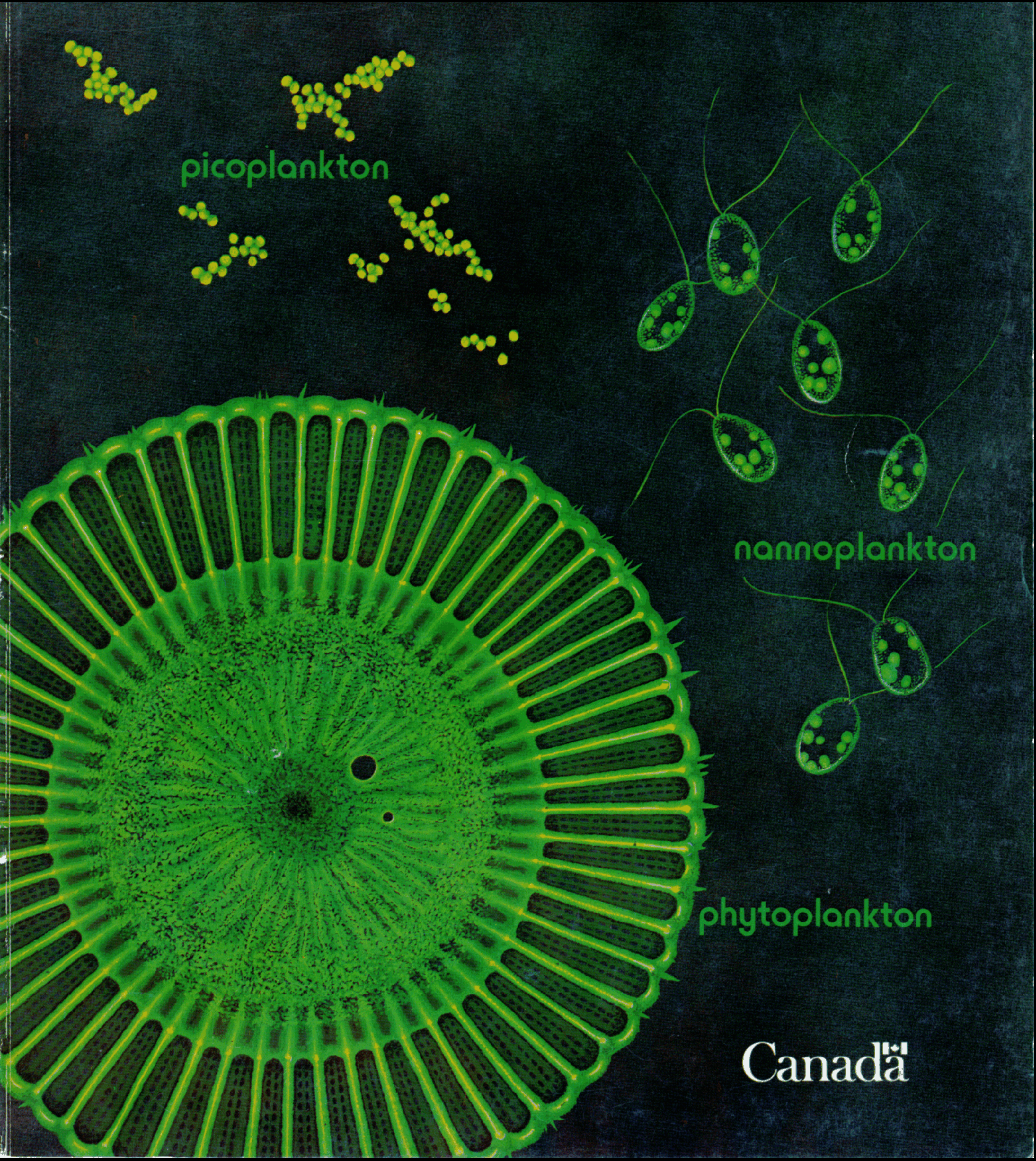
Bedford Institute of Oceanography

BIO REVIEW '82



Canada

The Bedford Institute of Oceanography (BIO) is the principal oceanographic institution in Canada; it is operated within the framework of several federal government departments; its staff, therefore, are public servants.

BIO facilities (buildings, ships, computers, library, workshops, etc.) are operated by the Department of Fisheries and Oceans, through its Director-General, Ocean Science and Surveys (Atlantic). The principal laboratories and departments are:

Department of Fisheries and Oceans (DFO)
- Canadian Hydrographic Service (Atlantic Region)
- Atlantic Oceanographic Laboratory
- Marine Ecology Laboratory
- Marine Fish Division

Department of Energy, Mines and Resources (DEMR)
- Atlantic Geoscience Centre

Department of the Environment (DOE)
- Seabird Research Unit

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

BIO has four objectives:

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

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

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

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

T.D. Iles - *Chief, Marine Fish Division, DFO*

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

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

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

G.T. Needler - *Director, Atlantic Oceanographic Laboratory, DFO*

D.N. Nettleship - *Seabird Research Unit, Canadian Wildlfe Service, DOE*

Introduction

Oceanography is a very young science. During the 20 years since BIO was established our knowledge of the oceans has changed out of all recognition. In the early 1960s the first modern hypothesis for sea-floor spreading, in the form of an interpretation of linear magnetic anomalies in the ocean basins, was just becoming available and a comprehensive theory of plate tectonics had yet to be formulated; the deep circulation patterns of the oceans, and indeed some major currents, were just beginning to be described and the transfer of energy between ocean and atmosphere had been little worked on; solid-state electronics were not yet available for oceanographic instruments and sensors, and ocean chemistry relied on standard laboratory techniques for its analyses; the earliest integrated descriptions of marine ecosystems were recently published, but the computing ability to simulate their interactions without great labour was lacking. Perhaps only those actively engaged in oceanographic research fully understand how great is the distance still to go, and it is our purpose here to try to illustrate the nature of the problems we still face in unravelling the extraordinarily complex processes in the ocean.

Oceanography is not only a rapidly developing scientific discipline of great difficulty, but it is also an essential input to many of our economic activities in the ocean. Despite the limits of our knowledge, we must provide information on wave climates for offshore platforms, analyze geological histories of continental margins for the likelihood of hydrocarbon formation in their deposits, model the exchange of heat between ocean and atmosphere to predict climate change, and predict the consequences of contamination and stress on marine ecosystems. In our first edition of *BIO Review,* we described how our work was applied to what are presently perceived to be Canada's major national needs for information about the ocean. In this edition we look at our longer term research.

How should we define the proper balance between applying our stock-in-trade of knowledge to today's problems, and continuing to research problems not yet resolved - between applied and basic science, in fact? One of the dangers, which we wish to emphasize in this second *BIO Review,* is to proceed as if our knowledge of a complex process is complete simply because we can say something useful about it based on what we already know. Because we have enough skill to deal with some practical oceanographic problems, it is sometimes thought that what we chiefly lack is the resolve to turn all of our resources to today's practical problems, using techniques already at our disposal, rather than continuing to study fundamental problems with some of our resources.

In the last ten years, there has certainly been a very significant swing to practical oceanography and the solution of pressing problems, and BIO has played its part in this movement to the full. At the same time, we have tried to maintain a sensible balance between this work and continuing to attack the really difficult problems in ocean science, being very conscious how limited our present understanding is of even the most fundamental processes in the ocean. As every scientific quipster has said more elegantly, an admission that there are still great areas of ignorance is the first step towards remedying them, and a review of topics that are incompletely understood is a good point of departure for further advances. That is the purpose of the present *BIO Review;* what follows are samples of our targetted basic research selected as reminders of the danger of assuming that solutions are already available to any practical problem that arises. Today's solutions will solve few of tomorrow's problems, and not all of today's.

In Canada, federal research institutions bear much of the responsibility for sustained basic research in oceanography, especially when major programs at sea are required. We like to think that BIO has contributed its share to the extraordinarily rapid progress made in global oceanography over the last two decades, and we hope that it will continue to do so in the future: there is no doubt as to the magnitude of the remaining task.

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BIO REVIEW is intended not only to inform you about the progress of our research and survey programs, but also to serve as an up-to-date and useful guide to the Institute itself. The latter part of this edition is intended to bring some sections (our bibliography and chart production) up to date, and to complement some of the information provided in *BIO Review '81* with different kinds of listings and guides. Each item of information will be brought up to date in successive editions at an appropriate interval.

A.R. Longhurst
Director-General
Ocean Science and Surveys, Atlantic
Department of Fisheries and Oceans

High gain VHF radio antennas being mounted to the aftermast of CSS *Hudson.* They receive signals from sonobuoys used in geophysical studies.

John Dodge, Frank Zemlyak. and Eric Levy on a CSS *Hudson* dory. The tetrahedral screen sampler in Eric's hands is used to collect surface film from the water.

Wang Ying and Gus Vilks split a deep-sea sediment core aboard CSS *Hudson.* One half the core will be subsampled and analyzed; one half will be archived.

John C. Smith processes samples aboard CSS *Hudson* for size fractionation studies of carboxylating enzyme activity in phytoplankton

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On the cover:

An illustration by Pat Lindley of the Marine Ecology Laboratory to show how very small are the picoplankton now found to be so abundant and important in the economy of the ocean. Shown to the same scale are cyanobacteria of the picoplankton (about 0.8 micron in diameter), flagellated algal cells of the nannoplankton (about 10 microns in diameter), and a typical species of the diatoms once thought to dominate the phytoplankton (about 80-100 microns in diameter).The role of such micro-organisms in primary productivity is discussed in the article beginning on page 23.

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chapter 1

Physical and Chemical Oceanography

Most of the heat received from the sun by our planet goes to warming the water of the great ocean basins, with minor inputs to warm the atmosphere and the solid earth; heat is then exchanged between air, sea, and ice - between the atmosphere, the hydrosphere, and the cryosphere - in response to changing seasonal and latitudinal solar heating; these exchanges of heat drive the ocean currents, the winds, and the waxing and waning of the polar snow and ice cover. This heat engine is so energetic under the conditions presently existing on earth - we are now between two glacial periods within a general epoch of ice-ages - that heat flow between tropics and poles is very active, and water just above freezing is drawn to the deep equatorial ocean below the warm upper layers heated by the tropical sun.

Variations in the working of this heat engine occur from day to day (the weather forecast), from month to month (summer and winter), from year to year (good seasons and bad), and over decadal, secular, and millenial time scales, as expressed in climate changes. The working of the heat engine in its steady state and also its variations over different time scales are just beginning to be understood, and it would be vain to pretend that study of the physics and chemistry of the ocean during the past 100 years has done very much more than identify the nature of its problems, and sketch the rough outlines of a descriptive and analytical science.

However, what we also know is the value of oceanography as a predictive science, and we have some idea of how to set about it. If we were in a position to predict the heat budget and circulation pattern of the ocean on reasonable time and space scales, we would hold in our hands one of the principal missing keys to prediction of climate over periods of some months to possibly several years. It requires little imagination to understand the value of that for Canada, a country standing across the margin of the climate zone in which industrial and agricultural life is feasible. It requires more imagination to understand the consequences for individual sectors of our economic life: fisheries management urgently needs to understand why reproduction, and hence subsequent recruitment of fish stocks varies so much between years - we know enough of the processes involved at least to say that variable reproductive success is caused most often by variability in ocean conditions. Comparable examples could be stated for prediction of arctic ice cover, for agricultural growing seasons, for seasonal urban snow loads, for routing of ships on ocean passages, and on.

In this chapter we present half-a-dozen examples of studies by the Atlantic Oceanographic Laboratory designed to help move oceanography towards the ideal of a predictive science: to do this we must not only understand very much better the processes and mechanisms by which the parts of ocean and atmospheric circulations interact, but we must also put real-time description of ocean circulation on a footing comparable with the day-to-day monitoring that is routine and global in meteorology, and on which all weather forecasting depends. Monitoring of ocean conditions from month to month is in a very undeveloped state, and Canadian oceanographers must rely almost entirely on foreign products for their monitoring data.

In the first three sections of this chapter, we describe studies in the northwest Atlantic Ocean. Clarke discusses work by the Ocean Circulation Division, undertaken mostly in mid-winter in the Labrador Sea under very difficult conditions, to investigate the formation there of the cold water masses that spread downwards and southwards from their point of origin and that can be detected widely at great depth over much of the North Atlantic; these play a critical part in the deep circulation of the oceans, balancing the transport of heat towards the poles. In this case, success came only by riding out the worst possible conditions at sea, for significant deep convection occurs only under very severe winter conditions, particularly when there are persistent strong winds: this could only have been done with the large and capable *Hudson*, which in 1982 undertook the same kind of study between Greenland and Spitzbergen, reaching almost to 80°N in early March. Smith of the Coastal Oceanography Division, and Sandstrom and Elliott of the Ocean Circulation Division describe studies of the seasonal upwelling that occurs in the southwest Nova Scotia region, and of the dynamics of the frontal zone between shelf water and ocean water at the edge of the continental shelf. Both of these are highly variable processes and both are implicated in the supply of nutrients to fuel the biological cycle on the continental shelf, hence drive fisheries production. During the shelf-break studies of tidal mixing, a very unexpected result was the unequivocal observation of internal solitary waves, or solitons, generated ahead of tidal bores.

Fowler, Dessureault, and Elliott discuss the problems of transmission of ocean data by satellite channels, a technique rapidly coming to be developed as a standard tool in ocean science, and in which BIO is increasingly active in almost all of its divisions. Finally, Stoffyn and Yeats discuss Chemical Oceanography Division's studies of the manner in which the distribution of trace metals in the deep oceans is affected by biological processes: water mass circulation can only be traced by following chemical 'labels' if we know the extent to which these are truly conservative - that is, how much they react with their surroundings and are transported actively by processes such as particle sedimentation or biological migration. Again, an area of great uncertainty in which an incomplete understanding of the particulate chemistry could give seriously misleading results.

Deep convection and renewal of deep waters

R. A. Clarke

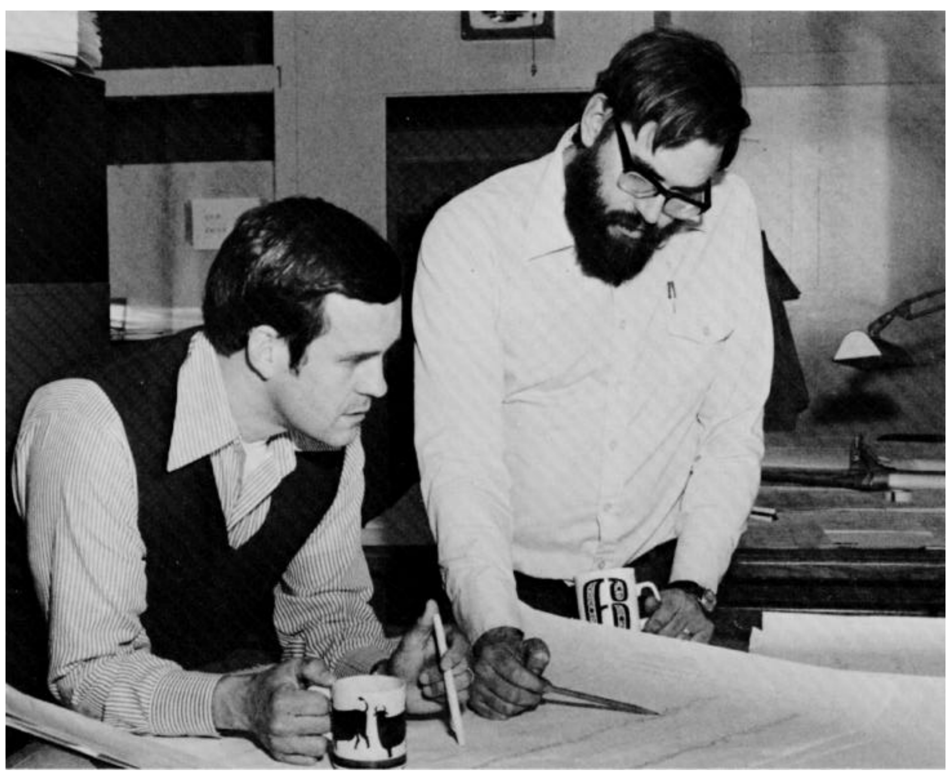
Over most of the world's oceans, the upper several hundred metres of water serve as a global heat engine. This water is warmed in the tropics then carried poleward by western boundary currents such as the Gulf Stream in the North Atlantic. At these higher latitudes, it loses its heat to the atmosphere then begins to move in the central and eastern parts of the ocean basins equatorward. This general flow and the role it plays in moderating climate particularly along the eastern boundaries of the various oceans has been taught in geography classes for decades.

The oceans, however, are on the average 4000 m deep. What role then does the water below the upper few hundred metres play in the distribution of heat globally? The upper ocean currents, at least for the North Atlantic, have been known since the 17th century through the observations of mariners. In contrast, the deep ocean was believed to be cold, motionless, and lifeless up to the last part of the 19th century. The development and use of the deep-sea reversing thermometer on the major oceanographic expeditions of the late 19th and early 20th centuries revealed a deep ocean consisting of a series of core layers defined by local temperature, salinity, or oxygen extremes in the vertical. Wust (1937) put together long longitudinal sections along the axis of the Atlantic Ocean. He traced a number of core layers on these sections and suggested that water types were formed in polar regions at the surface then sank and spread equatorward at subsurface depths. The movement of these deep water masses was believed to be quite slow. Their rate of renewal at the surface was also believed to be small (about 0.1 % of the total volume of such water being renewed each year).

Oceanographers believed that these water types were formed during winter by deep convection over broad areas within the marginal seas of the Atlantic Ocean. Deep convection occurs when the sea surface is strongly cooled by cold winds. The water at the surface both cools and becomes saltier due to heat loss and evaporation and becomes denser than the water below it. It therefore convects or sinks to the depth appropriate to its new density. As the winter progresses, the surface waters will get denser and convection will occur at greater depths. An area in which deep convection is occurring will be characterized by deep and homogeneous mixed layers whose temperature, salinity, and density are close to the appropriate values for the water types that are believed to be formed in that region. The fact that the few winter observations in these regions up to the 1970s showed no such deep mixed layers at the appropriate densities led researchers to propose other mechanisms by which deep water masses might be formed below the sea surface.

A series of winter observational programs in the western Mediterranean in 1969 revealed some of the complexities of oceanic deep convection (Medoc Group, 1970). These observations showed that the process took place in a very restricted geographic area and consisted of a number of events of small horizontal scale (a few kilometres). On the basis of these observations, oceanographers now believe that the areas of deep water formation are all very restricted geographically. The deep mixed-layers only lasted for a few days in the Mediterranean before surface water of lower density moved over top of them. Because of both the restricted geographical extent and short lifetime of deep water formation it is now believed that deep convection could have been operating and yet could have been missed by winter surveys in areas such as the Norwegian Sea.

The processes of deep convection and deep water renewal are studied for several reasons. Firstly, by measuring how much deep water is formed in any given year, one can develop the models needed so that the effects of deep water renewal can be parameterized in large scale climatic, atmospheric, and oceanic models. Secondly, it has been proposed that carbon dioxide can be removed from the atmosphere through deep water renewal. The amount of carbon dioxide that will be taken up by the newly formed deep water will depend on: (a) how fully equilibrated to the atmospheric carbon dioxide the newly forming deep water becomes as it is being cooled at the surface, and (b) how much subsurface water is entrained into the deep water as the newly formed denser surface water sinks to its equilibrium depth. To obtain such information, direct measurements must be made in regions where deep convection occurs.

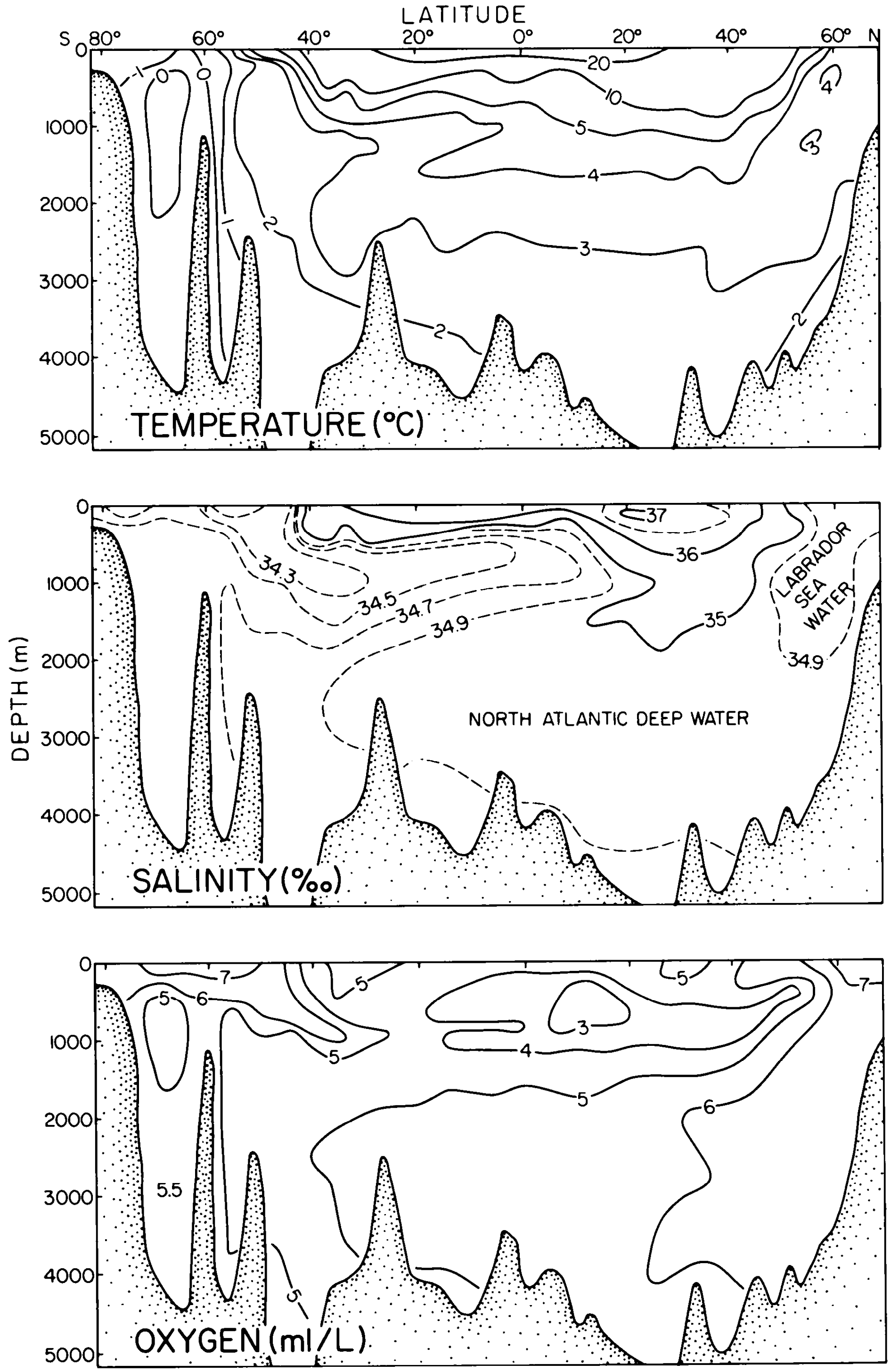


Peter Smith and Allyn Clarke.

Studies in the western Mediterranean Sea during the late sixties and early seventies, and our work in the Labrador Sea from 1976 to 1978 revealed a surprisingly similar picture of oceanic deep convection. Both share a similar oceanographic/meteorological environment. From the limited information available about the other regions of deep water formation, it would appear that such an environment is also present at these sites.

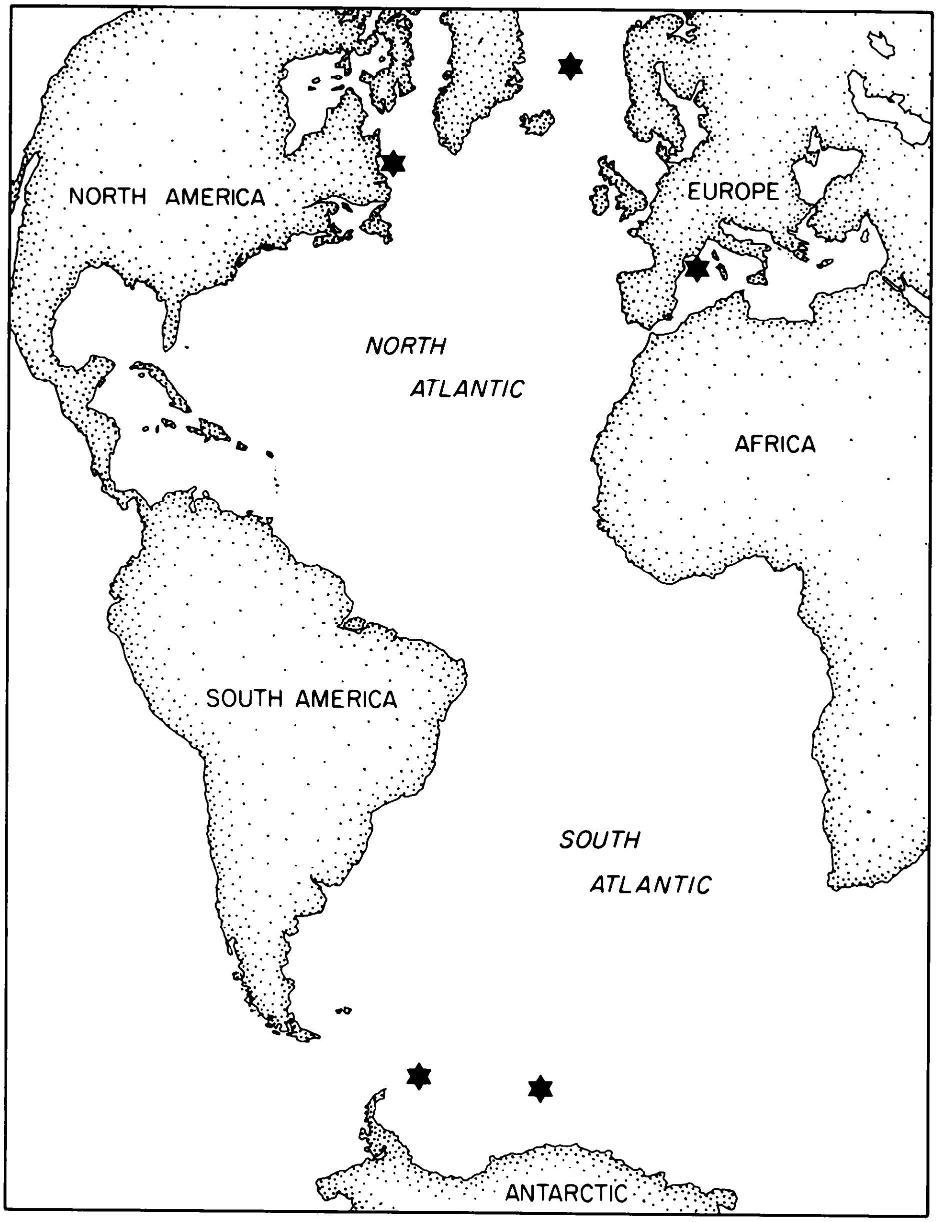
One characteristic of regions of deep convection is that they occur near the centre of a region of cyclonic circulations. Within such a circulation, the isopycnal surfaces dome upwards at the centre. This means that the deep density surface to which the newly formed water will sink is closest to the surface and hence less water must be cooled and mixed to the required density for deep convection to occur at these locations than elsewhere. These cyclonic circulations are present throughout the year; however, the initial stages of the deep convection process intensify the circulation by creating even denser water columns in their central regions. In the case of the Labrador Sea, a smaller cyclonic circulation forms around the renewal region in early winter. This circulation, named the western Labrador Sea winter gyre, lies within the cyclonic circulation about the entire Labrador Sea, and its development was proposed on the basis of observations made by CSS *Hudson* in the winters of 1976 and 1978.

A second feature of a deep convection region is that it contains warm, salty, subsurface cores of water around the edges of the cyclonic circulation. These cores are important because, when the surface layers cool and become as dense as the cores, the water in the cores is mixed into the new deeper surface layer. The incorporation of these cores makes the columns warmer and saltier but does not affect their density. The added heat is quickly lost to the atmosphere and this produces a column denser than its surroundings because it is saltier but not significantly colder. The fact that deep water renewal only takes place in the Atlantic Ocean is a consequence of the fact that the Mediterranean Sea provides the Atlantic Ocean with subsurface warm salty cores that are carried into the subpolar regions where they play this role in deep water renewal. In the Labrador Sea convection, these warm salty cores (at 500 to 1000 m depths) arise from the cooling and sinking within the Irminger Sea of even warmer salty water.



South-north longitudinal sections of water characteristics along the western trough of the Atlantic Ocean (after Wust, 1936).

The final characteristic of a deep convection region is that it experiences intense air-sea exchanges in winter. In these regions very cold, dry winds usually blow off a continent out over the adjacent water. In the western Mediterranean, such a region is the Golfe du Lion where cold winds blowing from the Alps and the Pyrenees are funnelled by river valleys into a local area. In the western Labrador Sea, there is a region north of the principal storm track where frequent and strong northwesterly winds blow off the Labrador Plateau and across the Labrador ice pack before encountering the open water of the Labrador Sea. With air-sea temperature differences as great as 25°C and wind speeds of 25 m/s or more, a very great deal of heat can be very quickly lost from the sea surface by conduction and evaporation.

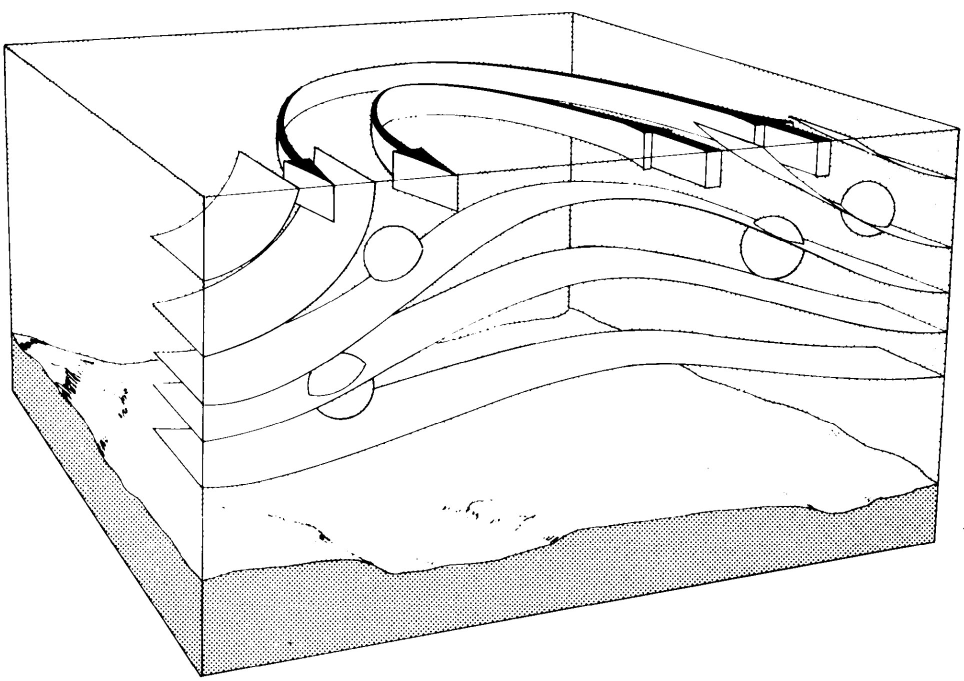


Sites in the world ocean where deep convection is believed to take place.

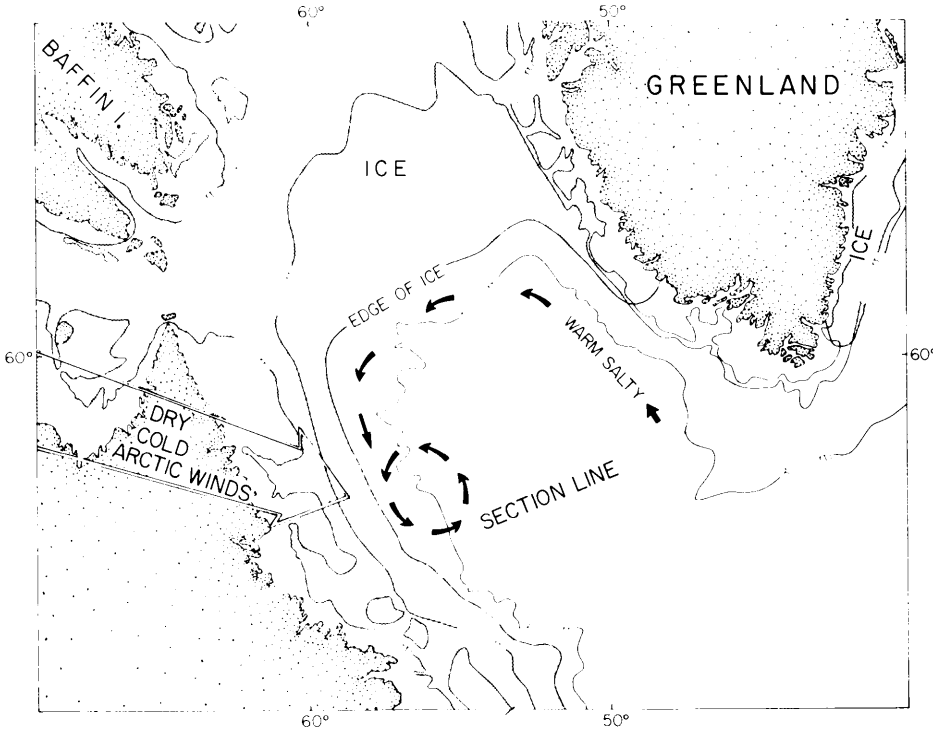
The circulation patterns set up in a region of deep water renewal are very complex. The largest scale of organization is the cyclonic gyres discussed earlier. In the western Labrador Sea, this gyre is some 200 km in diameter. Within it there appears to be an organization of both the current velocities and the water masses at a scale of 40-50 km. This is called the mesoscale organization, and it appears as an anticyclonic vortex. The water within the mesoscale vortex is generally denser, more homogeneous, and cooler than that outside; in particular, the depth of the mixed layer is considerably deeper within the mesoscale than without. Around the periphery of the mesoscale are found the warm, salty, subsurface cores. In fact, the principal role that the mesoscale is believed to play in the overall process is to mix these warm salty cores from the edges of the cyclonic gyre into its interior.

The setting up of the mesoscale structure has not yet been adequately modelled. We know that velocity disturbances of 40-50 km scale are propagating through the area in the form of planetary or topographic waves. Perhaps, as these waves propagate near the edge of the gyre interior, they precondition the water within their own interior to mix with this saltier water, cool, and form denser, more homogeneous blobs of water rotating anticyclonically even after the planetary wave itself has moved on.

These mesoscale blobs of water can be shown to be baroclinically unstable. Within such 40-50 km vortices, features at 10-15 km scale, which we call eddy scale features, form. The sense of rotation about these features is also anticyclonic. Like the mesoscale vortices, the eddy scale features, have much deeper, denser, and more homogeneous mixed layers within than outside them. The radii of these eddies is the Rossby internal radius of deformation. If, in a rotating fluid, one has a blob of water of greater density than the water at the same level around it, it will begin to spread laterally into the surrounding fluid. However, as it spreads outward,



A schematic depiction of cyclonic circulation in the Labrador Sea. The arrows depict the currents, the ribbons the doming of the isopycnal surfaces, and the balls the blobs of warm, salty water carried around the periphery of the circulation.

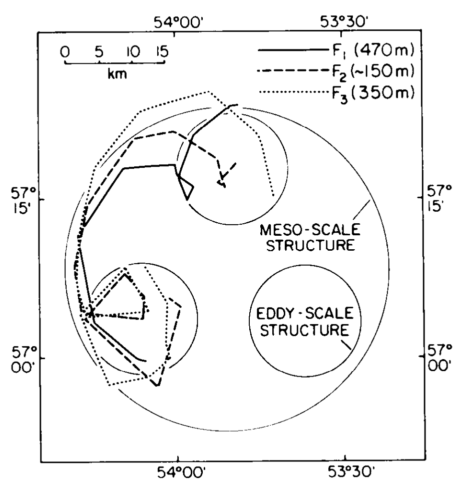


A schematic depiction of the development of a cyclonic gyre in the western part of the Labrador Sea from the combined effects of winter ice cover and northwesterly arctic winds.

the Coriolis force begins to turn the fluid in an anticyclonic sense. By the time the fluid has spread out a Rossby radius. its flow is entirely tangential about its original position and it will spread no further. One is left with a blob rotating anticyclonically in geostrophic equilibrium with its surroundings and only the slow processes of viscosity and diffusion act to slow it down and allow further spreading.

This is in fact what happens with the eddy scale features. Being quite stable, they provide a mechanism by which deep and dense mixed layers can remain in contact with the atmosphere for a considerable time. Thus they are able to continue to cool and become more dense. In the Mediterranean Sea, these eddies eventually penetrate to the ocean bottom. At this point. bottom boundary layers are formed and viscosity becomes much more important. The water within the eddies can be drained off by these bottom boundary layers and lower density surface layers can be re-established.

Within the deep convection area, a number of other processes take place that transfer water masses vertically. These processes are particularly important in moving the warm salty cores from their normal depth range of 500-1000 m to the near surface where they can participate in the air-sea exchange. Some of the processes are associated with the flow fields around the eddy and mesoscale features in analogy with the vertical motions induced in the atmosphere by flow around low pressure areas. Some of the processes are associated with internal waves in a fluid whose vertical density gradients are so low that the entire inertio-gravity wave band has collapsed to practically a single frequency. Other processes are associated directly with atmospheric forcing, with dense plumes of water sinking from the surface to their equilibrium depths. Vertical current meters have measured all of these processes both in the Mediterranean and the Labrador seas. The processes seem to take place on such short space scales (less than 1 km) and time scales (6-36 h) that it is hard to see how with existing technology one can collect enough information concerning their structure to properly model them. Thus, while we can measure how much deep water is being renewed in a given area over several weeks at the height of the cooling season, we cannot reliably measure the rate that surface water might be sinking to at the peak of an individual cooling event: this information is important to determine how long a parcel of water is likely to remain at the surface during an intense cooling event and from this to estimate whether newly formed deep water does in fact equilibrate with atmospheric gases before sinking.



The tracks of three neutrally buoyant floats (F_1, F_2, F_3) over eight days in March 1976 in the Labrador Sea are superimposed on a schematic depiction of the boundaries of the meso-scale and eddy-scale organization observed during the same period.

These conceptual models of deep convection were developed when the Labrador Sea data collected in 1976 showed such striking similarities to the early French, American, and British work in the Mediterranean Sea. In February-March 1982, CSS *Hudson* will attempt to measure the deep convective processes in the Norwegian/Greenland Sea. In this basin is believed to be formed the water masses which, after they flow into the North Atlantic Ocean, become the North Atlantic Deep Water and Bottom Water. The first of these water masses forms over half the volume of the entire Atlantic Ocean. It will be important to confirm that our simple conceptual models of deep convection will also apply to the Norwegian/Greenland Sea.

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The Cape Sable experiment

P. C. Smith

The continental shelf waters off southwestern Nova Scotia are among the most productive on the eastern coast of North America. Here are found the principal spawning sites for various demersal and pelagic fish (Colton and Temple, 1961), the largest commercial lobster catches in Nova Scotia, and the largest nonbreeding concentrations of seabirds in the northwest Atlantic (Sutcliffe et al., 1976). For physical oceanographers, this region is also rich in interesting but complex phenomena associated with the coastal circulation and local tidal regime. For instance, Bigelow (1927) was one of the first to recognize that

> The cold Nova Scotian current brings a large volume of water of low salinity into the gulf (of Maine) from eastward, past Cape Sable,. . . .

