribution in the Gulf of St. Lawrence.Part I. Shipborne survey. *FRB Tech. Rep. No.* 332.

PLATT, T., and IRWIN, B. 1971. Phytoplankton production and nutrients. FRB Tech. Rep. No. 247.

PLATT, T., and IRWIN, B. 1972. Mapping the chlorophyll concentration in Bedford Basin, Nova Scotia. FRB Tech. Rep. No. 299.

PLATT, T., and IRWIN, B. 1972. Phytoplankton productivity and nutrients in Petpeswick Inlet, Nova Scotia. FRB Tech. Rep. No. 374.

PLATT, T., and **IRWIN, B.** 1972. Primary productivity and nutrients in St. Margaret's Bay, 1966. FRB Tech. Rep. No. 327.

SAMEOTO, D. D. 1971. The distribution of herring (Clupea harengus L.) larvae along the southern coast of Nova Scotia with some observations on the ecology of herring larvae and the biomass of macrozooplankton on the Scotian Shelf. FRB Tech. Rep. No. 252.

SAMEOTO, D. D. 1971. Macrozooplankton biomass measurements in Bedford Basin., 1969-1971. FRB Tech. Rep. No. 282.

SAMEOTO, D. D. 1972. The feasibility of mapping euphausiid concentrations in the Gulf of St. Lawrence using high frequency sonar. FRB Tech. Rep. No. 350.

SAMEOTO, D. D., and JAROSZYNSKI, L. O. 1972. Macrozooplankton biomass measurements in St. Margaret's Bay, 1967 to 1970. FRB Tech. Rep. No. 333.

SRIVASTAVA, V. M. 1971. Fish of the Gulf of St. Lawrence - an unabridged bibliography. FRB Tech. Rep. No. 261.

D

Atlantic Geoscience Centre Geological Survey of Canada Department of Energy, Mines and Resources 1971/72

Director's Remarks

The events leading to the formation of the Atlantic Geoscience Centre (AGC) are discussed in the foreword to this Biennial Review.

The Atlantic Geoscience Centre is responsible for the scientific description and inventory of that part of the geology and geophysics of Canada which is in the eastern offshore region and contiguous sedimentary basins onshore. This responsibility requires a program of reconnaissance and systematic geological and geophysical mapping and studies of sample cuttings and cores in order to understand the origin and development of the geological framework. In addition, the observation and study of modern geological processes is carried out in order to interpret those processes which operated in the past.

The acquired body of knowledge is analyzed and interpreted to provide:

- an inventory of resources;
- information for rational management of these resources;
- a scientific basis for decisions affecting the offshore regions;

- advice and information to Canadians in all sectors of economic and cultural life;

- a contribution to the world storehouse of knowledge.

The AGC mission is to provide Canada with the information, knowledge and expertise necessary for successful exploitation and effective utilization of the non-living resources of the marine environment. The strategy for this mission requires both long-term and short-term tactical plans.

The short-term program requires an immediate contribution to the national program of energy and mineral resources reserves evaluation. In the offshore region, gas and oil are the important potential resources. In view of the large Canadian continental shelf, and considering estimates that up to 40% of world hydrocarbon production will be from offshore areas by 1985, we have an urgent need to develop techniques and ability to estimate accurately the potential reserves available to Canada.

Exploitation of these resources, as well as other activities of man, impinge on the marine environment, and the Atlantic Geoscience Centre has an important role to play in evaluating probable consequences of such activities. We are again concerned with immediate or short-range problems and frequently have to study a remedial action necessary to restore the already damaged environment. Typical problems are oil pollution of beaches, removal of shore material by erosion and dredging, and the effect of industrial activity on benthic fauna.

Within the long-term program, the aim is to complete a geological description of the history, composition and structure of the eastern Canadian offshore region. The important component of this work is geological mapping wherever continental structures can be extended under sea. The size of the region, over 40 degrees of latitude, requires a judicious use of the reconnaissance approach in order to be able to prepare a generalized description of the area. A number of scientific problems must be solved before systematic mapping can be considered. A fundamental problem is the nature of the boundary between the continental and oceanic crust at the continental margin. We know very little about the continental margins and yet they are a worldwide geological feature of first order importance. There are strong indications that they will be an oil province of the future.

The other component of the long-term program is research and development, both of the methodology and technology necessary for carrying out various projects within the Centre. Modern marine research is dependent on sophisticated instrumentation which rapidly changes with technological advances in electronics. It would be unreasonable to expect significant contributions from marine surveys and research if they were not backed up by advanced instrumentation development.

Both short-term and long-term programs must be supported by administrative and technical services. Some support can be assigned to individual projects but the majority must be in a pool ready to be assigned to different campaigns as required. The support is the backbone of every project. Insufficient and inadequate support represents an unrecognized constraint on every project which in the end sets a limit to our accomplishments.

Program thrusts

The work of the Centre is described in detail in the following pages under the following main headings: Regional Reconnaissance and Mapping; Resource Potential Evaluation; and Environmental Geology.

ATLANTIC GEOSCIENCE CENTRE

DIRECTOR

B. D. Loncarevic

RESEARCH

EASTERN PETROLEUM GEOLOGY B. Sanford

MARINE GEOLOGY B. R. Pelletier

MARINE GEOPHYSICS D. I. Ross

SUPPORT

TECHNICAL SUPPORT K.S. Manchester

EXECUTIVE ASSISTANT TO DIRECTOR T. S. Hillis

Research, Survey and Senior Support Staff

Director and Administration

- B. D. Loncarevic Director
- T. S. Hillis Executive Assistant to Director

Eastern Petroleum Geology

- B. V. Sanford Division Head
- P. Ascoli
- M. S. Barss
- D. F. Clark
- R. D. Howie

Marine Geology

- B. R. Pelletier Division Head
- D. E. Buckley
- R. E. Cranston
- G. B. Fader
- C. A. D. Godden
- A. C. Grant
- I. M. Harris
- L. H. King
- J. D. Leonard
- **Marine Geophysics**
 - D. I. Ross Division Head
 - D. L. Barrett
 - R. T. Haworth
 - D. E. Heffler
 - C. E. Keen
 - R. F. Macnab

B. MacLean

L. F. Jansa I. A. Newman

G. L. Williams

J. Wade

- M. A. Rashid
- C. T. Schafer
- G. Vilks
- F. J. E. Wagner
- D. A. Walker

- K. S. Manchester
- S. P. Srivastava
- K. G. Shih
- W. J. M. van der Linden

E. H. Owens
Regional Reconnaissance and Mapping



Continental Shelf and Margin

A study of the geology on and beneath the sea floor of the Grand Banks is presently under way; the field aspects of a similar study of the Scotian Shelf and Bay of Fundy have been completed and the results are being published as a series of surficial and sub-Pleistocene geological maps.

Three surficial geology maps of the Scotian Shelf have been released which complete coverage in this area; similar maps are in preparation for the Bay of Fundy and approaches. These maps are printed in colour at a scale of 1:300,000 and are accompanied by papers describing the stratigraphic succession and geologic history of the Quaternary map-units. They are of value to fishermen, oil companies, various engineering construction groups, mining engineers, cable companies, environmental scientists, and others.

The bedrock or sub-Pleistocene studies contribute to our knowledge and understanding of the surface and subsurface geology, geologic history, and broad tectonic setting of the Mesozoic-Cenozoic section on the Scotian Shelf. The studies also aid in the economic evaluation of the region. A geological map of the Scotian Shelf and adjacent areas on a 1:1,000,000 scale is in the final stages of preparation; this will be accompanied by a departmental publication.

Investigations on the Grand Banks during the 1972 field season consisted of one 5-week cruise on the CSS *Dawson*. Attention was directed mainly to the western part of the Grand Banks: across the Laurentian Channel, and St. Pierre, Green, and Whale Banks. The cruise was designed primarily to obtain seismic, gravity, and magnetic coverage of the area and will be followed in 1973 by a bedrock and bottom sampling cruise; 1150 miles of seismic reflection profiling, and 3300 miles of gravity and magnetic profiling were completed.

The main scientific objectives of the Grand Banks program are:

- to obtain a better understanding of Appalachian geology between Nova Scotia and Newfoundland.

- to extend our knowledge of Appalachian geology seaward beneath the submerged Atlantic Coastal Plain Province in the Grand Banks area,

- to obtain information on the broad structural framework of the area,

- to map the surficial geology of the area, and

- to map the sub-Pleistocene bedrock geology of the area.

Preliminary results suggest that Carboniferous strata are continuous from Cape Breton to within a few miles of the south coast of Newfoundland. The Mesozoic and Cenozoic coastal plain units onlap the Carboniferous and older basement rocks which flank the Avalon and Burin Peninsulas.

L. H. King, B. MacLean, G. Fader, H. Josenhans

A geophysical investigation of the Laurentian Channel and Southern Grand Banks of Newfoundland was undertaken during a 1972 cruise on the CSS *Dawson*. Gravity and magnetic field data were collected (in addition to the shallow seismic reflection data collected by L. H. King and associates) on a series of lines, totaling 8141 km, extending from the western edge of the Laurentian Channel to the Avalon Peninsula between the Newfoundland coast and the continental slope.

The most prominent feature of the entire survey was a 1500-gamma positive magnetic anomaly coincident with a 70 mgal positive free air gravity anomaly in the centre of Whale Bank. There is an indication that the anomaly is elongated in a WNW-ESE direction although, if this is the case, there is a very abrupt termination in the vicinity of Whale Deep to the east. All lines to the east of this termination showed little magnetic activity although gravity anomalies remained conspicuous.

At the western edge of the survey area, the tracks were planned to trace the eastern extension of the Orpheus gravity anomaly. It appears that the two 'claw'-like limbs of the anomaly in the Laurentian Channel extend over to St. Pierre Bank where the 'claws' converge and the anomaly reduces in magnitude. The anomaly does not seem to die out as it reaches the eastern wall of the Laurentian Channel as was earlier thought. Coincident with the northern limb of the gravity anomaly in the Channel is a positive magnetic anomaly whose high frequency characteristics die out while crossing the Channel, and whose extension across the Channel is less pronounced.

The 1972 data have been compiled with all other data previously collected in this region preparatory to detailed model studies to be carried out in 1973. In trial runs with the gravity modelling program it is clear that very low density rocks at shallow depth are responsible for the isolated gravity lows which fall within the eastern portion of the Orpheus anomaly.



Outline of the Orpheus gravity anomaly according to data collected in 1964 and 1972.

R. T. Haworth

An interpretation of gravity data from the Gulf of St. Lawrence east of the Magdalen Islands (Watts, A. B. 1972. *Can J. Earth Sci., 9:* 1504-1528) suggests that the series of isolated negative gravity anomalies is caused by salt bodies. The area is described by Watts as one of the largest salt provinces in eastern Canada.