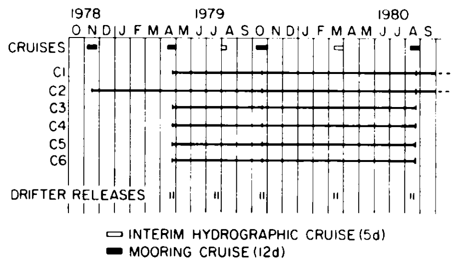
and that the flow is

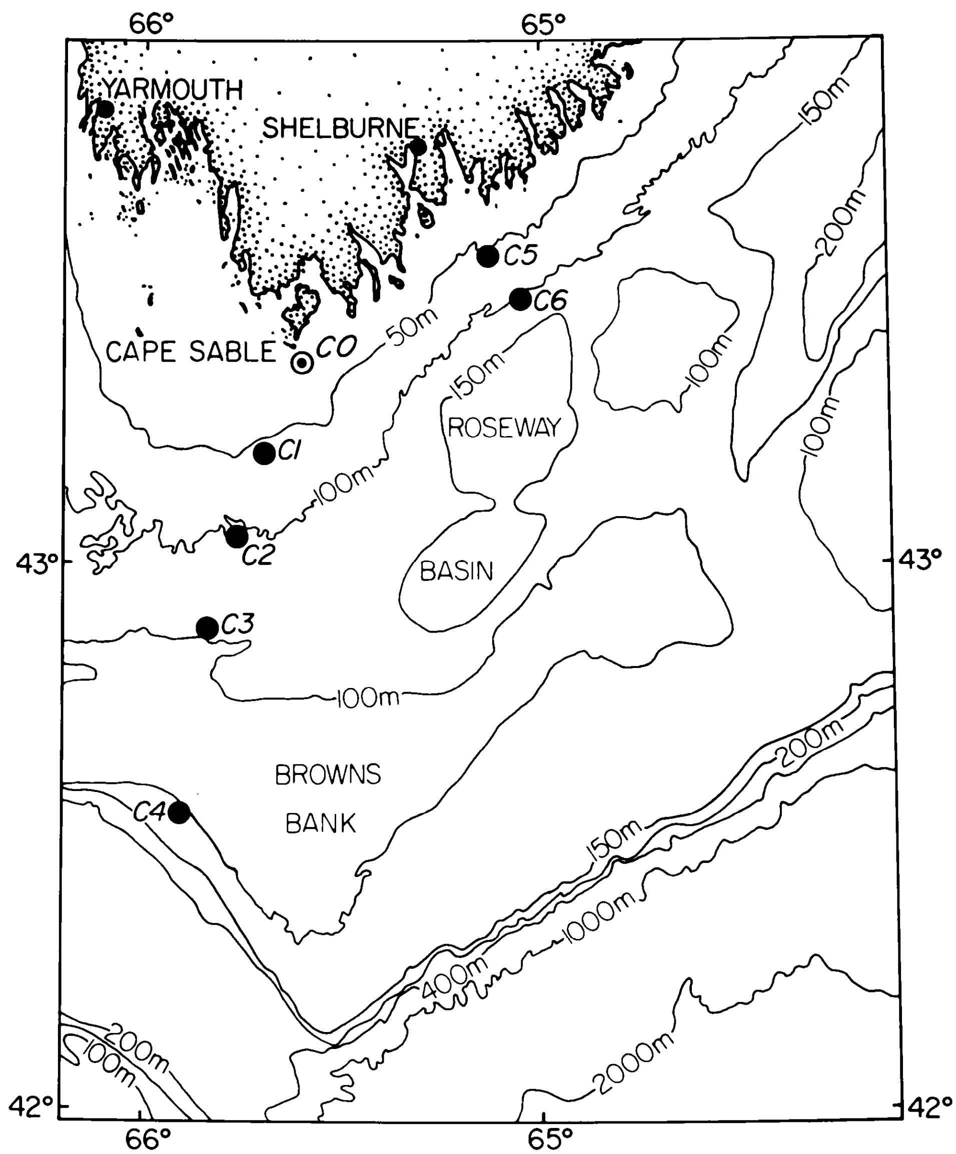
> . . . certainly the chief source that contributes cold water of northern origin to the Gulf of Maine - almost certainly the only source making a contribution of this sort sufficient in amount and cold enough to exert any appreciable effect on the temperature of the gulf.

The idea of an ‘oceanographic pathway’ stretching from the St. Lawrence estuary through the Gulf of Maine was later pursued by Sutcliffe et al. (1976, 1977), who demonstrated that at least 50 % of the fish catch fluctuations in many major commercial species are related to such environmental factors.

On a smaller scale, Lauzier (1967) first observed persistent coastal upwelling in which he could detect no seasonal variations. Examining various possible dynamical balances, Garrett and Loucks (1976) concluded that the most likely driving force is the pressure gradient associated with the tidal flow along the curving Nova Scotian coastline and therefore dubbed this circulation ‘centrifugal upwelling’. Another manifestation of the strong tidal streams is the existence, particularly in summer, of a sizeable zone of well-mixed water in the vicinity of Cape Sable, which is thought to reflect a local dominance of tidal dissipation over stratifying influences. lles and Sinclair (unpublished MS) have noted that the principal spawning sites for Atlantic herring in the Gulf of Maine lie within these well-mixed zones and speculate that the associated tidal residual circulation (including centrifugal upwelling) provides a physical mechanism for larval retention.

Considering the complexity of the factors affecting the circulation off southwest Nova Scotia, the multiplicity of hypotheses surrounding it, and its biological importance, the need for physical oceanographic input to the understanding of the system is obvious. First, a precise description of the velocity and density fields, including a definition of the all important temporal and spatial scales, must be provided, based on appropriate observations and measurements. In particular, it is necessary to separate mean and persistent seasonal fluctuations from sporadic and transient events. The measurements must also be used to quantify certain aspects of the circulation such as the strength, persistence, and vertical structure of the up-





Mooring array and original timetable for the Cape Sable Experiment. Moorings Cl and C2 have been maintained beyond August 1980 to the present and C0 has been recently deployed for the winter of 1981-82.

welling and the magnitude of the longshore transports of mass, heat, salt (or freshwater), and nutrients. Finally, it is essential to develop and validate dynamical models of the circulation in order to provide a conceptual framework for monitoring and interpreting changes in the regime.

To address these needs, the Cape Sable experiment was launched in November 1978. The mooring array consists of a line of four sites (Cl-C4) across the shelf at Cape Sable as well as two sites (C5, C6) off Shelburne, N.S., to monitor 'upstream' conditions. The major portion of the data set has been collected between April 1979 and August 1980; however, two of the nearshore moorings (C1, C2) have been maintained to the present for long-term monitoring purposes. Each mooring consists of at least three Aanderaa current meters at near-surface (15 m), mid-depth, and near-bottom (10 m above) locations. To carry out detailed studies of the tidal boundary layer for selected periods, six additional instruments were placed on the two nearshore moorings (Cl, C2) off Cape Sable and a third (C0) has recently been added. In addition to the moored measurements, hydrographic surveys were conducted as part of the mooring cruises and meteorological and sea surface temperature observations have been obtained from the Atmospheric Environment Service.

To date, much of the Cape Sable data analysis has been focused on defining the mean and seasonal components of the circulation. Comparison of the average velocity fields from three different seasons reveals several distinctive features of the overall mean circulation:

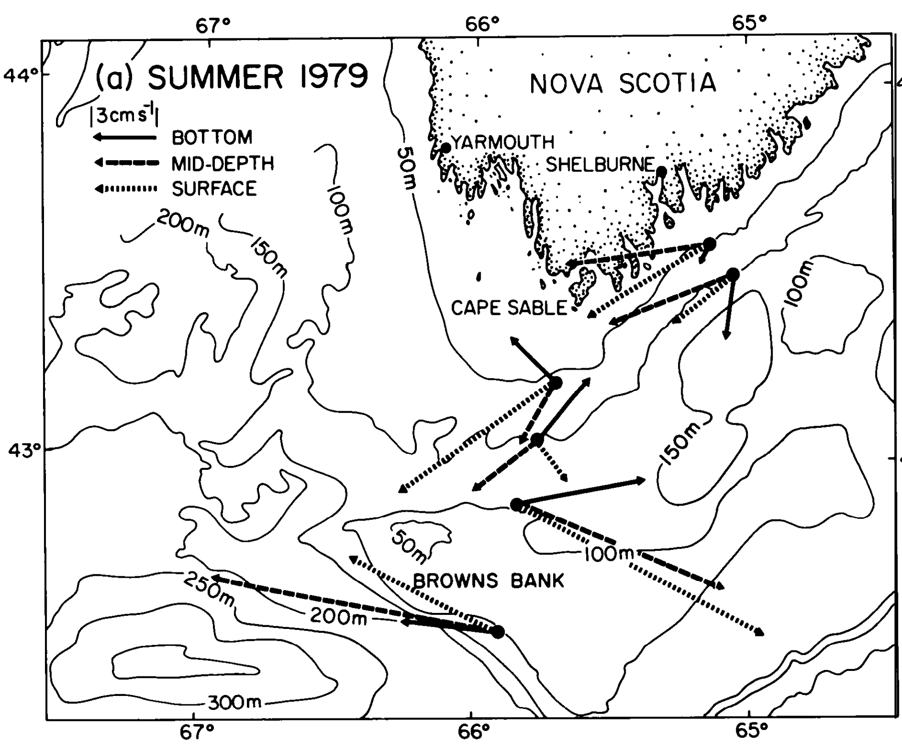
(1) an alongshore (southwestward) current component is found in the nearshore zone (i.e., within the 110-m isobath),
(2) the opposing currents at C3 and C4 suggest a permanent clockwise gyre around Browns Bank, which is also confirmed by some of the Lagrangian measurements, and
(3) the persistent, but radically different, vertical structures of the cross-isobath velocity component off Cape Sable and off Shelburne.

This last observation clearly demonstrates the 'centrifugal' upwelling phenomenon off Cape Sable associated with onshore bottom currents with offshore components at surface and mid-depth, as compared to offshore bottom and onshore mid-depth currents off Shelburne. The Browns Bank gyre, on the other hand, is an entirely unexpected result that suggests strong topographical control of the circulation.

Some of the seasonal features of the circulation may be detected by comparing the two summer patterns to the winter regime. For instance, the winter inflow to the Gulf of Maine at the two moorings off Cape Sable is stronger (6 to 20 cm/s) than in summer and extends to the bottom on the 110-m isobath, where it apparently defeats the upwelling circulation. The character of the inflow, as illustrated by the filtered near-surface records on mooring C2 during the winter of 1979-80. is not smooth variation but rather a succession of pulses, some of which are clearly associated with the arrival of sharp fronts in the surface water mass. The magnitude of these thermal discontinuities (3 to 4°C) ought to permit synoptic observations of these events using properly enhanced satellite infrared imagery, provided cloud-free coverage is available.

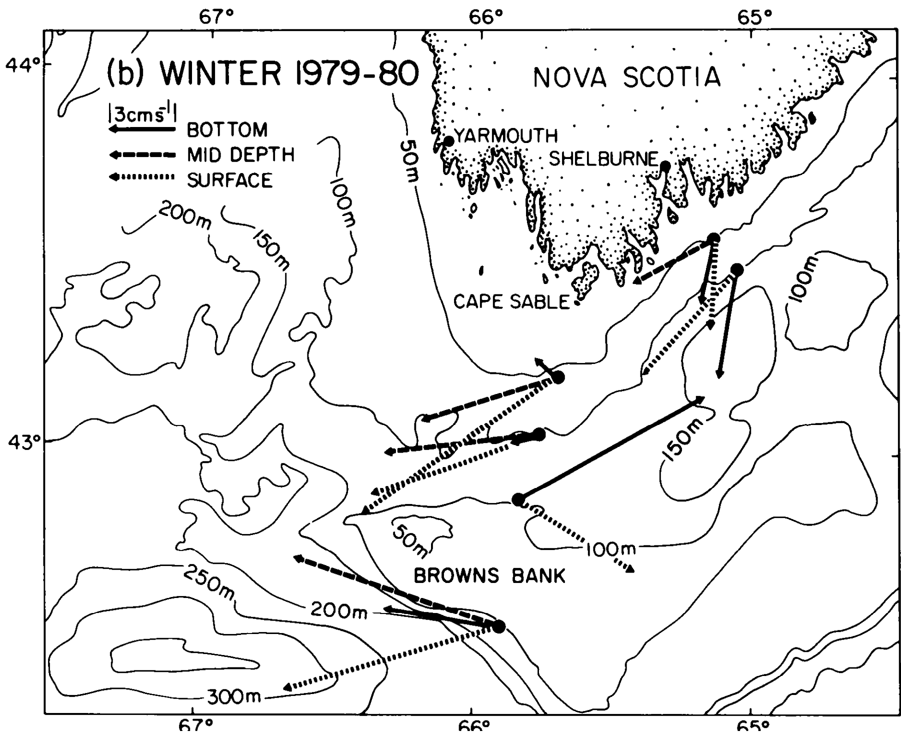
Much of the irregularity in these records may be removed by considering time series of monthly mean values, which may then be used to quantify the important seasonal variations. Monthly mean longshore currents, for example, may be used to estimate variations in the transport through the Cape Sable section, assuming each normal velocity represents roughly the same fraction of the total cross-section (except on the shallower Cl mooring). Despite large estimated errors (and poor resolution), the seasonal cycle is clearly defined in the first year's data, with a minimum in late summer and a maximum in winter. On an annual basis, the average measured transport is consistent with budget requirements (Hopkins and Garfield, 1979) for Scotian Shelf water based on seasonal water-mass analysis in the Gulf of Maine and also with two years of geostrophic computations (Vermersch *et al.*, 1979). Furthermore, preliminary comparison of annual average Cape Sable transport with contemporaneous measurements collected by U.S. scientists indicates that the sum of inputs from the Scotian Shelf and deep portions of the Northeast Channel is roughly balanced by the outflow on the New England Shelf. This suggests that net losses of shelf water to the offshore by processes such as entrainment by Gulf Stream rings may not be as important to the overall mass budget of the Gulf of Maine as previously considered.

Another interesting aspect of the monthly transport computations is that the estimates from the two inshore moorings alone are nearly equal to the total net transport through the section. This result implied that the Browns Bank gyre is basically a closed circulation that makes no

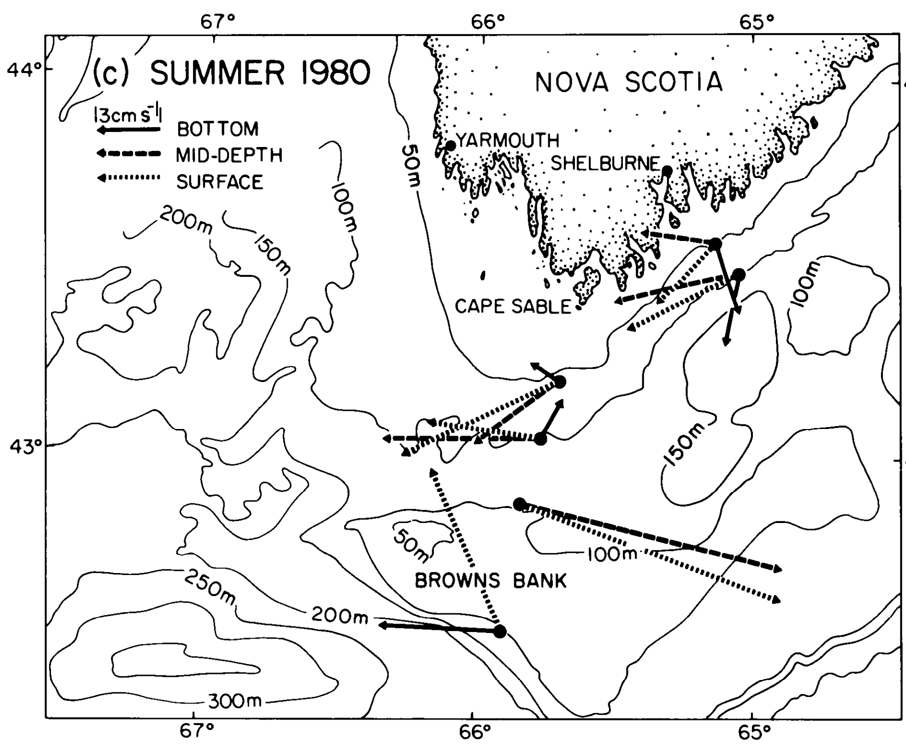


Seasonal mean velocity pattern for: (a) summer 1979 (April-October) significant contribution to the *mass* balance in the Gulf. Hence the major portion of the seasonal inflow may be effectively monitored by instruments placed only in the nearshore zone off Cape Sable.

From a dynamical viewpoint, it is important to note that the least-squares analysis of the Cape Sable monthly mean data reveals very strong seasonal cycles in temperature (6 to 10°C, total range) and salinity (0.8 to 1.4 ‰) with consistent phase lags of 7 to 9 months at all sites in the Cape Sable array. The temperature variations are governed primarily by solar input and winter cooling, but for salinity, which controls density, advective effects such as the arrival of the fresh water from the Gulf of St. Lawrence, clearly dominate. Moreover, when longshore advection is combined with regional variations in tidal mixing and/or residual circulations, it is possible to set up horizontal density gradients that, in turn, are in balance with the mean and seasonal circulation patterns. Csanady (1976) has formulated a simple linear diagnostic model for the mean circulation in shallow seas that includes bottom friction, surface wind driving, offshore density gradients, and an alongshore pressure gradient impressed on the shelf by the deep ocean. This model has been modified to include longshore density gradients and is presently being used to investigate the Cape Sable data set. Preliminary results suggest that longshore pressure and density gradients are of prime dynamical importance, at least in summer. The former is responsible for the southwestward longshore current near the coast in opposition to the mean wind stress, whereas the latter, acting up the Scotian shelf, produces a flow reversal offshore similar to that associated with the deep current on the C2 mooring and through the water column at C3. In contrast, the structure of the velocity field off Shelburne may be accounted for by invoking only the longshore pressure gradient, which is consistent with its displacement from the strong tidal mixing regime. Future plans include the development of more sophisticated diagnostic models, whose main advantage lies in providing an interpretation of the dynamical balances supporting an observed circulation without having to consider the details of its evolution. These calculations will then be compared to results of nonlinear tidal residual flow models in an effort to establish the dominant driving mechanism(s) for the circulation.



(b) winter 1979/80 (October-March)



(c) summer 1980 (March-August)

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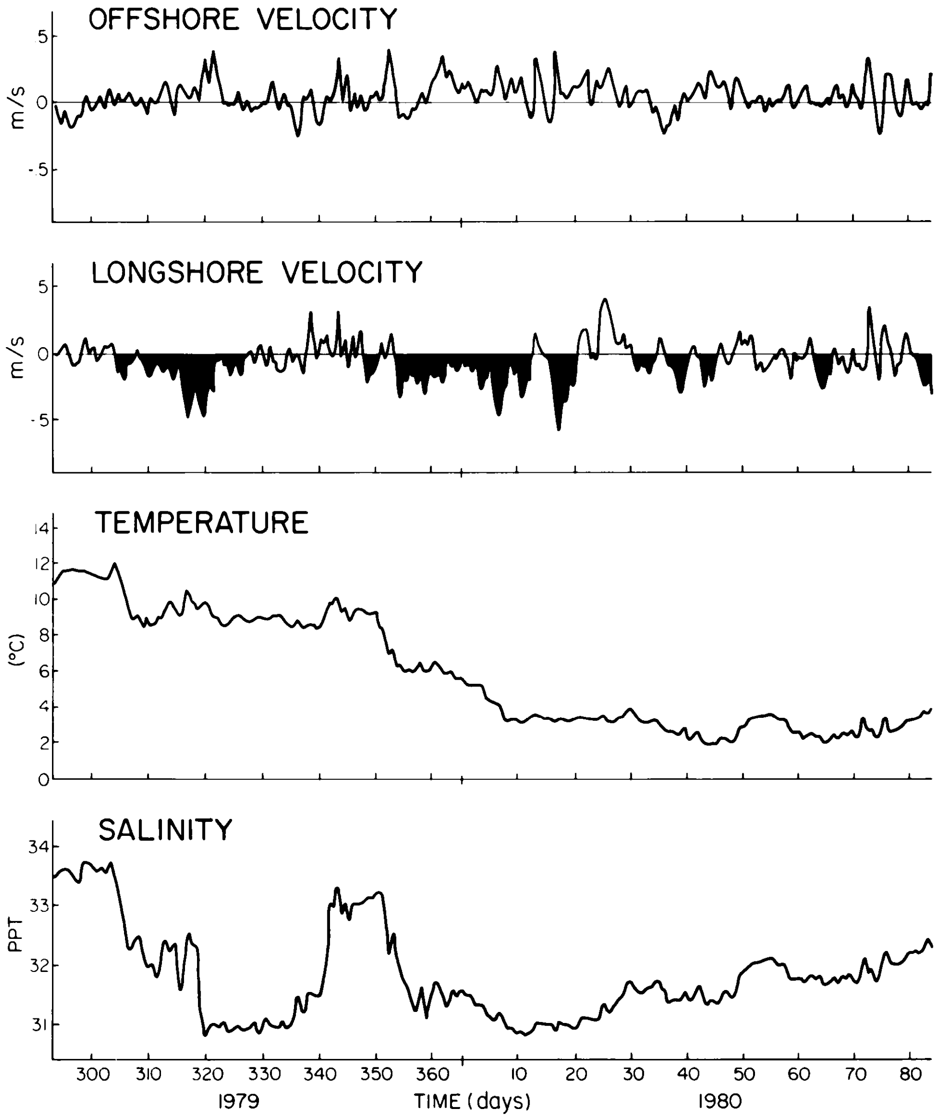
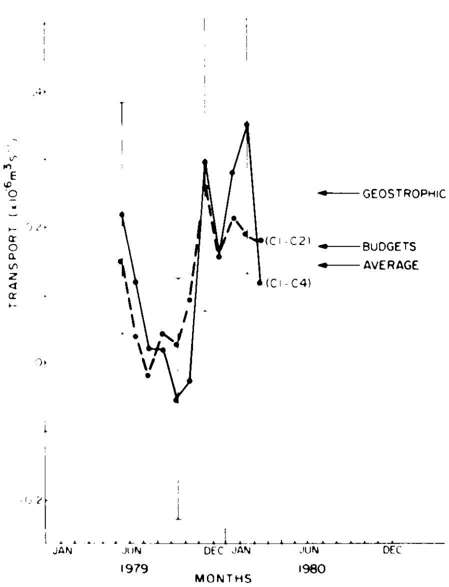


◄
Filtered records of offshore and longshore velocity components, temperature, and salinity for the near-surface instrument at C2 during winter 1979/80. Velocity components have been resolved such that the positive longshore current is directed at 104°T (true) so that darkened lobes represent episodes of flow into the Gulf of Maine.



◄
Volumetric transport through the Cape Sable section during 1979/80. Positive values represent flow *into* the Gulf of Maine; solid curve for moorings C1 to C4, dashed for C1 and C2 only. Annual averages for measurements (0.14×10^6 m^3/s), budget requirements based on seasonal water mass analysis (0.17×10^6 m^3/s), and geostrophic computations from earlier hydrographic data (0.25×10^6 m^3/s) are indicated. Error bars are based on the standard errors in the monthly mean velocity measurements.

Tidal mixing at the shelf edge (or how to hunt the soliton?)

H. Sandstrom and J.A. Elliott

One of the fundamental problems concerning continental shelf biology is how the nutrient supply necessary to sustain the observed primary production can be maintained. On the Scotian Shelf, the primary supply of nutrients probably comes from deeper waters off the shelf so that high phytoplankton and zooplankton production on the shelf requires that deeper waters beyond the shelf break be able to mix with the shelf's surface water.

The shoreward flux of nutrients at depth can be explained in terms of subtidal transports, such as wind-driven flows and offshore forcing effects (Smith, 1978), but vertical mixing is required on the shelf to explain the observed nutrient concentrations in the euphotic zone. There is also evidence (Fournier et al., 1977) that increased nutrient input and therefore increased vertical mixing take place in the shelf-slope region. They suggest that mixing may accompany the shelf-slope front, but Smith (1978) estimates that the frontal mixing processes are at least six times less efficient than large-scale low-frequency events.

We carried out an experimental program at sea to examine the connection between turbulence and tidal currents at the edge of the shelf to determine if tidal mixing could be a mechanism for the vertical transfer of nutrients, and how it would compare with such mechanisms as mixed layer deepening as a result of surface wind stress (cf., Smith *et al.*, 1978).

The exact linkage between internal waves and turbulence is not known, but internal wave energy may be converted to turbulence by shear and convective (overturning) instabilities. The energy of the internal tide is high on the upper slope and near the edge of the shelf, and the conditions for baroclinic shear instability are favourable. Petrie (1974) showed that baroclinic tidal energy was largely absent about 15 km shoreward from the shelf edge, which suggests that dissipation near the shelf edge is high.

We planned our first field experiment as a test of the linear (i.e., small-amplitude) model of the M2 tide. We were hoping to examine our observations for a correlation between tidal phenomena and smaller scale events to see if such small structure, including turbulence, was modulated at tidal periods.

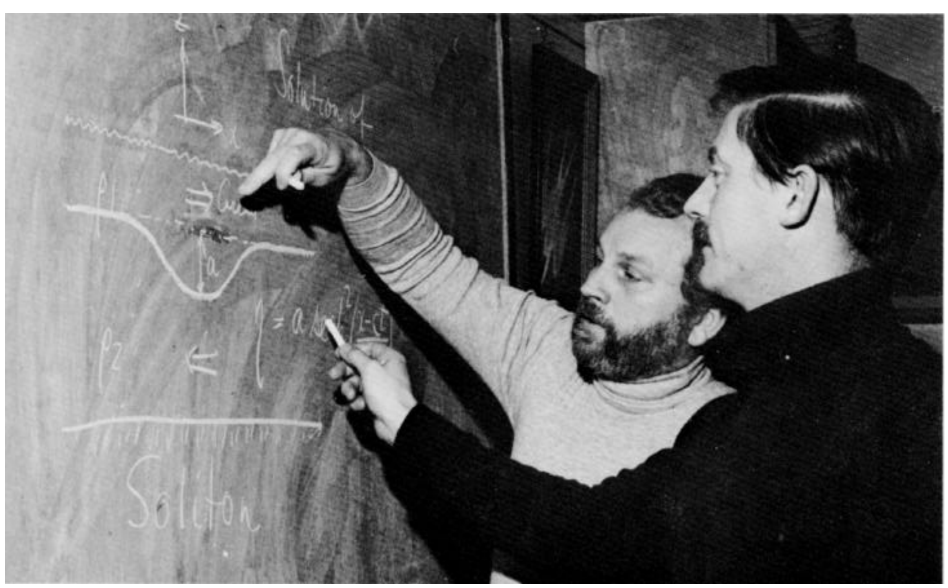
Our first experiment covered a rectangular area roughly 50 km across the slope and outer shelf and 25 km along the shelf edge. Our work consisted of a CTD survey of the whole area followed by a detailed study of water structure near the centre of the rectangle at two moorings that were located at 4 and 10 km inshore from the shelf edge, and consisted of current meters and thermistor chains. During the survey we yo-yoed the CTD at successive sites over at least one tidal cycle per site. At some sites a sequence of CTD, OCTUPROBE, and Profiling Current Meter casts was made, although strong winds hampered some of this work; data on sonic scattering layers were collected with two acoustic echo sounding systems operating at 12 and 120 kHz.

During the cruise, a first examination of the CTD data indicated that our preconception of the shelf edge dynamics was grossly inadequate. Beams of baroclinic energy were not apparent and we saw that the base of the surface mixed layer contained most of the activity. This was confirmed by a subsequent thorough examination of the data set. Although a passing storm in the middle of the cruise caused a change from a mainly tidal to a mainly inertial regime, the fact remained that the main current shear appeared across the base of the mixed layer with large vertical displacements and bursts of microstructure activity. The non-linear nature of the baroclinic tide became evident to us, but it was also obvious that we were not able to follow the evolution of its non-linearity with the methods we had used.

On a second cruise to the same area we used the Batfish (a towed body that cuts a vertical saw-tooth pattern through the water as the sensors mounted on it measure pressure, temperature, and salinity) as the main observational tool. The hydrographic properties during the two cruises, which were almost one year apart, were similar, with the surface mixed layer well developed to a depth of approximately 40 m. No evidence of the shelf-slope frontal activity could be found and the density field was horizontally uniform.

Three 15km sections each of at least 12.5-h duration were traversed with the Batfish and echo sounders from the upper slope across the shelf break to approximately 40 km onto the shelf in order to describe the steepening of the baroclinic tide near the shelf break and its subsequent evolution as it propagated across the shelf.

Watching the acoustic record, we began to see features in the scattering layers that indicated the presence of numerous internal instabilities. The internal wave field was sporadic, with short waves of generally less than 10-m amplitude. On other occasions, however, we saw large vertical



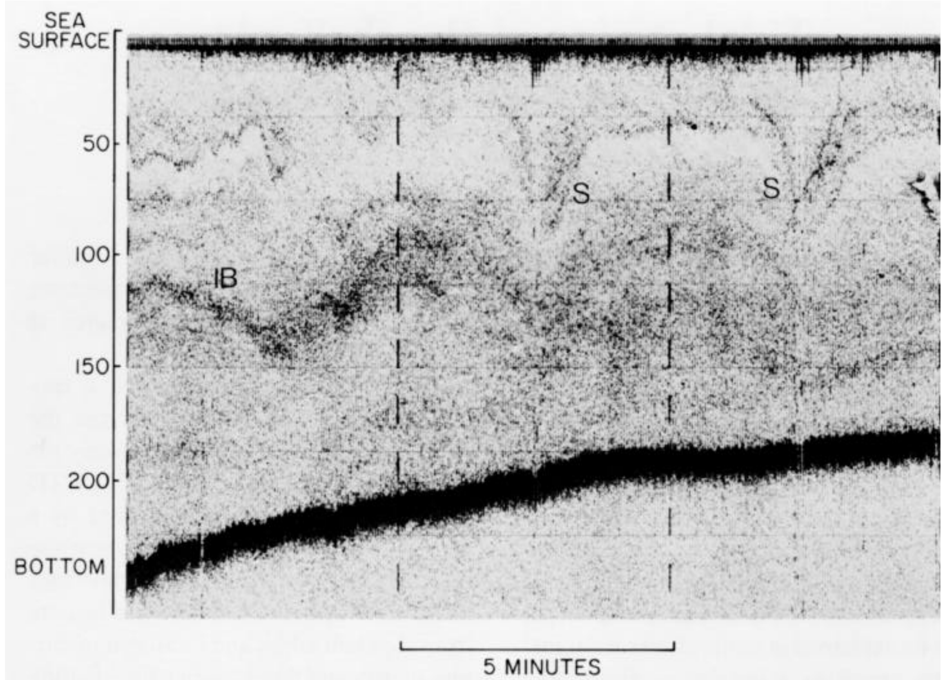
Hal Sandstrom (at left) and Jim Elliott.

displacements, which we identified as internal bores or hydraulic jumps, together with what appeared to be solitons - solitary waves of a kind previously only observed with certainty in experimental wave tanks. On at least two occasions we observed an internal bore and a soliton seemingly emerging from the bore front and propagating away from it. We believe we were watching a soliton being born, perhaps the first that has been so observed.

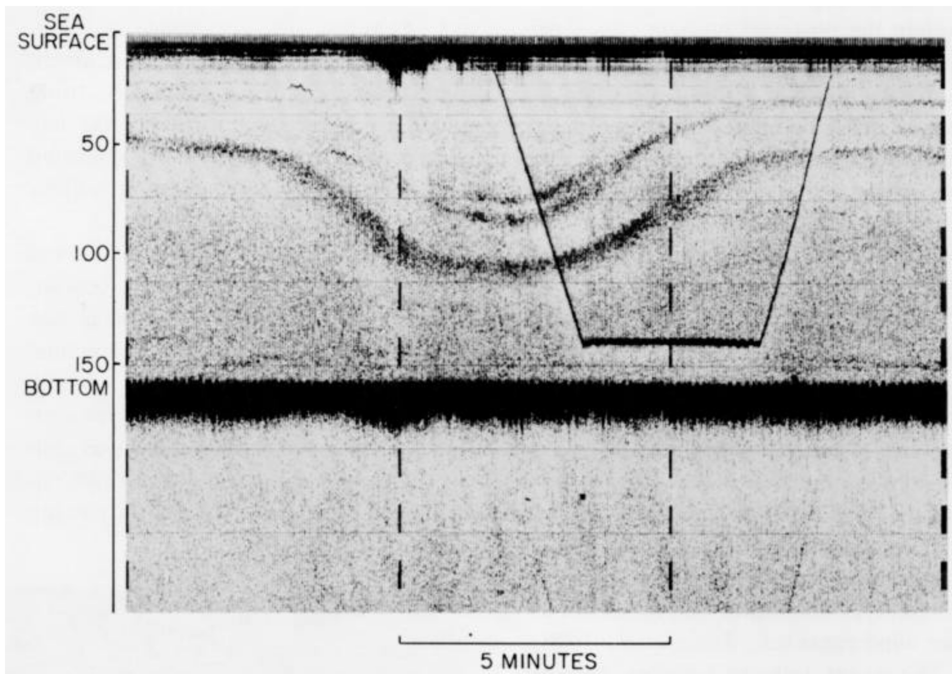
With the completion of our systematic survey, we went hunting for bores and solitons with the Batfish and acoustic system; we tracked them to determine their speed of propagation and duration by having the ship continually retrace its track along the sections.

We plotted all the sightings of internal bores and solitons in terms of cross-shelf co-ordinates and time of high tide in Halifax. During 19 semi-diurnal tidal cycles, we plotted 41 separate sightings, of which about half are clearly or probably solitons. They appear to have a propagation speed of approximately 2 knots. Bores and solitons first appear near the shelf edge at the beginning of the flood tide, propagate northward over the shelf for less than 30 km, and disappear. Only one doubtful soliton was seen more than 30 km from the shelf edge, and none were seen over the slope. When individual solitons were identified and tracked, they seemed to dissipate and be lost over about 10 km.

From these observations we offer the following tentative analysis of the internal tide near the shelf break: during the flood tide, the interface between the mixed layer and the denser water below is depressed over the top of the slope and shelf edge, due to the baroclinic adjustment of the flow as it crosses the slope. On the shelf, the front of the depression steepens and develops undulations in the rear due to dispersive effects. This can lead to an internal bore, which in turn may provide at times the proper milieu for propagation of one or more solitons. The solitons travel somewhat faster than the bore, which travels at essentially the same speed as small amplitude internal waves. As the solitons separate from a bore, they remove a large portion of its energy. The energy in the soliton is then dissipated gradually as it propagates across the shelf. Whatever the details of this dissipative process are, the net effect is the internal tide acting as a source of energy for stirring and mixing. Moreover, we can estimate the energy that a soliton carries, and from the rate of disappearance of solitons we can also estimate the rate at which this energy is available for mixing.



An internal bore (IB) at the edge of the continental shelf with two escaping solitons (S).



A soliton on the shelf; depth = 160 m. The “bucket’* is the CTD trace.

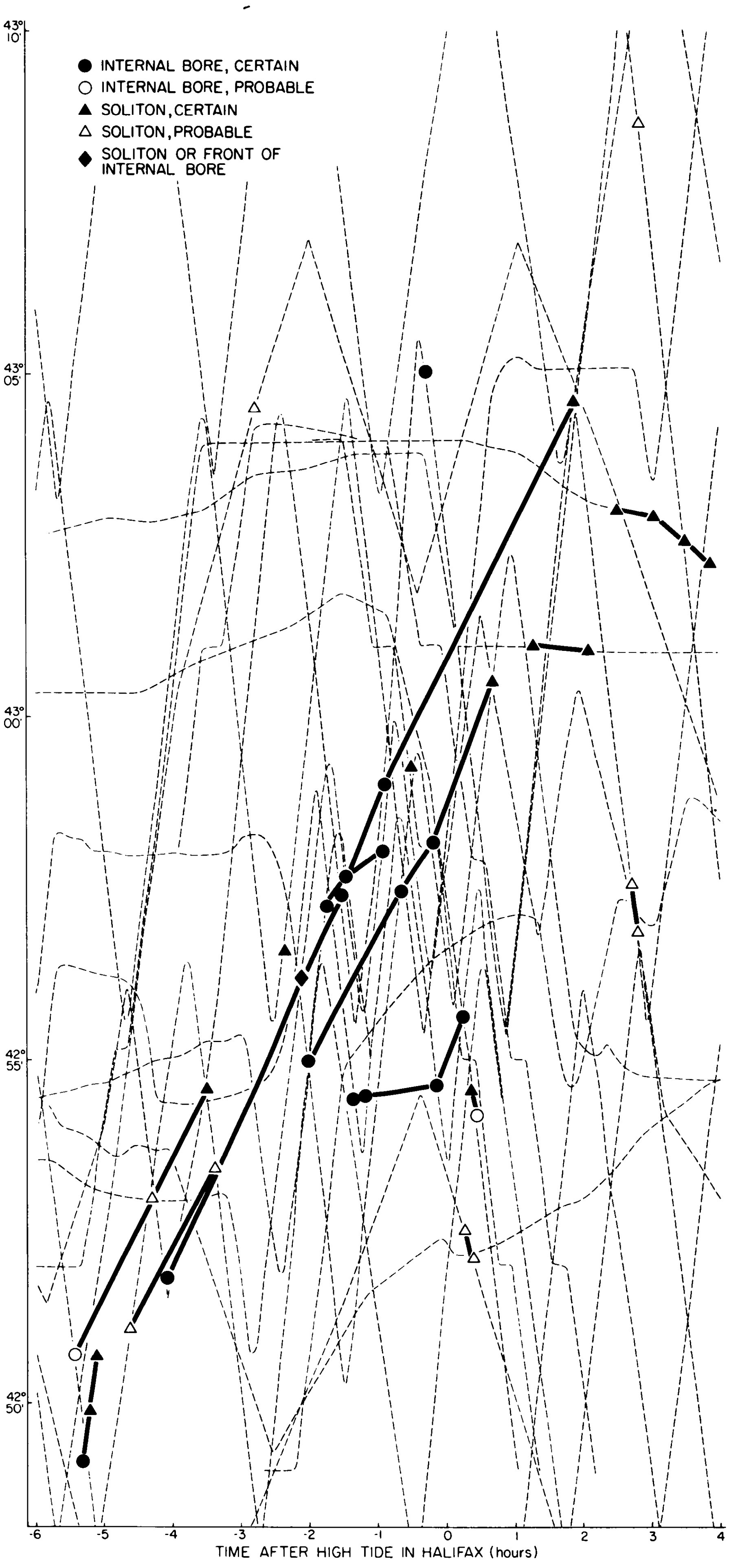
The solitons had amplitudes of about 25 to 60 m, and were characteristically 500 to 1000 m long. They seemed to dissipate in about 10^4 s, or in a distance of about 10^4 m at a propagation speed about 1 m/s. Basing our estimate on a soliton with *50-m amplitude and 1000-m length,* and using the observed density difference in the two-layer system of $\Delta\rho$ = 3 kg/m^3, we obtain the total energy of the soliton as about 10^8 J/m and dissipation as about 1 W/m^2. Perhaps a more conservative estimate is 0.1 W/m^2, after the dissipation is spread over a tidal cycle.

Part of this energy goes into *in situ* mixing of the water column resulting in increased potential energy, and part goes into production of turbulence in the form of kinetic energy. The ratio of the two in the ocean has been estimated to range from a few per cent to perhaps as high as a third. If we adopt the 0.1 estimate (e.g. Osborn, 1980) we have about 10^{-2} W/m^2 available to erode the base of the mixed layer. As a comparison, Denman's (1973) model of mixed layer erosion with a 10 m/s wind blowing at the sea surface yields about 2 x 10^{-3} W/m^2 at the base of the mixed layer.

A storm in the middle of our first cruise led to strong inertial motions in the mixed layer. We recorded inertial currents of about 0.3 m/s after a period of 50-knot winds. If we assume that the currents are uniform in a 100 m layer and that the energy is supplied during one inertial period, energy flux through the sea surface is about 0.1 W/m^2, or equal to the soliton dissipation. Thus, if our observations are typical for this region of the continental shelf, mixing due to the baroclinic tide is estimated to be equal to, or more important than, energy supplied by storms.

Petrie (1974) estimated the energy flux in internal tides as 8 x 10^2 W/m for the Scotian Shelf and Slope system, though estimates for other sites are somewhat smaller. Our calculation of energy dissipation for the soliton exceeds all the published estimates of energy flux in internal tides and, because this energy is available on the shelf, it is especially significant.

We conclude that the instabilities including internal bores and solitons associated with the baroclinic tide are energetic enough to be the primary mixing mechanism near the edge of the shelf. They extend perhaps 20-30 km inshore from the shelf edge, and also along the periphery of the fishing banks on the shelf.



Space-time plot of sightings of internal bores and solitons on a background of the ship's track.

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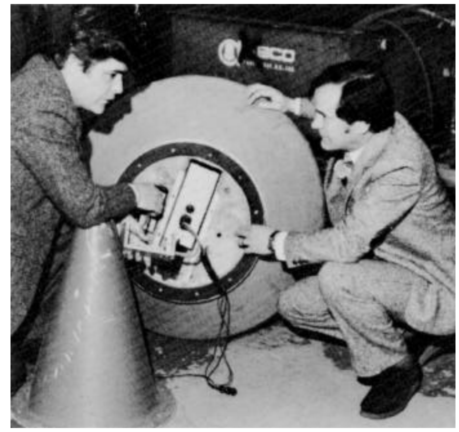
Real time data transmission via satellites

G. Fowler, J.-G. Dessureault, and J.A. Elliott

Traditionally information about the oceans has been gathered either in real time by actually going out on ships to make measurements or by leaving moored self-recording instruments in place to recover data over an extended period of time. The former method, although allowing the greatest flexibility in type, quality, and location of measurements, is very expensive and normally limited in duration to a few weeks. The latter, although it offers the possibility of obtaining continuous time series data for a more limited range of parameters at a fixed location, is risky because all or part of the data may be lost due to equipment failure or destruction.

Recent advances in satellite communication technology, which permit data acquisition from small surface buoys, can augment the collection of data on the oceans by combining the advantages of real time data gathering with the longer term characteristics of moored systems. More importantly, however, the near immediate nature of the transmission system allows studies or activities to be completed that heretofore have been impossible. Specifically, it is now possible to monitor oceanic processes virtually as they occur; this improves forecasting ability or permits a response to observed changes. An interesting additional advantage of the ability to 'see' data as it is collected is evident when it is necessary to operate in an area where there is a high risk of equipment loss due to, for example, sea traffic or ice. Although there is no real difference in the loss of a satellite buoy or a self-recording system in a physical sense, at least the researcher is in possession of the satellite transmitted data up to the point of failure whereas the recovery of self-recorded data is unlikely. Because the data transmission infrastructure is continuously in place, one can take advantage of it to quickly deploy a transmitting platform to deal with an emergency such as an oil spill.

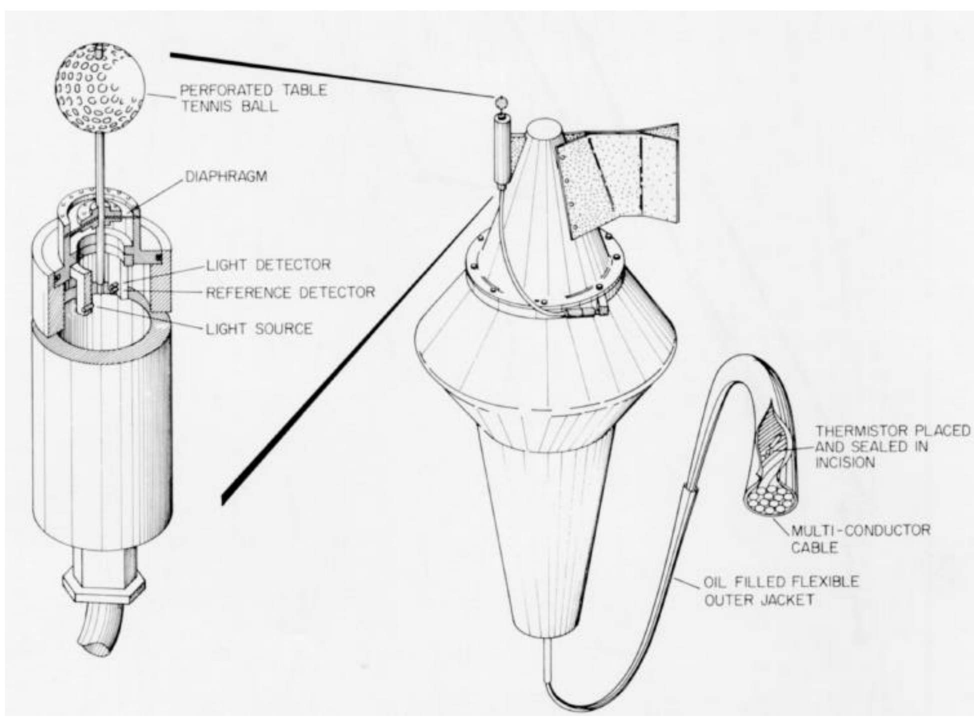
The manner in which the physical oceanographer is capable of taking advantage of the system is largely dependent upon the availability and type of sensors that may be successfully integrated with these platforms. Much effort has been expended in Canada and other countries in the application of this technology to, largely but not exclusively, atmospheric studies. Programs of a global nature such as FGGE (First GARP Global Experiment) or STREX (Storm Response Experiment) (Kerut, 1981) in the northern Pacific have taken advantage of these relatively low cost systems. Satellite buoys typically carry sensors to measure air temperature, barometric pressure, surface water temperature, and subsurface temperature. In practice, the buoys are deployed in the area of interest in a tethered or free drifting mode to measure and transmit continuously updated data on a preset schedule. These signals are picked up by satellites capable of storing the data and retransmitting it to a ground station where buoy location (for drifting buoys) may be calculated and forwarded with the measured data to the user. Several buoys of this type have been developed by private firms throughout the world including Hermes Electronics Ltd. of Dartmouth, N.S. (under the Canadian Ocean Data System - CODS - program); they have proven to be highly



George Fowler and Jean-Guy Dessureault.

successful and reliable. To expand the usefulness of the systems in an oceanographic sense, effort is being expended on the development of new sensors and on studying the actual drift characteristics of buoys.

To assist the physical oceanographer in studies of the upper layer of the ocean, temperature information is being sought with the aid of thermistor chains attached to satellite communicating buoys (Beacht, 1981; Albrecht, 1981). Several attempts have been made to design a successful chain attachment to a surface following buoy (including a design completed as part of the CODS program) but these have suffered from premature failure. A common difficulty in designing a reliable system is the attachment point between the buoy and the chain. Continuous motion of the buoy



Satellite-data transmission buoy showing details of the anemometer and thermistor chain.

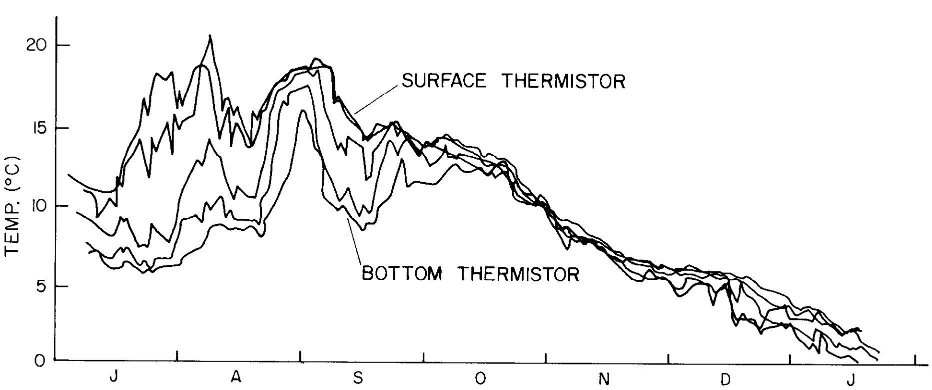
in response to surface waves places inordinate flexural stress on any electrical connection suspended beneath the buoy. Using the failure analysis performed on the original CODS thermistor chain buoys, an alternate method of attachment was developed within BIO and evaluated for use in the open sea.

The design chosen to reduce attachment difficulties involves the separation of the thermistor string cables and the mechanical connection between the buoy and a drogue, if used, or a mooring line. To reduce the cost of the system, the design incorporates 'off-the-shelf' components. The assembly consists of a multiconductor, plastic-insulated, electrical cable in which miniature bead thermistors are inserted in incisions made at desired points. The cable is then fed through a nylon/polyurethane hose equipped with metallic end fittings and the interstitial space is vacuum filled with oil. On deployment, the only stress on the conducting cable is that imposed by its own weight in oil. The damaging flexing action near the attachment to the buoy is reduced by bend limiters applied to the outside of the hose.

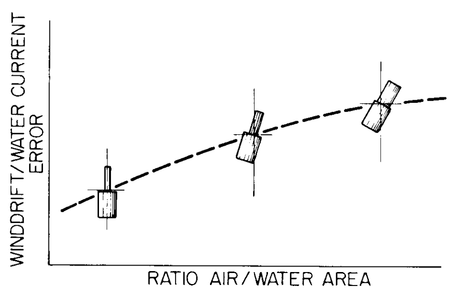
Field trials of the system have consisted of two experimental moored deployments of 25-m systems for periods of six and five months in Bedford Basin, N.S. In both cases the buoys had to be removed because ice cover threatened serious damage to the system. Both units transmitted 8 channels of data at 55-s intervals using standard satellite-link transmitters on a direct radio link with BIO, and this permitted us to keep a close watch on the system's survival. The first unit operated from July 1980 to January 1981 carrying eight temperature sensors. The second operated from August 1981 - January 1982 with an extended suite of sensors, including a transducer, at the bottom end of the chain.

One operational field trial of a 10-thermistor, 75-m long chain was made on a slack mooring on Flemish Cap off Newfoundland in 200 m of water for a period of 67 days in the spring of 1981. Although design studies had indicated that chain failure would most likely occur at or near the buoy attachment point, the one thermistor in this area survived while those located at 30 and 20 m failed after 10 and 47 days respectively. Unfortunately, the chain was cut a short distance below the buoy during the scheduled recovery so that no information is available on the cause of failure of the temperature sensors or their associated conductors. A problem has subsequently been detected with the compatibility of the oil used with the electrical insulation in the chains and steps have been taken to alleviate this difficulty. Nevertheless, further evaluation trials are required.

The second mooring in Bedford Basin also carried a novel single-axis thrust anemometer, and in addition had the capacity to record the associated wind direction. The wind force on a ping-pong ball target is transmitted via a compliantly supported vertical beam to an optically coupled device that measures the deflection of the opposite end of the beam. The restoring force in the beam mounting closely resembles the square-law relationship of the wind force/speed relationship. This significantly improves the range of possible wind measurements. A vane attached to the buoy above the water line keeps the buoy lined up with the wind so that wind direction is available through an internally mounted compass. The wind



Thermistor chain data for Bedford Basin (July 1980 to January 1981) acquired using a moored 25-m chain attached to a Hermes' satellite buoy.



Qualitative representation of error encountered for cylindrical buoys of varying air/water frontal area ratio. The observed non-linearity is due in part to the variation in shape and frontal area caused by tilt of the buoy.

direction sensor performed adequately throughout the test period but the wind-thrust sensor failed after a few days of operation due to electronic circuit deterioration caused by condensation. A solution to this problem is available, and it is expected that an improved system will be tested during the 1982 field season.

Another area of concern to the researcher is the magnitude and direction of currents at the surface, their effect for example on the motion of oil, and the ability to track oil patches in real time. The drifting buoys, as presently conceived, are designed to track subsurface currents using drogues deployed at depth. Converting the role of a conventional surface drifter to an oil-tracking device where the oil is possibly in lumps or tar balls is of questionable value because of the effect of wind forces applied to the buoy above the waterline. For this reason extensive work has been done on the commercial development of buoys for this application. However in an attempt to understand the forcing processes and their effects on the drift characteristics of buoys, a series of buoys with different above-water profiles but the same underwater profiles have been built and tested. A helicopter-based photographic survey system has been developed to map the movement of these various buoys in Bedford Basin and it is expected that tests in the open ocean will be attempted in the near future. Future tests with buoys of different subsurface shape will also be attempted and the data obtained will be used to estimate the wind-drift error that can be expected with surface-piercing drifting buoys. Successful completion of this analysis combined with ongoing evaluation of existing buoy shapes will allow accurate surface current monitoring or, alternatively, will assist in the design of more efficient units in the future.

The potential of real time data collection from remote sensors is only now being realized. The researcher can look forward to a wider range of data with which to understand the ocean and its mechanisms. However this potential will only be tapped if sufficient effort is directed toward the development of suitable sensors, sensor platforms, and data-conditioning systems in concert with the development of hull specifications tuned to the desired application.

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Biological influences on the oceanic distributions of trace metals

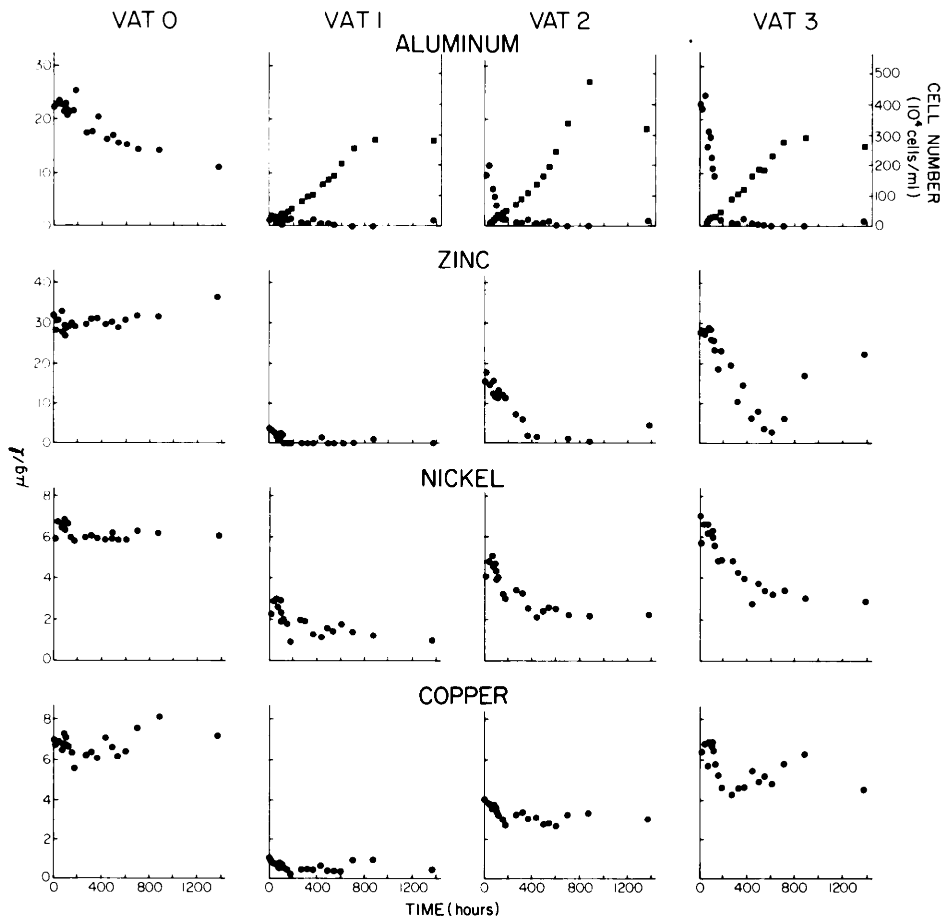
M. Stoffyn and P.A. Yeats

The influence of biological processes on oceanic metal distribution has been investigated by recording ambient metal distributions in the ocean and studying metal uptake by batch cultures in the laboratory. Precise vertical distributions of metals have only been available for the few years since chemical oceanographers have markedly improved their ability to measure the concentrations of trace metals in sea water. This improvement is something of a breakthrough and has added to our understanding of metal behaviour in the ocean. Most oceanic profiles collected to date are from the Pacific Ocean, but several profiles from the Atlantic Ocean have recently been added and the number of metals for which such profiles exist has been increased.

The distributions of cadmium, chromium, nickel, and zinc in the Pacific Ocean are similar to those of the nutrients nitrate, phosphate, and silicate: in surface water they have low concentrations that increase to maxima at intermediate depth (Bruland, 1980; Cranston and Murray, 1978). The vertical distributions of the nutrients in the ocean are mainly a reflection of their uptake by marine microorganisms in the euphotic zone and their regeneration, or dissolution, during the decay of the sinking organic debris. Thus the similarity of some trace-metal and nutrient profiles suggests that biological activity is a major process controlling the distribution of these metals in the ocean. Obviously the most pronounced concentration gradients of both the metals and the nutrients, especially nitrate and phosphate, occur in the upper layers of the ocean where biological recycling predominates. In the deep waters, the vertical distributions are more strongly influenced by horizontal advection than by biological activity. Thus the consistently strong covariances of zinc with silicate, and cadmium with phosphate, throughout the entire water column of the Pacific are an indication of the uniformity of the Zn-Si and Cd-P ratios throughout this ocean basin.

Manganese and lead profiles contrast sharply with those of the nutrient-related elements (Klinkhammer and Bender, 1980; Schaule and Patterson, 1981). Both manganese and lead concentrations are elevated in surface waters and decrease with depth to fairly uniform concentrations throughout most of the deep layers. The high surface concentrations are a consequence of the large injections of these elements to the surface waters through atmospheric precipitation and freshwater discharge from land. Within the water column these metals are removed by adsorption onto both biogenic and inorganic (e.g., clay) particles and, in the case of manganese, by authigenesis. Other metals, such as copper, have vertical profiles that are intermediate between these two extreme types. The concentration of copper is lower in surface water than deep water but its vertical distribution does not closely resemble that of any nutrient and is probably controlled by interactions with inorganic particles in the water column (Bruland, 1980). Marine sediments can also be a source of dissolved metals and the elevated concentrations of some metals such as manganese and copper near the sediment/water interface in various regions are a consequence of such releases.

The principal region of interest to scientists at BIO is the Atlantic Ocean. Trace-metal profiles we have obtained for this ocean are generally similar to those obtained by others for the Pacific Ocean but the concentration gradients involved, both for the metals and the nutrients, are less pronounced. These reduced gradients are a reflection of the physical oceanographic conditions in the Atlantic. As in the Pacific, zinc and cadmium are depleted to very low concentrations in surface water and increase in concentration with depth to maxima coincident with the nutrient maxima. Nickel and chromium also exhibit a nutrient-like profile but are not depleted to near-zero concentrations at the surface. However, while the general vertical distribution of zinc resembles the distribution of silica, the relationship between zinc and silica in the Atlantic is quite different from that in the Pacific. The Zn-Si ratio for the Sargasso Sea station, and for several other stations further north in the North Atlantic is two to four times larger than the corresponding ratio in the Pacific. It is perhaps relevant that high zinc concentrations have been found in surface samples at several stations in the North Atlantic, but we are at present uncertain whether these observations are a consequence of high rates of zinc precipitation from the atmosphere or local, ship-derived contamination. The profiles of aluminum, manganese, iron, and copper are unrelated to the nutrients. They reflect the predominance of inorganic injection and removal mechanisms that have been invoked to describe the behaviour of Mn, Cu, and Pb in the Pacific Ocean and Al elsewhere in the Atlantic (Hydes, 1979). The profiles of these metals are dominated by the input of metals from the atmosphere and through continental run-off and removal by adsorption onto particles throughout the water column. At some locations there is also evi-



Plots of trace element concentrations versus time in each vat. Curves defined by squares in aluminum plots represent cell concentration versus time in each inoculated vat.

dence of aluminum releases into the bottom water from the underlying sediments.

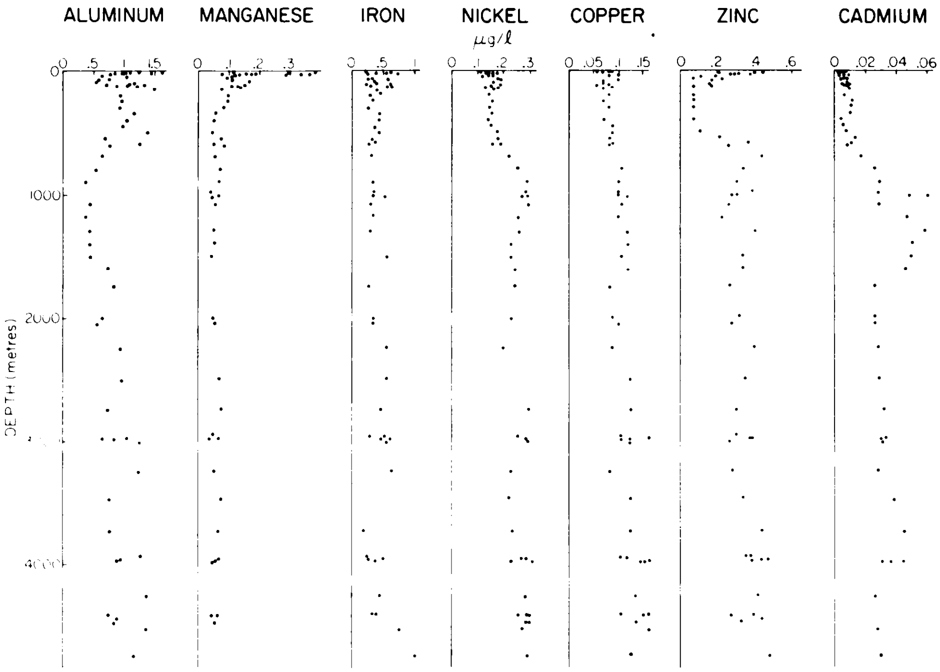
The strong correlation between metals, such as cadmium and zinc, and the nutrients provides a measure of the metal/nutrient relationship in dissolved material regenerated from decaying organisms. However, it provides little information on the biological uptake of metals other than to show that there is net removal of such constituents in the surface waters. More detailed information on metal uptake by primary production can be gained from culture experiments in the laboratory and through detailed investigations of metal profiles in oceanic surface waters using closely spaced sampling depths.

In an attempt to quantify the relative uptake rates of trace metals and nutrients, a series of batch-culture experiments have been performed in which diatoms *(Skeletonema costatum)* were grown in artificial sea water containing various trace concentrations of zinc, aluminum, nickel, and copper. Diatoms were chosen as the experimental organism because they are siliceous organisms that take up silica as well as nitrate and phosphate from sea water. In batch cultures, such as were used for the experimental work, the growth of the organisms continues until the nutrient resources are depleted. The initial concentrations of the metals in the growth media were comparable to those found in rivers and about an order of magnitude larger than typical oceanic concentrations. Previous experiments of this type using controlled enclosures in the coastal environment (CEPEX enclosures) have partly addressed such questions of uptake and regeneration for cadmium and copper (Kremling *et al.,* 1978; Topping and Windom, 1977). Although these experiments are in principle more realistic than laboratory batch experiments using a single organism (in ecosystem enclosures natural plankton assemblages can be utilized), their results have been clouded by problems of exchange of water over the sides of the enclosures and adsorption of metals onto the enclosure walls. The experiments described here are considerably simpler but the results provide some measure of the extent of uptake of metals by diatoms.

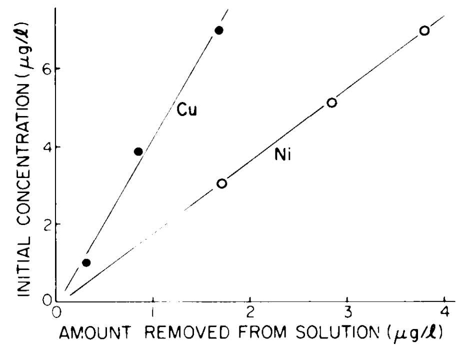
Diatoms were cultivated in 17 L vats, each of which contained a growth medium with a different trace metal concentration. In other respects the culture media were identical. The initial metal concentrations were approximately 10, 20, and 30 times natural seawater concentrations in vats 1, 2, and 3 respectively. A control vat containing the same metal concentrations as those in vat 3 was not inoculated with diatoms and was used to monitor non-biogenically mediated changes in the metal concentrations. These changes could be a result of adsorption onto the walls of the vat or internal precipitation. All four vats were sampled periodically until well after the cultures exhausted the nutrient supply and waned. This was done to determine both the uptake of metals and any releases back into solution that might occur after the cultures ceased growing. The pH and diatom cell concentrations were also measured at the time of sampling.

During the first 600 h, growth of the diatoms in the three inoculated vats was similar as indicated by the uptake of silica, the dry weight concentrations of the diatoms in the collected samples, and the number of diatoms in each vat. After 600 h the cultures began to wane. The aluminum and zinc concentrations were reduced to levels approximating those in surface ocean waters from initial concentrations up to 30 times those in sea water. While the nickel and copper concentrations were also reduced, the levels in solution were not depleted to the same extent. Thus, it appears that the intimacy of the association with biological activity is more pronounced for aluminum and zinc than for nickel and copper.

Until aluminum and zinc became severely depleted in the cultures, their removal from solution was proportional to the removal of silicate. Furthermore, this inferred metal to silicate ratio in plankton is similar in all the cultures despite the initially differing metal to silicate ratios in the vats. These ratios, 0.007 g Al/g SiO_2 and 0.002 g Zn/g SiO_2, are similar to the ratios measured in marine diatoms and are considerably higher than the corresponding ratios in the culture media. Thus it seems likely that the diatoms selectively concentrate these elements to maintain certain ratios in the organism. However, after the aluminum and zinc became depleted in the culture media, the diatoms continued to grow without apparent ill



Vertical profiles of dissolved (filtered) trace metals in the Sargasso Sea.



Plot of initial concentration of copper (Cu) and nickel (Ni) in each inoculated vat versus the amount removed from solution at 600 h after inoculation.

effect. Therefore, it seems that aluminum and zinc are not restricting the growth of the diatoms at the low concentrations attained in the growth media. In contrast, nickel and copper were removed from solution in amounts proportional to their initial concentrations in the vats. This indicates a more passive mode of metal incorporation into the organism. Following the completion of the growth stage of the cultures (after 600 h), the zinc concentrations in solution began to increase, particularly in vat 3. There appeared to be no concomitant release of other metals or remineralization of the major nutrient, silicate.

These observations are consistent with deductions made from the measurement of metal and nutrient distributions in surface ocean waters. For example, we have sampled surface water on the Scotian Shelf at depth intervals of 5 m for nutrients and trace elements. The profiles show that zinc is depleted in the photic zone (0-20 m) presumably due to biological uptake, but that its concentration increases below the photic zone at depths shallower than those at which nutrient regeneration becomes evident. This distribution suggests that at least part of the zinc taken up by plankton is loosely bound and can be rapidly released back into solution within the surface layer. More rapid remobilization of zinc than silicate is therefore indicated by both the results of the culture experiments and the vertical distributions of the metals and nutrients on the Scotian Shelf. Nickel and copper appear to be more strongly bound to biogenic particles since no releases to solution were observed in either the vertical profiles or the experimental batch cultures within one month after the cessation of growth. The extensive removal of aluminum revealed by the batch culture experiments is, however, not observed in the oceanic profiles. This suggests that although aluminum is removed from solution by biological activity, the distribution is dominated by the input from the atmosphere and removal by inorganic precipitation and adsorption/exchange reactions with non-biogenic particles in the ocean.

All metals will be involved to some extent in the marine biological cycle. Whether or not their oceanic distributions resemble those of the major nutrients will depend upon the relative rates of the various inorganic and biological injection and removal mechanisms. The marked improvement in the accuracy and precision with which trace constituents of the ocean can be determined has enabled us to start to look more closely at the mechanisms by which trace metals, introduced to the ocean through both natural processes and man's activities, are recycled and ultimately incorporated into sediments. Biological activity is only one process that has an influence on the behaviour and distribution of metals in the ocean. It does, however, give rise to some clear distributional features that simplify closer examination of other processes. Many of these processes are more complex and their influences are masked by competing mechanisms. As our technological capability improves, we should be able to improve our understanding of these processes and make better assessments of the consequences of anthropogenic disturbances of the marine environment.

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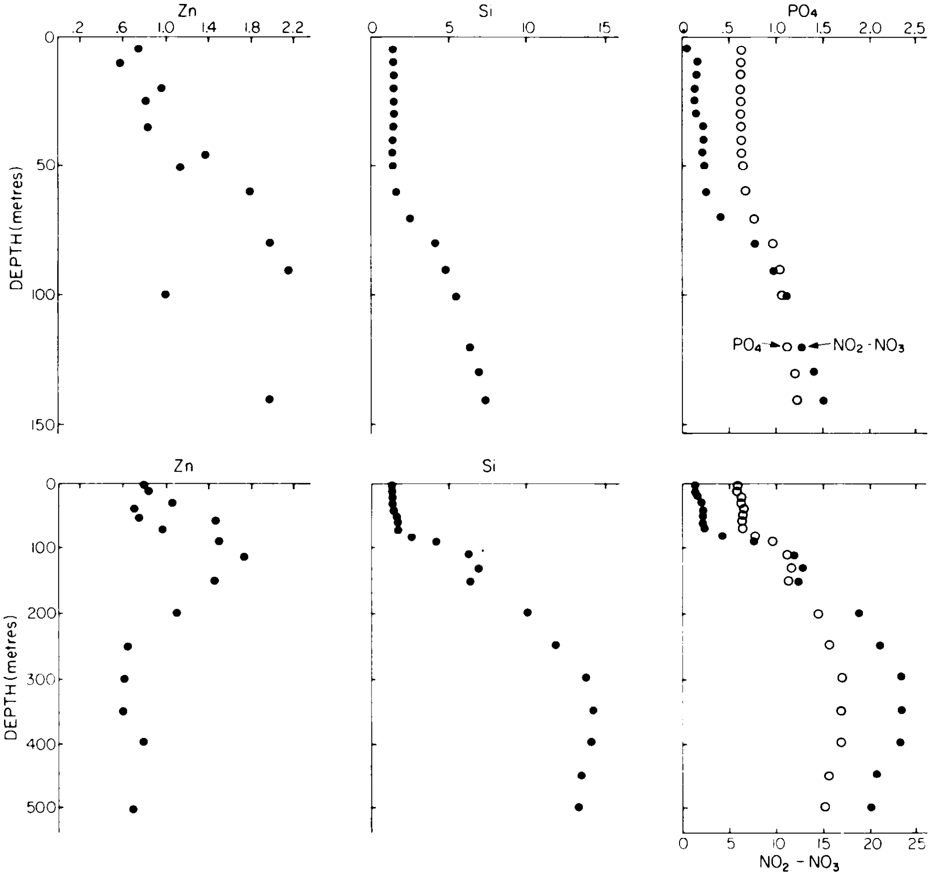


Vertical profiles of Zn, Si, NO_2-$N0_3$. and PO_4 observed on the Scotian Shelf in April 1979. Both profiles were sampled at the same location (42°40'N, 61°32'W) at an interval of two days.

chapter 2

Biological Oceanography

If we feel that we may be approaching the development of a predictive science in physical oceanography, we know that we are very far from it in biological oceanography. Despite the recent development of numerical simulation models in ecology, and their contribution to our general understanding, we know very well that the number of energy pathways that permanently or temporarily exist in any marine ecosystem are sufficiently numerous as to swamp our understanding, and therefore our ability to accurately predict ecological response to environmental change. Yet ecological prediction of purposeful and accidental environmental modification is one of the most important activities currently required of biologists by society and government.

State-of-the-art prediction is always possible provided it is done with proper caution, but doing it may lead one to overrate the results and to establish routine procedures that have the guise of certainty. It is our intention in this chapter to present some of the current BIO studies designed to reduce our degree of uncertainty about ecological processes in the sea. When we remember that the concept, first announced in 1914, of a 'critical period' in the first few days of a larval fish's life was not demonstrated to be true for any species until 1975 (and even then the demonstration was not entirely conclusive), it is not hard to understand how other, less simple hypotheses still await verification.

Surprise discoveries in oceanography today come most often in the field of marine biology. Not only are the organisms themselves incompletely known - remember the coelacanth, *Neopilina*, and the fauna of abyssal thermal vents - but apparently unexpected processes turn out to be very important : not much more than ten years ago, populations of commercial fish were managed as entities isolated from one another, and from environmental change. It was thought that a mathematical solution of their population dynamics alone was satisfactory. Now we know that the modification of a fish population by fishing has consequences that echo down through a whole marine ecosystem, so that other fish populations sympathetically become modified as predation pressure and food supply change; and we now know that heavy fishing pressure can so deplete the food of seabirds as to threaten the existence of major populations.

The various sections in this chapter are all intended to illustrate the high level of uncertainty that still exists in biological oceanography, and the fact that it can only be reduced by sustained fundamental research of the kind reported here. It should be obvious from reading these sections just how simplistic our current attempts at environmental risk assessment are, and just how unrealistic our current attempts are to map environmental sensitivity.

The first two sections, by Li and Harrison, review current studies on the primary production process and illustrate both surprises and uncertainties: classical food chain studies based on the diatom-copepod-fish concept assumed that phytoplankters of the order of 100 µm in diameter were the 'base of the food-chain'; over the last 10 years or so, phytoplankton ecologists have been worrying about the contribution of smaller naked flagellates, about 10 µm in diameter, and concluding that they were really very important. In the last 2 or 3 years, it has become known that there also exist extremely small photosynthetic bacteria, about 1 µm in diameter, in most ocean surface waters. To find during our BIOSTAT cruise off Central America in 1981 that such bacteria comprised around half of the photosynthetic material and produced about half of the daily increment of organic carbon was, to put it mildly, startling. As Li describes, this appears not to be a local phenomenon, and may require a very substantial revision in the current paradigm for plant production in the whole ocean. Similarly, based on experiments in several widely separated parts of the ocean, Harrison has been able to propose a new model for the supply of inorganic nutrients to phytoplankton that may be a sufficient explanation for the ability of open ocean plant cells to maintain high growth rates in the apparent absence of nutrient material.

Next, Longhurst and Herman discuss the fine details of spatial relations between plants and herbivores in the ocean, a subject that has only recently been made amenable to proper study by the development of high-precision sampling tools: the results are logical, but unpredicted, and essential for simulation modelling, even of the most simple kind. McGlade on the measurement of the form of fishes, and Iles and Sinclair on oceanography and herring reproduction illustrate the range of topics that now perforce occupy fisheries biologists, and also the extent to which pragmatic ends now depend on widely diverse intellectual means. McGlade goes far back into classical biology as a base for her studies on the evolution of form for the identification of gadoid stocks on the Scotian Shelf, and Iles and Sinclair combine oceanography and fisheries research to explain through larval retention mechanisms the stock structure of herring.

Finally, biological production in a totally different environment is reviewed by Gordon, who co-ordinated the BIO studies in the Bay of Fundy performed in response to plans for the development of a tidal power barrage there. In this kind of situation not only are the fundamental biological processes themselves in question but, because of the difficulty and danger of working in Fundy - where tides rise and fall about 16 m -, the environmental matrix for the biological processes was almost undescribed at the start of the study. As Gordon indicates, our concepts of how this ecosystem functions have altered radically during the course of the study. Just what any realistic ecologist would have predicted, in fact!

Oxygenic photosynthetic micro-organisms and primary productivity

W.K.W. Li

Phytoplankton (algae) and bacteria are the main unicellular micro-organisms in planktonic marine environments. They differ in their cellular structure and function as well as in many fundamental molecular traits and their differences are so striking that phytoplankton and bacteria belong to separate kingdoms of the living world. Yet, only recently has the widespread occurrence of a type of micro-organism possessing ecologically important characteristics of both phytoplankton and bacteria been recognized in many oxygenated marine ecosystems. At one site in the eastern tropical Pacific Ocean, we estimated that, in the upper 70 m of water, 48% of the primary productivity was attributable to these hitherto uninvestigated micro-organisms. In light of findings such as this, traditional views regarding ecological relationships in the lower trophic levels of plankton ecosystems must be re-evaluated.

To the marine ecologist interested in studying the transfer of material and energy among the various components of ecosystems, the most important difference between phytoplankton and bacteria is their modes of obtaining the energy they require to live. Phytoplankton are able to perform photosynthesis: that is, they obtain their energy directly from solar radiation and use it to synthesize new organic material from carbon dioxide, water, and a few essential nutrients. On the other hand, most bacteria that live in oxygenated ocean waters must obtain their energy from organic matter. Thus, they are ultimately dependent upon phytoplankton for their nutrition. In the process of utilizing organic matter for their own purposes, bacteria regenerate the carbon dioxide and nutrients essential for phytoplankton photosynthesis.

A second ecologically important distinction between phytoplankton and bacteria can be made on the basis of size. The former are large in comparison to the latter. This is an important feature because it allows the researcher to physically separate the two types of micro-organisms using screens with uniform pores. By carefully selecting the pore diameter, it is possible to retain most of the phytoplankton on the screen while allowing most of the unattached bacteria to pass through.

William Li.

Researchers throughout the world have long noticed apparent photosynthetic activity in samples presumed free of phytoplankton by virtue of experimental filtration. Almost a quarter of a century ago, the hypothesis was put forward that there exists in the oceans a type of photosynthetic micro-organism of a size similar to bacteria (Holmes, 1958; Holmes and Anderson, 1963).

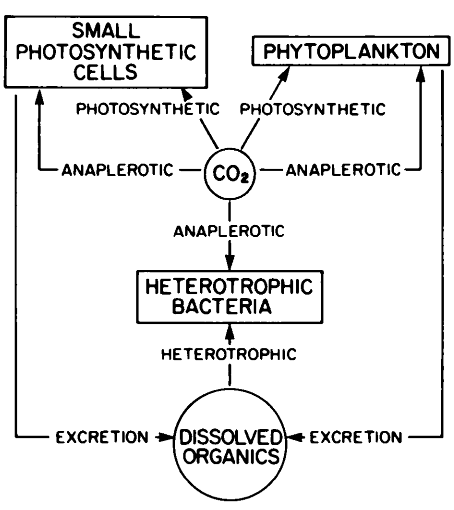
At the Marine Ecology Laboratory, we have adopted the differential filtration approach to study the relevance of such small photosynthetic micro-organisms in marine ecosystems. We addressed the following three aspects of the problem. First: how large is the population of small photosynthetic cells in comparison with the total population of photosynthetic cells? Second: can we measure photosynthesis by these small cells in natural plankton assemblages‘? Third: how large is the contribution by these small cells to overall primary productivity?

A rapid and specific method for assessing the biomass of photosynthetic cells in an assemblage containing a myriad of other organisms is the measurement of chlorophyll *a*, the principal light-absorbing pigment present in all organisms capable of oxygenic photosynthesis. During a cruise to the eastern tropical Pacific Ocean in 1981, Cullen of the Marine Ecology Laboratory (MEL) measured the amounts of this pigment in plankton retained on 1 pm screens and also those in plankton passing 1 pm screens but retained on 0.2µm screens. He estimated that from 20 to 70 % of the chlorophyll *a* contained in the samples was associated with plankton in the small size fraction. The median value for samples taken over depth and time was 33 % at one site, 54 % at another.

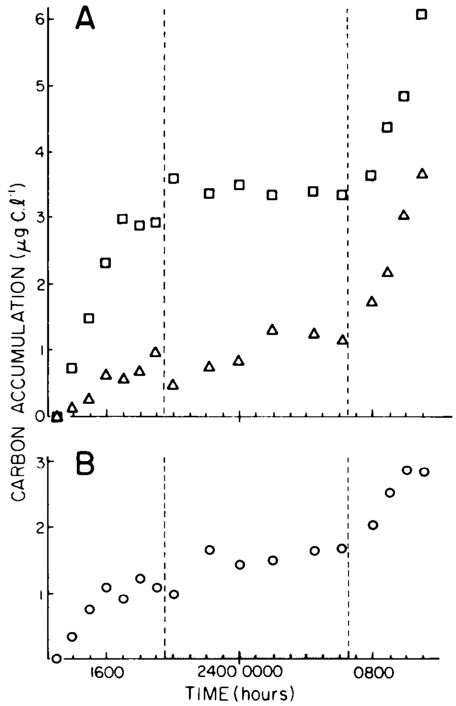
Subba Rao of MEL has made direct visual observations of small red and orange spherical cells in these samples using a fluorescence microscope. The conditions of the microscopic technique were such that only cells containing phycobiliproteins would fluoresce red or orange. Such proteinaceous accessory photosynthetic pigments occur only in cyanobacteria and in algae belonging to the classes Rhodophyceae and Cryptophyceae. It is particularly relevant that others have recently reported on the widespread occurrence in marine waters of coccoid cyanobacteria (Johnson and Sieburth, 1979; Waterbury *et al.,* 1979). Subba Rao has tentatively identified the small fluorescent cells as cyanobacteria. Electron microscopic work in progress will allow a definite taxonomic assignment of the cells. The number of fluorescent cells found in one litre of these tropical samples varied from 2 million to 1 billion. The median value for samples taken over depth and time was 8 million at one site and 770 million at another site.

Our second concern was whether we could measure photosynthetic carbon uptake by these small cells in natural plankton assemblages. Usually, plankton photosynthesis is estimated by measuring the rate at which cells accumulate radioactively labelled carbon dioxide ($^{14}CO_2$) under illumination. In a mixed assemblage of micro-organisms, there are several routes by which ^{14}C may be incorporated into cellular material. Both phytoplankton and the small photosynthetic cells directly take up $^{14}CO_2$. This uptake of inorganic carbon satisfies two requirements: (1) the carboxylation of ribulose-1, 5-bisphosphate in the photosynthetic reductive pentose phosphate cycle, and (2) the β-carboxylation of various three-carbon compounds. The latter sequence of reactions forms four-carbon dicarboxylic acids. These reactions serve the essential role of anaplerotic replenishment of metabolic intermediates that are channelled from the tricarboxylic acid cycle for macromolecular synthesis. Heterotrophic (non-photosynthetic) bacteria also take up ^{14}C. Direct uptake of $^{14}CO_2$ is associated with anaplerotic sequences. Indirect uptake of ^{14}C is through the intervening pool of dissolved organic compounds to which both phytoplankton and the small photosynthetic cells contribute by excretion. In order to assess the productivity of the small photosynthetic cells in relation to that of phytoplankton, it is necessary to examine the relative importance of these various routes of radiolabelling. This we did by monitoring time courses of ^{14}C accumulation in different size fractions of the plankton.