The gravity data used by Watts is part of that collected by the Canadian Hydrographic Service in conjunction with the Atlantic Geoscience Centre (AGC) on marine surveys covering the eastern half of the Gulf of St. Lawrence. This data has been compiled for the complete survey area and is now available in the form of Natural Resource Charts at a scale of 1:250,000 from the Canadian Hydrographic Service in Ottawa.

R. T. Haworth

A reconnaissance bottom-sampling, seismic profiling and sonar sidescanning survey was carried out in an area immediately northeast of Belle Isle, Newfoundland. Using a newly designed electric rock core drill (for description, see subsection on Rock Core Drills in the AOL Metrology report, Part B of this volume) a total of 25.4 metres of core was drilled at eight drill sites, and a total of 5.2 metres of core was recovered. Approximately 25 percent of the drilling was in bedrock and 75 percent in unconsolidated overburden. Concurrent seismic profiling and sonar side-scanning established the general nature of the substrate along a crisscrossing survey track of approximately 150 km, thereby providing a basis for selecting the drill sites. A BOLT air-gun fitted with a one cubic inch firing chamber was employed as the seismic energy source. A Defence Research Establishment Atlantic (DREA) design *Moby* fish, containing a side-scan transducer, was the acoustic source employed in side-scanning.

The preliminary findings of the survey are as follows: seismically 'hard' rocks with lithologies comparable to Lower Paleozoic and Late Precambrian rocks on Belle Isle and nearby Newfoundland and Labrador extend at least 40 km northeast of Belle Isle. Gently folded rocks with good seismic penetration occur beneath a till mantle of variable thickness to the east of Belle Isle. Previous seismic records obtained by the Bedford Institute of Oceanography indicate that rocks of this general type underlie an area of roughly 1300 km² and pass beneath relatively undeformed Mesozoic and Cenozoic rocks to the northeast. The side-scan sonar records reveal numerous linear features on the sea floor, apparently caused by the grounding of icebergs (see illustration in subsection on Applications of Underwater Sound in the AOL Metrology report, Part B of this volume).

I. M. Harris

Reconnaissance geophysical coverage of the western margin of the Labrador Sea was completed from Hudson Strait to Davis Strait in 1971. In contrast to the inner shelf off Labrador to the south, where relatively undeformed coastal plain-type deposits abut crystalline Precambrian rocks, the inner shelf off southern Baffin Island is underlain by an erosional surface cut on folded sedimentary strata. Based on previous geophysical and geological investigations in Ungava Bay-Hudson Strait these folded strata on the southern Baffin shelf are tentatively identified as lower Paleozoic in age. These rocks appear to have undergone faulting during deposition of the overlying coastal plain sediments, which in turn have been structurally disturbed by the early Tertiary volcanic episode that affected the Davis Strait region.

Geophysical coverage of the Labrador Sea region is now adequate to define areas of interest for detailed surveys and sites for collection of vital stratigraphic data. Much of this information will be obtained through industrial exploration for petroleum, particularly the stratigraphy of the Mesozoic-Cenozoic coastal plain-type deposits. The logical thrust to complement these resource-oriented surveys lies in



Labrador Sea

defining the regional setting of the coastal plain deposits in terms of the history of interaction between their continental and oceanic basement. The central problem is that of tracing the evolution of the Labrador Sea by processes of sea floor spreading. The immediately critical areas for further geophysical investigation are the central Labrador Sea, including Davis Strait to the north, and the region of Orphan Knoll and Flemish Cap. Selective refraction surveys may assist in locating the continent/ ocean boundary off northern Labrador. Potential sites for recovery 'of valuable stratigraphic information, using in-house capabilities (dredge and underwater rock core drill), have been defined on Flemish Cap, in Flemish Pass, on the inner shelf east and northeast of Newfoundland and off central Labrador, and on the inner shelf off southern Baffin Island.

A. C. Grant

The Labrador Sea Project (LSP), as broadly defined at present, involves a five-year plan integrating geological and geophysical activities to delineate the structural framework of the Labrador Sea, trace its geological history and evaluate its resource potential. Compilation of available potential field data, gravity and magnetics, is being undertaken; much of this data was made available on a free exchange basis, predominantly by foreign marine earth scientific institutions. Several thousand miles of seismic reflection lines over the shelf and shallow parts of the continental slope have been purchased from geophysical exploration and processing contractors and are being analyzed. This information complements approximately 3000 miles of high frequency reflection data already surveyed by A. C. Grant since 1965, between the Strait of Belle Isle and Cape Chidley.

From September 28 to October *29, 1972,* the CSS *Hudson* undertook a multi-disciplinary survey in the Labrador Sea, combining hydrographic and geophysical operations. This year for the first time seismic reflection shooting was incorporated in the exercise. Some 5000 miles of track was covered, producing potential field information at a 10-mile line spacing in an area off Hamilton inlet, between 52° and 54°N. Every other line (i.e. at 20-mile intervals) was sailed at half speed, about 6 knots, to enable reflection profiling. Using a 1000-inch gun, about 1300 miles of record was obtained over the continental margin and the deep basin area. With penetrations of up to 2 seconds, the upper structure of continental slope and rise could be defined. In the deeper regions penetration limits up to 3 seconds were set by oceanic basement arrivals (layer *2*). An extension of the survey to site 112 of the Deep Sea Drilling Project provided stratigraphic control for the upper 664 metres of deep basin sediment.



Tracing of 1000 inch-gun reflection profile over the continental margin off southern Labrador.

The CNAV Sackville occupied bottom gravimeter stations over the shelf off Hamilton Inlet (an Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, project) prior to the *Hudson's* Labrador Sea exercise. This provided ground control for the surface gravimeters aboard the *Hudson*. At the same time bottom-grab samples were taken over Hamilton Bank, which will help delineate the sediment variability in the Bank area. Other bottom samples, gathered on an opportunity basis, were collected off Saglek from the CSS *Dawson* by Memorial University, St. John's, Newfoundland.

The continental margin off Labrador is underlain by gently seawarddipping Mesozoic-Cenozoic coastal plain deposits, similar to the coastal sequences along the Atlantic seaboard from Florida northward. Because of differential glacial erosion during the Pleistocene, these sediments are separated by a deep marginal trough from predominantly plutonic Precambrian Labrador rocks. A veneer of varying thickness of Recent predominantly glacial drift sediments and moraines covers the shelf, obscuring the pre-glacial history of the Labrador continental margin.

High frequency magnetic anomalies are restricted to the inner shelf of Labrador and contrast sharply with the relatively smooth fields over the shelf off northeast Newfoundland, the Labrador Shelf Banks, and the deep basin anomalies. Towards the central part of the Labrador Basin these anomalies appear to align, parallel to the Basin axis, providing control for the spreading history of the Labrador Sea. In the central Basin, too, the oceanic basement shoals to within a few thousand feet below the sea bottom and in places crops out as isolated seamounts and/or ridges.

From the *Hudson* survey it appears that some trends in the gravity field align NE-SW, which is in the direction of northeast Newfoundland structure.

W. J. M. van der Linden, A. Jackson

A sedimentological study of the Lower Paleozoic Goldenville Formation is being conducted in an area of well-exposed coastal sections in eastern Nova Scotia. Previous work indicates that the flysch-like Goldenville Formation resembles recent sediment accumulations of the western Atlantic continental slope and rise.

Sedimentary structures generally associated with turbidity current deposition, such as sharply defined lower bedding surfaces, gradational upper bedding surfaces, sole markings, intraformational mudstone inclusions, and laterally continuous bedding, are present in the majority of the sandstone beds and in many of the finer-grained beds that make up the Goldenville Formation. The present study has shown that slump, slide, and exceptional dewatering structures are present in many of the beds. These structures suggest that appreciable sea water was entrapped in the sediment at the time of deposition. Large-scale sedimentary structures, regional relationships, and the sandstone petrography indicate that the Goldenville sediments were ultimately derived from a distant continental land mass.

The typical Goldenville sandstone consists primarily of quartz, sodic feldspar, chlorite, muscovite and epidote. The sodic feldspar and epidote are partly the products of diagenetic alteration from calcic and potassic feldspars and ferro-magnesian minerals. Alterations of this type are characteristically associated with marine sedimentation involving rapid deposition and deep burial. Sea water entrapped in the sediment probably provided the chief source of sodium in the development of the sodic feldspar.

I. M. Harris

Multidisciplinary Surveys

The many features common to both hydrographic and geophysical surveying make possible a very fruitful and economical sharing of resources and facilities for offshore surveys. It was a realization of this that prompted geophysicists at BIO to install their equipment aboard ships conducting hydrographic surveys, thereby capitalizing on an existing program which suited geophysical purposes very well.



Areas and distances covered in joint hydrographic- and geophysical-offshore surveys.

Since its inception in 1964, this combined project has met with considerable success in the field. The accompanying figure indicates both the areas and the distances covered in the course of joint operations. (There are no mileages shown for 1965, when a major ship breakdown forced a cancellation of the project for that year, or for 1970, when the project was temporarily shifted to the western Arctic.) The large mileage jump in 1967 reflects the decision to commit geophysical resources to a total involvement in the project. Complementing the regular hydrographic staff that year, a complete team consisting of at least one professional geophysicist, three equipment watchkeepers, a data processor, and an electronic technician were aboard the ship for the entire field season. In following years, as hydrographic staff became increasingly familiar with the techniques of gravity and magnetic measurements, more and more of the geophysical

functions were absorbed by the Hydrographic Service. Besides leading to considerable economy and efficiency in the use of manpower, this process resulted in the development of sufficient expertise for the Hydrographic Service to assume the major responsibilities associated not only with the mobilization and execution of offshore surveys, but also the processing of geophysical data to the stage where it is ready for publication as Natural Resource Charts. At present, a typical offshore survey team consists almost entirely of hydrographic staff. The exceptions are a geophysical instrument technician, who repairs and maintains the equipment within his area of specialization, and a geophysical consultant, who accompanies the party at the beginning of a survey to ensure that all systems are operating satisfactorily. This consultant is provided by the Atlantic Geoscience Centre on a year-round secondment basis. Besides providing advice in the field he supplies geophysical input for cruise planning and oversees the post-survey processing and analysis of gravity and magnetic data.

In 1971 the CSS *Baffin* spent five months mapping parts of the Grand Banks of Newfoundland and the whole of the Flemish Cap. The survey was designed in part to investigate and compare the nature of the gravity and magnetic fields over these two features, which are separated by the Flemish Pass. By yielding a picture of the deep structure in this area, potential field measurements contribute to a clearer understanding of the relationship between the Grand Banks and the Flemish Cap.