First, we assume that all micro-organisms smaller than phytoplankton are non-photosynthetic. We then proceed to test whether or not this is tenable based on experimental evidence. If the hypothesis were true, appearance of ^{14}C in small micro-organisms would be due either to anaplerotic uptake of $^{14}CO_2$ or to heterotrophic uptake of ^{14}C-exudates from phytoplankton. Anaplerotic uptake is independent of light, and would not be expected to proceed at rates that differ between light and dark periods. An experiment in which radiolabelling of a plankton assemblage was monitored over 22 h

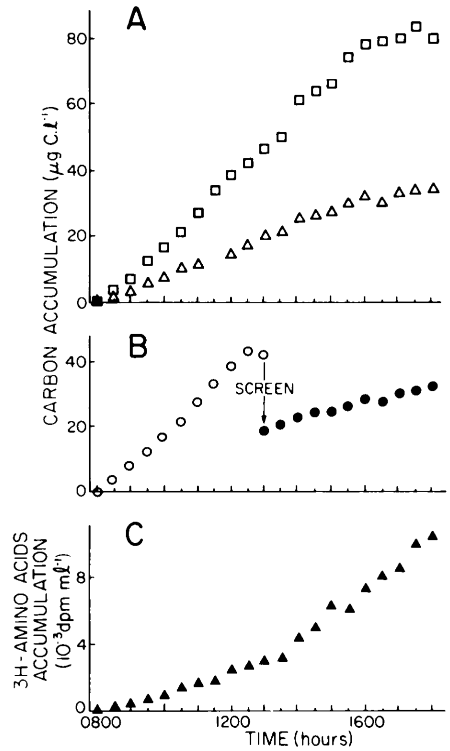


Routes by which CO_2 is transferred into phytoplankton, small photosynthetic cells, and non-photosynthetic (heterotrophic) bacteria.



Time course of ^{14}C accumulation by plankton. (A) ^{14}C was introduced to the intact sample at 1300 h. At the times indicated, plankton were collected on 1 µm Nuclepore filters (□); filtrates passing 1 µm were collected on 0.2 µm Nuclepore filters (Δ). (B) ^{14}C was introduced at 1300 h to the portion of the sample passing a 1 µm Nuclepore filter. At the times indicated, plankton were collected on 0.2 µm Nuclepore filters (o).

showed that the rate of ^{14}C accumulation in the small cells was less during the dark period compared to the light periods preceding and succeeding it. This suggests that the anaplerotic uptake evident during the dark period was not the sole route of ^{14}C accumulation in illuminated small micro-organisms. These results, however, do not allow a rejection of the hypothesis of non-photosynthetic small micro-organisms. It is possible that the light dependence of ^{14}C accumulation in these cells reflected a tight coupling in the sequence of tracer movement from CO_2 to phytoplankton to excreted dissolved organic material to the small micro-organisms. Although the approximately parallel nature of the accumulation curves for phytoplankton and the plankton less than 1 µm are consistent with this coupling hypothesis, we found this to be untenable for the following reason. In a parallel incubation of the same water sample from which phytoplankton were initially excluded by screening, the same light-dependence was observed in the rate of radiolabelling in the



(A) Time course of ^{14}C accumulation by plankton. Parallel incubations were performed with an unscreened sample (□) and with one screened through a 1 µm Nuclepore filter prior to radiolabelling (Δ). (B) A third parallel incubation was performed with an initially unscreened sample (o); at 1300 h. the sample was screened through a 1 µm Nuclepore filter and the incubation continued (●). (C) Time course of ^{3}H-amino acids accumulation by plankton. A fourth parallel incubation was performed with a sample screened through a 1 µm Nuclepore filter prior to radiolabelling (▲). All samples were collected on 0.2 µm Nuclepore filters.

plankton less than 1 µm in size. We therefore conclude that the small micro-organisms were indeed photosynthetic.

Given that the small micro-organisms included photosynthetic members, we must admit the possibility that these members excreted radiolabelled photosynthates, which were then taken up to heterotrophic members of the same size class. The following experiment provided indirect evidence of the relative unimportance of this contribution to the observed radiolabelling of the small micro-organisms.

A water sample was radiolabelled and illuminated for 5 h and then passed through a 1 µm screen to remove the phytoplankton. The small micro-organisms passing through the screen were then incubated for another 5 h. Since carbon is transferred from CO_2 to photosynthetic cells to soluble organic carbon to heterotrophic bacteria in a simple linear sequence, it might be expected that a time lag would be evident in the appearance of the radiolabel for components in the sequence further from the initial source, CO_2. During the first 5 h of incubation, we assume that the pool of soluble photosynthates, whether derived from phytoplankton or from the small photosynthetic cells, is uniformly available for uptake by the heterotrophic bacteria.

When the phytoplankton are rapidly removed after 5 h, we might expect some time to pass before the heterotrophic bacteria diminished the photosynthate pool from the phytoplankton and then shifted down to a rate of ^{14}C accumulation commensurate with excretion by only the small photosynthetic cells. If this were the case, the observed rate of ^{14}C accumulation by plankton less than 1 µm after removal of phytoplankton should gradually diminish. However, we found that this was not the case. The rate of ^{14}C accumulation by small micro-organisms after removal of phytoplankton was constant. Moreover, this rate was the same as that for a parallel plankton sample that was radiolabelled in the absence of phytoplankton right from the beginning of the experiment. This means that the rate of ^{14}C accumulation was independent of the rate of ^{14}C excretion by photosynthetic cells. This indirect evidence for the relative unimportance of exudates in accounting for ^{14}C in small micro-organisms is corroborated by a distinctly different kinetic pattern for the accumulation of a mixture of tritiated amino acids formulated to resemble a typical algal protein hydrolysate.

The simplest hypothesis that we find to be consistent with all these observations is that much of the ^{14}C that appears in the small micro-organisms during the light period is due to photosynthetic assimilation.

Having established this, we asked: how large is the contribution by these small photosynthetic cells to overall primary productivity‘? For the two sites visited in the eastern tropical Pacific, Harrison of MEL determined that, depending on depth, from 20 to 80 % of total plankton photosynthesis was attributable to the small cells. In the eastern Canadian arctic, we have found a lesser contribution (5 15 %) from the small photosynthetic cells.

In conclusion, we have been able to unequivocally measure rates of photosynthetic carbon uptake for bacteria-sized cells and found a significant, though variable, contribution from these cells to overall primary productivity.

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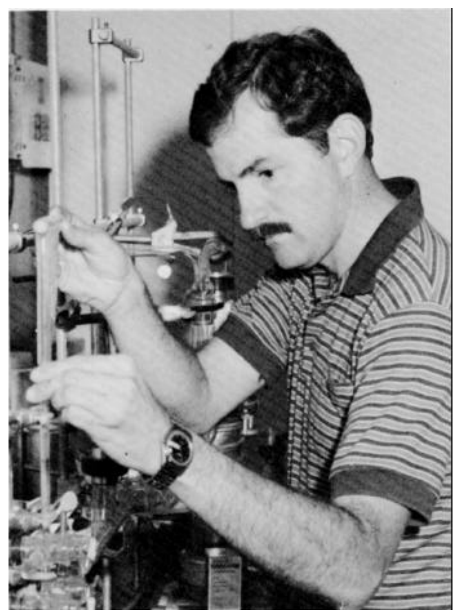
Nitrogen nutrition of marine phytoplankton: open questions

W.G. Harrison

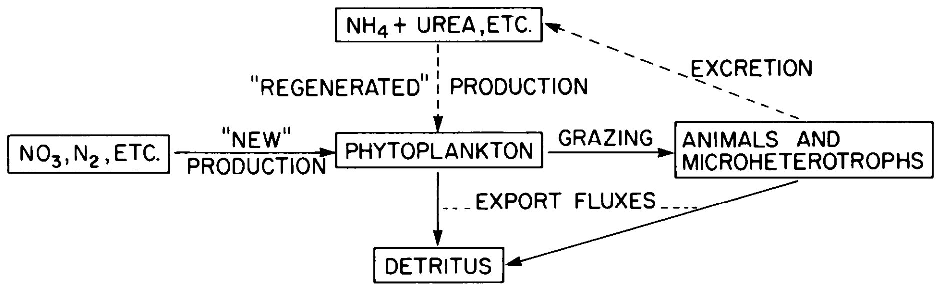


Glen Harrison

Historically, phytoplankton research has placed much emphasis on the identification and elucidation of the major processes that regulate algal growth and productivity. The main focus has been on the importance of nutrient limitation, specifically on phytoplankton nitrogen nutrition. Despite the recognition of a link between dissolved nutrients and the biological production cycle as early as 50 years ago, only recently have the quantitative relationships been established. The pioneering theoretical and experimental studies of Dugdale (1967) and Dugdale and Goering (1967) have been the model for most subsequent research, which has in turn formed the basis of our present understanding of nitrogen regulation of marine primary production. Recent research, however, has begun to question the validity of the concepts upon which most of these past studies were based and has called for a serious reassessment and possible re-interpretation of the earlier work. The Marine Ecology Laboratory has been involved in studies of the nitrogen nutrition of phytoplankton for a number of years and has as a result joined in efforts to resolve this current conflict.

The early conceptual framework

The first serious attempt to develop a theoretical framework for studies of nitrogen limitation of primary productivity (Dugdale, 1967) described the oceanic domain of phytoplankton as a two-layered system in steady-state; an upper, nutrient limited layer (the upper-mixed layer) and a lower, light-limited layer. Dugdale identified two further distinctive components of primary production in the nutrient-limited zone based on modes of nitrogen supply. Primary production supported by *externally* supplied nitrogen (i.e., advection or diffusion of NO_3^- from below the mixed layer) was designated as *new* production and production resulting from *internally* supplied nitrogen (e.g., NH_4^+ from the metabolic wastes of planktonic animals) was labelled *regenerated* production. At steady-state, new production and export losses (e.g., sinking) should balance as well as regenerated production and metabolic losses (e.g., grazing). The availabil-



The production system of the near surface waters of the ocean indicating the pathways of "new" and "regenerated" production. (Modified from Eppley and Peterson (1970).)

ity of isotopically labelled forms of nitrogen ($^{15}NO_3^-$, $^{15}NH_4^+$) led Dugdale to suggest that the relative importance of new and regenerated production could be experimentally measured in ocean water and directly related to phytoplankton productivity.

Field studies

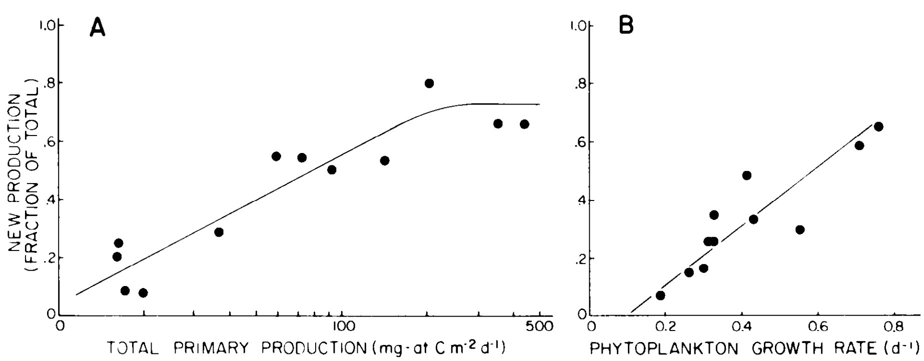
Much of the subsequent field work and its interpretation has relied heavily on the concepts of new and regenerated production. A sufficiently large body of data has, in fact, accumulated and permits a number of generalizations to be made concerning the role of nitrogen, specifically its mechanisms of availability in regulating phytoplankton growth in the global context (Dugdale, 1976; Eppley and Peterson, 1979; Harrison, 1980; Eppley, 1981). Probably of singular importance has been the elucidation of a clear quantitative relationship between the source of nitrogen (i.e., new or regenerated) and the magnitude of oceanic primary production and phytoplankton growth rate. One conclusion drawn from this analysis, for example, has been that most (about 80 %) of the world's oceanic primary production is turning over relatively slowly (low growth rates) and is supported by nutrients recycled *in situ*. At the Marine Ecology Laboratory we have demonstrated the utility of the new and regenerated production concepts in our more general studies of environmental control of primary production in local marine waters. For example, nitrogen tracer studies have been instrumental in our detailed investigation of the seasonal cycle of phytoplankton production in coastal embayments. Our results have not only confirmed the classical picture - spring and fall production maxima supported by external nutrient sources (new production) and summer production by internally recycled nutrients (regenerated production) - but suggest that new/regenerated production ratios may prove valuable in explaining some of the shorter term variability in primary production we commonly observe in these coastal waters.

This experimental approach may also prove useful in assessing the importance of mixing processes on nutrient availability for primary production in other coastal environments. Our studies on the Scotian shelf have shown a significant correlation between estimates of new production and phytoplankton productivity. Elevated primary production rates were most evident at the shelf-break, often the site of tidally induced mixing, and offshore in the region of the shelf water - slope water front. The coincidence of these peaks with elevated new production estimates strongly suggests that nutrient (NO_3^-) injection into the near surface waters in these areas is an important underlying cause. Furthermore, the new production estimates may provide a quantitative measure of the proportion of total photosynthetic production maintained by these physical processes.

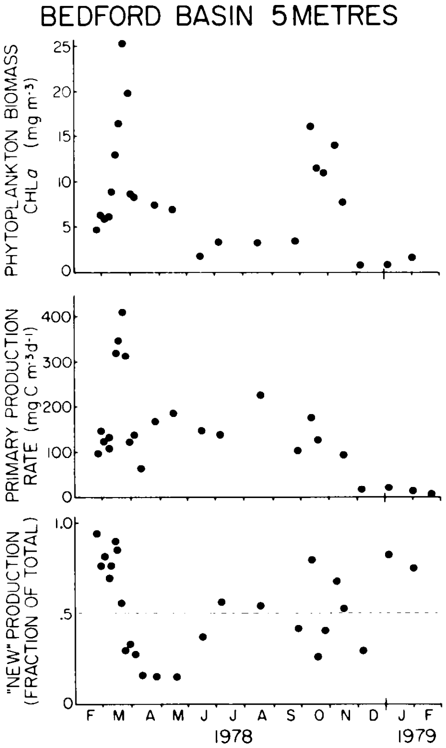
Our recent nitrogen studies in the eastern Canadian Arctic have also provided insight into the environmental control of high-latitude phytoplankton production. Our results have been noteworthy in two respects. Firstly, regenerated production was considerably more important than we expected, which suggests a 'metabolically active' planktonic community despite extremely low environmental temperatures and, secondly, measured primary production rates were far too low relative to new/regenerated production ratios to be attributed to nutrient-limitation. We have, therefore concluded that light and temperature are probably more important than nutrient availability in regulating phytoplankton growth and production in this region.

Laboratory studies

The most substantial advances in modelling the relationship between limiting nutrients and algal growth and in resolving the underlying biochemical mechanisms has been accomplished using cultured phytoplankton. Continuous-culture systems have proven ideal for studies of nutrient-phytoplankton interactions at steady-state and have, in many cases, been used as a complement to field work to provide more insight for the interpretation of oceanographic measurements. Laboratory studies have further advanced the notion of balanced growth (i.e., that nutrient uptake and growth are coupled), which depends on the concentration of the limiting nutrient. This model has been applied with some success in phytoplankton growth and speciation. For example, it has been generally concluded that open ocean phytoplankton are characterized by a high affinity for the limiting nutrient while being restricted to a low growth rate because of the limiting nutrient's near absence in that environment. The appropriateness, however, of this steady-state assumption in nature has been questioned

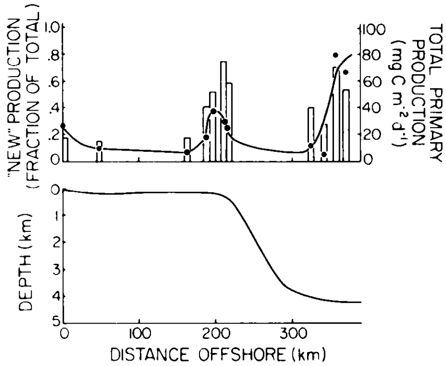


The relationships between "new" and "regenerated" production and phytoplankton production and growth. (Modified from Harrison (1980) and Eppley (1981).)



The seasonal cycle of phytoplankton production and nitrogen utilization in Bedford Basin, 1978-1979.

(Jannasch, 1974) and recent evidence points to the inadequacies of this model. In nitrogen-limited continuous cultures, for example, growth rates near the maximum attainable for particular algal species can be maintained without any measurable limiting nutrient in the medium. Furthermore, nitrogen-starved phytoplankton have demonstrated the capacity to take up the limiting substrate (e.g., NH_4^+) at a rate far in excess of their steady-state growth requirement when supplied as a discrete pulse, i.e., nutrient uptake and growth become uncoupled.



Relationship between total primary productivity and "new" production off the Scotian Shelf, April 1979.

The new conceptual framework

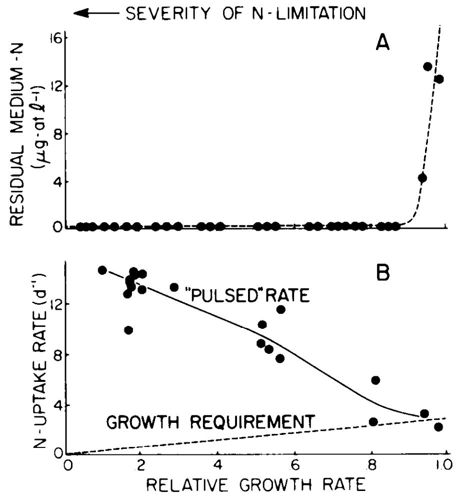
Based on these findings and other recent studies showing uncoupling of nutrient uptake and growth, a new view of the interaction of limiting nutrients and phytoplankton nutrition has emerged. It has been proposed that, in nature, limiting nutrients are not generally supplied continuously as earlier conceptualized but rather episodically as a consequence of the temporally and specially varying nature of nutrient supply, e.g., from excretion wastes of individual zooplankton organisms (McCarthy and Goldman, 1979). Moreover, nutrient-starved phytoplankton having the capability to take up nutrients rapidly (uncoupled from growth) could maintain their nutritional requirements for growth with only infrequent and intermittent exposures to pulses of the limiting nutrient. One implication of this, for example, would be that open ocean phytoplankton populations could attain near physiological-maximum growth-rates despite the apparent absence of nutrients.

The conflict

The implications of this new concept are particularly relevant with regard to the interpretation of nitrogen studies done in the field for the past 15 years, including our own. The problem is basically a methodological one (Harrison, 1982). If the important physiological time scales for phytoplankton nutrition are on the order of minutes or less and experimental protocols have been designed, as in the past, to look at processes occurring on the scale of hours or tens of hours, then to what extent can we rely on the results from past experimental work to reflect accurately the dynamics of the relationship between nitrogen nutrition and phytoplankton growth? How does this new perspective affect the concept of new and regenerated production, which largely developed from past experimental results?

These new ideas concerning nutrient-phytoplankton interactions are not, however, without their own problems. For example, it has been argued recently that the likely ephemeral nature of such nutrient 'pulses' (or 'patches') in a physically turbulent environment would not allow sufficient time for them to be effectively exploited by phytoplankton, even with enhanced nutrient uptake capacities (Jackson, 1980).

Clearly, the general applicability of



Relationship between relative growth rate (severity of N-limitation) and: (A) residual limiting nutrient concentration; (B) enhanced nutrient uptake capacity for phytoplankton grown in continuous culture. (Modified from: (A) Goldman and McCarthy (1978); (B) McCarthy and Goldman (1979).)

these new theories will require more study, particularly of phytoplankton populations in their natural environment. Preliminary work by other groups has already demonstrated that elevated nutrient uptake capacities exist in field phytoplankton populations from coastal waters. We have recently focused on this problem and results from our field studies spanning tropical to arctic waters should extend considerably the range of natural environments in which these new theories have been tested. A further aim will be, by comparison of results from conventional and new experimental protocols, to evaluate past interpretations of nutrient-limited phytoplankton production and growth. The more formidable tasks lie ahead - documenting the small-scale 'patchy' nature of nutrients in the ocean and quantitatively relating these findings to phytoplankton growth rates.

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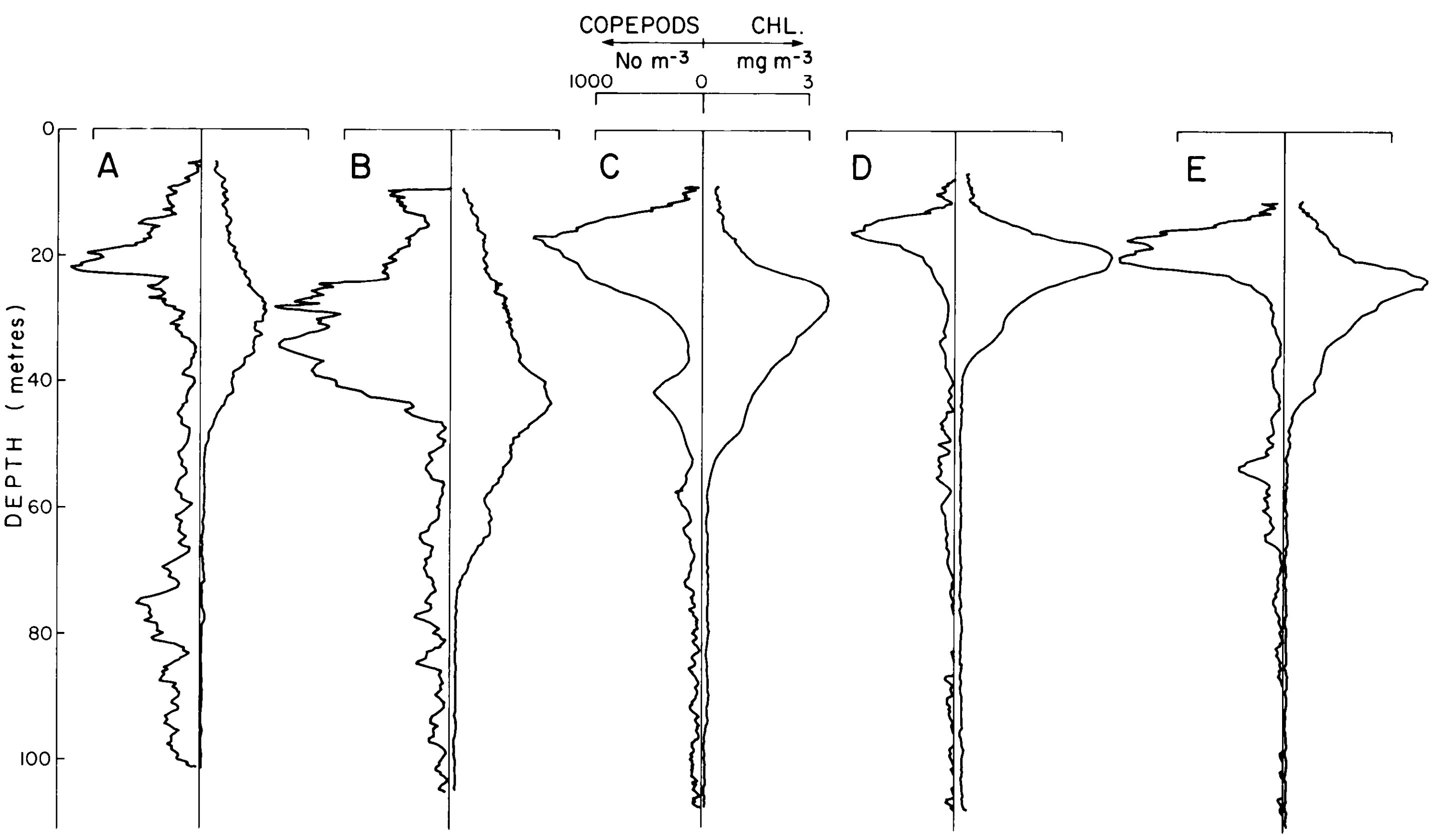
Do zooplankton aggregate at, or near, the chlorophyll maximum?

A.R. Longhurst and A.W. Herman

Alex Herman and Alan Longhurst.

Models of plankton ecosystems depend on understanding spatial relations between interacting groups of organisms in order for energy to be transferred; for example, we must assume that herbivores exist in the same places as the plants on which they feed. Because it was discovered very early in the history of plankton investigations that distributions of biota were neither uniform nor random, much effort was put into understanding patchiness: studies of spatial relations in the plankton were initially concentrated on horizontal patchiness, as controlled by physical processes, in one or two-layered systems, and much progress was made, especially after the application of spectral analysis to the phenomenon (Platt and Denman, 1975; Platt, 1978). More recently it has come to be understood that vertical profiles contain a much more highly ordered and biologically mediated kind of variability than is exhibited by horizontal patchiness, so that studies have tended to swing toward understanding vertical relationships between animals, plants, nu-



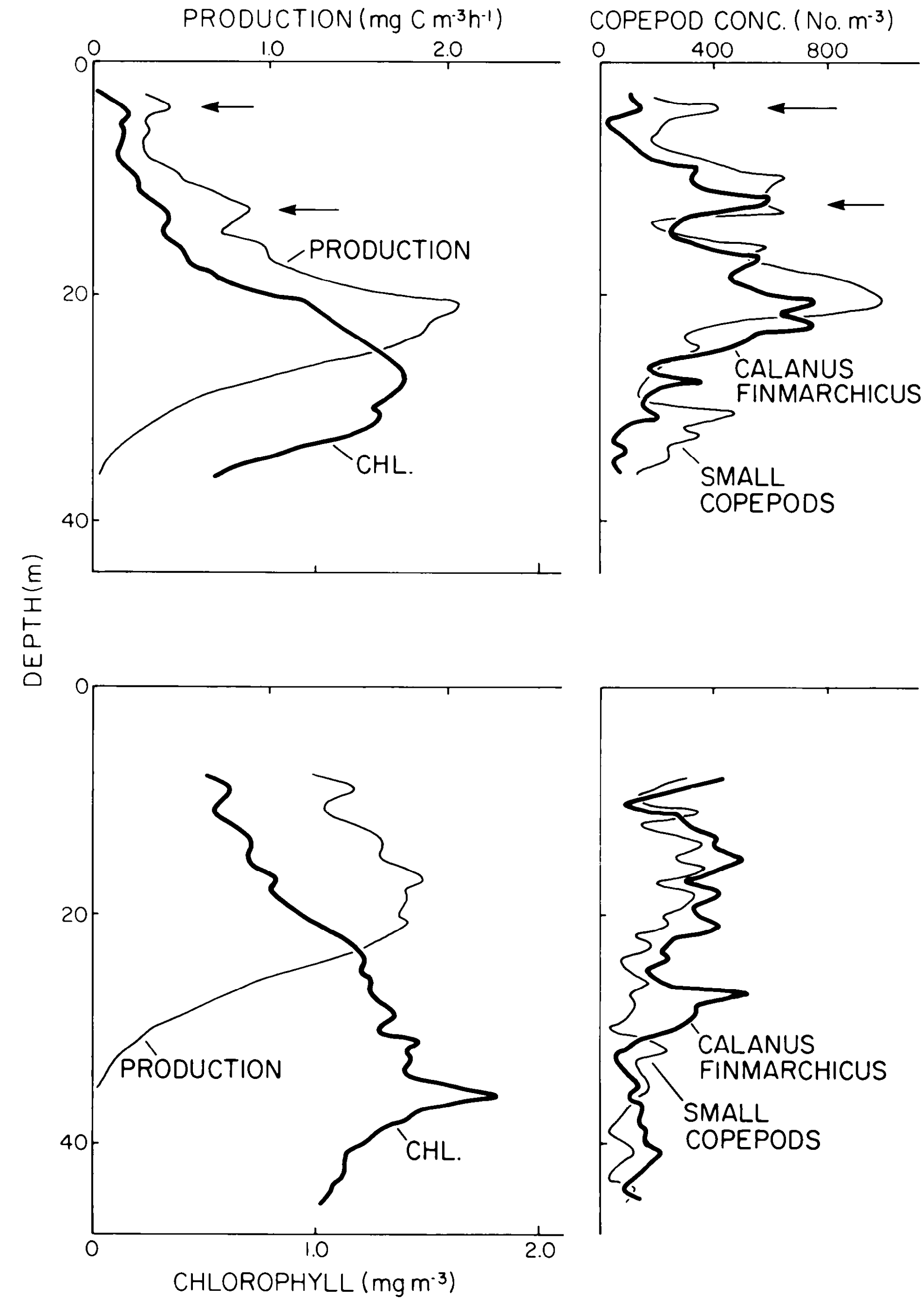
(A-E) Vertical Batfish profiles from the Scotian Shelf representing chlorophyll on the right- hand scale and total copepods on the left.

trients, and the physical profile; it was quickly found that production, consumption, and remineralization were logically sequenced at depths closely related to the physical thermocline. It has remained only to obtain high precision, high resolution profiles of all relevant variables simultaneously to push these studies forward very rapidly.

Using multiple-serial plankton samplers at 80 stations in the eastern Pacific, Longhurst (1976) was able to corroborate, for that region, Venrick *et al.'s* (1973) suggestion that herbivorous zooplankton generally aggregated not at the depth of maximum chlorophyll but slightly shallower and closer to the depths of the maximum rate of production of plant material.

This result appeared to contradict the very many papers, based on data obtained with profiling instruments of lesser vertical resolution, that described apparent coincidence between herbivore and plant maxima in vertical profiles. Now, however, there is mounting evidence through the wide deployment of the Batfish (an undulating, towed, instrument body equipped with chlorophyll and copepod sensors that has a vertical resolution of only about one metre) that copepods often do aggregate at depths shallower than the chlorophyll maxima. From studies on the Scotian Shelf (Herman *et al.,* 1981) it was determined that the dominant copepods *(C. finmarchicus* IV & V, *M. lucens* V, *P. minutus,* and C. *arcuicornis)* were situated about 8-10 m above the chlorophyll maxima, and thus possibly near the depth of maximum carbon production. Using a recently developed formulation (Jassby and Platt, 1976) for phytoplankton production as a function of light, simulated profiles of production per unit volume were generated for each Batfish profile of chlorophyll. From the production profiles, it is apparent that the maxima of carbon production agree closely with the copepod maxima; this is borne out by a statistical comparison of their evaluated maxima for about 90 Batfish profiles.

Similar relationships were found using a Batfish on the Peru shelf and in Arctic waters; however, in the latter case, in northeastern Baffin Bay, copepods were situated above the chlorophyll maxima in only about two-thirds of the profiles analyzed. In addition, only C. *finmurchicus* and C. *glacialis* were situated shallower while C. *hyperboreus*

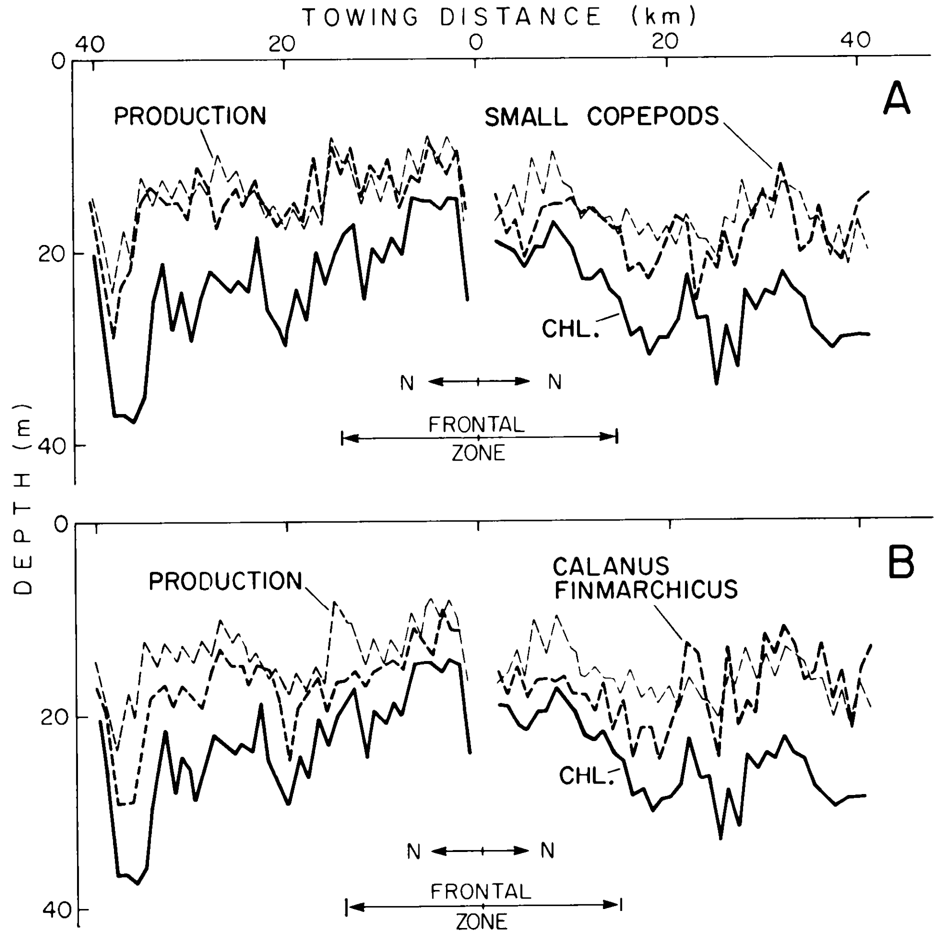


Batfish profiles from the Scotian Shelf separated into two components: (1) estimated production and chlorophyll on the left, and (2) copepods on the right consisting of *C. Finmarchicus* IV and V and the small copepods *Pseudocalanus minutus* and *Clausocalanus arcuicornis.*

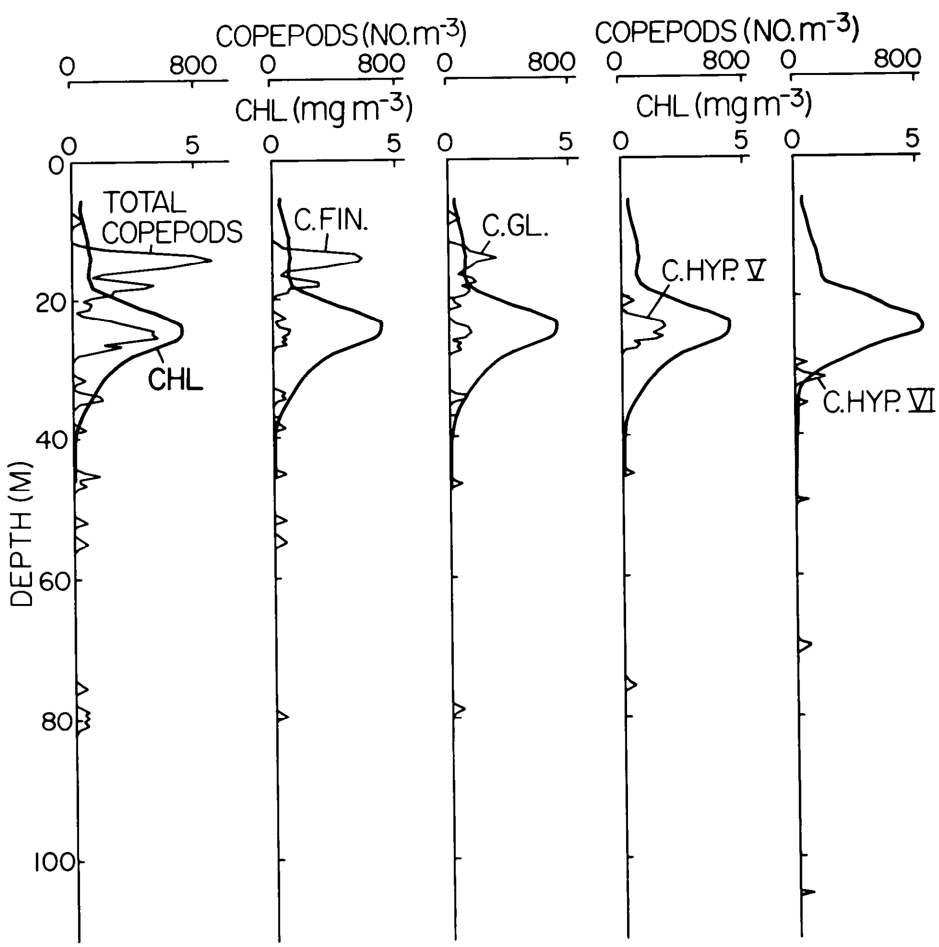
was concentrated at or slightly below the chlorophyll maxima.

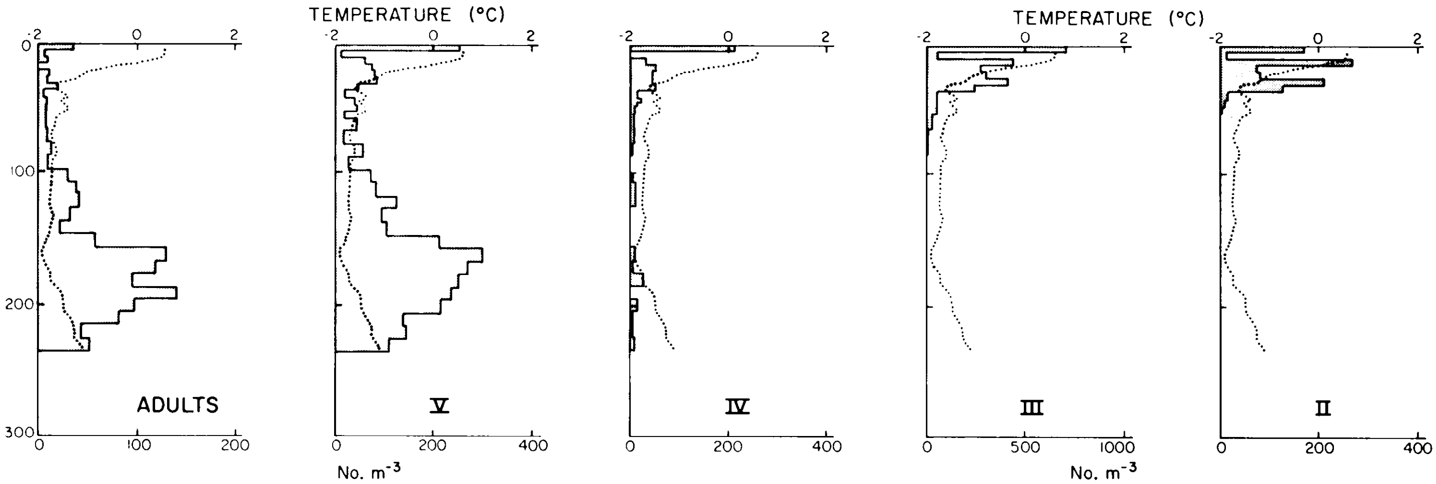
Recently a numerical model describing the 24-h vertical carbon budget on the Scotian Shelf was formulated by Herman and Platt (MS in preparation). The model defined the equation of state for three terms: (i) production, (ii) grazing, and (iii) the standing stock, represented by three measured profiles of production, copepods, and chlorophyll respectively. Although simple in structure, the model yielded two fundamental conclusions: (i) that die1 carbon production above the chlorophyll maximum was sufficient to sustain copepods, and provided a maximum daily ration of about 50 % (body weight per day) and (ii) that ammonia was regenerated above the chlorophyll maximum, so that inputs and needs were well balanced throughout the water column. This work resolved a problem of previous models, such as that of Jamart *et al.* (1979), in

(A-B) A comparison of the vertical centres of gravity of chlorophyll, copepods, and estimated production. In the two cases of small copepods and *Calanus finmarchicus*, it was found that the centres of gravity agreed more closely with those of production than chlorophyll.



A Batfish profile consisting of copepods and chlorophyll sampled in northeastern Baffin Bay. The copepods species have been separated in the plots indicating C. *finmarchicus* and C. *glacialis* to be situated above the chlorophyll maximum, while C. *Hyperboreus* is situated at the chlorophyll maximum.





Vertical distributions of adults and four larval stages of *Calanus hyperborius* in eastern Lancaster Sound, August 1980. LHPR profiles taken from HUDSON. Dotted line is temperature profile.

which ammonia regeneration occurs at the chlorophyll maximum with the result that ammonia input exceeds that required for the growth of phytoplankton.

Investigations of biological profiles are continuing using the Batfish and other instruments, and data from a wide range of arctic conditions and from two five-day stations worked during the BIOSTAT cruise at and north of the Costa Rica Dome are under analysis. It is becoming increasingly clear as these studies progress that the upper part of the water column is a highly structured ecosystem in the spatial sense. All profiles contain information on the ordered differential distribution of organisms that indicates that control by animal behaviour, light, and nutrients is greater than by physical processes alone.

It is also becoming clear that not only are individual species of animals specialized to certain very restricted depths within the profiles examined, but that individual growth stages of a single species usually occur in an ordered manner down the profile; sequences and depth-locations alter between day and night, and seasonally, as well as during the growth of individual animals. Thus, we appear to be approaching a resolution of "the paradox of the plankton" (Hutchinson, 1961): how can a fauna so taxonomically diverse as the zooplankton inhabit a uniform habitat that seemingly lacks individual-species niches? Apparently, a resolution only awaited our having a closer look at the phytoplankton habitat.

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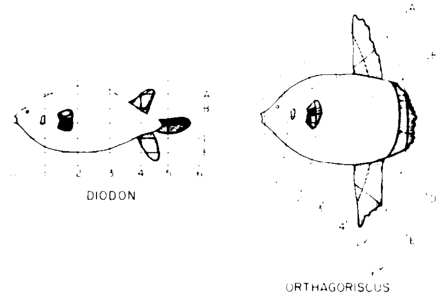
Shape measurement in fishes

J.M. McGlade

The structure of a fish stock governs not only its response to fishing pressure and environmental change, but also its ability to recover from over-exploitation. Yet the spatial and temporal delineation of fish stocks is still a fundamental problem in fisheries management (Ihssen *et* al., 1981). During the past two decades there has been growing concern amongst fisheries biologists that the genetic implications of many management strategies have been overlooked (Thorpe *et al.*, 1981). Thus it is imperative that existing stocks be defined both phenotypically and genetically.

The Marine Fish Division initiated a project in 1981 on shape measurement in fishes, as part of a larger study to define

Jacqueline McGlade.



Cartesian transformation from *Diodon* to *Orthagoriscus* (= *Mola).* (From D' Arcy Thompson, 1917).

the structure of gadoid stocks on the Scotian Shelf. This aspect of stock identification has been overlooked in the past, but it represents an important characteristic at the infraspecific level of differentiation (Ihssen *et al.*, 1981). One reason why this component of morphology has been neglected is the complexity of the procedures needed to quantify shape changes: thus biologists have generally restricted their studies to comparisons of linear measurements along one or two axes.

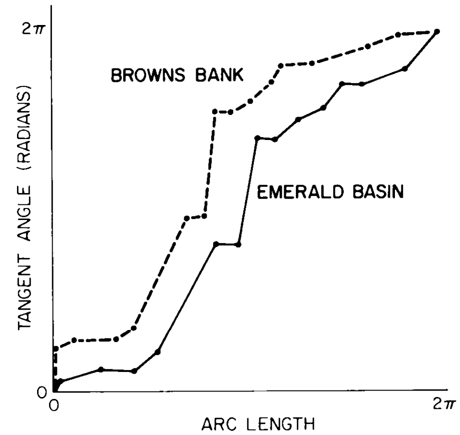
Historically, the major exception to this was the work of D'Arcy Thompson (1917). He used a method of transformation based on the distortion of Cartesian grids; the effect was similar to that of using a rubber sheet to transform an entire form. One famous application of his method is the superimposition of related grids on the figures of *Diodon* and *Orthagoriscus (= Mola).* However, there are certain problems associated with this work such as inconsistencies in the grids and an inadequate explanation of the procedures, which make it impossible to extract a quantitative result.

Development in this field was also conditioned by an underlying need to define the principles of biological similarity (Economos, 1982), rather than a clearer exposition of variability. Morphologists such as Galileo, Raschevsky (1960), Huxley (1924), and Tessier (1936) concerned themselves with the relationships between body length, and trunk diameter and weight across phyla. It was not until the latter half of this century that interest in variation at the population level began to rise, and morphologists turned to traditional methods, such as Huxley's allometric equation, in a surprising reversal of application. Gould (1966), however, concluded that positive and negative allometry in different body parts could be used to infer shape changes, which in turn meant that both ontogenetic and population differences could be quantified.

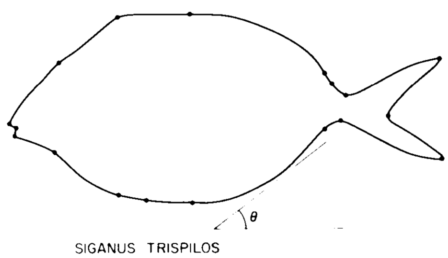
Yet, the direction of the axes along which growth occurs had to be realized in advance of any allometric analysis using Huxley's equation. Invariably this led to a single axis along the most prominent growth gradient upon which all the morphological variables were imposed. This of course further distorted the perception of any subtle shape changes. Avery (1933) attempted to overcome these problems by combining growth gradients with Cartesian grids to gain some geometric insights into the development of a tobacco leaf. He inked in a grid on a leaf and photographed it as it grew, and then extracted the areas of the grid quadrilaterals. Subsequently, Richards and Kavanagh (1943) reanalyzed Avery's data, using derivatives to ascertain the directions of maximum and minimum growth across the leaf figure. This approach was clearly a significant step towards the measurement of shape differences and transformations, despite Tobler's (1978) subsequent work, which showed unsystematic errors in their analysis.

One major stumbling block to analyzing shape is that it is often inextricably bound up with size. For example we may say that a rat is approximately twice the size of a mouse but nearly the same shape. Thus to compare the complexities of shape between different organisms it is clearly necessary to remove the size component. A number of methods have been suggested, such as that of Penrose (1954), which express character values as a ratio of a standard measure of size (e.g., weight or volume). Other methods include a multivariate approach (Jolicoeur, 1963; Albrecht, 1980), in which the first principal component of a principal components analysis is assigned to size, and the remaining components to shape (Pimental, 1979). It can be argued, however, that the independence of the first principal component, as one of size, is a function of its orthogonality to the second, rather than of any intrinsic differentiation between size and shape (McGlade, 1981).

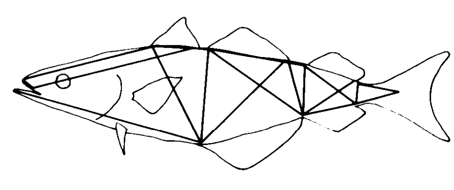
In ichthyology, the problem is increased because the characters traditionally used in morphology lie along the vertebral axis of the fish. They are thus strongly conditioned by allometry. Bookstein (1978) provided ichthyologists with a geometric approach to measurement that overcame this problem of linearity. Landmarks (points that are homologous between individuals) are initially defined around the outline of a fish. The tangent angle (the azimuth of a straight line lying along the outline at the landmark) and position along the arc length for each landmark are then taken and standardized to a scale of 0 to 2π. In a study of pollock *(Pollachius virens),* sample populations from the edge of Browns Bank and Emerald Basin were compared using this method. As may be



Tangent angle versus arc length for two samples of pollock *(Pollachius virens L.)* from Browns Bank and the edge of Emerald Basin on the Scotian Shelf



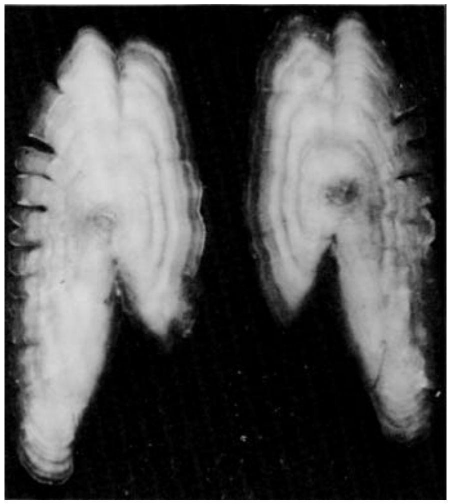
Measurement of the tangent angle at a landmark for the outline of *Siganus trispilos*, a tropical fish.


Truss configuration proposed for fish (Strauss, unpublished MS). The points at which the truss touches the outline represent landmarks.

seen from the accompanying figure, there are certain differences along the arc length that can be traced to various landmarks, and that are open to multivariate analysis once a criterion of closure has been established. (This latter step ensures that the data contain an implicit sense of ordering, without which the points are meaningless.)

This method is very useful in determining differences between samples, but it gives no information about shape changes across the surface of a fish. One potential approach to this problem is that of Bookstein (unpublished MS, University of Michigan, Ann Arbor), who has developed the idea of biorthogonal grid analysis. The simplest family of curves is derived from conic sections. These can be linked by splining such that each curve best fits the data of its sub-arc of the outline: it then passes smoothly into its neighbour's sub-arc. Strauss (unpublished MS, University of Michigan. Ann Arbor) proposed a truss configuration to act as the basic framework for this type of analysis. Landmarks are defined, and the distortions are based on an orthogonal co-ordinate system derived from affine transformations in which the angles remain constant: the changes between forms are thus relative curve spacing. Two or more curves are fitted at each landmark so that error of fit is minimized.

Initial studies in this area have shown that gadoids from areas across the Scotian Shelf show recognizable levels of differentiation. However, another and perhaps more promising area that has surfaced from this research is the use of the technique to differentiate between otoliths (the 'ear bones') taken from the same species but from different areas. These samples are collected routinely by the Marine Fish Division for ageing purposes (the otolith's rings are counted to establish the number of summer and winter periods that a fish has experienced). Experienced 'age' readers can identify where certain otoliths originated not only from the size of each ring but also from its shape. The Marine Fish Division has therefore undertaken a preliminary study to examine ontogenetic variation in the otoliths of fish from different areas. If successful, the results will provide an invaluable source of information for population studies of gadoids on the Scotian Shelf and adjoining areas, including the rationale for separation of stocks for management.



Pair of herring *(Clupea harengus)* otoliths. The opaque and translucent areas were deposited during winter and summer growth periods: these rings are used to age the individual fish.

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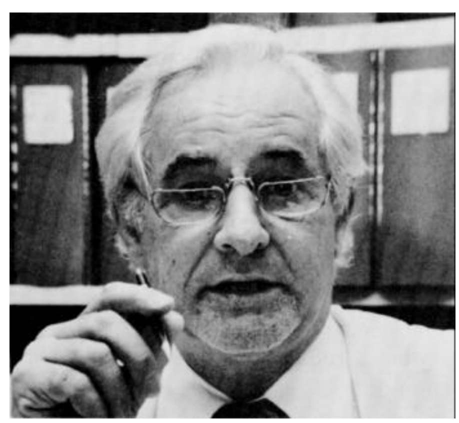
Herring and hydrography: the stock question

T.D. Iles and M. Sinclair

The term "stock" is widely used in marine fisheries studies. It refers to an infraspecific group with a characteristic spatial distribution and, in many instances, differences in life history parameters. Stock distribution is important because managers like to account for fish catches by well defined administrative areas; the biological differences between stocks raise questions that go surprisingly deeply into ecological and evolutionary theory.



Derrick Iles.

Literally dozens of herring stocks *(Clupea harengus)* have been named in the

North Atlantic, and in both European and North American waters, but the fact that the distributions of different stocks overlap, in many instances to a significant degree, makes it almost impossible in some areas to manage them on a rational biological basis. Indeed, in the eastern Atlantic there has been a tendency to ignore the biological problems because of the impractibility of applying the results of research.

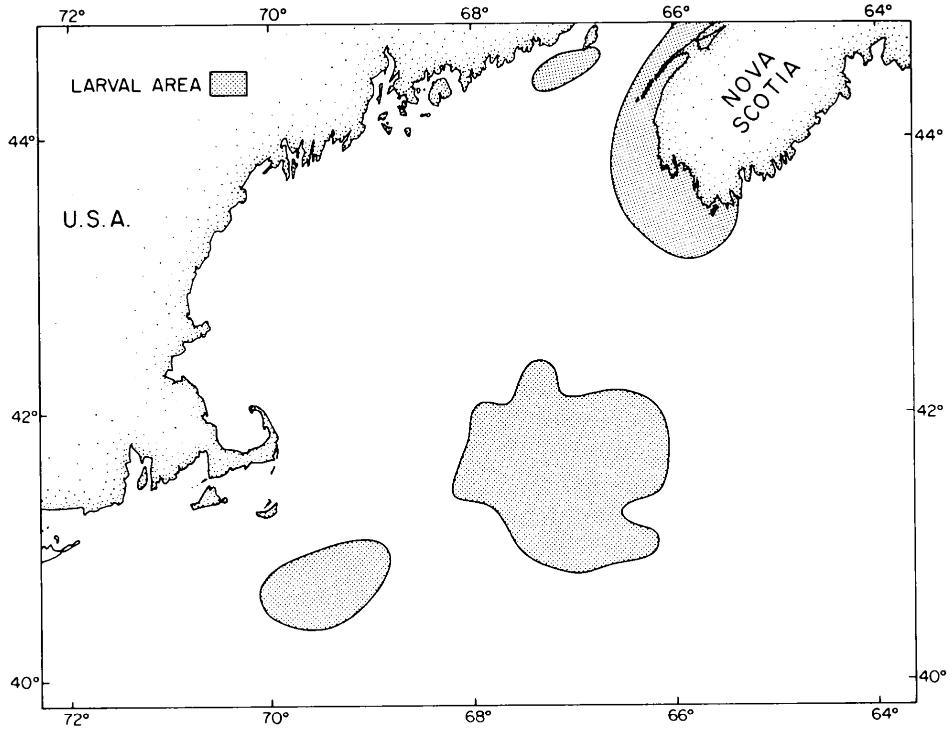
Fortunately the management of herring in Canadian waters is administratively and politically organized and effective so that the purely scientific aspects are amenable to study. A hypothesis to account for many of the biological characteristics of herring stocks has been recently put forward (Iles and Sinclair, 1982) that opens the whole stock question for debate.

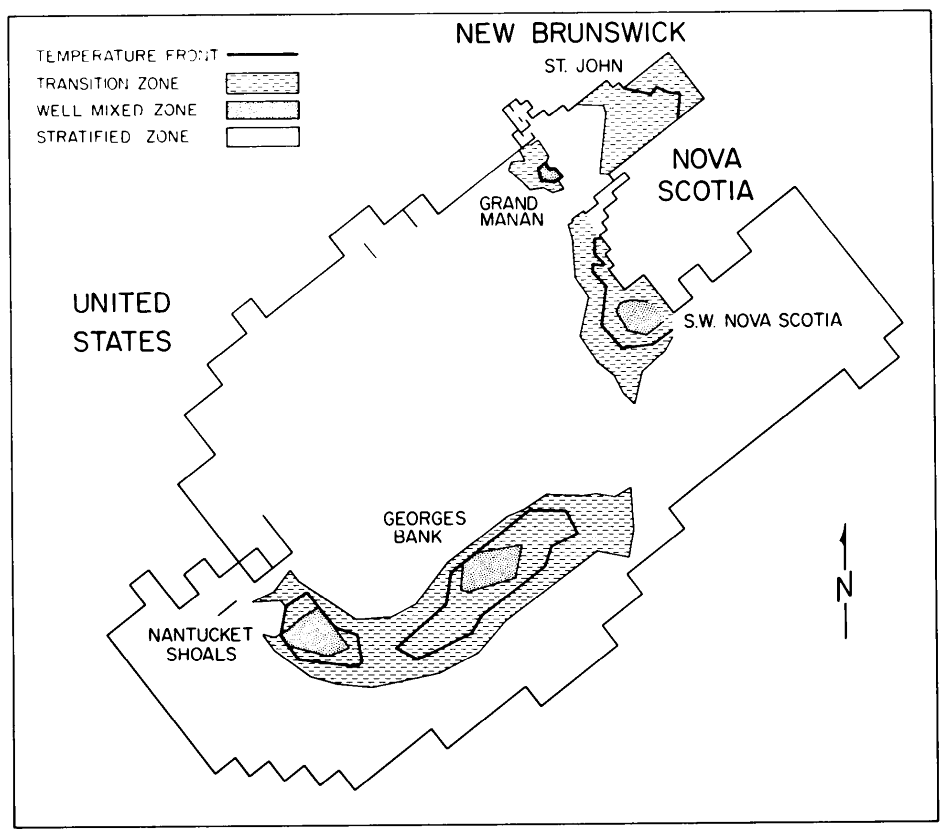
The fundamental biological problem is the definition and explanation of the existence of genetically isolated groups within species and the approach to its solution is, in retrospect, simple and obvious. Individual herring "stocks" spawn on the sea bottom in well defined areas at well defined times of the year (Zylastra, 1964). Isolation, if it occurs, is relatively easily recognized at the time of reproduction. Beginning at this stage, one follows the life history until isolation breaks down (i.e., until mixing of the progeny of different spawning groups occurs) and then asks whether or not isolation until this stage can be sustained over an indefinitely large number of generations.

The crucial factor that led to the formulation of the new hypothesis was the recognition that certain discrete hydrographic systems, with boundaries defined by a "stratification parameter" and that represented areas of marked vertical mixing (Simpson and Hunter, 1974), corresponded to known discrete areas of distribution of herring larvae.

The larval-postlarval stage is also the "density-dependent" stage; within this stage intra-population competition leads to the reduction of the vast numbers of fertilized eggs (tens of thousands per female) (Cushing, 1973) to the level of the preadult adult population. It is reasonable to accept that isolation up to this stage could be sustained (Hempel and Blaxter, 1967).

At subsequent stages, when swimming power is much more marked, mixing amongst stocks is possible, but the known ability of adults to home in on spawning grounds allows a desegregation into the





Distribution of: top - herring larvae shortly after spawning; bottom - the Simpson-Hunter Stratification parameter in the Gulf of Maine area.

original isolated spawning groups. The larval stage in a well mixed area is dispersed throughout the area but boundary conditions result in the "retention" of the progeny of spawning within the area. Indeed, one can then define the stock as all of those individuals that contribute to the larval population of a given retention area. That retention areas are determined by hydrographic features assures their relative stability from year to year and the similarity in the seasonal variability.

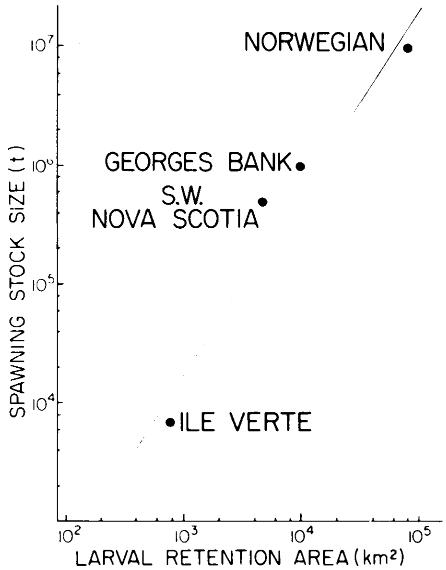
A very important extension of the hypothesis then follows. Herring stocks vary in abundance (as demonstrated by their yields as fisheries) over several orders of magnitude (Iles and Sinclair, 1982), and there are no consistent differences in their life history parameters to explain this variation. The size of the retention areas also varies to much the same degree, and it is concluded that the absolute abundance has essentially a physical rather than a biological explanation.

There is also a suggestion that the other major biological difference between herring stocks - the seasonal time of spawning that, altogether, covers the whole year (Parrish and Saville, 1964) - may be explained by reference more to the physical characteristics of individual retention areas than to the production characteristics within them, but this aspect of the hypothesis is not fully developed as yet.

The hypothesis, or its implications, challenges a number of widely accepted concepts and ideas and it is unlikely to be fully accepted without debate and perhaps modification. For example the concept of "passive larval drift" is seriously questioned. Certainly larval dispersal occurs, but the interaction of hydrographic conditions at the retention boundary with the structured vertical behaviour of the larvae sets up effective limits to larval distribution. Drift does not define distribution.

If these boundary conditions are too 'porous', the stock cannot be sustained. Variability of the boundary porosity within these limits, from year to year, and remembering that under normal unfished conditions a herring stock would be made up of a number of year classes, would account for a proportion and perhaps a large proportion of year class variability.

However, reducing the emphasis on primary and secondary production processes as the major determinants of population size is difficult for some to accept. Indeed, the raising of the question of what does affect absolute population size - as a general question of basic ecological and evolutionary theory - is in many ways the most important aspect of the hypothesis. Linked to this is the status of stocks as taxonomic units at the intraspecific level. They do not conform to criteria usually used within currently accepted evolutionary theory to differentiate subpopulations of individual species. For example the "gradualist" approach assumes or implies that subspecies are incipient. It seems highly unlikely that this (Gould, 1980) is true for all, or even many, herring stocks. There could well be sufficient non-selective flexibility and plasticity to accommodate to the environmental differences that most individual stocks experience.



Relationship between spawning stock size in metric tonnes (t) and the respective larval retention areas. The spawning stock estimates are those observed during periods of moderate fishing when the populations were at relatively natural levels.

The question also arises - why herring? The answer seems to be that the same general hypothesis can be applied to any planktonic marine organism or any marine organism that has a planktonic stage within a region that includes retention areas - potentially, continental shelf marine teleosts and most invertebrates that support commercial fisheries, as well as zooplankton.

This is not to imply that all species will show the same kind of structuring as herring, only that a different type of analysis of life history and ecology is now available that seems particularly appropriate to marine ecosystems. As most of the body of current ecological theory has been derived from the study of terrestrial, aerial, or freshwater systems, this approach is likely to present new and different problems to be addressed.

For herring, important management issues are raised; the implied reality of stocks as biological units and the implied inability of one "healthy" stock to recolonize an area vacated by an overexploited stock obviously suggest an ideal type of management system based on the stock at its "unmixed" stage.

The extent to which the hypothesis can be sustained and extended cannot yet be predicted, but it has created considerable attention as an interesting basis for both discussion and debate and the setting up of field programs to explore and test its various aspects; this amongst a surprisingly wide range of disciplines.

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Ecological research in the Bay of Fundy

D.C. Gordon, Jr.

In 1977, the Marine Ecology Laboratory (MEL) initiated an ecological study of the upper reaches of the Bay of Fundy. This region, famous for its high tides, has extensive intertidal mud- and sandflats, strong tidal currents, and high concentrations of suspended sediment. Although our field programs have covered all parts of the Bay, we concentrated on the Cumberland Basin at the head of Chignecto Bay, the site recommended for tidal power development in 1977 (Gordon and Longhurst, 1979).

No ecological studies had been conducted in the Cumberland Basin when the project began. Because of the area's high levels of physical stress and lack of easily visible organisms, it was generally considered to be biologically barren. Considerable effort, also involving other laboratories, was initially devoted to conducting ecological surveys of the organisms present and their distribution in space and time. As the project progressed, more attention was given to dynamic aspects such as determining the production rates of different parts of the ecosystem and how these were influenced by environmental factors.

A basic mechanism in any ecosystem is the primary production of organic matter by photosynthesis, and MEL has investigated this process intensively in Cumberland Basin where four different types of marine plants are present; unicellular mudflat algae, phytoplankton, seaweed, and salt-marsh grass. Each has been considered.

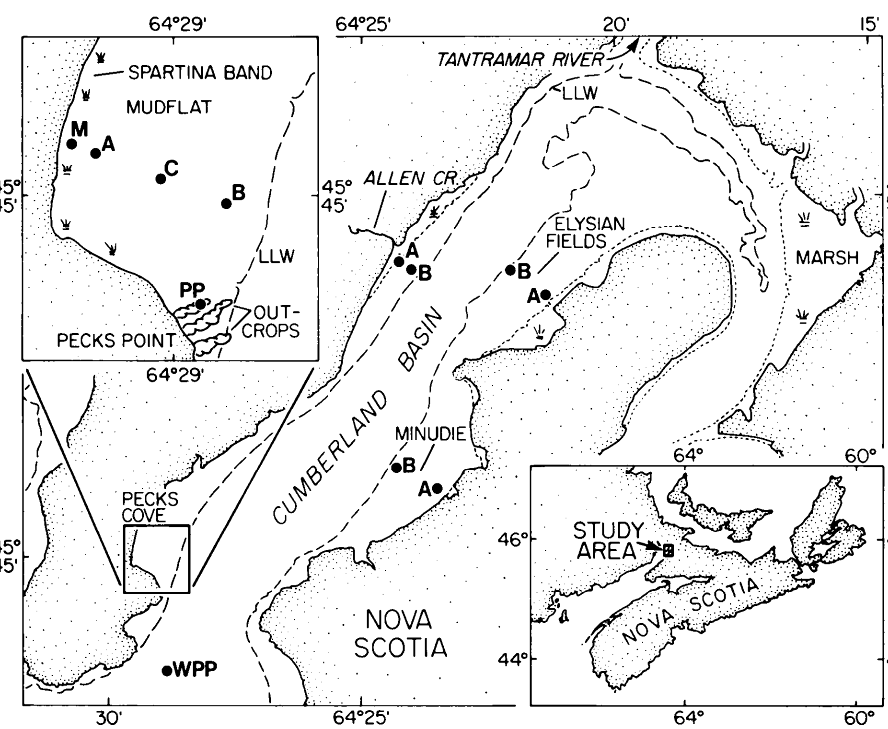
Because 40 % of the Cumberland Basin area below the extreme high tide mark is intertidal mudflat that is exposed twice daily, the primary productivity of mudflat algae was investigated first. Methods of measurement were developed and that adopted was based upon following dissolved oxygen changes in sealed cores (some exposed to solar radiation and others darkened) that were implanted in the exposed mudflat. Experiments were conducted at the Pecks Cove mudflat for almost two years at weekly or monthly intervals. Chlorophyll analysis and microscope observations indicated that mudflat algae are present and especially abundant during the warmer months of the year when brown algal films can be seen readily on the sediment surface. Primary productivity was appreciable and varied seasonally with the maximum occurring between late spring and early fall when solar radiation and temperature are greatest (Hargrave ***et** al.*, 1982). Productivity rates are very low in the winter when stranded drift ice commonly covers the exposed mudflats.

Sediment samples were collected from other mudflats in the Cumberland Basin on a regular basis using a helicopter, and these were analyzed for chlorophyll and organic content to estimate the relative productivity in different intertidal locations. The same seasonal cycles occur at all locations, but some mudflats appear to be more productive than others due to differences in exposure to waves and currents. There is no photosynthesis by mudflat algae when the sediment is flooded because of the very rapid attenuation of light in the turbid water, even during the summer when the solar radiation reaches a maximum and suspended sediment a minimum.

Despite the turbidity of the water and contrary to expectations, there is a significant and diverse phytoplankton assemblage in the upper reaches of the Bay of Fundy. Standard phytoplankton productivity experiments using carbon-14 were conducted in deeper water up to and including the mouth of Cumberland Basin on the CSS *Dawson* and in the shallow water flooding the Pecks Cove mudflat at high tide. Productivity is generally restricted to the upper one metre of the water column because of rapid light attenuation, but on an annual basis amounts to about 10 % of the benthic algal productivity for a given area of the Pecks Cove mudflat (Hargrave *et al.*, 1982). The relative importance of phytoplankton productivity increases in deeper water away from the mudflats as the turbidity decreases and light penetration thereby increases. Inorganic nutrients are abundant in Cumberland-Basin waters all seasons of the year and thus light and temperature are the major limiting factors controlling algal productivity.

Seaweed productivity was not investigated. Although the intertidal area is extensive, suitable rocky substrates are very limited and the few seaweeds present are presumed to contribute only a trace amount of organic matter to the Cumberland Basin ecosystem.

When the project began, the extensive



The principal features of the Cumberland Basin and mudflat study sites.

salt marshes around Cumberland Basin were not considered an important source of nutrition for animals inhabiting the mudflats and water column because recent research elsewhere suggested that salt marshes exported very little of their production. However, it soon became apparent that salt-marsh debris was common in the Basin and some marsh areas lost almost all of their annual growth by late fall. Therefore, MEL undertook a study of production and its export at eight salt marshes around the perimeter of Cumberland Basin. Study sites were visited monthly for over a year and changes in the amount of live and dead material were recorded. Elevations and dominant plant species were also determined.

Two general types of salt marsh occur. High marsh, located above the mean high water mark, is flooded just a few times a month by the highest spring tides. It is dominated by *Spartina patens*. Low marsh, located below the mean high water mark, is flooded at almost every high tide. It is composed exclusively of the cordgrass, *Spartina alterniflora.* Much of the high marsh area in existence when the first Acadian settlers arrived in the 17th century has been dyked and today the areas of natural high and low marsh are almost equal. Like the mudflat algae, most marsh grass grows during the six-month period between April and September when solar radiation and temperature are greatest. For a given area, low marsh is more productive than high marsh, but both are more productive than mudflat algae. The productivity of low marshes is closely related to elevation and flooding frequency; their greatest productivity is at the highest elevations, just below the mean high water mark. In contrast, the lowest marshes have the lowest productivity rate. Export of production is also related to elevation and flooding frequency, but in an inverse fashion. Most of the annual production of low marshes is lost within a year due to the action of water and ice, while most of the high marsh production appears to decay in place.

For the entire Cumberland Basin, the total marsh productivity is estimated to be slightly less than that of the mudflat algae. Since most of the low marsh production is exported, it is clear that salt marshes play an important role in the nutrition of marine organisms in this region. In contrast to mudflat algae and phytoplankton, which are eaten directly by grazing animals, marsh grass decomposes into soluble and particulate components before it is utilized, and micro-organisms play an important role in increasing its palatability.

An attempt was made to determine the relative importance of organic matter produced my mudflat algae and salt marsh grass in the Pecks Cove mudflat ecosystem using stable carbon isotope ratios (Schwinghamer *et al.,* 1982). Unfortunately the ratios of the two source materials could not be distinguished and it was impossible to determine their relative contributions. The dominant organisms in the mudflat all had ratios very similar to algae and fresh marsh grass, which indicates both are potentially important food sources. The isotope ratios of dead marsh grass were observed to change during the decomposition process by a mechanism that is not yet completely understood. Heavily decayed marsh grass and bacteria appear to be relatively minor food sources in the mudflat ecosystem.

Other co-operative projects conducted in the Cumberland Basin region during the same time period, many of them by other government and university laboratories, have focused on the animals living on and in the mudflats and salt marshes (Hicklin *et al.,* 1980), the zooplankton (Daborn *et al.,* 1982), the fish (Dadswell *et al.,* 1982), and the migrating shorebirds. All results indicate that the area is not a biological barren as was earlier thought but that instead it supports a diverse and moderately productive ecosystem. The basis of the ecosystem is organic matter produced primarily by mudflat algae and the low-lying salt marshes. The productivity of both plant forms is intimately linked to the twice daily rise and fall of the tide, a natural process that would be altered by the construction of a tidal power project. If such a project is undertaken, the ecological data collected by MEL will play a critical role in the prediction of its likely impact on the environment (Gordon and Longhurst, 1979).

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chapter 3

Earth Sciences Offshore

Two hundred million years ago Eastern Canada was in a sense the centre of the known world, strategically located at the heart of the supercontinent Pangea. The most recent phase of major shift in continents began about that time, and one of the effects of this reorganization was the formation of the Atlantic Ocean. The continents that now surround the Atlantic were separated in a process of continental rifting and drifting, and creation of new ocean floor at the mid-ocean ridges. We live on one of the new margins of the ancient continents, and margins of this type are called "passive" because they have not been involved dramatically since some time after their birth in the demonstrably active processes of collision, mountain building, and volcanism that have affected continental margins like those of western North and South America. Because the margins of the Atlantic over a substantial part of their history have been relatively passive - by comparison with active margins - the history of the Atlantic Ocean and the oceans with which it has connected is relatively well-recorded within the wedge of sediments at the margin and within the sediment formed on the new crust of the Atlantic Ocean basin itself. Furthermore, the record of vertical motions is contained within the sedimentary wedge; these motions depend upon the changing loads on the earth's surface and upon the changing physical properties of the outer part of the earth, so that the record in the sedimentary wedge places constraints on physical models of the rifting process and subsequent subsidence at the continental margins. Naturally, although the distinction between "active" margins and "passive" margins is rather clear conceptually, the inference should not be drawn that nothing exciting ever happens on passive margins.

The geological record of a trailing margin such as ours documents the complex interactions of paleogeography, paleoclimate, fertility and biota development, sedimentation, ocean circulation, and tectonics, and there are many future challenges to document. Examples are the relationships between sea level changes, circulation, the development of mid-ocean ridges, and gaps in the sedimentary record. All investigations like these demand the best geological time scale that can be devised. These points are illustrated in the papers that follow.

We describe various aspects of the story of the development of the new Atlantic Ocean and its margins in five papers. Jansa gives an account of the early history of this new ocean, and of recent attempts to solve some remaining problems, those related not only to the oceanographic nature of the ocean but to the location of the boundary between the continental crust and the newer oceanic crust at the ocean's margins. Keen describes recent efforts to model the development of the margins themselves, in which she ends up predicting observable properties - the shape of the sedimentary basins offshore, and the temperature history of the margins, for example - starting from elementary observations concerning the crust. This work, as does Jansa's, depends upon a valid stratigraphy, a record of time from the sedimentary wedge, and good correlations from oil well to oil well. Gradstein, with his colleague Agterberg, has developed a statistical method of correlating and defining events in time that takes biostratigraphy out of the realm of the qualitative, and into the realm of the quantitative.

Jansa refers to early sources of organic matter, and Keen is concerned with predicting its maturation - the field in a time-temperature plot where source rocks will be oil or gas producing. Bujak and Davies describe a new method for observing this maturation in palynomorphs, which depends upon observing a secondary fluorescence that may result from prolonged heating. They are the first to agree that the method is not yet securely based.

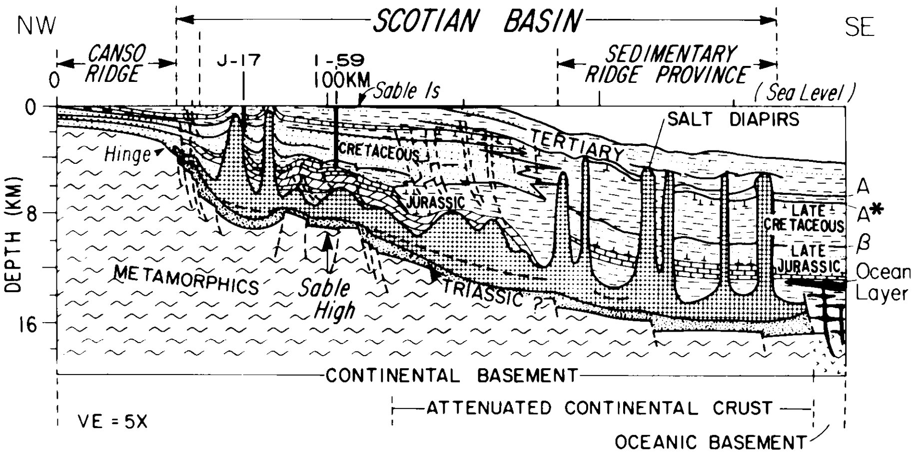
Hydrocarbons will be exploited within the next few years from Eastern Canada's offshore. This will first be from the shelf, but later and less certainly from the slope. Among the geological constraints to development are earthquakes, such as the well known large one of 1929, south of the Grand Banks. This occurred on the slope above the Laurentian fan, which developed in the latest stages of development of the Atlantic Ocean, a garbage dump for debris from the continent. Piper describes recent investigations of this fan, one of the major morphological features of our margin.

The early North Atlantic

L.F. Jansa

Even though exploration of the Atlantic Ocean has substantially progressed over the past 15 years, mainly as a result of the Deep Sea Drilling Project, many oceanographic and geological questions are unanswered, and its history has been interpreted in many different ways.

When the continents surrounding the North Atlantic began to drift is still not well-known since the earliest oceanic crust has not been drilled. The drift of the continents is estimated to have began from 160 to 195 Ma ago (Hallam, 1971, 1977; Pitman and Talwani, 1972; Jansa and Wade, 1975; Klitgord and Behrendt, 1979; Schlee *et al.,* 1979). The location of the boundary between ocean and continent has been disputed. Some argue that the prominent magnetic anomaly off the east coast of North America marks this, but others



A schematic section through the Scotian Basin (line A of the next figure). The major stratigraphic and tectonic features of the Basin are shown including the boundary believed to separate oceanic from continental crust. (Reproduced from Jansa and Wiedmann, 1982.)

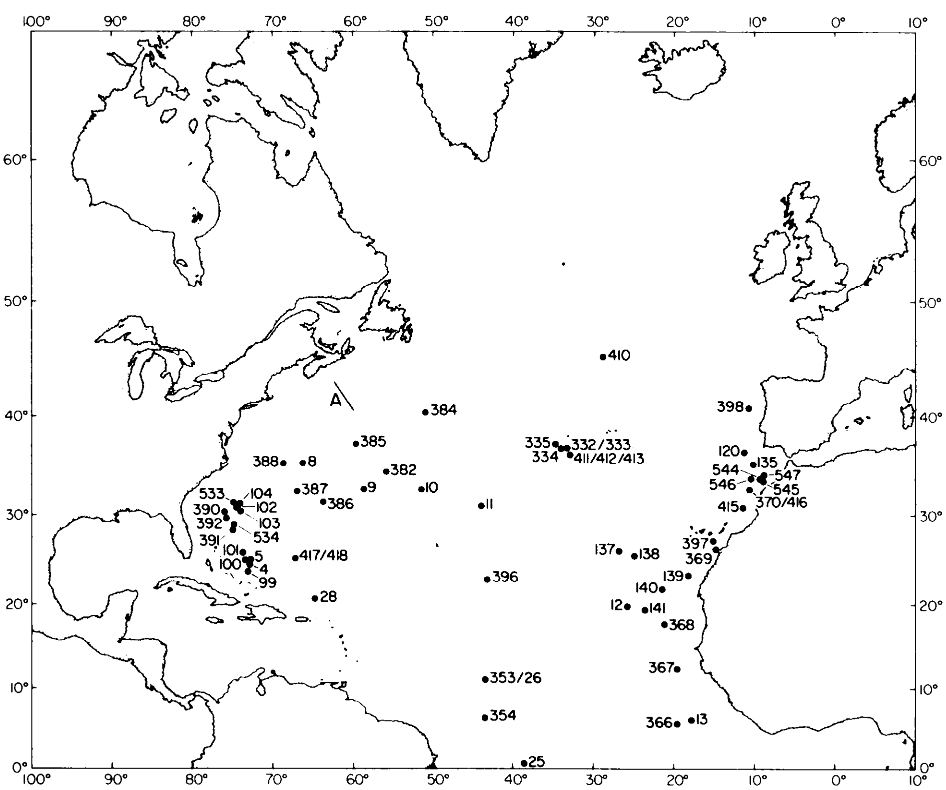
that the Quiet Magnetic Zone seaward of the anomaly is itself floored by continental crust (Schlee *et al.,* 1979; Klitgord and Grow, 1980; Hallam, 1977). Conflicting theories have been proposed concerning the origin of the earliest sediments of the North Atlantic. Evaporites have been recognized in seismic profiles or exploration wells from the rise and slope off Nova Scotia and from the sedimentary basins off Morocco (Beck and Lehner, 1974; Jansa and Wade, 1975; Lancelot and Winterer, 1980). Jansa and Wade suggested that these evaporites were originally deposited in the shallow waters of Late Triassic to Early Jurassic age rift basins. Lancelot and Winterer, however, thought that those off Morocco were deposited during a period of dessication over oceanic crust of Middle Jurassic age. At least on first reflection, such contradictory hypotheses make it difficult to draw conclusions on the early development of the North Atlantic.

Two legs of the Deep Sea Drilling Project in the north Atlantic have recently been completed, and I draw upon them - Leg 76 and Leg 79 (especially Site 534) - to present new information related to these problems.

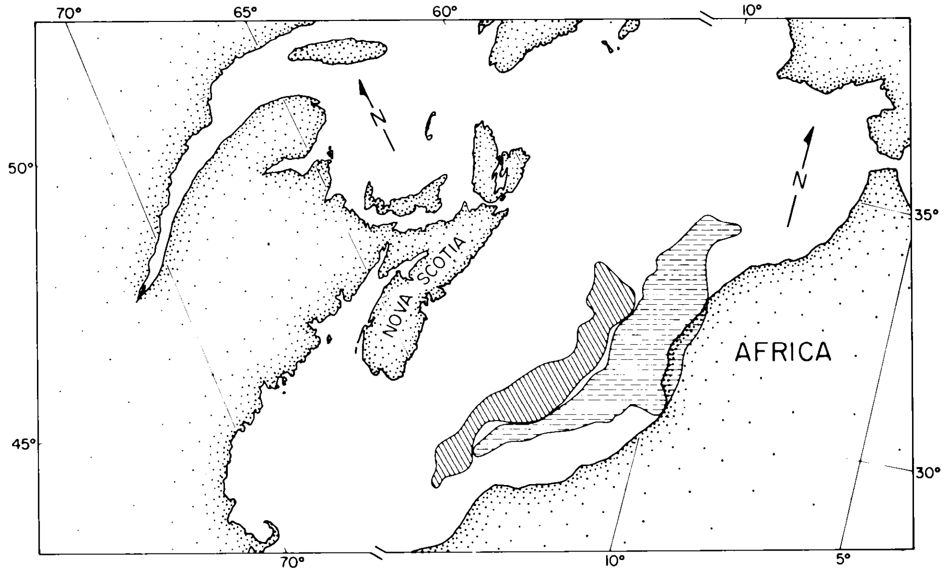
Seafloor spreading and crustal boundaries

Progress was made in defining the ‘landward’ boundary of oceanic crust during Leg 79 of the Deep Sea Drilling Project off Morocco (Hinz et al., 1982b). Holes were strategically located on a series of structures that may have been diapirs of salt or shale, or fault blocks of igneous or metamorphic rocks. One hole (Site 544) penetrated a gneiss below red-beds of Triassic age; a second hole seaward of this (site 546) penetrated evaporites also covered by red-beds of a continental nature. These results suggest that the boundary between oceanic and continental crust lies beyond the region in which drilling encountered salt diapirs, and one possible location is the seaward boundary of the diapir ‘province’. This hypothesis can be tested by matching the boundaries between the diapir provinces off Nova Scotia and off Morocco; if this is done, the fit is very good (Hinz et *al.,* 1982b). Consequently the suggestion follows that the evaporites forming the diapir fields off both regions were deposited in a single basin, in a continental environment (on account of the red-beds, which are intercalated with halite), and this basin was rifted apart (in the early Jurassic). The boundary between oceanic and continental crust must then be the seaward boundary of each diapir field; care must be taken to recognize later flowage of salt that would, obviously, obscure the boundary.