During the same cruise, an investigation determined the feasibility of using Loran C in the two-range mode for the precise positioning control needed. Seismic reflection measurements were also performed on a limited trial basis to evaluate the potential for routine operations.

In 1972 the offshore survey project was divided between two ships and two areas: MV *Minna* was chartered from Karlsen Shipping Co. Ltd. for three months to work the northern edge of the Grand Banks, while the *CSS Hudson* spent a month surveying a portion of the south Labrador Sea.

An important new development in 1972 was this first use of a privately owned ship. The *Minna*, a 2350-ton ice-strengthened freighter, proved to be very well suited to the project and in terms of survey performance compared quite favourably with the *CSS Baffin*. The ship possessed a large amount of hold space which accommodated an office trailer, a computer trailer, a portable laboratory for the gravimeter, and a specially constructed plotting room. The latter space housed all electronic instrumentation and served as the navigation control and operations centre. Routine seismic operations were also introduced in 1972. The survey team on the *Hudson* was augmented by personnel who operated seismic reflection equipment over a number of preselected lines. At present this activity is carried out semi-independently by a small team of specialists. This, however, does present opportunities for training and familiarization of hydrographic staff in the operation of seismic equipment and in the interpretation of results, eventually leading to the point where hydrographers will be able to undertake routine seismic operations on their own.

A new generation of shipboard computers has considerably broadened the scope of our data processing techniques in the field. In the early years, the use of Digital Equipment Corporation Family-of-8 machines permitted shipboard processing for purposes of checking and quality control. This processing was of a preliminary nature only and final reduction had to be done after the cruise on a larger shore-based computer. This inevitably entailed a delay of several months, during which time the results were unavailable for analysis, interpretation, and the production of final maps. At present, however, the situation is undergoing rapid change, due to the phased replacement of our Family-of-8 machines by the HP-2100 computer. This latter system has a larger memory, is capable of handling FORTRAN programs, and is equipped with higher speed input/output devices. It has expanded our shipboard computing power by an order of magnitude and this is reflected in the increased extent and sophistication of our geophysical data processing in the field. Our aim is to carry out complete data reduction in the field; current software production is oriented towards the processing and storage of final results on IBM-compatible magnetic tape. The ultimate goal is to have all processed geophysical data available immediately on completion of a cruise, ready for input into computerized map production or for analysis and interpretation.

Complementing our field activities in 1972 was the negotiation of a contract for the production of draft Natural Resource charts from a very large backlog of gravity and magnetic data. While the bulk of this information had been collected on offshore survey cruises dating back to the first year of the project, most of it remained stored on magnetic tape in digital form. Due to limited manpower resources, no serious in-house effort to produce charts could be contemplated, and it was decided to enlist the aid of a firm specializing in this sort of work. Further details on this particular aspect of the offshore surveys project follow.

R. Macnab

The data collected on all Bedford Institute of Oceanography cruises prior to 1972 in which there has been geophysical participation have been reduced and digital magnetic tapes containing the data in a standard format have been produced. To allow for the expeditious release of this data an industrial contract has been issued to produce draft Natural Resource Charts at a scale of 1:250,000 (in the areas shown) from the 128,000 gravity and 181,000 magnetic field data points



Areas for which Natural Resource Charts are being prepared under contract.

available. (The gravity editions of the areas indicated 'Magnetics only' in the Gulf of St. Lawrence have already been prepared at AGC and are either published or in press.) Since such a contract is unique both with this type of data and to operations of the Atlantic Geoscience Centre, considerable effort was expended in identifying the criteria necessary to define the contractual requirements. All companies considered competent to bid were invited to a bidders conference at which time the tender specifications were discussed. All bidders were required to furnish proof of their competence by completing two trial charts. On the basis of the quality of these and the tender price, a contract has been issued to Computer Data Processors of Calgary as a result of which 72 draft Natural Resource Charts will be completed by January 1973. It is anticipated that these charts will be published by the Canadian Hydrographic Service within a further six months. By the end of September 1972, 26 charts had been submitted to AGC for consideration as final products, and an additional 30 charts had been

produced in some preliminary form.

R. T. Haworth

Deep Sea

Analysis of geophysical data obtained from the CSS Hudson in the Baffin Bay area in 1971 has continued. The seismic refraction data has provided good crustal structural control across the Bay from Baffin Island to Greenland (Keen, C. E., and Barrett, D. L., 1973. Geophys. J. Roy. Astr. Soc., 14). The central oceanic basin consists of 4 km of sediment with seismic velocities varying from 2.1 km s⁻¹ to 4.2 km s⁻¹ underlain by 4 km of oceanic basement giving a total depth of 10 km to the Mohorovicic discontinuity. Mantle velocities of 7.7-8.5 km s⁻¹ were observed. The sediment thickness across the Basin is surprisingly uniform although it increases to 6 km towards the northern continental margin. It is presumed that both layer 2 and layer 3 exist within the oceanic basement although two distinct velocities were not observed on all oceanic lines. The thickness of these layers increases somewhat towards Greenland. This is consistent with the interpretation of gravity data obtained. Bouguer and free-air gravity maps of the area have been prepared which enable the continental/oceanic boundary to be mapped with considerable precision over the majority of the area.

Seismic reflection and refraction data have provided information on a number of basinal features on the adjacent continental shelves. The two largest of these features are the Melville Bay graben off northwest Greenland and the Lancaster Sound graben between Baffin and Devon Islands. Other troughs of significance have been delineated trending northwest-southeast in southern Nares Strait region. The extent of these has not yet been accurately defined but it seems likely that they are tensional features developed as Greenland and Arctic Canada separated during the formation of the oceanic basin.

Cooperative work with the Greenland Geological Survey has enabled the known onshore geology of central West Greenland to be extended offshore in an attempt to explain the major features of the central and northern West Greenland shelf. In particular the Melville Bay graben appears to be a true marginal graben developed during the initial rifting of Canada and Greenland and therefore predates the period of active sea floor spreading in the Bay. Gravity data indicate that the maximum thickness of sediment 10 km) occurs at the southern end of the graben. A maximum sedimentary velocity of 4.6 km s⁻¹ was observed in the central region of the graben. Although the Tertiary basalt



Map of the Baffin Bay area showing in simplified form the geology and bathymetry.

province of Disko Island - Nugssuaq Peninsula has been extended out into the offshore region it is still not clear how it is connected with the basalt province of Cape Dyer and the thick pile of oceanic basalt forming the Davis Strait sill. Additional seismic data in the southern Bay-Davis Strait area is required before the significance of the occurrence of Tertiary basalts can be related to the history of the formation of the Bay. (See also 'Baffin Bay - One piece in the jigsaw puzzle of global tectonics,' by D. I. Ross, in Part A of this review.)

D. I. Ross, C. E. Keen, D. L. Barrett

Detailed interpretation of the geophysical data collected off the west coast of Canada during the HUDSON 70 expedition (Srivastava, S. *P.,et a/.*, 1971. *Can. J. Earth Sci., 8*: 1265-1281) show that the continental margin off Vancouver Island is severely faulted. Compilation and interpretation of gravity data across the margin show that the area west of the margin is in isostatic equilibrium. The thickness of the sediments lying at the foot of the slope off Vancouver Island decreases to the north as obtained from the Bouguer gravity anomaly map of the region. This variation in the thickness of the sediment at the base of the slope has resulted from a change in the direction of motion of various plates in this region as revealed by the change in the tectonic pattern along the margin from south to north and by the characteristics of the magnetic anomalies across the margin (Tiffin, D. L., et *al.*, 1972. *Can. J. Earth Sci., 9:* 280-296; and Chase, R. L., and Tiffin, D. L., 1972. *24th Internatl. Geol. Cong. Section 8. Marine Geology and Geophysics:* 17-27).

The magnetic data collected by the National Ocean Survey group of National Oceanic and Atmospheric Administration, Department of Commerce, Rockville, Maryland, U.S.A., in the northeast Pacific has been interpreted jointly (by D. Elvers, S. P. Srivastava, K. Potter, J. Morley, and D. Seidel). The compilation of magnetic data in the form of profiles shows that a high order of correlation exists among the



Map showing the lineations of various magnetic anomalies (thin broken lines) as obtained from the correlation of profiles plotted along 37 eastwest tracks. The numerals designate anomaly numbers according to the Heirtzler et *al* scheme. Also shown are fracture zones, rises, and faults (thick black lines).

magnetic anomalies in the northeast Pacific. The decrease in the offset of the anomalies to the east along the Surveyor fracture zone and the presence of undisturbed north-south lineations east of it show strong evidence of differential sea-floor spreading in this region. The extension of the Blanco fracture zone has been delineated northwestward to about 113°W. It is suggested that this fracture zone began about 15 million years ago. The undisturbed north-south trend of the magnetic anomalies between latitudes 42°N and 48°N and longitudes 133°W and 136°W is interpreted as the interval (22 to 15 my) during which Juan de Fuca and Gorda rises were one continuous structure. West of 137° the Surveyor, Sedna, and three minor fracture zones were mapped.

S. P. Srivastava

Research and Development

Magnetic data from simultaneous recordings at several places along the Gulf of St. Lawrence (Srivastava, S. P. 1971. *Earth and Planet. Sci. Letters*, 70: 423-429) were used in estimating the errors involved when using magnetic variation data from the Institute to apply diurnal correction to the Gulf of St. Lawrence data. The errors were not found to be significant. Thus a system was set up to apply diurnal correction to the Gulf of St. Lawrence data. The system has been used on a routine basis to apply diurnal correction to the marine magnetic data using the recordings from a nearby shorebased station. The development of such a system has resulted in more reliable magnetic Natural Resource Charts of the Gulf of St. Lawrence.

Field trials of the equipment to monitor the magnetic variations at sea were carried out during a cruise over the continental margin off Nova Scotia. A magnetometer housed in a surface buoy was moored in 4000 metres depth of water at about 41.5°N, 60°W. Due to malfunctioning of the magnetometer, only one and a half days' recording was obtained. This recording is being used in estimating the error involved when using the recording from the Institute to apply diurnal correction to the magnetic data collected beyond the Nova Scotia shelf.

S. P. Srivastava

A PDP-11 computer delivered in April 1972 has been used for development of seismic data processing programs. The system was taken on the *CSS Hudson* in July, mainly to record digitally some seismic data sampled over a wide-band and high dynamic range. A system failure precluded success on that phase. The system remained on the *Hudson* after repair and useful data were acquired in the Labrador

Sea during October.

A core residual monitor system has been developed to provide keyboard control of seismic data processing. An operator may direct the execution of various subroutines and control values of important parameters during real time operation. Data handling routines are available for inputting or outputting analog signals, reading from digital tape, or displaying on the storage cathode ray tube.



A section of a seismic profile displayed on the PDP-11. computer cathode. ray tube and simulating a variable area display seismic record.

Several efficient digital filters have been designed using the BASIC program on the PDP-11 and these have been implemented in Assembler language. A very sharp 60 Hz notch filter as well as a time variable filter are now used. Correlation and simple dereverberation programs have been written and are currently under test.

D. E. Heffler

The data storage and retrieval system GEOFILE is a computerized system of storing and accessing geophysical data. GEOFILE was developed for storing and retrieving data in time order according to cruises. The system includes facilities for storing data, methods for processing and retrieving data, computer programs, index information, and methods for data exchange and dissemination. At present, there are 500,000 km of gravity and magnetic data in the final processed files.

During the past two years, the geographic based data system GEODATABASE and underwater photographic data system have been developed and tested. GEODATABASE is designed to store data in geographic order and to access data from any defined geographic region. The underwater photographic system is used to store the interpretation codes on magnetic tape and to retrieve data for producing statistical information or a geological description of each underwater camera station.

Shipboard data processing techniques using a new HP-21OOA computer were developed and tested to increase the efficiency of the data checking and storage stages in producing the raw data file. The results indicated that much of the computing and manual checking time normally done on return to the Institute can now be done at sea. Thus cruise data can be available within a short period after the ship returns.

K. G. Shih

Resource Potential Evaluation



Basin Analysis

The Basin Analysis group describes and interprets the subsurface geology of the potentially prospective petroleum provinces of eastern Canada. These include the early Paleozoic sedimentary basins that lie in the Central Canadian Shield (Hudson Platform) and extend along its southeastern margin (St. Lawrence Platform), the late Paleozoic basins of the Atlantic provinces, Gulf of St. Lawrence and Bay of Fundy, and the Mesozoic-Tertiary basins that lie along the eastern continental margin.

This group was formed by the Regional and Economic Geology Division of the Geological Survey of Canada (GSC) in January 1971 and was transferred to the Bedford Institute of Oceanography (BIO) in August of the same year. On January 1, 1972, the group was united with Marine Geology and Marine Geophysics sections of the Department of Energy, Mines and Resources at the Bedford Institute of Oceanography to form the Atlantic Geoscience Centre.

A variety of detailed and regional studies are pursued which provide an insight into the geological history of the eastern Canada offshore basins and contiguous onshore areas. Projects utilizing the disciplines of stratigraphy, sedimentology, geochemistry, geophysics and paleon-tology are important components of a basin analysis program directed towards the ultimate objective of assessing the potential oil and gas resources of eastern Canada sedimentary basins.

Much of the scientific data is derived from the analysis and geological interpretation of sample cuttings and cores from wells drilled for oil and gas in eastern Canada. For the most effective use of this data, a cooperative arrangement was established with the Resource Management and Conservation Branch (Department of Energy, Mines and Resources) to combine their offshore well sample collection with the onshore collection which has long been curated at the Geological Survey of Canada in Ottawa. Both collections are now at BIO and are being curated and maintained by the Resource Management and Conservation Branch for the use of BIO, the petroleum industry, and academic institutions.

The arrival at BIO of considerable volumes of sample residues necessitated suitable laboratory procedures to process and analyze the material on an assembly line basis. Consequently, much of the period from August 1971 to January 1972, inclusive, was dedicated to the installation of instruments and equipment in the micropaleontology, palynology and sedimentology laboratories, and in training technicians

to process the sample residues. Near the end of January 1972 the laboratories were operational, and from that date to December 31, 1972, 23 wells, representing some 251,000 feet of drilling were processed. This material is now providing the raw geological data for a number of ongoing projects.

B. V. Sanford

Detailed and regional surface and subsurface geological investigations are being conducted in the Hudson Bay Basin. Prior to the period of the present report helicopter-supported field operations were carried out in the Hudson Bay Lowlands and on the islands (Mansel, Coats and Southampton) in northern Hudson Bay. This work was undertaken in collaboration with other GSC staff. In the summer of 1971 an offshore bedrock and Quaternary mapping project (with C. F. M. Lewis) was carried out in Hudson Bay with the MV Hudson Handler, owned and operated by International Hydrodynamic Ltd. of Vancouver, B.C. Equipment used in the survey included a two-man submersible (Pisces ///), a small portable over-the-side core drill, side-scan sonar, and shallow seismic profiling equipment. As a result of the above onshore-offshore surveys, the distribution of Paleozoic rocks in the Hudson Bay region has been established over the area of some 375,000 square miles. This work has confirmed the presence of a major sedimentary basin beneath Hudson Bay consisting of Ordovician, Silurian, and Devonian rocks with a combined thickness of upwards to 8000 feet. The Silurian and Devonian systems of the Hudson Bay Basin contain a number of sedimentological similarities with rocks of comparable age which are productive of oil and gas in the Michigan Basin. These comparable conditions make the Hudson Bay Basin a major potential petroleum province. Large anticlinal structures in the central part of Hudson Bay also add to the future economic potential of the region.

B. V. Sanford

Regional subsurface stratigraphical investigations were initiated in June 1972 of the Mesozoic and Tertiary rocks of the Atlantic Continental Margin Basins. By means of sample cuttings, cores, mechanical logs, and well history reports, stratigraphic correlation was established in 36 wells drilled on the Scotian Shelf and Grand Banks. These data were integrated with some 8500 miles of marine reflection seismic data to prepare a suite of maps at scales of 1:1,000,000 and 1:2,000,000 illustrating basin fill, isopachous maps of Jurassic and Carboniferous salts, post-salt Jurassic, Cretaceous and Tertiary strata, and structure contours of the basement, Jurassic and Cretaceous. In addition, regional

structure cross-sections have been constructed across the Scotian Shelf and Grand Banks which illustrate the stratigraphic and tectonic relationships between the two regions. The results of these studies indicate the presence of at least two major centres of deposition containing thick Jurassic, Cretaceous and Tertiary sedimentary sequences capable of generating and retaining large volumes of hydrocarbons.

J. A. Wade

Sedimentological and stratigraphical analyses, using data from wells drilled on the Scotian Shelf and Grand Banks, were initiated in August 1971. This investigation was supported by a sedimentology laboratory with a technician to prepare thin sections and acetate peels of cores for petrographic analysis. From the study of mechanical logs, cores and sample cuttings of 33 wells, a suite of maps and cross-sections, in which depositional environments are reconstructed, were prepared demonstrating the thickness, lithology, and sand-shale ratios for the Mesozoic and Tertiary rocks on the Scotian Shelf and Grand Banks. The above study demonstrates a wide range of depositional systems in time and space along the continental margin of Nova Scotia. These vary from desert to alluvial, delta coastal plain, inner-outer shelf, and epibathyal environments. Areas of predominant carbonate, evaporite and sand-stone accumulation were delineated. Several stages of elastic outbuilding by prograding coastal plain and deltas were also established.

The sand-percentage maps in combination with facies and isopachous maps of the various formations delineate the most favourable areas for the future exploration of petroleum and natural gas.

L. F. Jansa

Surface and subsurface stratigraphic studies of the Carboniferous and Permian rocks of the Atlantic provinces have been carried out over a period of several years; this has recently been extended into the offshore regions of the Gulf of St. Lawrence and Bay of Fundy. The studies are based largely on the microscopic examination of samples and cores from wells drilled for oil and gas in various parts of the Maritime provinces and adjacent offshore areas. The investigations to date provide an insight into the stratigraphic and tectonic framework of the Carboniferous basins which in some areas reach thicknesses of 30,000 feet. The presence of diapiric structures beneath the Gulf of St. Lawrence greatly enhance the economic potential of the region as a possible trapping mechanism for petroleum and natural gas. These structures would appear to occur in considerable numbers east of the Magdalen Islands as well as at various onshore localities of the Maritime provinces. Offshore drilling has also provided additional information with respect to the thickness and distribution of coal measures in the Pennsylvanian, particularly east and north of the Magdalen Islands.

R. D. Howie

In May 1972, a project was initiated to curate systematically the subsurface data from wells drilled onshore and in the offshore regions of eastern Canada. An index will be prepared of all pertinent data for each well including formation tops, biostratigraphic zonation, petrographic data, fluid and hydrocarbon recovery, geochemistry and geophysics, etc. This will greatly facilitate the compilation of subsurface data onto maps, charts and cross-sections. Once the material has been indexed it can be readily transposed to a computer system for rapid printout of isopachous, structure contour and facies maps. Although much of the subsurface data for eastern Canada wells can be examined in the offices of Provincial agencies and at the Resource Management and Conservation Branch of the Department of Energy, Mines and Resources at the Institute, this is the first attempt to combine all of the subsurface information of eastern Canada into a single filing system.

I. A. Newman

Micropaleontological studies of the Mesozoic and Tertiary strata of the Atlantic Margin Basins were initiated in August 1971. The studies are biostratigraphical in nature and are based on the identification and zonation of foraminifera and other microscopic organisms recovered from the sample residue of wells drilled for oil and gas on the Scotian Shelf and Grand Banks. The objective of the project is to establish local, regional and worldwide correlation and to reconstruct ecological environments of the Mesozoic and Cenozoic sediments of the Atlantic Margin Basins. It will provide a standard time control to enable other scientific disciplines such as stratigraphy, sedimentology, geophysics and geochemistry to correlate the succession of geological events that took place on the Atlantic Shelf during the Mesozoic and Tertiary periods.

Because of the vast amount of sample residue arriving at BIO from offshore wells, five technicians on temporary professional contract were hired and trained to pick the microfossils from the sediment and mount these on cardboard slides. From January 1971 to December 31, 1972, 23 wells were processed in this manner and this represented some 251,000 feet of offshore drilling. Preliminary interpretation of the



 $\ensuremath{\mathsf{Preparation}}$ of sample residues during the extraction of microfossils from rock samples.

microfossils from 8 wells completed on the Scotian Shelf has resulted in the recognition of at least 17 biostratigraphical units ranging in age from late Middle Jurassic to Pliocene-Pleistocene.