The Quiet Magnetic Zone lies seaward of the diapir province, so it must be underlain by oceanic crust. This was shown to be so on Leg 76 of the Deep Sea Drilling Project off Florida (Sheridan *et al.,* in press). A hole at site 534 was drilled within the Quiet Zone above marine magnetic anomaly M-28 (Bryan *et al.,* 1980), which is not well-defined in terms of the magnetic anomaly time scale. The hole bottomed in the massive basalts typical of oceanic crust, and beneath the oldest sediments in the North Atlantic, which are of middle Callovian age - about 160 Ma old (Sheridan *et al.,* in press). If this date is a



Location of the Deep Sea Drilling Project sites in the North Atlantic. Sites drilled during Leg 76 of the project include 533 and 534: those drilled during leg 79, sites 544 to 547.



The reconstruction of the Late Triassic - early Jurassic salt provinces off northwest Africa (Morocco) and eastern North America (Nova Scotia, Maine) are shown. The extension of the diapiric salt provinces of Nova Scotia is shown by the vertical lines and that off Morocco by the horizontal lines. The boundary of the provinces was determined from geophysical surveys by Bundesanstalt für Geowissenschaften und Rohstoffe (after Hinz *et al.,* 1982).

reasonable minimum age for anomaly M-28, then spreading of the ocean floor occurred twice as fast as had been thought, and began some 20 Ma later than was once believed.

Sedimentary sequences and oceanographic regimes in the early Atlantic

Until recently we had information about the oceanographic conditions of the Atlantic back only to about 140 Ma. A gap in time and space existed between this information and knowledge acquired from exploration drilling for hydrocarbons on the shelves where evaporites and red beds of the latest Triassic or earliest Jurassic (195 Ma old) had been encountered.

The North Atlantic during the Late Jurassic (140 Ma) was still relatively narrow and well oxygenated, but without a strong bottom circulation. The climate was warm, rather dry, and favourable for the deposition of carbonates on shelves and in deep sea basins. There was an open marine connection with the Tethys - of which the Mediterranean is the successor - and the same type of sediment was being deposited in the North Atlantic and western Tethys; this is known as the “Rosso et Aptici”, and Ammonitico Rosso (on account of the colour and the presence of aptici of ammonites in the former) and Maiolica facies; and it is found on land in Greece, Italy, and Spain (Bernoulli, 1972; Jansa *et al.,* 1978).

Legs 76 and 79 filled much of the knowledge gap. On Leg 76, the Callovian deposits (163 Ma old) discovered above oceanic basalts are brown and greenish-black claystones rich in radiolaria, and reposited limestones (Sheridan *et al.,* in press). If the colours reflect the original environments (as is likely) then they may reflect alternating oxidizing and reducing conditions in the Late Jurassic. Alternation of oxidized and reduced sediments points to a delicate balance in the Jurassic ocean of organic input from the land (with perhaps a periodically wet climate) and oxygen depletion, which suggests a weak bottom circulation. The only other evidence for the oceanographic conditions in the earliest Atlantic basin comes from Leg 79 off Morocco. At Site 547 an almost complete sequence of Jurassic sediments, underlain by Triassic red-beds was encountered (Hinz *et al.,* 1982b). The Lower and perhaps Middle Jurassic sediments are mostly dark grey sandy mudstones. One interpretation suggests that these sediments also reflect less oxygenated bottom waters, as was interpreted to be the case for the Callovian in the Blake-Bahama Basin.

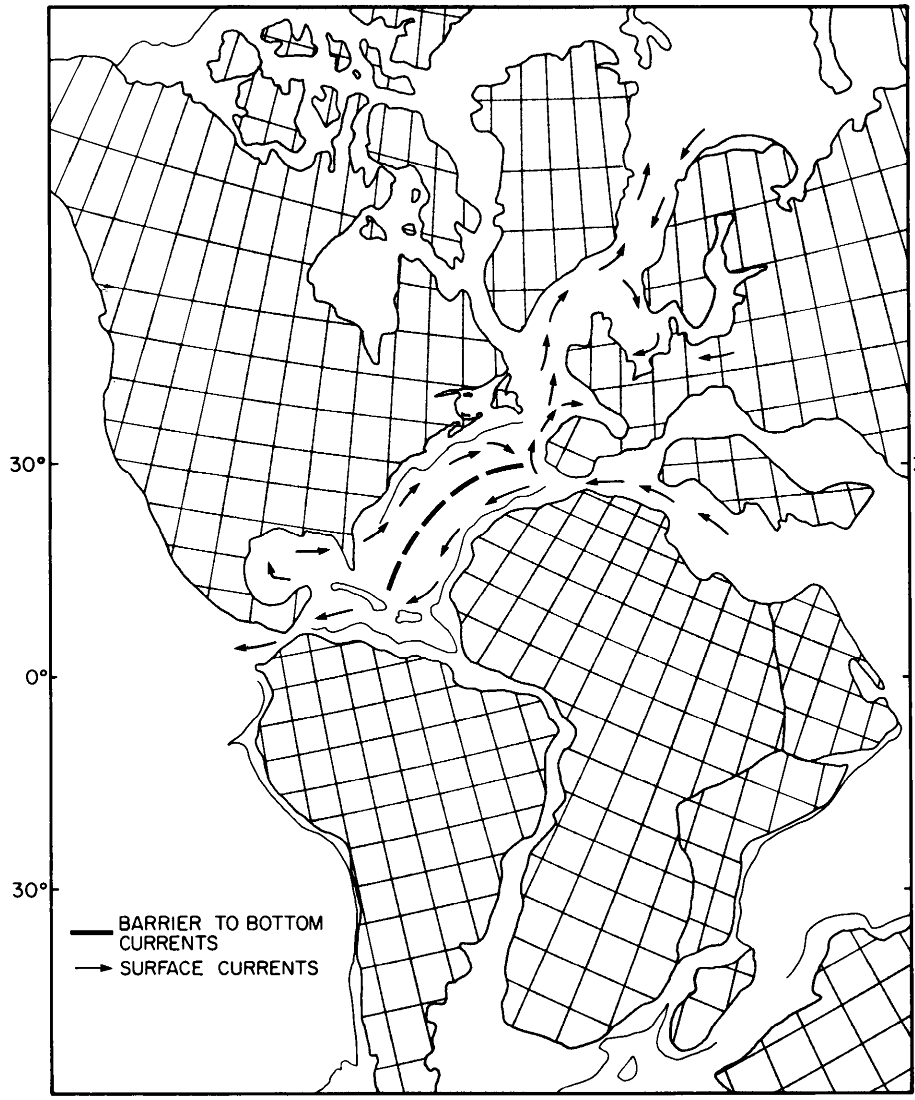
The surface waters at this time may, however, have been of normal salinity, nutrient rich, and with a wind driven circulation of surface water. The evidence for this is that Lower Jurassic limestones from Site 547 contain a rich, radiolaria fauna with a less-preserved nannoplankton, which is also characteristic of sediments deposited in deep water in the Tethys. Thus, there may have been an unrestricted surface flow between the Tethys to the early North Atlantic from 185 Ma ago onward - contrary to the suggestions of Ager (1974) Lancelot and Winterer (1980) and Seibold (1982).

Conclusions

Ocean floor spreading began 160-175 Ma ago, and the boundary between the oceanic and continental crust may lie at the outer, seaward boundary of the diapir salt provinces of the margins. At least part of the Quiet Magnetic Zone is underlain by oceanic crust.

The following working hypothesis for the oceanographic conditions in the early North Atlantic may be reasonable. The central North Atlantic during the latest Triassic and earliest Jurassic (pre-Sinemurian) was a site of evaporite deposition. The salts were precipitated in a basin being filled from the Tethys into a central rift graben; the water was probably shallow. As a result of a widespread transgression (Vail *et al.,* 1977) during Sinemurian times, 185 Ma ago, normal marine conditions were rapidly established. During Early and Middle Jurassic times, circulation was sluggish as a result of low latitudinal temperature contrasts, which contributed to the development of poorly oxygenated bottom conditions in the North Atlantic. The basin at this time was relatively narrow and about 350 km

Felix Gradstein, Lubomir Jansa. and Jon Bujak.



The circum North Atlantic region as it appeared 140 Ma ago. The location of the ancient shorelines is plotted on the plate reconstruction map as derived from average paleomagnetic pole positions. The paleocirculation pattern for the North Atlantic during the late Jurassic is marked by arrows (base map adopted from Barron *et al.,* 1981).

wide.

The reducing conditions on the bottom during this period were favourable for the preservation of organic matter in shale beds. The organic carbon content in some of the beds off Morocco was as high as 7 % (Hinz *et al.*, 1982b). The Lower Jurassic sediments beneath the outer parts of the continental margins may therefore be sources for hydrocarbon generation.

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Offshore eastern Canada: from plate tectonics to petroleum

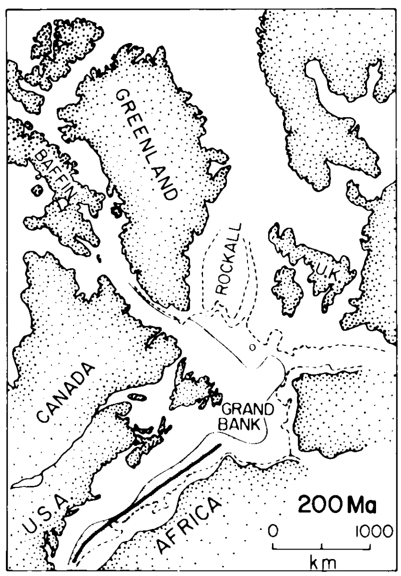
C.E. Keen

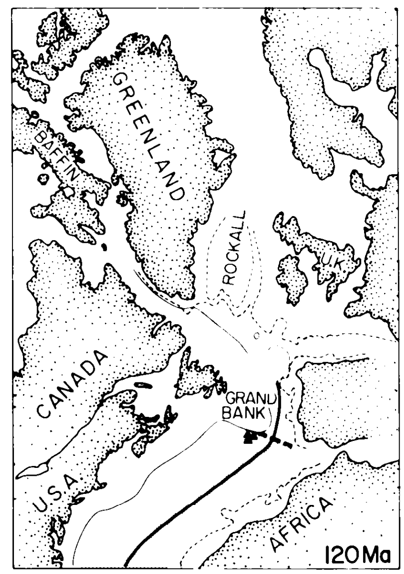
The so-called passive continental margins off Eastern Canada have in fact experienced an active history over their geological lifespan. It began about 200 Ma ago when the supercontinent of Pangea fragmented to open the Atlantic Ocean Basin and its northern extensions into the Arctic. The break-up of Pangea included several phases of plate tectonic separation that produced the margins off Eastern Canada (Keen and Hyndman, 1979). About 200 Ma ago, the Africa - North America plate motions began to create the continental margin off Nova Scotia and south of the Grand Banks. About 120 Ma ago, Iberia - Spain and Portugal - separated from the eastern Grand Banks. Finally, 80 Ma ago the region west of Great Britain rifted away from the northeast Newfoundland shelf, and Greenland separated from Labrador and Baffin Island. Thus, the formation of the margins off Eastern Canada is the product of complex rifting events over about 120 Ma. These rifting episodes produced progressively younger margins to the north, and created rather different structural styles for the various segments. Some of these differences appear to depend on the sense of relative motion between the separating continents, on the fabric of the crust being rifted, and on the length of time required to achieve complete continental separation. For example, differences due to the sense of direction are evident in the Nova Scotian rifted margin, and these resulted from plate motions roughly perpendicular to the margin, as compared to the sheared margin south of the Grand Banks where the continents slid past each other.

Understanding the evolution of the margins requires a knowledge of the plate tectonic motions that produced them. However, plate tectonics provides only part of the story; knowing the motions that created the margins does not explain the nature of the physical processes that were active during their creation. In order to understand the geological evolution of the margins, we must look for additional clues.

The data available for the margins of Eastern Canada are among the best in the world, and this makes them particularly appropriate for such investigations. These data include: samples from deep exploratory wells to determine the stratigraphic and geochemical properties of the sediments; seismic reflection data to delineate the thicknesses and structural characteristics of the sedimentary strata on a regional scale; seismic measurements of the deep crustal structure of the margin; gravity anomaly measurements; and observations on magnetic anomalies. Given this unique data set, the challenge is to use it well and determine what occurred during rifting and the subsequent evolution of the margins.

One way of approaching this task is to construct theoretical models to predict a number of parameters that can be compared directly with the observations. If the predictions and observations do not match





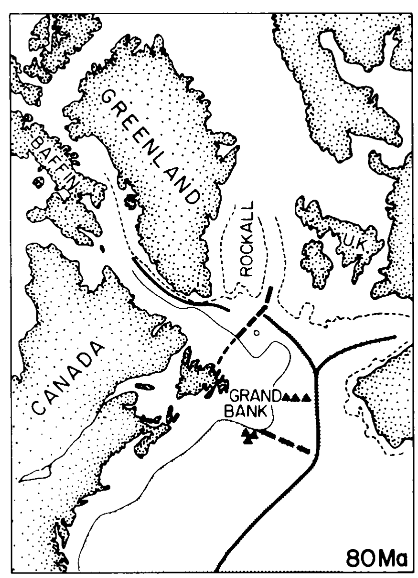


Plate motions responsible for the formation of the continental margins of Eastern Canada. Heavy solid lines represent mid ocean ridges. The stippled region is new oceanic crust. The three panels show the three phases of plate motions described in the text.

well, the model must be modified or discarded. This is the kind of model that Chris Beaumont of Dalhousie University and I have been developing. Others in the U.K., France, and U.S.A. have been working on similar studies. The models that best satisfy the observations are conceptually simple. They involve extension of the lithosphere during rifting (McKenzie, 1978). Extension thins and heats the lithosphere, as hot material from the asthenosphere rises beneath the thinned region. There will be changes in basement elevation during rifting due to the combined effects of thermal expansion of the lithosphere (causing uplift) and the replacement of light crustal material that has been thinned by more dense mantle material (causing subsidences). Whether the net result takes the form of uplift or subsidence depends on the details of the stretching process. As continental separation is completed, extension will cease and the lithosphere will cool and thicken towards its equilibrium thermal state. Thermal contraction causes the margin to subside and a depression is created in which sediments can accumulate. The weight of sediments produces further subsidence, in proportion to the mechanical strength, or rigidity, of the lithosphere. The rigidity will change with time as the margin cools; a young, hot margin is less rigid than an old, cold one.

All of the factors described in the last paragraph are incorporated in a mathematical model that allows the evolution of the margin to be computed (Keen et *al.*, 1981). The modelling needs two inputs: the amount of extension during rifting and the sediment influx over time. The amount of extension is determined from the thickness of crystalline crustal rocks now underlying the sediments. These were thinned by extension during rifting. Crustal thicknesses are measured in crustal seismic refraction experiments. Extension will, in general, vary across the margin and increase toward the ocean basin. The sediment influx is determined from biostratigraphic studies (Barss *et al.,* 1979) and from seismic reflection measurements. The evolution of the margin is then traced from the time of rifting to the present by computing the cooling of the lithosphere and the subsidence due to cooling and to sediment loading.

The models allow us to compute the total subsidence of the margin including the water depths, the rates of subsidence through time, the shape of the marginal sedimentary basin, the gravity anomalies across the margin, and the paleotemperatures in the sediments and basement rocks. All but the last can be directly compared with observational data to test the validity of the model. The paleotemperatures are significant because temperature and time determine the thermal maturation of organic matter. They can be used to estimate the petroleum potential of the sediments as source rocks; comments on this will be found in the accompanying article by Bujak and Davies.

Why is this kind of modelling particu-

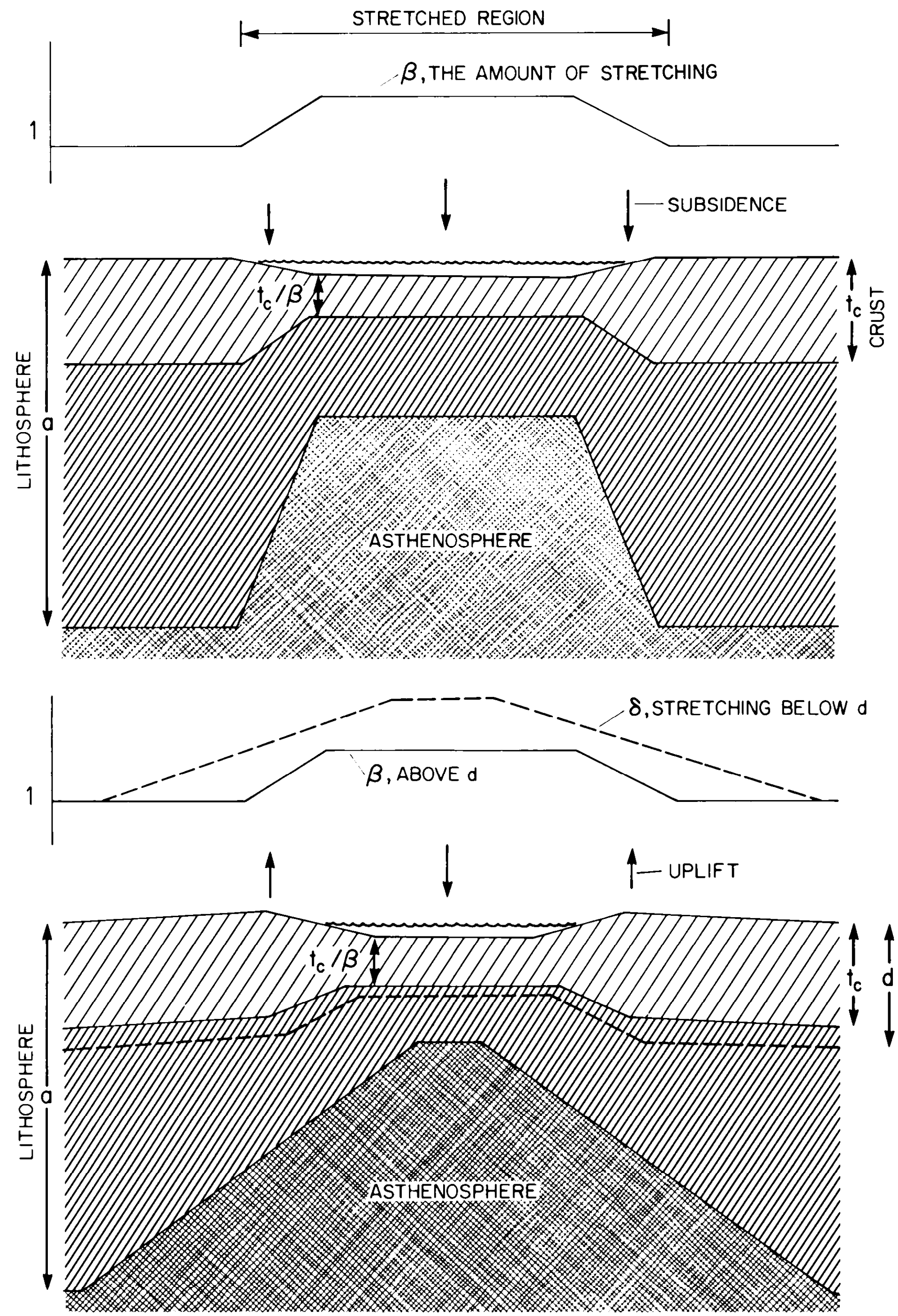
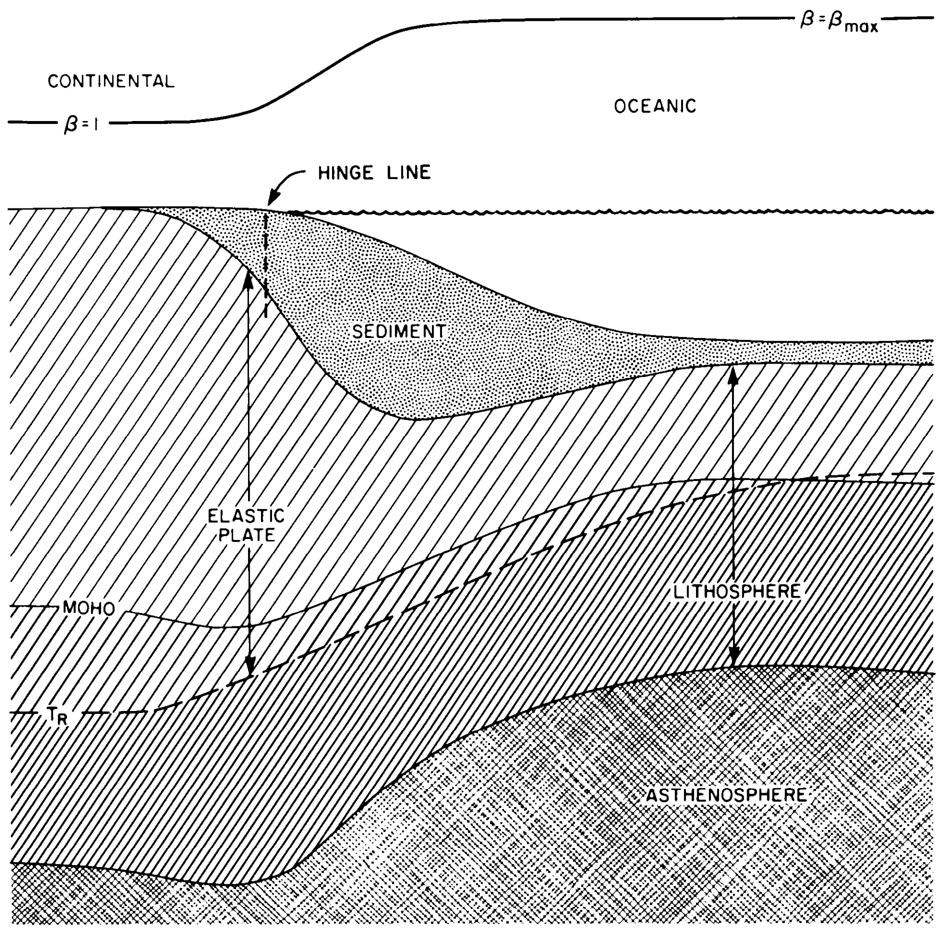


Illustration of the extension process. In the upper part of the figure the whole lithosphere is extended and thinned by an amount B. The crust whose original thickness is t_c is thinned to t_c/β. Hot asthenosphere rises beneath the thinned region and produces high temperatures in the lithosphere. For the model shown there will be subsidence during rifting indicated by the arrows.

The lower part of the figure illustrates what happens if stretching is not constant through the whole lithosphere. Instead the upper lithosphere is stretched by β and the lower lithosphere by δ. Uplift would then occur as illustrated by the arrows.

larly useful in studying the evolution of margins? Firstly, it allows us to integrate all kinds of data in one model, instead of studying one or two parameters in isolation from other observations. Secondly, the models allow us to predict certain facets of the margin's history that would otherwise remain difficult to extrapolate. An example is the prediction of paleotemperature. Thirdly, the models are quantitative: they allow a degree of precision in describing the evolution of the margins that is unattainable except through the introduction of a mathematical framework. These attributes are extremely useful in testing hypotheses of the behaviour on the margins against observational data.

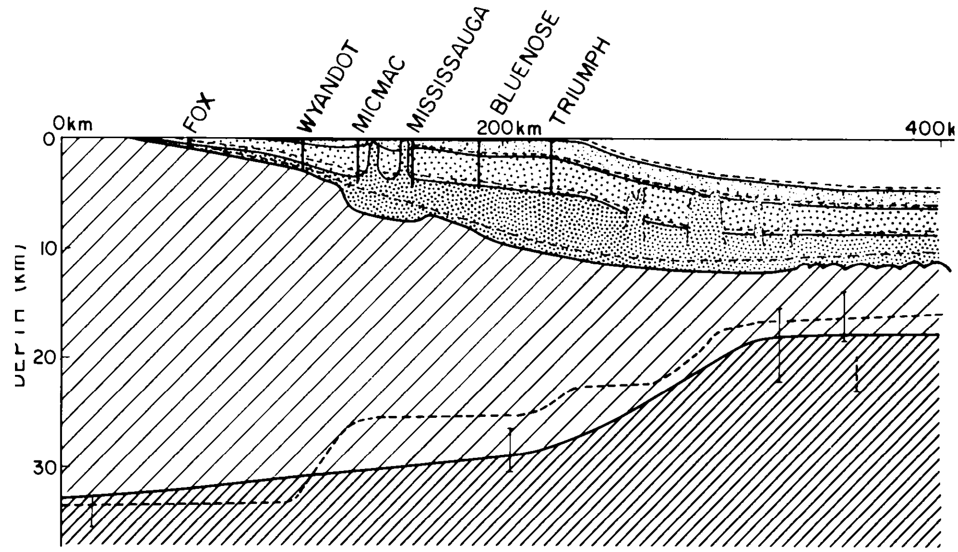
There is strong geological evidence to corroborate extensional models. On margins, where the basement rocks are not deeply buried by sediments, normal faults on listric surfaces have been mapped. Their geometry indicates extension by factors of 1.5 to 3 (Montadert et al., 1979). On the Labrador shelf the upper surface of normal faults can be seen in seismic reflection data and on the Grand Banks the presence of northeast-trending grabens such as the Jeanne d'Arc Subbasin probably result from extensional forces associated with rifting (Grant, 1975). Also, the crust beneath the sediments thins toward the ocean basin from typical continental thicknesses of 35 km to about 15 km beneath the axis of the marginal sedimentary basins. This thinning by factors of two to three is difficult to explain except by extension. Finally, the models are consistent with the development of thick sedimentary basins on the margins and with the stratigraphy of these basins (Umpleby, 1979). For example, the oldest marine sediments on the Labrador margin are Late Cretaceous. This is consistent with model predictions that the margin should have begun to cool and subside, and thereby allowed marine sediments to accumulate just after rifting was completed. The plate tectonic history suggests that rifting occurred in Late Cretaceous time, about 80 Ma ago. Thus the age of the oldest marine sediments coincides with the time that cooling should have begun as the model would predict. Similarly, on the Nova Scotian margin the oldest marine sediments are Early Jurassic (180 Ma), which agrees with the time of continental separation and the onset of cooling for that margin (Jansa and Wade, 1975). The models also predict that the rate of subsidence decreases with time after rifting. Therefore, subsidence and the depression available for sediment deposition will be greatest early in the history of the margin. Observations confirm this; for example on the Nova Scotian margin a large thickness of Jurassic sediments (180-135 Ma) occupies the basin, while lesser thicknesses of younger sediments have been deposited.



Schematic representation of the continental margin at some time during its evolution after rifting. The variation in the amount of extension across the margin is shown at the top. The lithosphere (and crust) have been thinned during rifting, but the lithosphere has cooled sufficiently since rifting to allow sediments to accumulate. The sediment load also produces subsidence, which depends on the rigidity of the lithosphere. These mechanical properties of the lithosphere are included in the model by proposing that the sediment load is supported by an elastic plate whose thickness and rigidity varies with temperature.

The model has been applied successfully to the rifted margins of Eastern Canada, as well as to other areas. Some of the results for the Nova Scotian margin are shown in the figure on page 45, where observations and model results are compared (Beaumont *et* al., 1982). The model predicts a sedimentary basin remarkably similar in shape and stratigraphy to that observed. It is important to remember that this is in no way "fixed" beforehand. The amount of subsidence is determined from the amount of extension, estimated from measurements of crustal thickness. If the model is inappropriate, the depression created by subsidence may be too great or too small to satisfy observations of sediment thickness and water depth. That good agreement is attained, and that there is a good match between observed and predicted gravity anomalies, is compelling evidence in support of the model. This also clearly demonstrates that a fundamental relationship exists between the sedimentary basin and the deep crustal structure, an important advance in understanding the geology in three dimensions.

Of practical importance are the model predictions of paleotemperatures within the sediments (Keen, 1979). Because the calculations trace the cooling history of the lithosphere since the time or rifting, the temperatures at any time and depth can be found. Data from the Triumph Well on the



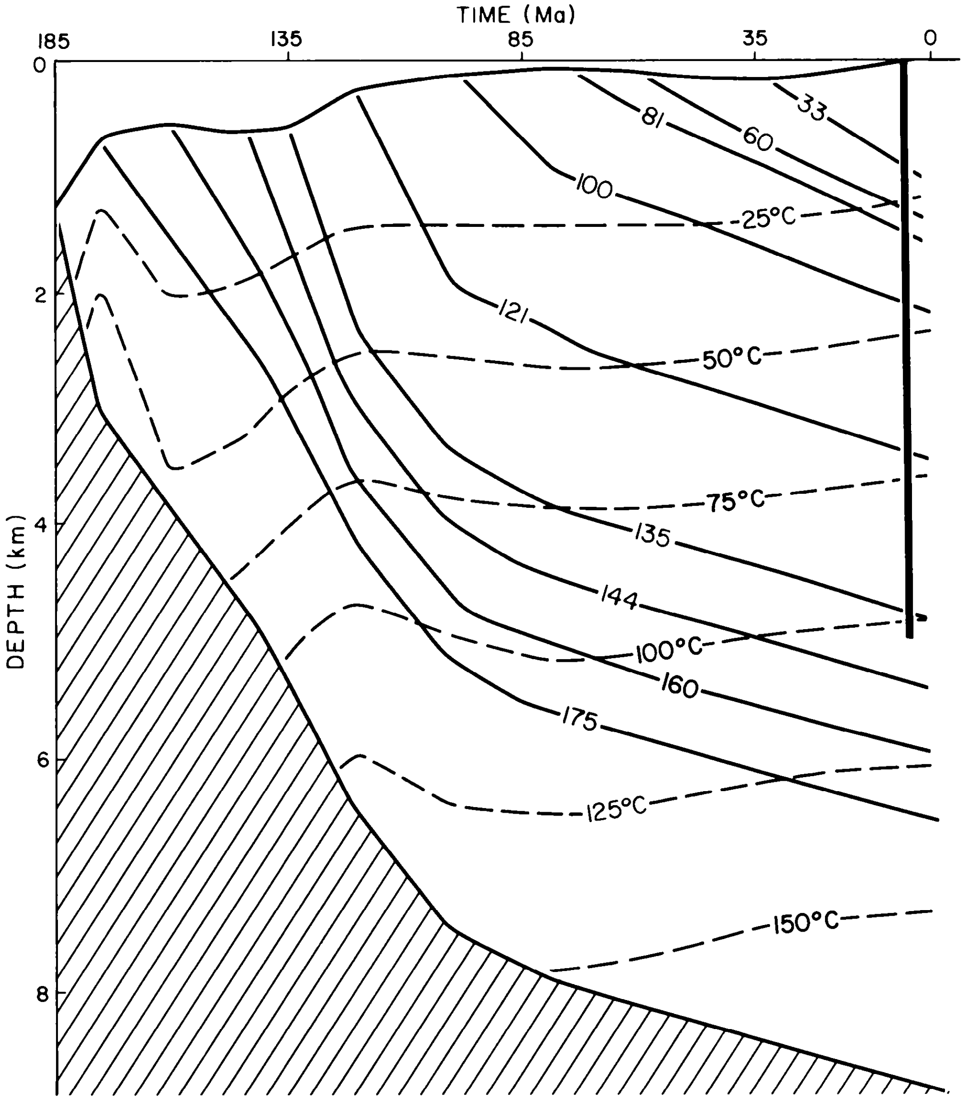
A simplified cross-section through the Nova Scotian margin along which observations (solid lines) and model predictions (dashed lines) are compared. Sediments are shown in the three stippled regions. The uppermost region corresponds to Tertiary and younger sediments (0-60 Ma); the middle region to Cretaceous sediments (60-135 Ma); and the lower region to Jurassic sediments (135-180 Ma). The hachured region below the sediments is crystalline crust underlain by the mantle. Six wells have been projected onto the cross-section and were used to determine the stratigraphy. Note that on the outer shelf and further seaward there is no direct sampling of the deeper seismic sediments. Their thickness and age was inferred from seismic data. The thinning of the crystalline crust is shown, as determined from deep seismic experiments; measurements of the depth to the mantle are shown with error bars. Salt diapirs are plentiful in this region. These were not included in the model because the time of diapirism is not known. The match between model results and observations can be judged by the correspondence between solid and dashed lines.

Ruth Jackson and Charlotte Keen - Atlasses of earth science?

outer Nova Scotian shelf near Sable Island are used here to illustrate the potential significance of this aspect of the model results. The Sable Island region is underlain by the Verrill Canyon Formation of Early Cretaceous - Late Jurassic age (125 Ma and older), which has tentatively been identified as the source rock for gas discovered in the region (Purcell et al., 1979). The subsidence histories for strata of various ages, are shown in the figure on page 46. Superimposed on the subsidence curves are the isotherms, the depths of which are computed as part of the modelling procedure. These two sets of curves give the entire depth-time-temperature history for the well.

The thermal maturation of the sediments is a function of the cumulative temperature-time history and can be computed from these model predictions of paleotemperature. The thermal maturity of the sediments is a guide to whether they have experienced a thermal history favourable for the generation of petroleum. The Time-Temperature Index of Lopatin (TTI) is one measure of thermal maturity that is easily computed from the predicted temperatures. The TTI is computed from the length of time the sediments spent in each 10°C temperature range (Wadles, 1980). For the Triumph Well, the results suggest that Jurassic sediments (135 Ma and older) will be thermally mature. Early Cretaceous and younger sediments will be immature. The curves shown in the figure (page 47) are also useful in determining how long petroleum generation will take and therefore provide estimates of the earliest time that petroleum could migrate from source rock to reservoir. For example, 160 Ma-old sediments attained thermal maturity 75 Ma ago and migration could not have begun before that time.

The models thus provide a potentially powerful petroleum exploration tool, that has not been fully exploited. However, many deficiencies still exist. We need measurements of thermal conductivity and radiogenic heat production for the sediments to compute paleotemperatures accurately. Bottom hole temperatures in the wells need to be carefully logged so that they can be corrected to equilibrium values. These temperatures are important in estimating present heat flow and in validating the model results. The relationship between geochemical models of petroleum generation and thermal maturity needs to be clarified so that the predictive capabi-



Time-depth temperature diagram for the Triumph well. Solid lines are the subsidence curves for strata of various ages. The ages are shown in million years (Ma). Isotherms are shown as dashed lines every 25°C. Paleotemperatures can be determined; for example, sediments deposited 121 Ma ago reached 25°C about 104 Ma ago, and 50°C about 59 Ma ago. Their present temperature is about 70°C. The hachured region is crystalline basement.

lities of both are strengthened. Many of these problems are being addressed, and it is likely that future exploration will see the integration of geochemistry, geology, and geophysics in predictive models for petroleum occurrences.

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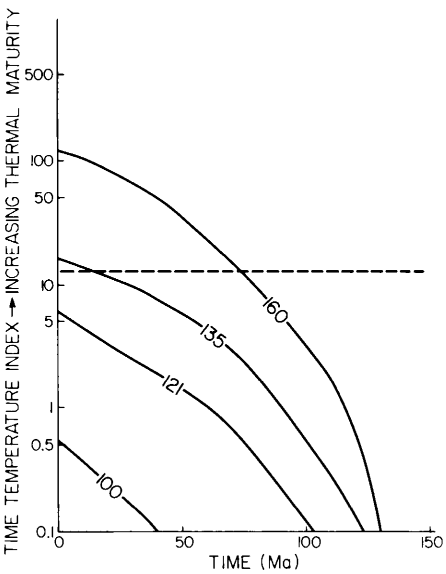


Lopatin's Time Temperature Index (TTI) of thermal maturity versus time. The curves give thermal maturity for sediments that are 160, 135, 121, and 100 Ma old. Thermal maturity increases with time since deposition, as the sediments experience higher temperatures and longer cooking times. The approximate value of TTI corresponding to the onset of oil generation is shown as a dashed horizontal line. If sediments reach values of thermal maturity above this line, their thermal history has been favourable for petroleum generation. It should be noted that the relationship between geochemical models for petroleum generation and thermal maturity has not been clearly established; future studies could change the relation shown here.

Stratigraphic modelling

F.M. Gradstein

Stratigraphers try to develop models that with a minimum of data will yield a maximum of "predictive potency" (Agterberg, 1978). The properties of a rock body such as its age or mineral and fossil content are the inputs and the outputs are, for example, a correlation of stratigraphic sections, a reconstruction of vertical crustal movements that have taken place, a reconstruction of successive environments of deposition, or a definition of the position and extent of a mineral resource.

The qualitative nature of conventional stratigraphic models is both their attraction and their weakness. The models are very flexible, but do not provide, for example, a rigorous stratigraphic correlation.

The rapid growth of information in the geological sciences, an improved linear time scale for the last 100 Ma, advances in computer technology, and successful cooperation between statisticians and geologists have led to powerful quantitative methods for solving stratigraphic problems.

Two such methods are briefly discussed here: (1) The organization of biostratigraphic data as recorded in different stratigraphic sections in a most likely sequence (RANKING) or a most likely grouping (SCALING) using the RASC (RANKING and SCALING) computer program (Agterberg and Nel, in press); (2) Organization of chronostratigraphic and paleo-ecological interpretations in a linear, numerical fashion in the direction of "the arrow of time" and calibrated to the geochronologic scale (van Hinte, 1978).

I apply these methods to construct zonations in a novel way using the Atlantic margin microfossil record in an effort to understand its post-rift depositional history. RASC was specifically developed to optimize (bio)stratigraphic resolution in that region (Gradstein and Agterberg, in press).

Ranking and scaling, RASC

Mathematical solutions of correlation type problems view biostratigraphic sequences as random deviations from a true solution and face the uncertainty that: (1) the optimum, most likely sequence of fossil events has been established (the ranking or composite standard problem of Shaw (1964)); (2) the distance of fossil events along a relative time scale is known (scaling problem as used in assemblage zones or in geochronologic calibration for geohistory diagrams); and (3) the geographic distribution of an event is known (traceability problem).

Paleontological events are appearance, peak, or disappearance of fossil taxa and differ from physical ones in that they are unique, non recurrent, and have an irreversible order (Darwinian philosophy).

The ranking (RA) part of RASC builds on the work of Hay (1972), Worsley and Jorgens (1977), and others. It tabulates how often each event occurs above, simultaneously with, or below all other events and arranges the events in an optimum sequence based on rank. Simultaneous events, which receive a score of 0.5, were ignored by previous authors. This led to a loss of information, particularly in a patchy data set such as is provided from the exploration wells drilled in the Labrador margin.

Suppose there is the following observed order of events A, B and C in four sections:

.C	.B		
.B	.C	.B	.A
.A	.A	.C	.B

A simple tabulation indicates that the likely order from bottom to top is A, C, B. A complex situation will arise with, for example, 200 events as distributed in 20 stratigraphic sections. In order to emphasize widespread and consistent events, and to define a minimum level of confidence, the events must occur in at least k_c sections with each pair of events occurring in at least m_c sections ($k_c \geq m_c$). However, there is a unique event option: a rare index fossil or ash bed can participate in the final optimum sequence using its observed position relative to two other participating taxa, but its true position remains undefined.

When events strongly cluster along the relative time scale (many 0.5 scores) and when the total number of pairs of events is small, a situation arises in which:

A occurs more often before B, than B before A

B occurs more often before C, than C before B

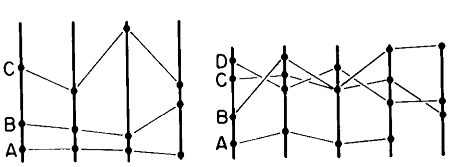
C occurs more often before A, than A before C

and the order A, B, C would be undetermined. Previous authors omitted all events that strongly cluster or appear to do so, but this is neither necessary nor desirable. In the RASC algorithms (Agterberg and Nel, in press), each cycle in the cumulative order matrix is located and the participating pair(s) of events with the smallest differences in relative order is (are) replaced with zeros, etc., until there is a ranking of events.

In the scaling (SC) part of RASC, the crossover frequency of events (P) is tabulated, e.g. if in 10 sections A occurs five times above B and five times below B, then $P_{AB} = 0.5$, or if A occurs eight times above B and two times below B then $P_{AB} = 0.8$. In the first case, A and B are probably closer in time than in the second, and we consider the crossover frequency, P_{AB}, to be an approximation of the distance between the mean position of A and that of B. In order to increase the number of observations, the distance d_{AB} between events A and B is also measured from their crossover frequency with event C such that $d_{AB} = d_{AC} - d_{BC}$ and in the final analysis the distance is weighted to the number of observations.

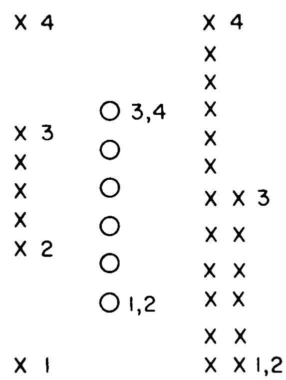
The position of each event along the relative time scale is modelled by a normal (Gaussian) distribution with equal variance (σ^2)). The crossover frequency (P) of events A and B is also supposedly normally distributed with unit variance and can be transformed in a weighted distance measure expressed in the conventional dendrogram pattern for objective classifications. An example will clarify the meaning of the model.