P. Ascoli

Biostratigraphical zonation of the Mesozoic and Cenozoic rocks of the Atlantic Margin Basins based on palynology was initiated in August 1971. Palynology is the study of the microscopic remains of plants including pollen, spores and dinoflagellates, the last named being single-celled organisms. Collectively, these fossils are referred to as palynomorphs. Palynomorphs are abundant in marine and non-marine sediments with concentrations of 1000 specimens per gram being common. They undergo (evolutionary) morphological changes in the geological column which permit the biostratigraphic zonation of sediments. Their abundance and species diversity make them useful for providing age determinations on small rock fragments of the type frequently recovered in the form of sample cuttings from wells drilled on the Atlantic Shelf. The investigator has recently completed a joint study of the palynomorphs present in 104 samples from 8 shallow core



(i) Pollen grain Sagebrush. Modern. X1200

Examples of polymorphs



(ii) Dinoflagellate Werzeliella coleorhrypra. Eocene. Grand Banks. X800

holes drilled on the Grand Banks. This has permitted the recognition of 22 biostratigraphic zones in the Late Mesozoic-Cenozoic sediments of this region. Studies of other, conventional wells drilled on the Grand Banks and the Scotian Shelf have also provided biostratigraphic control in the Jurassic and Early Cretaceous. Interpretations concerning paleoecology have been made based on the presence of distinctive dinoflagellate associations in some of the samples and from the dinoflagellate:spore and pollen ratio. The palynological zonation of Mesozoic-Cenozoic sediments implementing micropaleontological studies will permit more detailed correlation of the rock sequences from well to well and thus provide more accurate time control in the reconstruction of stratigraphic and tectonic events on the Atlantic Continental Shelf.

G. L. Williams



54 million year old nanofossil of the Scotian Shelf found in sample cuttings from a well drilled on Sable Island. Actual specimen size is 5 microns or .005 mm. This scanning electron micrograph has a magnification of 20,000x.

Studies of nannofossils from Mesozoic and Cenozoic sequences penetrated by offshore wells on the Scotian Shelf were begun in the latter half of 1972. Initial investigations were directed towards establishing a biostratigraphic zonation of the area based on nannofossils. Preliminary results suggest that these fossils will be useful as sensitive stratigraphic indicators for the Cretaceous and Early Tertiary. However, there has been observed a scarcity of the rosette-shaped Discoaster which, in other regions, normally has been a good stratigraphic tool for the Tertiary. This paucity can probably be attributed to a global cooling phenomenon experienced during the period, with the northernmost boundary of the Discoaster being south of the Scotian Shelf.

D. F. Clark

Palynological investigations of the Carboniferous and Permian rocks of the Atlantic provinces have been an ongoing project for many years and, upon the arrival of staff at BIO in 1971, these were continued and extended into the offshore regions of the Gulf of St. Lawrence and onto the Grand Banks. Preliminary biostratigraphic zonation of two wells in the Gulf of St. Lawrence and a third on Brion Island was completed which established a time-stratigraphic sequence ranging from Visean (Mississippian) to Stephanian (Pennsylvanian) in age. This project is supported by two technicians who process palynology and nannoplankton slides from cuttings and cores of wells drilled in Carboniferous basins as well as Atlantic Margin Basins. The training of the technicians took place over a period of several months during which time processing techniques were developed on a mass production schedule. The palynology laboratory became operational in February 1972, and to the end of December 1972, 20 offshore wells and 13 shallow core-holes (160,000 ft) were processed in addition to a variety of other samples that were required for reference material.

M. S. Barss

Environmental Geology



Geochemical Pathways in Water Column and Sediments

Inorganic geochemistry involves the detection and evaluation of the significance of elemental constituents in liquid and solid states. Processes of interaction such as dissolution, precipitation, adsorption, and flocculation are therefore of utmost importance in establishing mass balance and equilibrium. In marine systems the dynamic processes which transport water masses and entrained solids must be understood by the marine geochemist in order that appropriate models may be constructed which can satisfactorily account for observed anomalies and fluxes of chemical species from one environment to another.

Two interdependent aspects of marine inorganic geochemical research have been emphasized in the past two years. One has been the development of special analytical methods for the measurement and evaluation of chemical species in various phases, while the other has been the application of these methods in concentrated studies of a geochemical system in order to construct a model of metal pathways and fluxes through the system. R. Cranston has had principal responsibility for developing methods of silicate analyses of suspended and deposited sediments (Buckley, D. E., and Cranston, R. E. 1971. Chem. Geol., 7: 273-284; and 1972. Chem. Geol., 9: 311-314). In addition he has evaluated and adopted methods of cold-vapour mercury analyses for water and sediment samples (Cranston, R. E., and Buckley, D. E. 1972. Environ. Sci. & Technol., 6: 274-278). G. Winters has had principal responsibility for the development and testing of methods of trace element analyses in aqueous samples. In addition to development of chemical analytical methods there has been a continuing effort by the group to improve methods of statistical evaluation of all data and means of making these data available to a variety of uses (Cranston, R. E., and Buckley, D. E. AOL Data Series 1971-8-D; and Data Series/BI-D-72-I and 12).

Specific study areas and geochemical systems which have received attention during the past two years have been quite diversified. Some evaluation of industrial outfall areas has been made by analyzing trace element levels in waters and sediments from a settling pond at Boat Harbour, Nova Scotia; from a settling pond and adjacent marine area at Belledune, New Brunswick; and from pulp and chemical plants in northern New Brunswick. Intensive geochemical studies of the LaHave River and estuary system (Nova Scotia) have continued with some cooperative phases being undertaken with personnel from the Coastal Oceanography Division of AOL. In the LaHave system, a wide range of measurements has been made including dissolved major and trace elements, total suspended particulate matter, dissolved and particulate



Map showing the location of the LaHave estuary.

organic carbon, bacteria, and bottom sediment mineralogy and chemistry. All these data and observations, taken over a three-year period, are being used in compiling a complete geochemical description of a rural river-estuarine system so that some evaluation may be made of the significant processes which determine the geochemical role of such systems in effecting the nature and stability of coastal marine areas.

Some analyses of water and suspended particulate matter have been carried out in the Bay of Fundy and Minas Basin and at selected basins on the Nova Scotia Continental Shelf. The purpose of selecting these more diverse study areas was to determine the significance of suspended particulates in effecting the chemical partition between sea water and the solid phases. The exceptionally high concentrations of suspended sediments in the Bay of Fundy and Minas Basin (up to 10 mg l⁻¹) are unique in the dynamic tidal regime of that area and afford an excellent opportunity to evaluate their geochemical and sedimentological significance. In continental shelf depressions such as the LaHave and Emerald Basins, Nova Scotia, an anomalous layer of suspended particulate matter 30 to 50 metres thick and occurring immediately

above the bottom sediment interface was discovered using an optical attenuance meter (nephelometer). Sampling of these 'nepheloid' layers was carried out in a number of locations in 1972 in order to determine mineralogical and chemical composition and the mechanisms responsible for stability and distribution.

During 1972 R. Fitzgerald participated in a program of monitoring mercury levels in water along an oceanographic section between Halifax and Bermuda. Data from these cruises are being compiled to evaluate variability in different water masses at various times of the year.

Other analytical developments during the 1971-72 period include the adaptation of atomic absorption spectroscopy methods for shipboard use, and the evaluation of microfilters in analyses of suspended particulate matter (Cranston, R. E. 1972. *Geol. Soc. Canada Paper 73-1, Part A;* Cranston, R. E., and Buckley, D. E. Report Series/BI-R-72-7). Further tests and evaluations of a nephelometer have been conducted in the Bay of Chaleur and Gulf of St. Lawrence where nepheloid layers recorded by the meter were sampled, and the contained suspended matter was filtered for gravimetric and qualitative analyses.

D. E. Buckley

In organic geochemistry efforts were continued to determine the nature and chemical characteristics of major organic compounds associated with marine sediments and to correlate the important properties with various phenomenon related to accumulation of different trace metals. Investigations were undertaken of the effect of organic compounds on the solubility of different metals from their insoluble salts; the precipitation behavior of metallic cations; the migration and mobility of metals under the influence of different organic compounds; and other aspects related to geochemical recycling or accumulation of metals.

The Organic Geochemistry group continued its coordination with the Marine Ecology Laboratory and the Norwegian Institute of Seaweed Research, Trondhiem, Norway, in determining the role of various organic compounds in contemporary ecological or environmental problems.

Laboratory studies indicate that humic compounds isolated from marine sediments are effective in dissolving significantly large quantities of Cu. Co, Ni, Zn and Mn (up to 338 mg g^{-1} of organic matter) from

their insoluble carbonate or sulphide salts. The acid hydrolysate of humic acid, consisting of various amino acids, was twice as effective as the parent humic material, dissolving up to 682 mg of metal per gram of organic matter. Other important and geologically stable components of humic matter such as benzoquinone were also found effective in dissolving from 8.3 to 118.8 mg of Cu, Zn, Co, and Mn per gram of organic matter. From 1.5-8.5% of the total metal-dissolving ability of humic acid appears to arise from its quinone content.

Infrared analysis suggests that carboxyl, quinone, and amino groups participate in the organo-metallic reactions that are responsible for the solubility of the metals. The most likely mechanism of reaction appears to be that of chelation or complexing in which the metals are bonded firmly to organic molecules and are not released easily by exchange reactions.

The humic compounds were found effective not only in dissolving the insoluble salts of various metals but also in retarding their precipitation under favourable conditions. Humic acids and other organic compounds such as seaweed exudates were found to exert solubilizing and mobilizing effects on metals. Laboratory studies indicate that 'artificial' sea water consisting of humic acid solution or seaweed exudate mobilized up to 950 ppm of manganese in sedimentary columns. The seaweed exudate was found more effective in this phenomenon.

The results of the above experiments demonstrate the vital role played by marine humic and other organic compounds in the geochemical recycling of metals, including phenomenon leading to their concentration and accumulation.

Investigations carried out earlier and also during the period under report elucidate the influence of low molecular weight humic compounds in exerting stimulating effects on the physiology of dinoflagellates and diatoms. In the presence of these compounds the growth of the aquatic organisms was maximum, their rate of multiplication was faster and their C^{14} uptake was greater than during control treatment with no organic matter. Our research suggests that the low molecular weight organic compounds dissolved in natural waters play an important role in the fertility of coastal areas.

(Recent publications on this subject include papers by Rashid (1971. Soil Sci., 111: 298-306; 1972, Soil Sci., 113: 181-188; and 1972. Proc. 24th Internat. Geol. Cong., 10: 346-353), Rashid et al (1972. Geoderma, 8: 11-27; and 1972. Proc. Internat. Geochem. Cong., Moscow, USSR), and Rashid and Prakash (1972. J. Fish. Res. Bd. Can., 29: 55-60).)

Phosphorus is one of the vital nutrients that stimulates and supports eutrophic processes. Our investigations indicate that the interaction of humic acid with phosphate is likely to aggravate eutrophic conditions; the two were found to exert solubilizing effects on each other and not to precipitate upon their reaction with metals.

An important study initiated recently consists of detailed geochemical analysis of core cuttings to a depth of 9200 feet beneath the ocean bed. More than 200 samples were analyzed for their methane, ethane, propane, butane, total carbon and organic carbon. The high molecular weight organic fractions of geochemical interest are being isolated from these samples for further detailed investigations and geological interpretations. These studies are designed to determine the potentialities of the eastern seaboard for oil and gas production.

M. A. Rashid

Ecological Pathways of Recent Microfossils

For the past 10 years micropaleontologists at BIO have been actively engaged in a diversified research program aimed at discovering relationships to be used in the paleoecological and biostratigraphic interpretation of ancient sediments. In addition, certain investigators have attempted to develop baseline studies applicable to environmental monitoring programs especially in the coastal zone. A number of these programs are couched in what may be termed a 'reversed Uniformitarian Principle' which argues that if the present is the key to the past then perhaps the fossil record may reveal trends that will enable us to predict future changes in our environment. The key to the successful application of this principle is dependent on the degree of accuracy with which we are able to interpret the components of microfossil faunas. This in turn is dependent on our knowledge of the ecology and distribution of the living representatives of these fossil organisms. A specific effort in the micropaleontology research program has been directed towards studies designed to ascertain differences between living populations and their recent fossil counterpart in near-surface bottom sediments using specialized sampling equipment developed in cooperation with the Systems Engineering Group of Engineering Services, AOL. This type of approach will ultimately increase the degree of paleoclimatic interpretation possible using microfossils contained in Cenozoic marine sediments.

Micropaleontologists are presently investigating three major categories of marine organisms including planktonic and benthonic foraminifera, gastropods and pelecypods, and nannofossils. The general distribution of these organisms is well documented in the scientific literature (except in Arctic areas); their species diversity, reproduction cycle, rapid evolution, and ease of collection renders them among the most promising for environmental and paleoecologic studies. All groups under investigation generate skeletal material that is preserved in fossil form, thus enabling the chronographic determination of ancient as well as historic marine processes that have shaped our present coastline and continental shelf.

The study of living and fossil marine organisms has many ramifications with regard to geological as well as environmental needs. For example, fossil planktonic and benthonic foraminifera can be used to determine the Quaternary paleoclimatic record of the northern hemisphere for regional basin analysis and stratigraphic correlation. In coming to grips with the present marine environment the micropaleontologist has created an investigative framework well suited for the determination of the geological impact of urban man on the nearshore marine environment. In addition, the micropaleontologist, in concert with other scientists in related disciplines, is able to apply his expertise to problems concerning:

- potential side effects of a proposed activity in the coastal zone;

- potential for immediate environmental damage as a result of the exploitation of resources;

- effects of ocean disposal of wastes;

- documenting the source and subsurface stratigraphic succession of bodies of sediment formed in urbanized coastal areas during the Holocene submergence.

The historical evolution of micropaleontology can be traced through an early stage of data collection and description (1825-1900), followed by a period of stratigraphic application (1875-present) and finally an ecological phase (1925-present). Today's micropaleontologist is able to continuously reinterpret faunal distribution data with respect to current chemical and oceanographic studies utilizing more than a century of scientific effort as a data base. Specific investigations that will advance the frontier of knowledge and the diversity of applications of micropaleontological principles include: seasonal variation studies, paleoclimatological studies, taxonomic studies using the scanning electron microscope, distributional and ecologic studies, biological studies to establish the life cycle of important species, stratigraphic and basin analysis, and environmental monitoring.

Examples of the research efforts of this group are summarized below.

C. T. Schafer

During 1971/72 biweekly samples of algae from several tidal pools in the Halifax area were collected, from which living foraminifers were harvested. The purpose of this project was to observe and document morphogenesis and species succession in the tide-pool foraminiferal population.

By means of scanning electron microscopy, test ultrastructure was investigated to determine changes in microstructure relative to growth and seasons. Energy dispersive spectrometry of these benthonic



View of the JSM-2 scanning electron microscope.

foraminifers was begun to determine the chemical composition of the tests of each species and changes in element concentration relative to growth and seasons.


Orbulina universa; a planktonic foraminifer collected in the surface waters of the Atlantic Ocean.

Scanning electron microscopy of planktonic foraminifera was undertaken in collaboration with G. Vilks.

D. A. Walker

Observations on the molluscs from the Beaufort Sea collected during the HUDSON 70 Expedition and supplemented by samples collected during 1970 from the ships *Baffin, Parizeau* and *Richardson* and in 1971 from the *Parizeau* and a helicopter operation were presented at the 24th International Geological Congress in Montreal in August 1972. All of the 1971 *Parizeau* samples had not been processed at that time, but they have been now, and the accompanying map gives the most recent information on mollusc distribution in the area. More detailed coverage of distribution in the eastern part of the area will be possible when the *1972 Parizeau* collections have been studied. The area under investigation is characterized by shallow-water molluscan faunas. Eighty percent of all stations at which living molluscs were found were in



Distribution of benthonic molluscs in the Beaufort Sea showing areas of occurrence of living specimens (complete shells) in relation to areas of reworking (single valves and fragments) and barren areas.

depths of 75 metres or less. Comparison of fossil molluscs from Herschel Island and Kay Point, Yukon Territory, with the recent faunas indicates that in pre-Wisconsinan time water temperatures were possibly slightly higher than at present.

Benthonic foraminifera from all of the HUDSON 70 stations have now been identified. In general, arenaceous species are dominant at depths between about 500 and 1000 metres, with the exception of an area of abundance in the Beaufort Sea at about 50 metres depth north of Kugmallit Bay, Northwest Territories. Calcareous species are characteristic of the shelf area but several specimens were found at the three deep stations beyond the limit of the arenaceous forms.

F. J. E. Wagner

Studies of the foraminiferal fauna inhabiting the unpolluted areas of the Restigouche estuary, New Brunswick, describe a pattern which reflects the boundary between relatively stable and environmentally variable areas. The variable areas are represented by a hardy foraminiferal fauna dominated by species of *Elphidium, Ammotium* and *Eggerella.* These three genera are well represented between



Foraminifera biotopes in the Restigouche estuary and western Chaleur Bay.

Belledune and Dalhousie, New Brunswick. In August of 1971 the central part of Chaleur Bay between Belledune and Grand Anse, New Brunswick, was surveyed. A faunal change indicative of the persistent influence of Gulf of St. Lawrence water was noted. Specific faunal changes include an increase in the relative abundance of *Reophax spp.* and *Saccammina atlantica*. Analysis of the nearshore faunas near pollution sources in the estuary have enabled the determination of the geographic extent of local, intensely polluted bottom areas.

C. T. Schafer

In the Arctic a study of planktonic foraminifera in the surface waters and sediment was continued. During March and April of 1972 a field party based at Tuktoyaktuk, Northwest Territories, sampled plankton from waters on the continental slope and shelf of the Beaufort Sea. Plankton and sediment samples were taken at 36 localities in conjunction with temperature and salinity measurements in the water column. The late-winter early-spring field work was designed to supplement observations and field data gathered in the area during the summer of 1970 from the CSS *Hudson*. Logistics and field requirements were provided by the Polar Continental Shelf Project.

Oceanographic observations indicate that seasonal changes in the water column take place only within the upper 30 metres, with colder and



Area of study of planktonic foraminifera in the surface waters and sediment in the Arctic.



Retrieving an oceanographic sample in the Beaufort Sea.



Living quarters in a field-camp during the Beaufort Sea studies.

more saline surface water in the winter. The subsurface waters show basically similar density-depth relationships between the two sets of observations; a year-round upwelling of the subsurface water takes place along the continental slope.

The population of planktonic foraminifera under the winter ice is reduced by a factor of 200, with a corresponding reduction of the total biomass by about a factor of 4. This demonstrates the inability of planktonic foraminifera to maintain a standing crop under the less productive winter conditions in a manner comparable to the remainder of the zooplankton. Paleoclimatic implications from these observations are that in the Arctic Ocean the relative amounts of planktonic foraminiferal tests in sediment cores can be used as sensitive indicators of changes in the past ice conditions.

A comparative study of planktonic foraminifera between the eastern and western waters of the Canadian Arctic Archipelago is nearing completion. Material for this study was collected from the CSS Hudson during late summer of 1970 while *en route* through the Northwest Passage.

Intraspecific variation of *Globigerina pachyderma* collected from bottom sediments and surface waters along the route showed several trends. The Beaufort Sea population contain foraminifera that are significantly larger, with over 10% being dextral individuals in comparison to only 3% in Baffin Bay. The diluted surface layers of the highly stratified waters of the Beaufort Sea contain larger percentages of specimens with reduced last chambers, in comparison to the more saline and mixed waters of the eastern Lancaster Sound. Significantly larger and more robust specimens are found in the sediments, indicating a selective preservation of planktonic foraminiferal tests in the Arctic sediments.

G. Vilks

Planktonic foraminifera were analyzed from plankton tows collected in the North Atlantic and along the ship's track during the HUDSON 70 cruise in the South Atlantic, Drake Passage and South Pacific. At each station changes in species content were correlated to the changes in water temperature in the upper 300 metres.

Species diversity was found to be lower at stations in the polar and subpolar waters in comparison to waters at lower latitudes. The standing crops of planktonic foraminifera were highest in areas of water mass mixing and during seasons of weak surface thermoclines, e.g. off Bermuda higher numbers were counted per cubic metre of water filtered during April and December than during July. A diurnal variation of planktonic foraminifera in the upper 200 metres was also found off Bermuda, where analysis of variance tests on specimen counts demonstrated a significant increase in numbers during daylight hours.

G. Vilks

A considerable effort has been expended to develop instrumentation that will enable the marine geologist to make observations using techniques and methods that have been developed in the course of geological surveys on land. Prototypes of two tools have recently been tested by this group. The first, a sophisticated turbidity meter, will enable sedimentologists, geochemists and marine ecologists to gather information on the spatial distribution of suspended materials in the water column. A second device has been developed to enable SCUBA diving marine geologists to describe structures, processes, and faunal distributions more accurately. The instrument consists of a portable submersible video recorder which can be used by the scientist to accurately describe bottom phenomena. The operator records visual data using a video camera and simultaneously narrates the video tape (via an audio channel) using a specially modified diver air regulator containing a small microphone.



Portable audio-visual equipment for the use of SCUBA divers in the monitoring of near-shore environments.

C. T. Schafer

Sediment Dynamics

Bottom studies of the Beaufort Sea are being undertaken to obtain information on bottom sediments and their dispersal trends, and to make a quantitative analysis of ice-scour features on the floor of the Beaufort Sea and the occurrence of submarine pingos. The goals are twofold: (1) to provide an adequate inventory on the nature of bottom sediments, and to provide data and illustrative material for those agencies undertaking engineering studies with direct reference to the construction of underwater pipelines, construction of underwater installations, coastal construction such as port facilities, and as an aid to shipping with reference to anchoring sites; (2) to provide maps together with statistical and illustrative material that will provide a guidance to the petroleum industry and engineers dealing with problems related to underwater pipelines and installations to be placed on the sea floor and along coastal areas.