Consider the extreme case that all fossil events occur in the same order in all sections examined. There are no event crossovers and hence no dendogram clustering.



(left) The fossil events, A, B, and C occur in the same order in all four stratigraphic sections examined.
(right) Fossil events B, C, and D have a high crossover frequency, which means they have stratigraphically indistinct (close) positions and will cluster well, using scaling.

The real situation, particularly with a noisy record, is that some events show a more regular, consistent order than others in the sections studied. The more adjacent events cross over, the better they cluster in the optimum clustering diagram; conversely, the tighter events cluster in this diagram, the less their order is determined. Large breaks in the clustering sequence agree with stratigraphic horizons separating assemblages of events, which is exactly what a subjective zonation does. Since the zonation based on optimum clustering only uses the events common enough to occur in the most likely sequence, the objective zonation has a high practical value.



Properties of stratigraphic ranges of three (nanno)fossil taxa; x - rare, xx - common, 0 - abundant; 1 - lowest occurrence, 2 - consistent lowest occurrence, 3 - consistent highest occurrence, 4 - highest occurrence.

Late Cretaceous nannofossil range chart

Doeven *et al.* (1982) used the optimum sequence method of RASC to construct a probable range chart using 119 Late Cretaceous nannofossil events in 10 wells off eastern Canada. Optimum sequences were constructed ($k_c \geq 3$, $m_c \geq 3$) of four types of events: lowest occurrences, consistent lowest occurrences, consistent highest occurrences, and highest occurrences. The relative position of the events in these sequences is an average of all the relative positions encountered, and the range chart that connects the average tops and average bottoms, and average subtops and average subbottoms for each taxon is a "probabilistic" one. This chart and the zonation based on it, with an average resolution of 2.5 Ma, compares favourably to the most detailed subjective zonation in the literature. The subtop/subbottom concept improves biostratigraphic resolution, and the zonation has solved several longstanding issues in Canadian offshore subsurface stratigraphy.

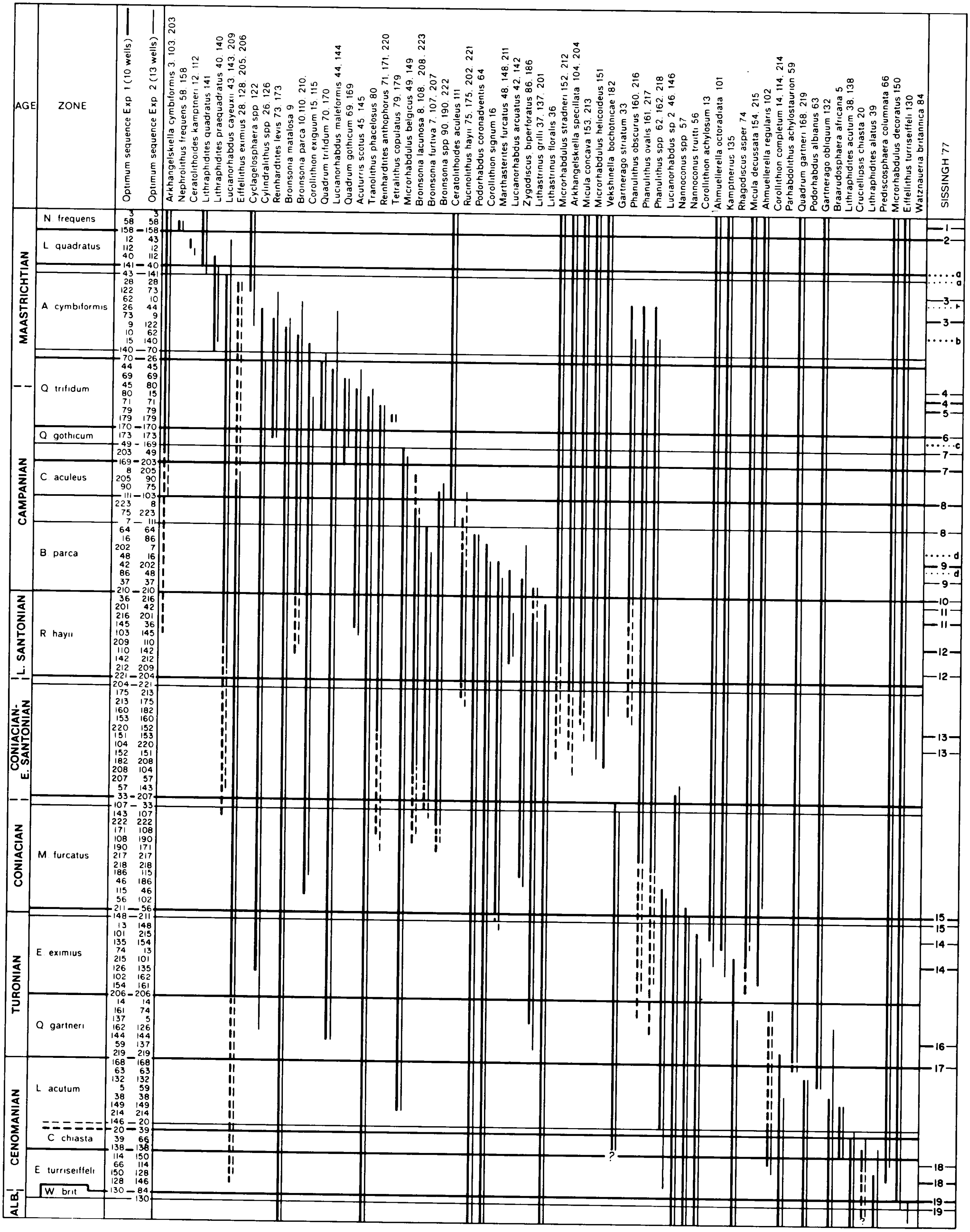
Cenozoic Labrador Shelf zonation

Gradstein and Agterberg (in press) applied RASC to the highest occurrences of 200 Foraminifera in 22 wells off eastern Canada. This large record suffers from 'noise' in the form of reworking, patchiness, and small samples; it shows endemism and to the north contains less and less index (planktonic) taxa. Difficulties include the many minor and the few major inconsistencies in the relative extinction levels of many benthonic taxa. These features hamper a detailed subjective zonation, particularly to the north of the Labrador shelf.

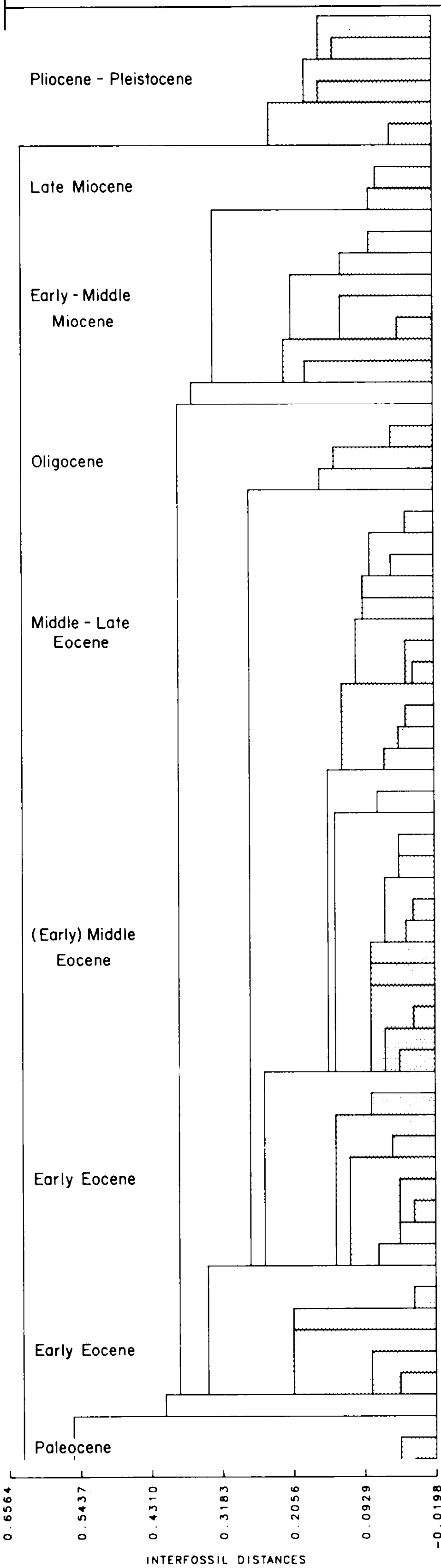
After a number of trials with RASC, the $k_c \geq 3$, $m_c \geq 3$ and $k_c \geq 5$, $m_c \geq 3$ ranking and scaling (clustering) solution for two groups of wells that are clearly separate geographically was chosen (16 in the north, 6 in the south); the choices optimize the provincialism in the record. The northern (Labrador Shelf) optimum clustering retains 68 events, grouped in distinct and progressively younger clusters that resemble assemblage zones. The progressively younger age follows from some index forms in the cluster. There is also a rather good match of corresponding species in a conventional Labrador Shelf zonation using 4 and 9 wells and the probable one, based on

►

Probabilistic range chart using Ranking of 119 Late Cretaceous nannofossil events, representing 64 taxa. The results of the first analysis, using ten wells from offshore eastern Canada, are in thick lines; those of the second analysis, which weighted three of the best wells through duplication in thin lines. The average range of a species is the interval between its lowest and its highest occurrence position, as determined in the optimum sequence. The intervals between the lowest occurrence and the subbottom, and between the highest occurrence and the subtop of a species are represented by dotted lines. To the left is the zonation, to the right is the sequence of comparable events in the literature. Note the excellent agreement (Doeven et al., 1982) in relative order.


AGE
ZONE
Optimum sequence Exp 1 (10 wells)
Optimum sequence Exp 2 (13 wells)
Arkhangelskiella cymbiformis 3, 103, 203
Nephrolithus frequens 58, 158
Ceratolithoides kamptneri 12, 112
Lithraphidites quadratus 141
Lithraphidites praequadratus 40, 140
Lucianorhabdus cayeuxii 43, 143, 209
Eiffellithus eximius 28, 128, 205, 206
Cyclagelosphaera spp 122
Cylindralithus spp 26, 126
Reinhardtites levis 73, 173
Broinsonia matalosa 9
Broinsonia parca 10, 110, 210
Corollithion exiguum 15, 115
Quadrum trifidum 70, 170
Lucianorhabdus maleformis 44, 144
Quadrum gothicum 69, 169
Acuturris scotus 45, 145
Tranolithus phacelosus 80
Reinhardtites anthophorus 71, 171, 220
Tetralithus copulatus 79, 179
MicrORhabdulus belgicus 49, 149
Broinsonia lacunosa 8, 108, 208, 223
Broinsonia furtiva 7, 107, 207
Broinsonia spp 90, 190, 222
Ceratolithoides aculeus 111
Rucinolithus hayii 75, 175, 202, 221
Podorhabdus coronadventis 64
Corollithion signum 16
Marthasterites furcatus 48, 148, 211
Lucianorhabdus arcuatus 42, 142
Zygodiscus biperforatus 86, 186
Lithastrinus grilli 37, 137, 201
Lithastrinus floralis 36
Microrhabdulus stradneri 152, 212
Arkhangelskiella specillata 104, 204
Micula concava 153, 213
Microrhabdulus helicoideus 151
Vekshinella bochotnicae 182
Gartnerago striatum 33
Phanulithus obscurus 160, 216
Phanulithus ovalis 161, 217
Phanulithus spp 62, 162, 218
Lucianorhabdus sp 2 46, 146
Nannoconus spp 57
Nannoconus truitti 56
Corollithion achylosum 13
Ahmuellerella octoradiata 101
Kamptnerius 135
Rhagodiscus asper 74
Micula decussata 154, 215
Ahmuellerella regularis 102
Corollithion completum 14, 114, 214
Parhabdolithus achylostaurion 59
Quadrum gartneri 168, 219
Podorhabdus albianus 63
Gartnerago obliquum 132
Braarudosphaera africana 5
Lithraphidites acutum 38, 138
Cruciellipsis chiasta 20
Lithraphidites alatus 39
Prediscosphaera columnata 66
Microrhabdulus decoratus 150
Eiffellithus turriseiffeli 130
Watznaueria britannica 84
SISSINGH '77
MAASTRICHTIAN
CAMPANIAN
L. SANTONIAN
CONIACIAN-E. SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALB.
N. frequens
L. quadratus
A. cymbiformis
Q. trifidum
Q. gothicum
C. aculeus
B. parca
R. hayii
M. furcatus
E. eximius
Q. gartneri
L. acutum
C. chiasta
E. turriseiffeli
W. brit

OPTIMUM CLUSTERING OF CENOZOIC FORAMINIFERAL EXITS
(16 Wells; $k_c \geq 3 / m_c \geq 3$)



			GRADSTEIN (Unpublished; 9 Wells)								GRADSTEIN & WILLIAMS (1976; 4 Wells)							
			NEOGENE			PALEOGENE					NEOGENE				PALEOGENE			
			T1	T2	T3	T4	T5	T6	T 7a	T 7b	C TERETIS	A GURICHI	C. CONTRARIA	S CARINATA	T. ALSATICA	PTEROPOD SP1	S. SPECTABILIS	G CORONA
9	0.1645	FURSENKOINA GRACILIS																
11	0.1388	NONIONELLA PIZARRENSE																
77	0.1958	ELPHIDIUM SP •	●								X							
10	0.1627	UVIGERINA CANARIENSIS		X														
65	0.2507	COSCINODISCUS SP1		X									X					
228	0.0461	CASSIDULINA TERETIS •	●								X							
17	0.6924	ASTERIGERINA GURICHI		●								X						
22	0.0603	COSCINODISCUS SPP		X									X					
16	0.0813	CERATOBULIMINA CONTRARIA											X					
67	0.3474	SCAPHOPOD SP1		●														
18	0.0820	SPIROPLECTAMMINA CARINATA •		?	●									X				
14	0.1331	TEXTULARIA AGGLUTINANS																
71	0.2209	EPISTOMINA ELEGANS			X									X				
181	0.1242	CYCLOGYRA INVOLVENS		X									?					
21	0.0329	GUTTULINA PROBLEMA		?	●									X				
20	0.2321	GYROIDINA GIRARDANA •			●									X				
15	0.1968	GLOBIGERINA PRAEBULLOIDES •			●									X				
26	0.3877	UVIGERINA DUMBLEI				X												
70	0.4157	ALABAMINA WOLTERSTORFFI			X		?							X				
24	0.0375	TURRILINA ALSATICA •				●									X			
25	0.1457	COARSE ARENACEOUS SPP.				X												
27	0.1675	EPONIDES UMBONATUS			?													
69	0.2848	NODOSARIA SP8			X									X				
81	0.0157	GLOBIGERINA VENEZUELANA				X									?	X		
33	0.0835	TURBOROTALIA POMEROLI •					●									X		
82	0.0425	SUBBOTINA LINAPERTA •					●									X		
31	0.0957	PTEROPOD SP1 •					●		?							X		
29	0.0908	CYCLAMMINA AMPLECTENS •					●									X		
84	0.0988	SUBBOTINA YEGUAENSIS					●											
173	0.0159	ANOMALINA SP1																
85	0.0010	PSEUDOHASTIGERINA MICRA					●											
34	0.1274	MARGINULINA DECORATA				?	●									X		
40	0.0129	BULIMINA ALAZANENSIS					X											
118	0.0261	EPISTOMINA SP5						X									X	
75	0.0528	LENTICULINA ULATISENSIS															X	
41	0.1572	PLECTOFRONDICULARIA SP1					●	X										
74	0.0622	EPONIDES SP5					X										X	
42	0.1450	CIBICIDOIDES ALLENI					X										X	
30	0.0301	CIBICIDOIDES BLANPIEDI						X									X	
35	0.0234	SPIROPLECTAMMINA DENTATA					X											
32	0.0524	QUADRIMORPHINELLA INCAUTA																
36	0.0007	PSEUDOHASTIGERINA WILCOXENSIS						●										
86	0.0184	TURRILINA BREVISPIRA					X	X										
57	0.0735	SPIROPLECTAMMINA SPECTABILIS •						●									X	
90	0.0757	ACARININA DENSA •						●										
88	0.0735	SIPHOGENEROIDES ELEGANTA						X										
49	0.0100	OSANGULARIA EXPANSA																
190	0.0580	ANOMALINOIDES ACUTA					X									X		
53	0.0232	UVIGERINA BATJESI						X										
44	0.2613	CIBICIDOIDES AFF WESTI																
45	0.0791	BULIMINA TRIGONALIS					X											
63	0.1353	NODOSARIA SP11						X										
43	0.0438	BULIMINA MIDWAYENSIS							X									
50	0.1167	SUBBOTINA PATAGONICA •							●									
46	0.0333	MEGASPORE SP1 •							●									X
96	0.0031	ACARININA INTERMEDIA WILCOXENSIS							●									
93	0.0291	ACARININA AFF. BROEDERMANNI						X	●									
230	0.0666	BULIMINA OVATA							X									
176	0.3711	ALLOMORPHINA SP1						X										
54	0.0049	TEXTULARIA PLUMMERAE								X								X
52	0.2143	ACARININA SOLDADOENSIS																
164	0.2189	NUTTALIDES TRUMPYI																
62	0.0820	GAVELINELLA DANICA																
47	0.0333	PLANOROTALITES PLANOCONICUS •							●									
159	0.4381	MOROZOVELLA ARAGONENSIS							●									
56	0.5972	GLOMOSPIRA CORONA							X	X								X
59	0.0342	RZEHAKINA EPIGONA								X								
55		GAVELINELLA BECCARIIFORMIS •																

◄
Optimum clustering, using Scaling, of 68 foraminеral (and a few other microfossils) highest occurrences in 16 wells on the Labrador Shelf ($k_c \geq 3/m_C \geq 3$). The clusters resemble assemblage zones, the stratigraphically most useful part of which has been shaded. There is a rather good match of corresponding species in a conventional Labrador Shelf zonation using 4 and 9 wells (right) and the probable one (left). T1 to T7 at the top refers to an informal Paleogene-Neogene zonation using nine wells (Gradstein. unpublished MS).

crossover frequencies, in 16 wells. This model verification shows that the statistics underlying RASC produce meaningful biostratigraphic results and provide objective guidelines for detailed stratigraphic correlation.

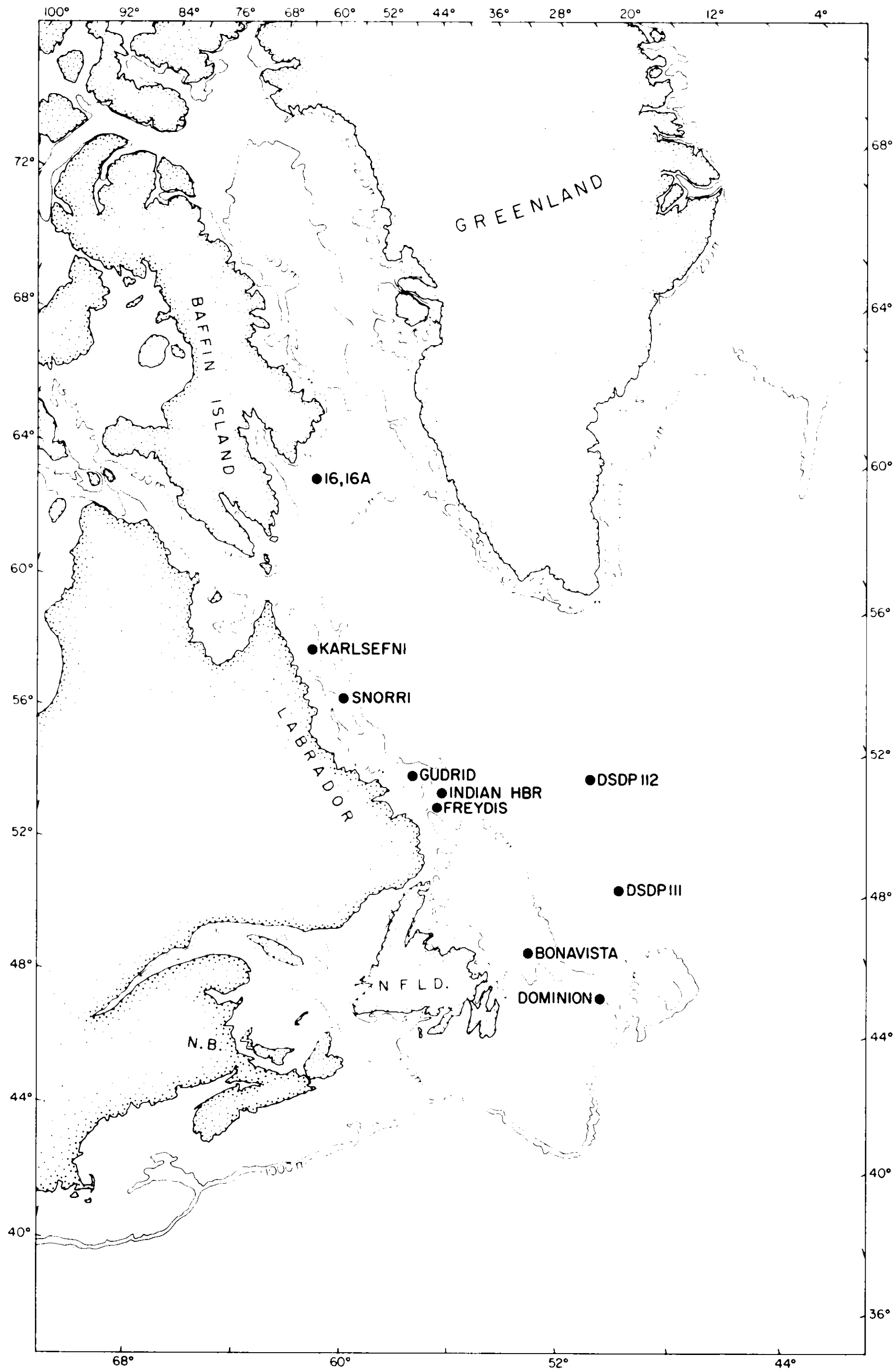
Labrador Shelf geological history

The RASC zonation for the Labrador Shelf, in combination with companion stratigraphic information, paleobathymetric estimates, and the plate-tectonic model of the adjacent Labrador Sea, has been used to reconstruct the broad scenario of depositional style and events over the last 100 Ma in that region (Gradstein and Srivastava, 1980).

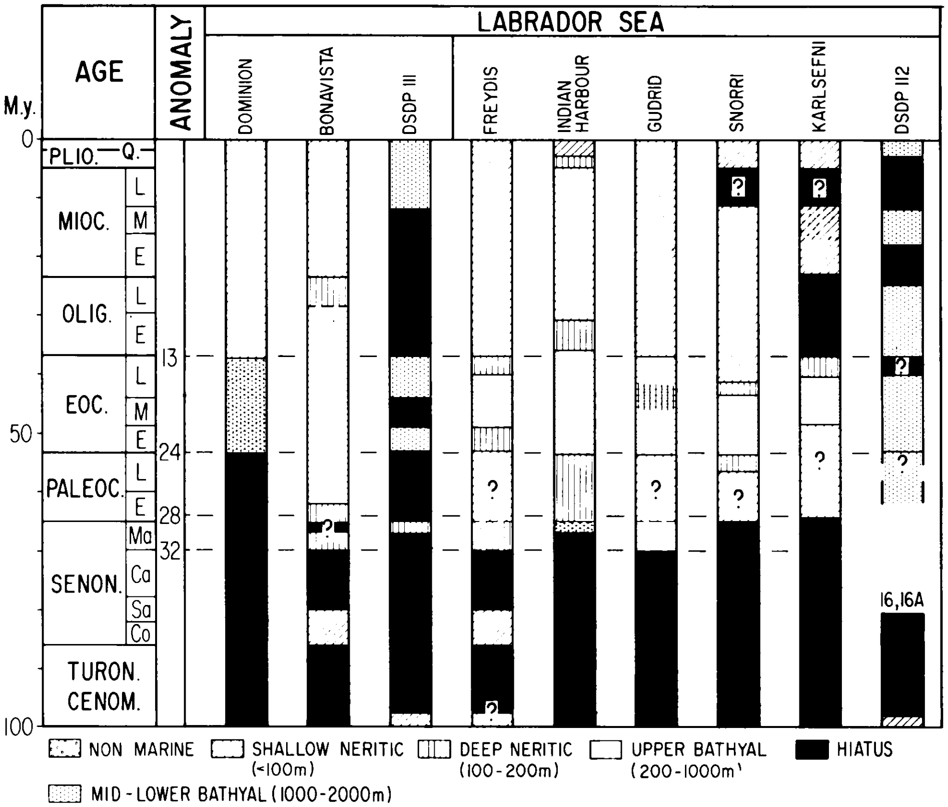
Firstly, the zonation was calibrated to the linear time scale, assuming that the local Labrador zones and standard zones in the commonly used geological time scale are reasonably correlated. Since we are interested in trends rather than accurate depiction of individual events, the errors involved may be tolerable. Also, some Maastrichtian to Eocene standard zonal events do occur in the region. The diagram on page 52 shows the stratigraphic distribution of sediments on the Labrador Shelf and surrounding regions, classified in five paleobathymetric facies: non-marine, shallow neritic, deep neritic, upper bathyal, and middle to lower bathyal.

The oldest marine sediments in the Labrador Sea are on the Baffin Island Shelf (Station 16) and are of Cenomanian age (± 100 Ma). Also, there are some neritic deposits of mid-Cretaceous age in some of the Labrador Shelf wells. Evidently, the global mid-Cretaceous sea-level-high stand left its mark in the still closed Labrador Sea. As can be seen from the figure on page 52, the main Labrador Sea transgression began during Maastrichtian time, and this conclusion agrees with the hypothesis that the onset of seafloor spreading in the southern Labrador Sea occurred during marine magnetic anomaly 32 time (70 Ma). Marine sedimentation of a (?) neritic and neritic-bathyal nature continued in Paleocene and Eocene time over the present shelf region as far north as the northern Labrador Sea approaches when the Labrador Sea further opened. The termination of opening, just prior to marine magnetic anomaly 13 time (about 40 Ma) near the Eocene/Oligocene boundary, coincides with the general change from deep to shallow marine conditions in the present Labrador Shelf region. Such conditions persist on the present shelf, although sediment starvation in front of the Precambrian Shield may account for a deeper than average shelf/slope break (around 500 m water depth).

If margin subsidence can be inter-



Labrador Sea wells. Data from these were used to construct the next 2 figures.



Late Mesozoic and Cenozoic depositional history of the Labrador Sea. The marine magnetic anomalies 32, 28, 24, and 13 are as recognized in the region. The main transgression of the Labrador Shelf coincides with the stratigraphic interval of anomalies 32-13, [i.e., the period of actual seafloor spreading (Gradstein and Srivastava, 1980)].

preted in terms of a simple thermal cooling model as empirically established for basins on oceanic crust, then regional (passive) continental margin transgression and seafloor rifting and incipient spreading in the adjacent oceanic basin can be expected to be causally and temporally correlative. Such insights into continental margin evolution and tectonic style come from comparative time/depth plots (van Hinte, 1978; Hardenbol et al., 1981).

The principle is simple. The paleobathymetric trends through time in wells are plotted with linear time in millions of years along the horizontal axis, and water depth in feet or metres along the vertical axis. Estimates of paleobathymetric error can be added to this graph using error bars (see Wood, 1981). The ancient seafloor is used as a baseline to plot cumulatively the thickness of sediment determined for each successive stratigraphic increment recognized. The resulting curve is a first order approximation of relative movements at well sites I used to illustrate tectonic and depositional trends of the Labrador Shelf.

Following a generally insignificant, slow sedimentation (0-3 cm/10^3 years) in late Cretaceous time, rapid subsidence and rapid sedimentation (often exceeding 10 cm/ 10^3 years) was initiated at the close of Cretaceous time, shortly after active seafloor spreading started in the southern Labrador Sea. Eocene sedimentation rates did not keep up with the subsidence, which allowed the ocean margin area to deepen. On the northern Labrador Shelf, an abrupt decline in sedimentation coincides in time with termination of opening of the Labrador Sea as if subsidence is of the (exponential) crustal cooling type (see Keen, 1979). In several wells the Oligocene section is either very thin, or absent and I postulate that the major mid-Tertiary eustatic sea level lowering (Vail et *al.,* 1977) may have accentuated the often abrupt shallowing and/or non deposition, or possibly even erosional, trend in the region.

Subsequent young tectonic movements, probably in combination with sediment loading, may have caused the renewed late Cenozoic high sedimentation rate at the Karlsefni (and nearby Snorri) well, a trend that from seismostratigraphic studies (Grant, 1980) appears to be enhanced northward along the Labrador Shelf. Grant (1980) used this post seafloor-spreading tectonic argument to denounce a simple link between "horizontal" spreading and vertical margin movements. However this may be, it is interesting that Cooke (1929) in his classical studies on the physiography of the Canadian Shield in Labrador remarks on the young tectonic activity on land. He infers that the Canadian Shield as a whole uplifted above its present altitude and tilted to the northwest in Pliocene time, followed by glacial depression and some postglacial re-elevation [see also McMillan's (1973) review of riverbed drainage through time]. These observations on young tectonic activities agree with Fillon *et al.* (1978), who found several successive Pleistocene deep shelf and slope terraces along the Labrador Shelf margin. These terraces tilt downward to the north parallel to shallow subsurface reflectors that dip northward toward a sedimentary basin off Hudson Strait.

In conclusion we note that the composite Cenozoic stratigraphic section of the Labrador Sea margin is continuously marine with deepest (bathyal) conditions in the Eocene. The latest Cretaceous-Eocene widespread transgression coincides with the opening phase of the Labrador Sea (anomaly 32-13). Sedimentation rates were generally high, in excess of 10 cm/10^3 years since Maastrichtian time, except locally in the mid-Tertiary when little or no sedimentation took place. The Labrador Shelf region and adjacent land has undergone renewed tectonic activity since (late) Neogene time.

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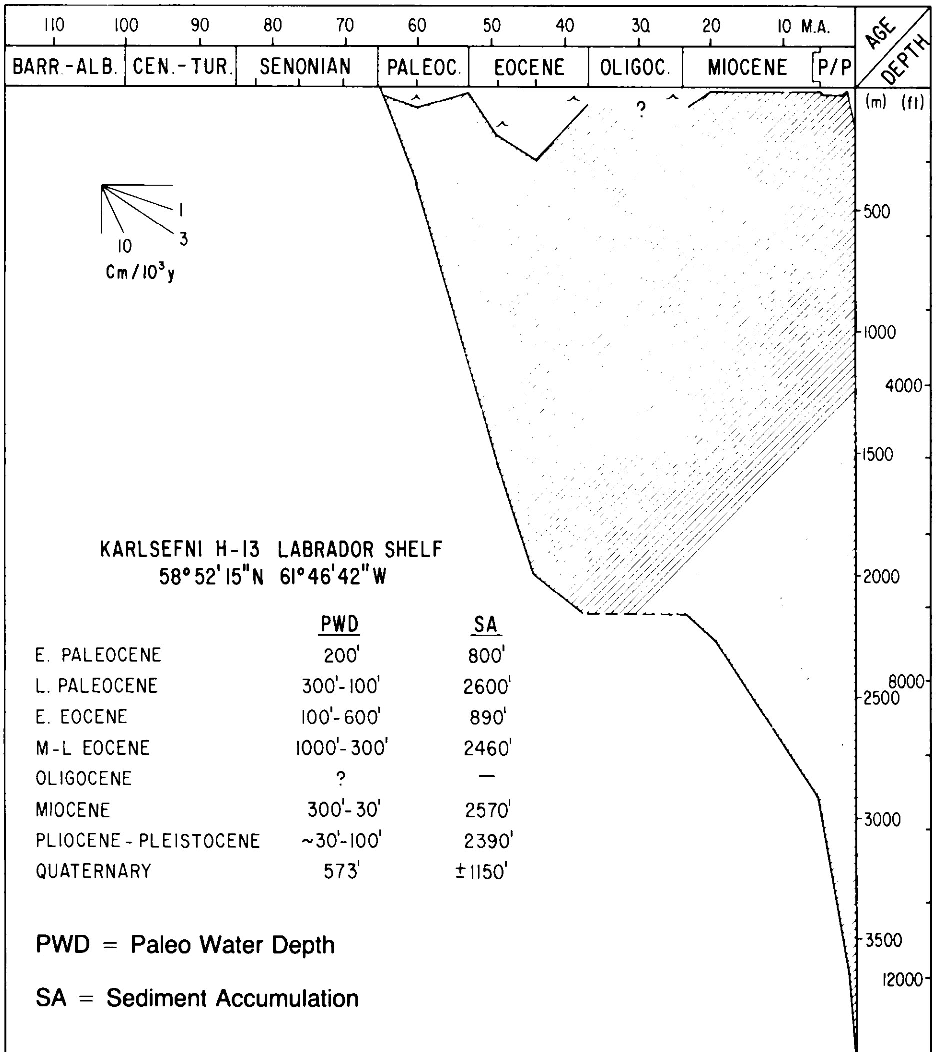
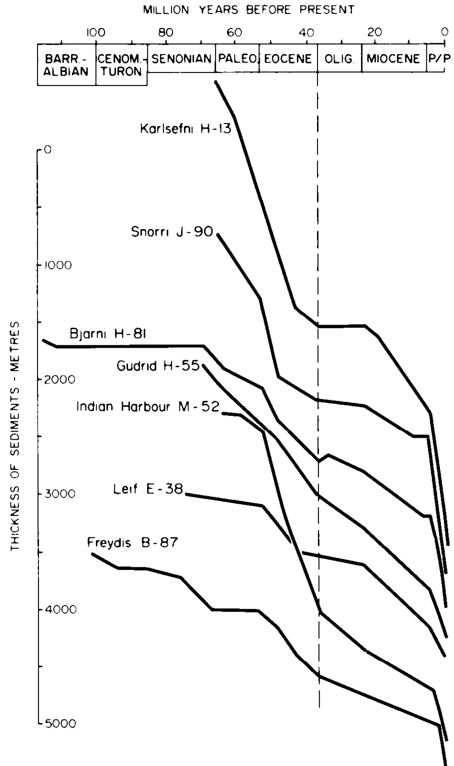


Paleobathymetric trends through time in wells are plotted with linear time in Ma along the horizontal axis, and water depth in feet along the vertical axis. The paleoseafloor is used as baseline to plot the cumulative thickness of sediment determined for each successive stratigraphic increment recognized. The resulting (lower) curve is a first order approximation of relative movement at the site.



First-order approximation of relative movement since mid-Cretaceous time at seven well sites on the Labrador Shelf. The main phase of subsidence occurs in Maastrichtian - Eocene time and coincides with the Labrador Sea opening.

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Fluorescence and the search for petroleum

J.P. Bujak and E.H. Davies

When certain substances are subjected to short wavelength radiation, they emit another radiation of longer wavelength. The exciting radiations may be x-rays, gamma rays, electrons, ultraviolet rays, or some visible wavelengths. This phenomenon of induced light emission is called fluorescence.

Fluorescence has many applications, one of the most widely used being in the early detection of cancer. Other applications include the identification of altered documents and fingerprints in police work, and the recognition of minute cracks or flaws in metals to give an early warning of failure.

In contrast to the medical and biological sciences, fluorescence was generally neglected in geology until about 20 years ago. Since then it has been used to examine both inorganic material and organic remains, particularly in mineralogical studies. Recent work also shows that fluorescence is a valuable tool in the search for petroleum, and geologists at the Atlantic Geoscience Centre are now using this technique to help locate the potential petroleum-bearing zones off Canada's east coast.

This work involves the examination of microfossils that have organic walls, including marine dinoflagellate cysts and the spores and pollen of land plants. These microfossils are excited with ultraviolet light and examined under the microscope. Using various optical filters it is possible to observe the fluorescence in selected parts of the spectrum; the most useful ones are a narrow band filter to observe the blue-green fluorescence and a broad band filter to observe the fluorescence in the yellow to red end of the spectrum.

These observations have shown that fossil organic material emits two distinct types of fluorescence for which the terms biochemical fluorescence and thermochemical fluorescence have been introduced.

Biochemical fluorescence

Biochemical fluorescence represents the fluorescence emitted by the original organic molecules. Modern material that fluoresces does so through the entire visible spectrum but, with increasing geological age, the shorter wavelength fluorescence is progressively eliminated. Pleistocene or Holocene material, which is geologically young, emits intense fluorescence colours through the entire visible spectrum. In older, Pliocene material, the shorter wavelength fluorescence is eliminated so that the blue fluorescence is generally absent. As material becomes progressively older through the Cenozoic, the fluorescence emission shifts to the yellow and red parts of the spectrum, and decreases in intensity. Biochemical fluorescence in lowest Cenozoic and Upper Cretaceous material is much reduced and at most appears as a dull red colour.

Biochemical fluorescence has several applications that aid in biostratigraphy, the science of using fossils to determine the age of rocks, some aspects of which have been described by Gradstein in one of the accompanying papers. These applications are most useful in younger, Cenozoic sequences where the organic material shows the greatest changes in biochemical fluorescence.

Palynology is the branch of biostratigraphy concerned with the microscopic remains of organic-walled fossils including marine dinoflagellate cysts and the spores and pollen of land plants. Sediments of a certain age are usually characterized by the presence of particular species, which constitute an assemblage diagnostic of that age. The palynologist is thus able to date sediments by identifying the fossils in them. However, this situation is often complicated by reworking. Consider the deposition of sediments today. Not only are organisms that live now being preserved in newly deposited sediments, but material from older, existing rocks is often also incorporated into these sediments through weathering of rocks on land and slumping or scouring by currents of older submarine deposits. This older, reworked material naturally includes microfossils that were originally deposited in the older sediments. In this way, a sediment may include microfossils of various ages and in certain situations the assemblage may be dominated by reworked species.

This situation is typical of the Cenozoic sequences of the Mackenzie Delta and the Beaufort Sea, which makes these sediments extremely difficult to date. The sediments were deposited during the 30 Ma history of the Mackenzie Delta. During this period, massive amounts of sediments and their associated microfossils were eroded by the river and reworked into younger deltaic deposits. The reworking is so extreme that in some sediments the reworked species comprise more than 98 % of the assemblage. Under these circumstances it is almost impossible to date the sediments using conventional microscopic techniques because the rare fossils that are not reworked can so easily be overlooked. This is where the application of biochemical fluorescence has provided a major breakthrough.

Palynologists at the Atlantic Geoscience Centre have examined sediments from a major oil discovery well, Kopanoar M-13, from the Beaufort Sea. Determining which fossils are reworked is difficult with normal optical techniques, but if a broad band filter is used to examine the yellow and red parts of the spectrum, several populations of re-

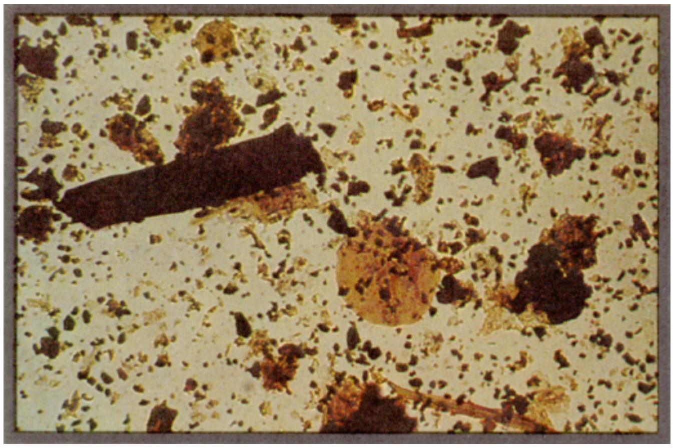
1 & 2 ➤
Organic remains from the Kopanoar M-13 well viewed with normal transmitted light. The organic material (spores, pollen, wood, and leaf fragments of land plants) is from about 1500 m below sea-level.

3 & 4
Yellow to green biochemical fluorescence emitted by the material in 1 & 2.

5 & 6
Blue biochemical fluorescence emitted by the material shown in 1 to 4. All material that does not show blue fluorescence is considered to be reworked.

7 & 8
Yellow and orange thermochemical fluorescence emitted by spores, pollen, and amorphous material in the mature, petroleum generating zone of the Hibernia P-15 well at about 4200 m below sea-level. The amorphous material probably mostly represents the remains of marine phytoplankton.