The work is being carried out from scientific vessels of the Department of the Environment and from helicopter-based operations over the ice (support from Polar Continental Shelf Project). In open waters conventional oceanographic sampling is being undertaken, but over the ice, holes must be drilled and the samplers lowered to the sea floor, and returned by means of a small motor-driven winch. Operations generally commence in early April over the ice (for a period of four weeks) and in early August in open waters (for a period of four to six weeks).

The subsea region can be divided into three main subdivisions which are as follows: (1) the continental shelf which is generally flat and extends seaward for about 75 miles to the shelf break at a depth of approximately 200 metres; (2) a region of low conical hills identified as pingos lying in a zone commencing about 30 miles offshore to approximately 70 miles offshore; and (3) the Mackenzie Canyon which is a dominant feature extending from the mouth of the Mackenzie River and widens to about 40 miles at the edge of the continental shelf. It has a broad floor, a steep western slope and a gentle eastern slope. The edge of the shelf trends northeasterly with the central portion leading into a steeper continental slope than on the extremities at the east and west ends. The slope extends to depths greater than 1500 metres and then beyond to the Canada Basin which lies at depths of 2500 metres.

Another prominent physiographic feature on a smaller scale is a profusion of scour features caused by ice that has been driven shoreward predominantly by winds and also by currents. An analysis of the trends of the scour features indicates a preferred southeasterly trend with a mean direction of 110°. Some of these scours are 10 metres in depth but in the shoreward area where oil exploration is most intense in terms of proposed drilling, the scour features are less than 2 metres deep. The age of the features is problematical and evidence from coring and extrapolated sedimentation rates suggest that the process has been recurrent for a period of 12,000 years. It also suggests that a major climatic change in the ocean occurred or that some other event coincided with the absence of scouring about this time, possibly a change in sea level, or an absence of ice cover.

The sediments so far examined are distributed in long zones or belts which trend parallel to the shoreline. Very close to the shore the sediments are mostly sandy, particularly where they accumulate from the Mackenzie River run-off as those waters are deflected easterly after emerging from the river system. However, most of the sediments in the Mackenzie system are very fine grained and consist chiefly of silts. Another zone of sediments which is predominantly muddy occurs seaward, and this in turn is followed by a sandy belt occurring near the edge of the continental shelf. Some sand was found in the cores only a few feet beneath the present marine muds; the occurrence of this sand, which is similar to beach sands, suggests that sea level has risen and the seas have transgressed further upon the land. The rapid disintegration of shore features including the pingos, which form nearby islands, offers evidence of this action,

B. R. Pelletier

A Marine Science Atlas of the Beaufort Sea is being compiled from the results of past and existing projects on the marine aspects of the Beaufort Sea, including oceanography, biology, bathymetry, ice, sediments, geology, and geophysics, access routes, and other cultural aspects. It is to contain maps, illustrative material (photos, sketches, graphs) and data on these aspects; all data will be plotted on a scale of 1:500,000 for reduction to atlas size of 15 x 12 inches.

Primarily this atlas is to serve the public as a guide to resources development in the Beaufort Sea, and will be of use to the engineering, petroleum, fishing and shipping industries; also it will provide baseline information for environmental studies.

B. R. Pelletier

A reconnaissance study of the coastal geomorphology of the southern Gulf of St. Lawrence was completed during 1972. The region was divided into ten zones. Within each zone a series of site investigations was carried out to describe specific features which were characteristic of the coast (the sites are indicated by the arrows), In addition, samples were collected from the littoral and backshore areas at a 10 km interval. From the initial results of the zonal study and the sampling program it is possible to define the major elements of the coastal zone and to provide an indication of littoral processes and sediment dispersal patterns. This type of reconnaissance data does not attempt to explain all elements of coastal processes and morphology but illustrates the major factors in shoreline development and present-day processes.



Coastal geomorphology study, southern Gulf of St. Lawrence. Zonal units and study sites.

Differences in sediment availability and exposure to wave processes vary considerably within the region. Zones 1 and 9 are characterized by resistant upland coasts with little or no littoral sediments. Zones 3, 6, and 8 have exposed coasts with low cliffs and narrow beaches or small barriers and spits. Zones 4 and 7 are sheltered areas with a variety of cliff and beach forms. Barrier spits and islands are common in Zones 2, 5, and 10, which are the most dynamic areas in terms of beach and dune changes and inlet migration.

On the basis of this initial study a detailed investigation of the coastal environment of the Magdalen Islands will be undertaken in future field seasons. This project will be aimed specifically at an explanation of the origin and form of the barrier beaches in relation to sediment dispersal patterns and littoral processes. In addition a series of permanent surveyed sites has been established in the southern Gulf in order to determine long-term morphological changes in areas of accretion and erosion.

E. H. Owens

An understanding of the dynamics of sediment movement in Minas Basin, Bay of Fundy, Nova Scotia, is important for two main reasons: (1) such an understanding is necessary in order to facilitate construction of any tidal power project in the Basin, and to foresee the ecological consequences of any such construction; and (2) tidal sand bars exist in many other parts of the world where conditions for studying them are less favourable than in the Bay of Fundy. At present, there is little fundamental scientific understanding of the processes by which such bars are formed or maintained. Such understanding is necessary for various practical purposes, such as the maintenance of navigable channels in estuaries, and the prediction of oil sand reservoirs which may be found in ancient tidal sand bars.

The purposes of this project are chiefly threefold: (1) to determine the relation of sand movement to tidal and other currents in Minas Basin; (2) to relate the sedimentary structures, textures, and mineralogical composition of the sand to its movement within the Minas Basin; and (3) to determine the rates and patterns of movement of the dunes, bars, and other medium-to-large scale sedimentary bedforms in response to hydrodynamic factors.

The Minas Basin, Bay of Fundy, area is unique because of its extremely large tidal range (in excess of 17 metres). Its extraordinarily high and low tides have both practical economic importance (as a potential source of tidal power) and scientific interest. The swift currents produced by the tides move large quantities of sand and mud; locally the sediment accumulates as sand bars and tidal mud flats exposed at low tide.

At present, our knowledge of intertidal sediments in the Basin is of a reconnaissance nature, except for a detailed study by Klein (1970. *J. Sediment. Petrol.*, 40: 1095-1127) of two sand-bar areas on the north side of the Basin. The area is one of exceptional scientific interest because the large tidal range makes it possible to observe features directly that can only be studied indirectly (and at much larger expense) in tidal areas elsewhere. Yet studies in the Basin are at present much less complete than those (for example) in the North Sea and along the Massachusetts coast.

During the summers of 1971 and 1972, R. J. Knight and R. Dalrymple (McMaster University), with assistance from the Atlantic Geoscience Centre, mapped and sampled four sand bars near Noel, Nova Scotia. Tidal currents, suspended sediment concentrations, rates of bedform migration and sediment dispersion directions and rates were determined. It is planned to extend these types of observations to other sand bars and to continue to monitor the bars already studied for two further field seasons.

Techniques used include use of current meters, water samplers,

echo-sounding devices, trenching, box-coring, and fluorescent-dyed sand. Most of the work had been carried out using boats rented locally or loaned by the Bedford Institute, which also loaned current meters and other equipment. Air photography of parts of the Basin, flown at low tide, was begun last summer and the same coverage will be flown each spring and fall for the next two years.

Certain preliminary conclusions and recommendations have already been reached. They may be summarized as follows: more field work is required to observe winter conditions in the field area; more information is required on internal structures, wave activity, and diurnal changes of bedforms; there appears to be a bedform hierarchy related to increasing current velocities; the variety of bedforms on Selmah Bar appears to be a function of the complex topographic relationships, grain size, and exposure to the various processes active on the sand bar: the occurrence of ebb-oriented bedforms at low tide is not necessarily conclusive evidence for ebb dominance: the presence of possible ebb-modified flood features should be confirmed through more extensive study on internal structures; the effectiveness of wave activity on the form and role in sediment transport is not known due to the lack of information: orientations of megaripple and sand-wave crestline appear to be controlled by the mean current direction; small scale ripple-crest orientations appear to be controlled by local shallow-water flow conditions; the magnitude of current velocities and the degree of time-velocity asymmetry is a function of location, point in the lunar-tide cycle, and water surface slopes; irregularities in velocity profiles and directional data suggest the presence of turbulence; tidal currents appear to be the most important agent in the transport of sediment in the intertidal environment.

This project is under the supervision of Dr. B. R. Pelletier (AGC) and Dr. G. V. Middleton (McMaster University, Hamilton, Ontario).

R.J. Knight

Appendix D1 Major Publications and Reports by AGC Staff, 1971/72

Bedford Institute of Oceanography Contributions

Publications indicated by an asterisk are joint papers with AOL and/or MEL; they are repeated in the corresponding lists for AOL and/or MEL.

AUMENTO, F., LONCAREVIC, B. D., and ROSS, D. I. 1971. Hudson geotraverse: geology of the Mid-Atlantic Ridge at 45°N. *Phil. Trans. Roy. Soc. Lond A*, 268: 623-650 (BIO Contribution 203).

BARRETT, D. L., KEEN, C. E., MANCHESTER, K. S., and ROSS, D. I. 1971. Baffin Bay - an ocean. *Nature*, 229: 551-553 (BIO Contribution 224).

BE, A. W. H., VILKS, G., and **LOTT, L.** 1971. Winter distribution of planktonic foraminifera between the Grand Banks and the Caribbean. *Micropaleontology*, 77: 31-42 (BIO Contribution 189).

BHATTACHARYYA, P. J., and ROSS, D. I. 1972. Mid-Atlantic Ridge near 45°N, computer interpolation and contouring of bathymetry and magnetics. *Marine Science Paper* 11. Information Canada, Ottawa. 9 pp. (BIO Contribution 307).

BUCKLEY, D. E. 1972. Geochemical interaction of suspended silicates with river and marine estuarine water. In: *Proc. 24th Int. Geological Congress, Montreal,* 1972, 10: 282-290 (BIO Contribution 276).

BUCKLEY, D. E., and **CRANSTON, R. E.** 1971. Atomic absorption analyses of 18 elements from a single decomposition of alumino-silicate. *Chem. Geol., 7:* 273-284 (BIO Contribution 222).

CRANSTON, R. E., and BUCKLEY, D. E. 1972. Mercury pathways in a river and estuary. *Environmental Science & Technology*, 6: 274-278 (BIO Contribution 283).

DRAPEAU, G. 1970. Sand waves on Browns Bank observed from the shelf diver. *Maritime Sediments, 6:* 90-101 (BIO Contribution 236).

DRAPEAU, G., and KING, L. H. 1972. Surficial geology of the Yarmouth-Browns Bank map area. *Marine Science Paper P/Geological Survey of Canada Paper* 72-24. Information Canada, Ottawa. 6 pp, (BIO Contribution 304).

DUEDALL, I. W., and BUCKLEY, D. E. 1971. Calcium carbonate monohydrate in seawater. *Nature*, 234: 39-40 (BIO Contribution 263).*

GRANT, A. C. 1972. The continental margin off Labrador and Eastern Newfoundland - morphology and geology. *Can. J. Earth Sci., 9: 1394-1430* (BIO Contribution 316).

HAWORTH, R. T. 1971. A geophysical profile in the South-East Pacific. Earth and Planetary Sci. Letters, 11: 83-89 (BIO Contribution 216).

HAWORTH, R. T. 1971. Cross-coupling errors as a function of the orientation of a Graf-Askania sea gravimeter Gss 2. *J. Geophys. Res.,* 76: 2663-2673 (BIO Contribution 225).

HAWORTH, R. T. 1971. The elimination of cross-coupling errors in systematic sea gravity surveys. *Geophys. J. R. Astr. Soc., 22:* 545-556 (BIO Contribution 221).

HOWIE, R. D., and HILL, J. V. 1972. Developments in Eastern Canada in 1971. The American Association of Petroleum Geologists Bulletin, 56: 1193-1204 (BIO Contribution 302).

KEEN, C. E., and **BARRETT, D. L.** 1971. A measurement of seismic anisotropy in the Northeast Pacific. *Can. J. Earth* Sci., 8: 1056-1064 (BIO Contribution 252).

KEEN, C. E., BARRETT, D. L., MANCHESTER, K. S., and ROSS, D. I. 1972. Geophysical studies in Baffin Bay and some tectonic implications. *Can. J. Earth Sci.*, 9: 239-256 (BIO Contribution 279). KEEN, M.J., LONCAREVIC, B. D., and EWING, G. N. 1971. Continental margin of Eastern Canada: Georges Bank to Kane Basin (Feb. 1969). In: *The Sea, 4, Pt II.* Ed. A. E. Maxwell. J. Wiley &Sons Inc.: 251-291 (BIO Contribution 181).

KING, L. H. 1972. Relation of plate tectonics to the geomorphic evolution of the Canadian Atlantic Provinces. *Geol. Soc. America Bull., 83: 3083-3090* (BIO Contribution 342).

KING, L. H., MACLEAN, B., and DRAPEAU, G. 1972. The Scotian Shelf submarine end-moraine complex. In: *Proc. 24th Int Geological Congress Montreal*, 1972, 8: 237-249 (BIO Contribution 356).

KRANCK, K. 1971. Surficial geology of Northumberland Strait. *Marine Science Paper S/Geological Survey of Canada Paper* 71-53. Information Canada, Ottawa. 10 pp. (BIO Contribution 269).

KRANCK, K. 1972. Geomorphological development and post-Pleistocene sea level changes, Northumberland Strait, Maritime Provinces. *Can. J. Earth Sci., 9:* 835-844 (BIO Contribution 300).

KRANCK, K. 1972. Tidal current control of sediment distribution in Northumberland Strait, Maritime Provinces. J. Sed. Per., 42: 596-601 (BIO Contribution 309).

LONCAREVIC, B. D., and PARKER, R. L. 1971. The Mid-Atlantic Ridge near 45°N. XVII. Magnetic anomalies and ocean floor spreading. *Can. J. Earth Sci., 8:* 883-898 (BIO Contribution 240).

MACLEAN, B., and KING, L. H. 1971. Surficial geology of the Banquereau and Miseine Bank map area. *Marine Science Paper S/Geological Survey of Canada Paper 71-52*. Information Canada, Ottawa. 19 pp. (BIO Contribution 271).

MARLOWE, J. I. 1971. Dolomite. phosphorite, and carbonate diagenesis on a Caribbean seamount. J. Sed. Per., 47: 809-827 (BIO Contribution 248).

PELLETIER, B. R., and MCMULLEN, R. M. 1971. Sedimentation patterns in the Bay of Fundy and Minas Basin. In: *Tidal Power. Proceedings of an International Conference on the Utilization of Tidal Power*, Halifax, Nova Scotia, May 1976. Eds. T. J. Gray and O. K. Gashus. Plenum: 153-187 (BIO Contribution 220).

PELLETIER, B. R., and SHEARER, J. 1972. Sea bottom scouring in the Beaufort Sea of the Arctic Ocean. In: *Proc. 24th Int. Geological Congress, Montreal*, 1972, 8: 251-261 (BIO Contribution 286).

RANALLI, G. 1971. The expansion-undation hypothesis for geotectonic evolution. *Tectonophysics*, 17: 261-285 (BIO Contribution 233).

RASHID, M. A. 1971. Role of humic acids of marine origin and their different molecular weight fractions in complexing di- and tri-valent metals. *Soil Science*, *111:* 298-306 (BIO Contribution 227).

RASHID, M. A. 1972. Amino acids associated with marine sediments and humic compounds and their role in solubility and complexing of metals. In: *Proc. 24th Int. Geological Congress, Montreal, 1972, 10: 346-353* (BIO Contribution 268).

RASHID, M. A. 1972. Quinone content of humic compounds isolated from the marina environment. *Soil Science, 113*: 181-188 (BIO Contribution 284).

RASHID, M. A. 1972. Role of quinone groups in solubility and complexing of metals in sediments and soils. *Chem.* Geol., 9: 241-248 (BIO Contribution 299).

RASHID, M. A., BUCKLEY, D. E., and **ROBERTSON, K. R.** 1972. Interactions of marine humic acid with clay minerals and a natural sediment. *Geoderma, 8:* 11-27 (BIO Contribution 303).

RASHID, M. A., and KING, L. H. 1971. Chemical characteristics of fractionated humic acids associated with marine sediments. *Chem. Geol.*, 7: 37-43 (BIO Contribution 214).

RASHID, M. A., and **PRAKASH, A.** 1972. Chemical characteristics of humic compounds isolated from some decomposed marine algae. *J. Fish. Res. Bd. Can.*, 29: 55-60 (BIO Contribution 280).*

RUFFMAN, A. 1972. In: Laughton, A. S., Berggren, W. A., et al., 1972. Initial reports of the Deep Sea Drilling Project, XII, Washington (Chapters 3- 10): 33-901 (BIO Contribution 293).

SCHAFER, C. T. 1970. Studies of benthonic foraminifera in the Restigouche estuary: 1. Faunal distribution patterns near pollution sources. *Maritime Sediments,* 6: 121-134 (BIO Contribution 239).

SCHAFER, C. T. 1971. Sampling and spatial distribution of benthonic foraminifera. *Limnol. Oceanogr.*, 76: 944-951 (BIO Contribution 281).

SEN GUPTA, B. K. 1971. The benthonic foraminifera of the Tail of the Grand Banks. *Micropaleontology*, 77: 69-98 (BIO Contribution 209).

SHEARER, J. M., MACNAB, R. F., PELLETIER, B. R., and SMITH, T. B. 1971. Submarine pingos in the Beaufort Sea. *Science*, 174: 816-818 (BIO Contribution 257).*

SRIVASTAVA, S. P. 1971. Diurnal variation of the total magnetic field along the east coast of Canada. *Earth & Planetary Sci. Letters*, 10: 423-429 (BIO Contribution 195).

SRIVASTAVA, S. P., BARRETT, D. L., KEEN, C. E., MANCHESTER, K. S., SHIH, K.G., TIFFIN, D. L., CHASE, R. L., THOMLINSON. A. G., DAVIS, E. E., and LISTER, C. R. B. 1971. Preliminary analysis of geophysical measurements north of Juan de Fuca Ridge. *Can. J. Earth Sci.*, 8: 1265-1281 (BIO Contribution 254).

WALKER, D. A. 1971. Etching of test surface of benthonic foraminifers due to ingestion by the gastropod *Littorina littorea Linné. Can. J. Earth Sci., 8:* 1487-1491 (BIO Contribution 258).

WATTS, A. B. 1972. Geophysical investigations east of the Magdalen Islands, Southern Gulf of St. Lawrence. *Can. J, Earth Sci., 9: 1504-1528* (BIO Contribution 322).

WINDER, C. G., and SANFORD, B. V. 1972. Stratigraphy and paleontology of the Paleozoic rocks of Southern Ontario. Guidebook, Field Excursion A45-C45, 24th Int. Geological Congress, Montreal, 1972. 74 pp. (BIO Contribution 357).

WOODSIDE, J. M. 1972. The Mid-Atlantic Ridge near 45°N. XX. The gravity field. *Can. J. Earth Sci.*, 9: 942-959 (BIO Contribution 306).

Bedford Institute of Oceanography Report Series

This series of technical reports was introduced on 1 January 1972 to replace the original AOL series. In the following list reports issued during 1971 are numbered according to the AOL series (AOL Report 71-). Reports issued during 1972 are numbered according to the Bedford Institute of Oceanography Report Series (BI-R-72-).

Reports indicated by an asterisk are joint reports with AOL and/or MEL; they are repeated in the corresponding lists for AOL and/or MEL.

BANERJI, R. K., SCHAFER, C. T., and VINE, R. N. 1971. Environmental relationships and distribution of planktonic foraminifera in the equatorial and northern Pacific waters. *AOL Report 71-7.**

CRANSTON, R. E., and **BUCKLEY, D. E.** 1972. The application and performance of microfilters in analyses of suspended particulate matter. *BI-R-72-7.*

SPARKES, R., HAWORTH, R. T., and COUSINS, H. G. 1972. Document storage and retrieval, *BI-R-72-5.*

Appendix D2 - Affiliations

During the years 1971-72 some staff members of the Atlantic Geoscience Centre were affiliated in various ways with the academic community.

At Dalhousie University, Halifax, several staff members were associate members of the Faculty of Graduate Studies. These included Dr. B. D. Loncarevic, who is an Associate Professor in the Physics Department, and Drs. B. R. Pelletier and L. H. King who are Special Lecturers in the Geology Department.

During the academic year 1972-73 B. R. Pelletier was an adjunct professor of geology at Acadia University, Wolfville, Nova Scotia giving a research course in sedimentology. He is also the editor of Maritime Sediments.

The following served on thesis committees: B. R. Pelletier, D. E. Buckley, C. E. Keen, D. I. Ross, C. T. Schafer and S. P. Srivastava.

Collaborative research projects with AGC are being undertaken at the University of South Carolina, McMaster University, Hamilton, Ontario and Dalhousie University.

Visitors to Bedford Institute











Design Direction: Clarridge House, Halifax Printing: Earl Whynot & Associates Publisher: Bedford institute of Oceanography