1



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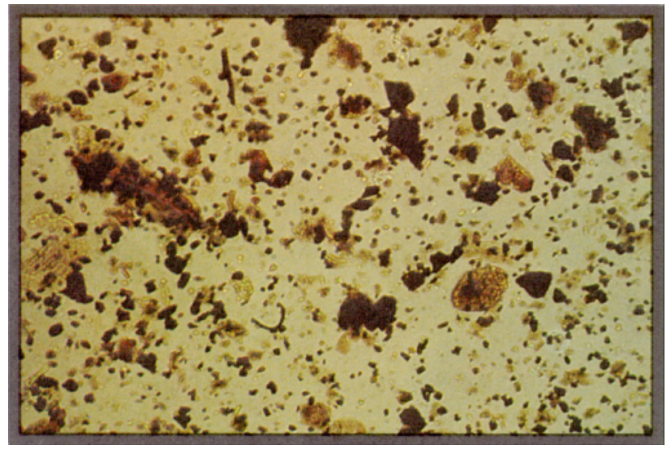

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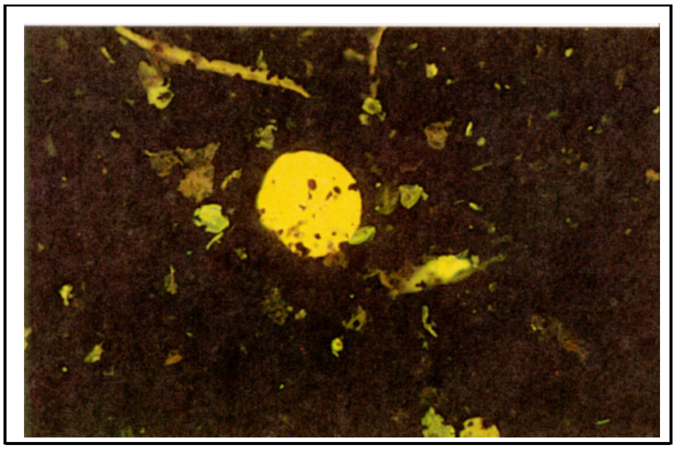

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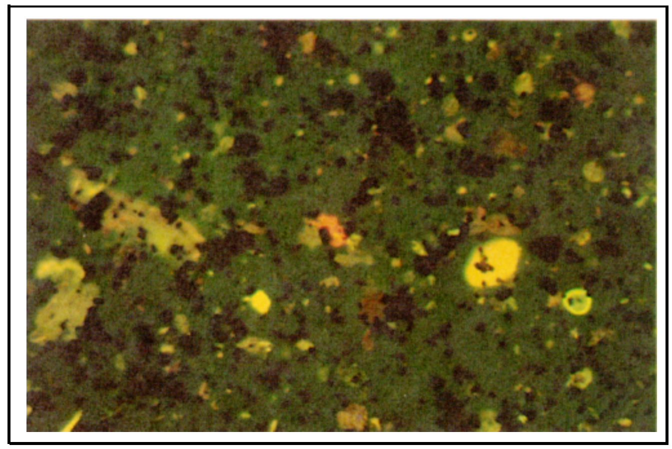

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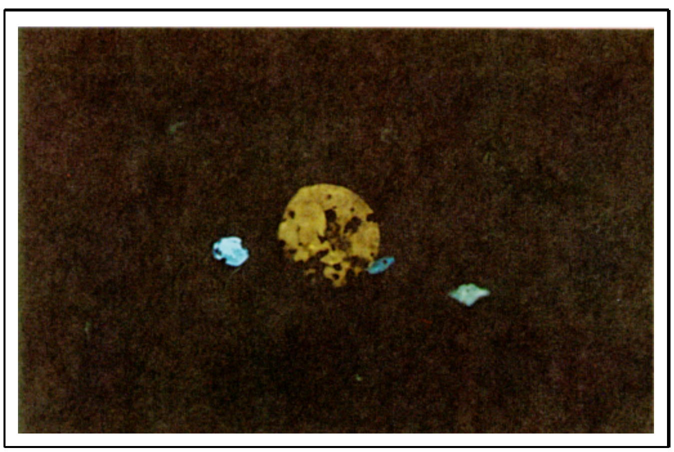

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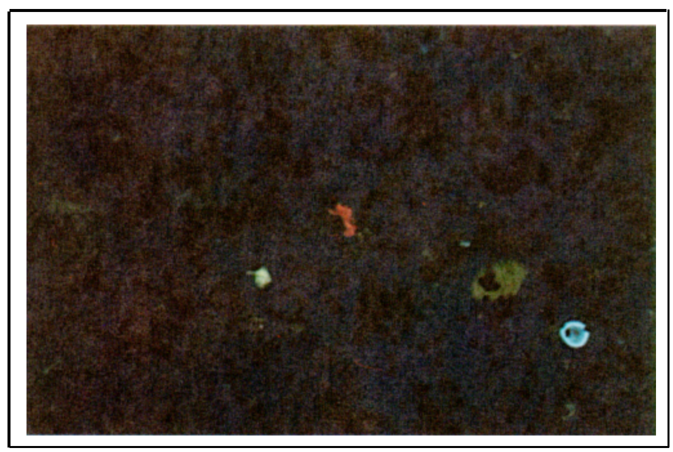

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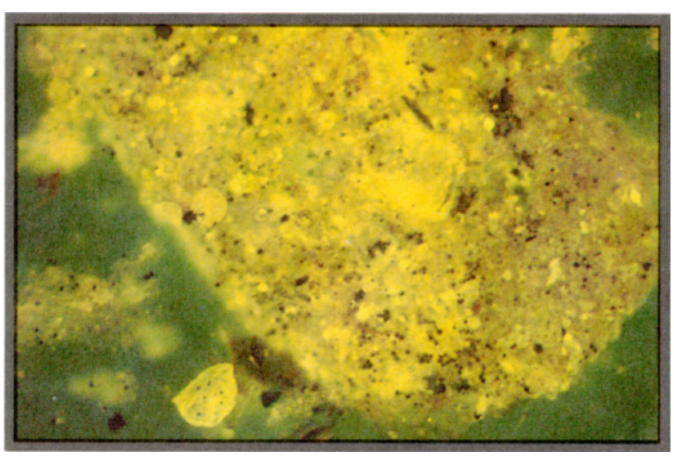

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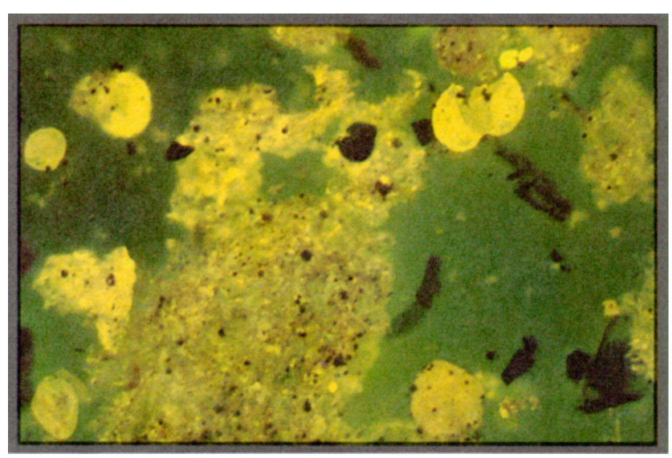
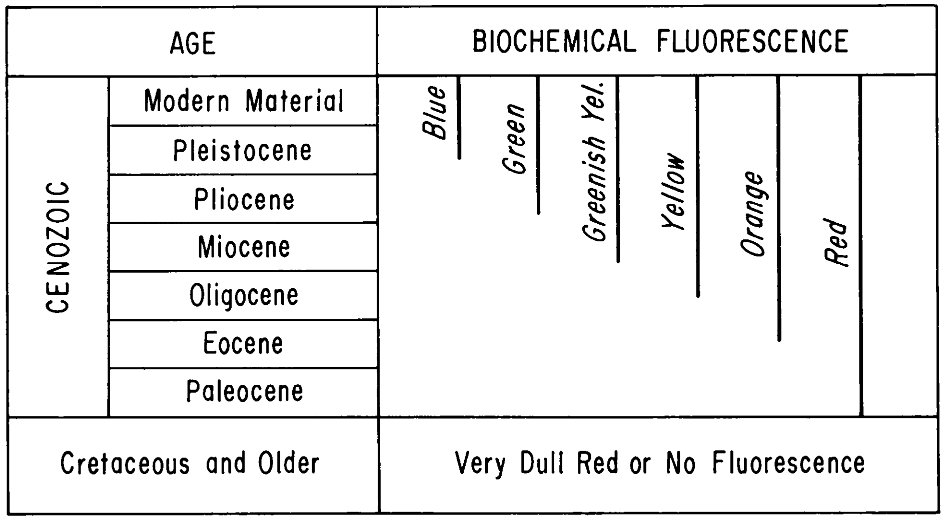


worked species can be distinguished because of their differing fluorescence characteristics. Using this technique the palynologist can identify species from this well and hence date the sediments in which they occur. This identification is often only possible using fluorescence, because the specimens may be too pale to be identified under ordinary light.

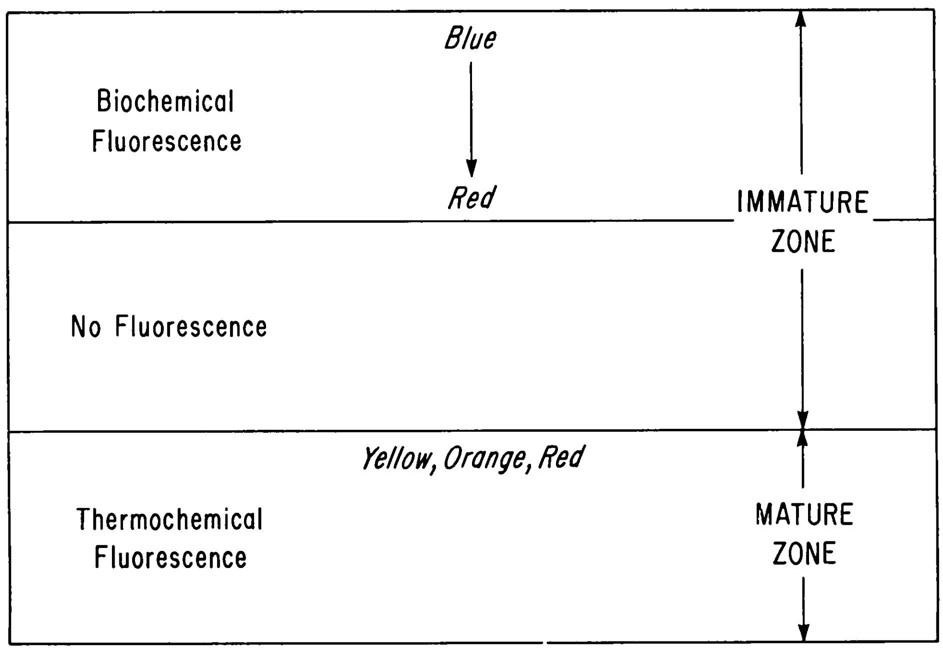
Thermochemical fluorescence

Organic material that emits thermochemical fluorescence is usually older than organic material that emits biochemical fluorescence. Unlike biochemical fluorescence, blue and green colours are absent, so that thermochemical fluorescence is characterized by colours in the yellow-red end of the spectrum. Thermochemical fluorescence appears to be related to changes (primarily caused by heating) in the molecular structure of organic material, so that the newly formed molecules have the capacity to fluoresce. It is typically confined to material in older sediments that has been heated for long periods of geological time, or to younger material that has been subjected to more intense heating for shorter periods, and is intimately associated with the formation of petroleum.

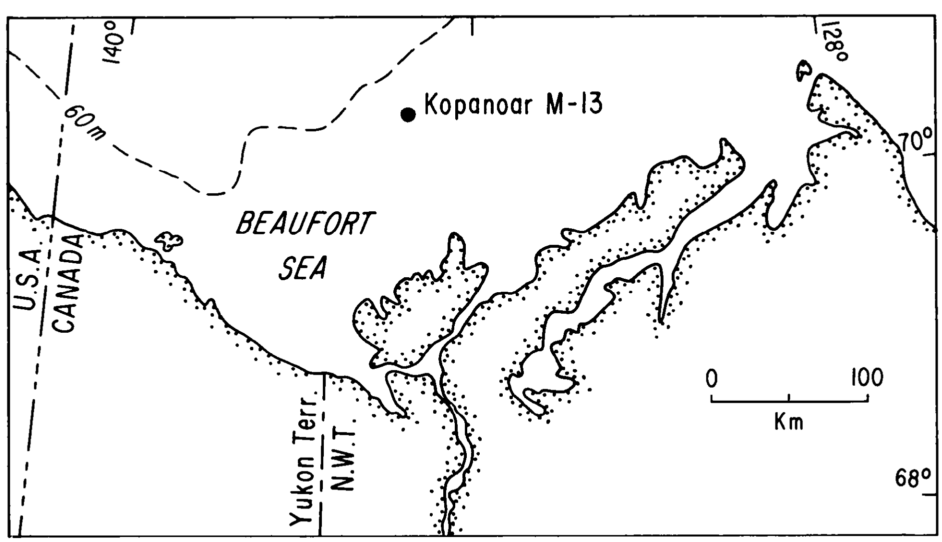
Liquid petroleum is formed mainly from the remains of unicellular phytoplankton such as diatoms and dinoflagellates. The seasonal concentrations of these organisms may reach several million individuals per litre of water in some areas, which gives the water a thick, soupy consistency: many fish and other marine organisms are killed by these overdense concentrations of phytoplankton. Under favourable conditions, the organic material is incorporated into the sedimentary sequence, but not as petroleum. The conversion of the organic material into petroleum is a slow process of heating that takes tens or hundreds of millions of years. When this condition has been attained the material is said to be mature, in contrast to immature material that has not been heated long enough to produce petroleum. In areas of low geothermal gradients and temperatures, the material takes longer to convert into petroleum. There is thus no worldwide generalization that can be made regarding the age or depth of the mature zone. It must be established individually for each region and, within this



Changes in biochemical fluorescence colours with increasing age of the material.



Relationship between the petroleum generation zone and fluorescence.

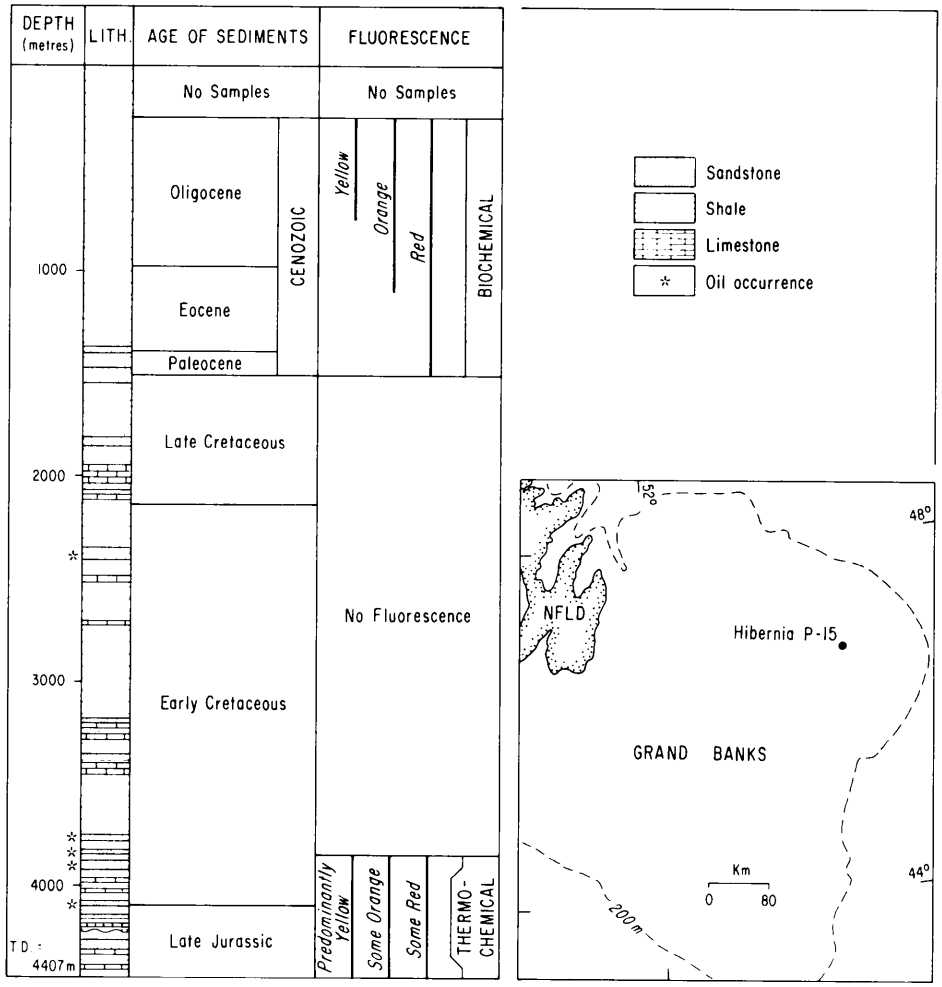


Location map of the Kopanoar M-13 well, Beaufort Sea.

framework, anomalous situations due to local variations in the geothermal gradient over the lifetime of the sedimentary basin must be recognized. Some aspects of this have been discussed by Keen in an accompanying article.

During the past five years it has become increasingly evident that one of the main reasons why many explored areas of the Scotian Shelf and Grand Banks have not yielded petroleum is that the sediments drilled are immature. It is thus important to determine the depth and age of the mature zone and, if petroleum is to be found, to understand how and why the zone varies regionally. The technique of fluorescence has great potential because research now underway indicates that the onset of thermochemical fluorescence coincides with the beginning of liquid petroleum generation in rocks.

The fluorescence changes seen in the Hibernia P-15 well illustrate how the technique is applied. This well, located on the eastern Grand Banks, was drilled to a total depth of 4407 m and terminated in Upper Jurassic sediments. Liquid petroleum was recovered from various horizons in Lower Cretaceous sandstones between 2422 m and 2443 m, and 3742 m and 4134 m. The largest occurrences are between 3742 m and 3858 m.



Stratigraphy and location of the Hibernia P-15 well, East Newfoundland Basin, showing the oil occurrences and fluorescence of organic material.

In the youngest sediments examined from the well, of Early Cenozoic age from about 225 m to 1400 m, the organic walls of the dinoflagellate cysts show yellow, orange, and red biochemical fluorescence. Shorter wavelength blue and green fluorescence is absent because the sediments encountered in the highest samples from the well are already too old to contain material emitting fluorescence of these wavelengths. The Oligocene material present fluoresces yellow, while the older, Eocene and Paleocene material fluoresces orange and red. Below about 1400 m, in the Upper Cretaceous and most of the Lower Cretaceous, some material shows a dull red biochemical fluorescence, but most of the organic walls do not visibly fluoresce.

A distinct and abrupt change occurs at about 3800 m in the well. In contrast to the overlying sediments between 1400 m and 3800 m. in which most of the material shows no fluorescence, the organic walls below 3835 m suddenly show bright yellow fluorescence. This fluorescence is thermochemical and coincides with the onset of liquid petroleum generation at the top of the mature zone in the well at 3800 m.

Recognition of the mature zone in the Hibernia well is important because it is then possible to determine whether the petroleum has migrated and, if so, from where it may have originated. The migration of petroleum is its movement from the source rock in which it was originally formed, through porous rocks or along cracks or faults in the rock, to a reservoir rock. Unlike petroleum, the organic-walled microfossils whose fluorescence is examined remain trapped in the sediments in which they were originally deposited, and so their fluorescence characterizes the rocks in which they occur. The geologist can therefore be certain that rocks containing microfossils with thermochemical fluorescence are mature and that younger rocks without thermochemically fluorescing microfossils are immature.

In the Hibernia P-15 well. fluorescence shows that the sediments above 3800 m are immature and those below 3800 m are mature. The petroleum occurring in reservoir rocks above this depth must therefore have migrated from source rocks in the mature zone and may have moved some distance laterally as well as vertically. The petroleum occurring below 3800 m lies within a mature zone and may have migrated only a short distance.

Although the use of fluorescence techniques to examine fossil organic material is a relatively recent innovation, it has already proved valuable in dating sediments with extensive reworking, as in the Beaufort Sea, and in the recognition of the mature petroleum zone, as discussed for the Hibernia P-15 well. In this way the sites and targets of exploration wells can be selected with greater precision through an increased understanding of the formation of petroleum and the accompanying changes in fluorescence of organic material.

The Laurentian Fan

D.J.W. Piper

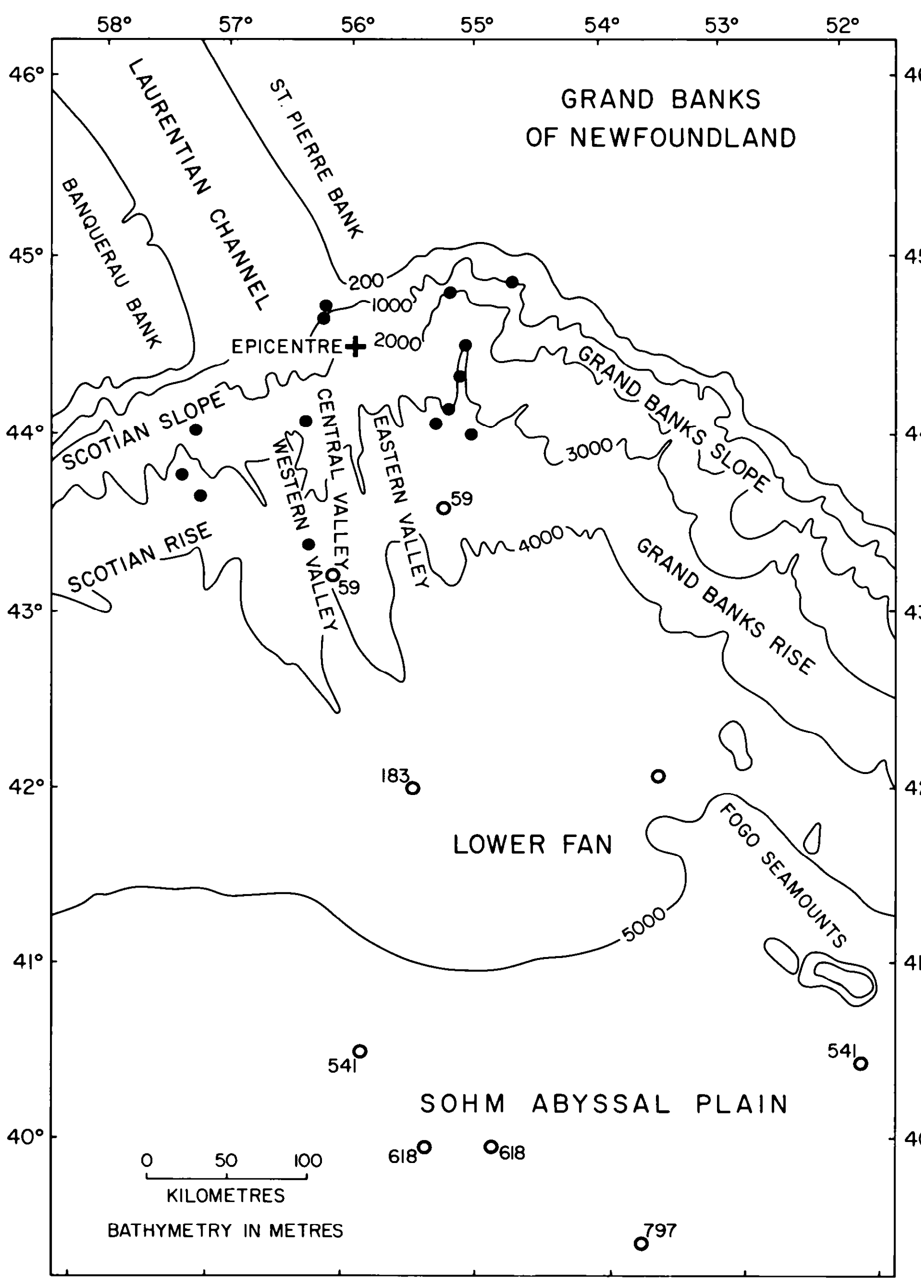
The Laurentian Channel, a feature that runs from the Gulf of St. Lawrence to the edge of the continental shelf, and the Laurentian Fan, a large accumulation of sediment at the foot of the continental slope, are the two most prominent morphologic features unrelated to bedrock configuration on the southeastern Canadian continental margin.

Seismic reflection profiling allows us to map the sediment layers beneath the sea floor of the Laurentian Fan, and their configuration leads us to an interpretation of how they were deposited (Piper and Normark, 1982). We can tentatively correlate particular layers to exploratory wells on the Scotian Shelf and Grand Banks, and to scientific holes drilled by the *Glomar Challenger*. The correlation suggests that during the last two or three million years, 0.5 to 1.5 km of sediment were deposited on the Laurentian Fan on top of older sediments with a different acoustic character (Uchupi and Austin, 1979). This change in sedimentation was probably associated with the onset of extensive glaciation in Canada two to three million years ago. During glaciation, there was periodic lowering of sea level, which allowed rivers to transport sediment across the continental shelf to the top of the continental slope. Analogous conditions of rapid sediment supply to the continental slope exist today where continental shelves are narrow, such as off the Mississippi delta, the Magdalena delta in northern Colombia, and in the San Diego region of California Under these conditions, submarine canyons on the continental slopes appear to funnel sediment from the shelf into deep water, where it accumulates as deep-sea fans. Generally, one canyon feeds one deep-sea fan, in the same way that canyons feed alluvial fans in semi-desert land areas.

Sediment is deposited in deep-sea fans by occasional, large, high-velocity, sediment-laden, underwater currents called turbidity currents. Such currents flow because they are similar in character to flooding rivers. Turbidity currents may start from rip-currents that transport coastal sediment to the top of the continental slope or by the mixing of sediment with water during landslides on steep submarine slopes. Because of their infrequency and destructive strength, such powerful turbidity currents cannot be directly observed at sea and most information about them is based on inference from their effects, and the sediment that they deposit. Turbidity currents appear to flow down through submarine canyons, across the channels on the upper parts of the deep-sea fan building up their walls, and then spread out and deposit their sediment load over a large area of the fan, and the abyssal plan beyond.

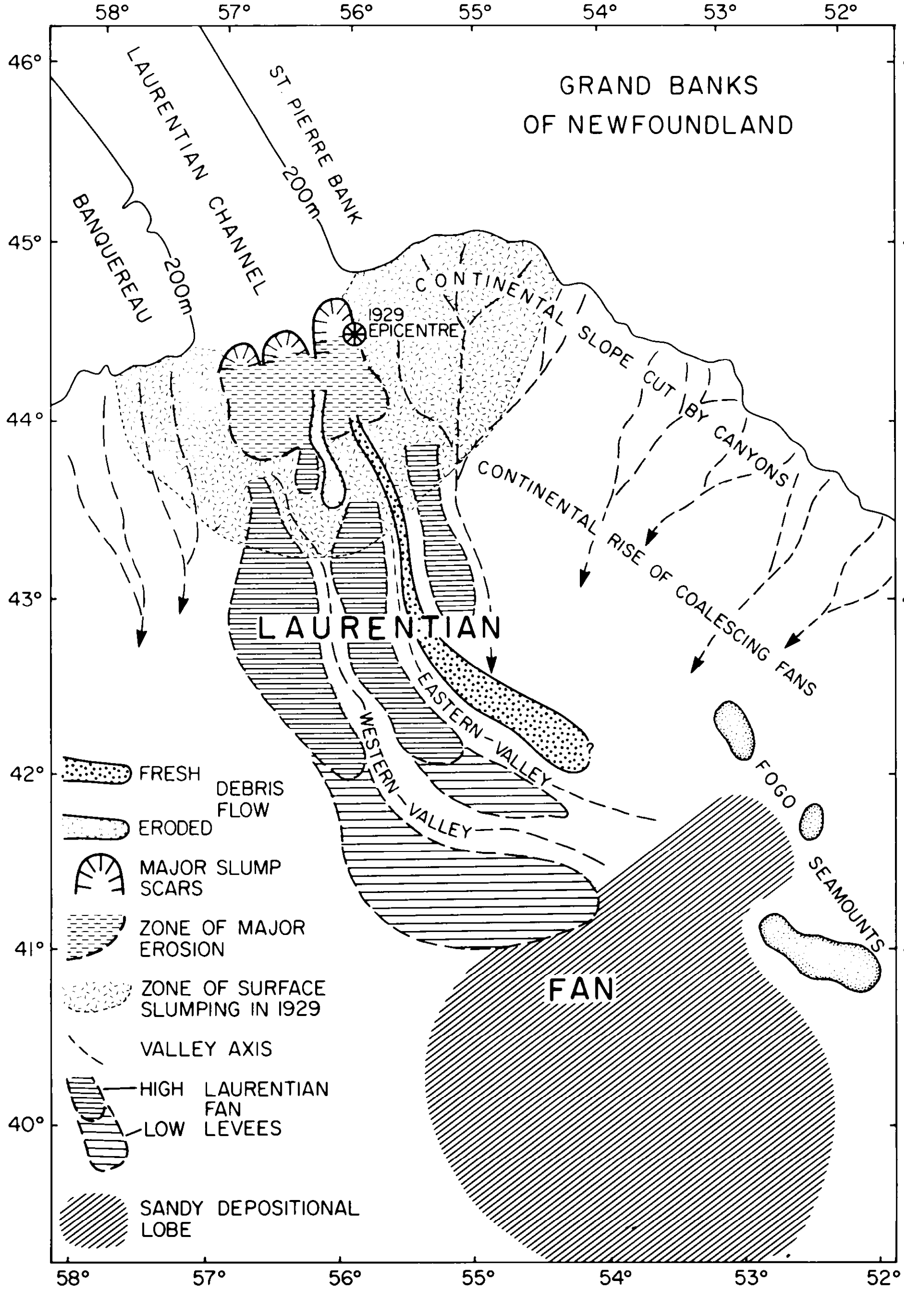
Seismic reflection profiles suggest that the Laurentian Fan was fed by a single channel, and accumulated sediment from turbidity currents as a typical deep-sea fan until 1 to 0.5 Ma ago. Since then, two or three channels have developed across the fan, at times accumulating sediment, but more recently undergoing substantial erosion (Piper and Normark, 1982).

At the present time, the Laurentian Fan, in contrast to most deep-sea fans, has two main channels, each about 15 km wide and eroded as much as 700 m below the general surface of the fan. These channels begin as



Bathymetric map of Laurentian Fan showing time of 1929 cable breaks (minutes after earthquake), a series of small tributaries on the continental slope: thus there is no continuous canyon leading from shallow water. Recent BIO cruises have shown that layered sediment has not accumulated on the slope at the head of the Laurentian Fan off the Laurentian Channel. Seismic reflection profiles and side-scan sonar images reveal large slumped blocks of sediment, and underwater mudflows 200 m thick and several kilometres wide. This suggests that the Laurentian Fan has recently grown as a result of sediment landsliding and slumping on the continental slope.

Confirmation of the slumping hypothesis comes from studies of sediment displacements caused by the 1929 earthquake on the Grand Bank, which had a magnitude of 7.2, and an epicentre on the continental slope above the Laurentian Fan. At that time, large numbers of submarine telegraph cables crossed the area around the epicentre, and the Laurentian Fan to the south. Those within 100 km of the epicentre were broken instantaneously; those further south broke in sequence from 1 to 13 h after the earthquake, with the most southerly cables breaking last (Doxsee, 1948). The cables near the epicentre were presumed to have broken by sediment sliding and slumping triggered by the earthquake on the steep slopes; those further away by a mudflow or sediment-laden current (turbidity current) initiated by slumped material mixing with seawater, and travelling downhill at speeds of 73 to 41 km/h. These inferences, which in the early 1950s provided powerful support for the turbidity current hypothesis of sediment transport (Heezen and Ewing, 1952) have been confirmed by later work. Freshly deposited sands have been cored on the surface of the Sohm Abyssal Plain to the south of the Laurentian Fan (Fruth, 1965). An uneroded mudflow has been mapped with deep-water, side-scan sonar by D.G. Roberts of the British National Institute of Oceanography and recently collected cores show that no pelagic sediments have accumulated above the mudflow, which suggests it is very young. High-resolution seismic reflection profiles show "missing" segments of layered seafloor sediment up to 10 m thick on steeper slopes within 100 km of the earthquake epicentre; these have presumably been removed by underwater landsliding. There is no sediment in cores taken above these landslide scars, a confirmation of their recent origin, and the geographic distribution of the scars

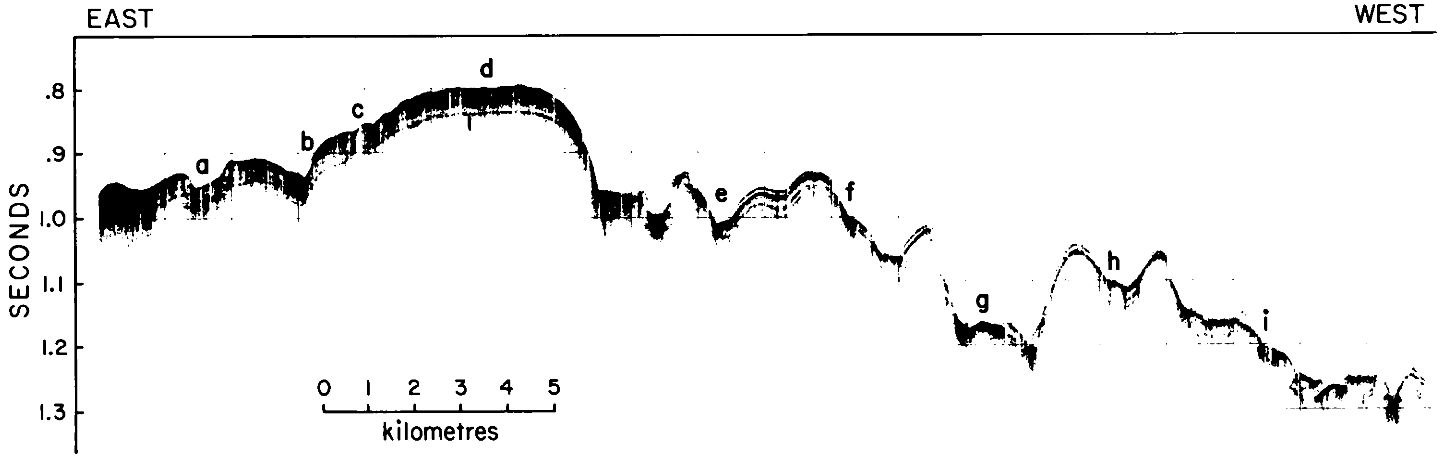


Cartoon of upper Laurentian Fan showing distribution of slumps and mudflows.

compares well with the distribution of instantaneous cable breaks in 1929.

Seismic reflection profiles record earlier mudflows, now partly eroded or buried by sediment, and deeper horizons of small and widespread landslide scars. One such older mudflow, perhaps several hundred thousand years old, formed a lobe-like deposit blocking the end of the valley some 250 km down-fan, which led to the valley hooking abruptly to the east as more sediment accumulated on top from later turbidity currents. The frequency of these mudflows and landslide horizons suggests that earthquakes with effects as severe as the 1929 'quake are very rare.

Cores up to 10 m long from the surface of the Laurentian Fan contain beds of sand and mud similar in composition to glacial till in the Laurentian Channel and with structures typically found in sediment deposited by turbidity currents (Stow, 1981). These beds occur up to 700 m above the bottom of the valleys, which are mostly floored with gravel and coarse sand - an indication that some turbidity currents must have been thick enough to reach this high above the valley floor. Detailed analysis of the size of material deposited from these currents, integrated with physical models of turbidity currents (based on hydrodynamic theory and



Acoustic profile (3.5 kHz) showing gaps in sediment sequence on continental slope above Laurentian Fan resulting from slumping in 1929.

laboratory experimentation), suggests that the currents, hundreds of metres thick, were slow (0.5 km/h) masses of turbid water, which must have lasted for several days (Stow and Bowen, 1980). These currents are very different from those inferred from the 1929 event, which were fast, but thin, and carried a large amount of coarse sediment. The muddy currents are apparently restricted to times of glaciation, when they are much more frequent (every 100 years) than mudflows and associated turbidity currents of the type that occurred in 1929. Their occurrence during times of glaciation suggest that they are related to the supply of sediment and, perhaps, very cold water. During glaciation, ice tongues or icebergs in the Laurentian Channel melted rapidly at the edge of the warmer offshore water, and dropped their sediment load on the continental slope, where only a small earthquake would be needed to set the unstable sediment in motion.

It is not yet clear in detail how the growth of the Laurentian Fan is related to the history of glaciation on the adjacent continental shelf. The abrupt change from a depositional fan with a single channel to a partly eroding fan with multiple channels took place some 1 to 0.5 Ma ago, and may be related to glacial excavation of the Laurentian Channel. Prior to erosion, the outer shelf would have been a shallow bank area that would be subaerially exposed whenever sea level was lowered during glaciation. Following erosion of the Laurentian Channel, the outer shelf was a deeper area that permitted ice-rafted transport of glacial sediments. Similar processes may have occurred elsewhere on the Eastern Canadian continental slope. An understanding of their history is important in assessing how stable the seabed is in areas on the continental slope where hydrocarbon drilling is planned.

Neither do we understand in detail how the different types of turbidity currents that we see on the fan are initiated, and their relative importance in building the Laurentian Fan and the Sohm Abyssal Plain. Because of the extreme seafloor morphology, the 1929 velocity data, and the very wide range of sediment grain sizes present, the Laurentian Fan is an excellent natural laboratory for answering fundamental questions on the nature of turbidity current flow and sediment deposition.

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chapter 4

Charts and Publications of 1981

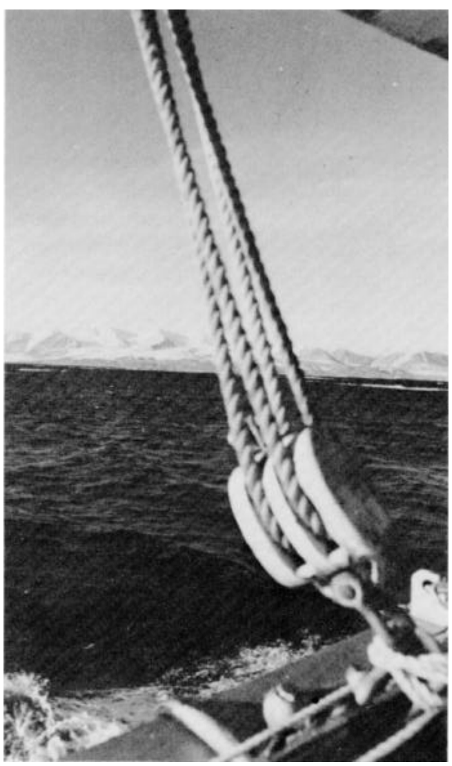
CHART PRODUCTION

The Atlantic Region of the Canadian Hydrographic Service has a cartographic staff of 25 with the responsibility for 436 navigational charts covering the region from the Bay of Fundy to Prince of Wales Strait in the Arctic.

During 1981, the thrust to produce new charts continued. Nineteen were in production including 12 in the final stages: five of the Bras d'Or Lakes, five of the St. John River, N.B., one of Miramichi Bay, N.B., and one of St. Mary's Bay, Newfoundland. Five new editions (4459, 4514, 5138, 7194, and 7831) were completed: two in the Arctic, one on the Labrador coast, one in Newfoundland, and one in Prince Edward Island. In addition, 17 Loran-C lattices were completed, 16 of which were drafted on commercial contract. The contract was monitored, and all corrections and reproductions were carried out by CHS's Atlantic Region. Apart from the new editions and corrections listed below, over 100 reprints were produced during 1981 to meet demand for navigation and fishery charts. The first edition of a tidal current atlas for the Bay of Fundy and Gulf of Maine was also published in 1981.

New Editions

4023 Northumberland Strait (Loran-C)
4317 Liscomb Island to Egg Island (Decca)
4317 Liscomb Island to Egg Island (Loran-C)
4320 Egg Island to West lronbound Island (Decca)
4320 Egg Island to West Ironbound Island (Loran-C)
4321 Cape Canso to Liscomb Island (Decca)
4321 Cape Canso to Liscomb Island (Loran-C)
4363 Cape Smoky to St. Paul Island (Decca)
4363 Cape Smoky to St. Paul Island (Loran-C)
4367 Flint Island to Cape Smoky (Decca)
4367 Flint Island to Cape Smoky (Loran-C)
4374 Red Point to Guyon Island (Decca)
4374 Red Point to Guyon Island (Loran-C)
4375 Guyon Island to Flint Island (Decca)
4375 Guyon Island to Flint Island (Loran-C)
4404 Cape George to Pictou (Decca)
4404 Cape George to Pictou (Loran-C)
4405 Pictou Island to Tryon Island (Decca)
4405 Pictou Island to Tryon Island 'Loran-C)
4406 Tryon Schoals to Cape Egmont (Decca)
4406 Tryon Shoals to Cape Egmont (Loran-C)
4451 Iles de la Madeleine (Decca)
4451 Iles de la Madeleine (Loran-C)
4459 Summerside Harbour and Approaches/et les approches
4700 Belle Isle to Resolution Island (Loran-A and -C)
7194 Cape Hooper to Arguyartu Point including Ekalugad Fiord
7831 Viscount Melville Sound and/et McClure Strait
8012 Flemish Pass (Decca)
8012 Flemish Pass (Loran-A)
8012 Flemish Pass (Loran-C)
8013 Flemish Cap (Decca)
8013 Flemish Cap (Loran-A)
8013 Flemish Cap (Loran-C)
8014 Grand Banc Partie Nord-Est/Grand Bank Northeast Portion (Decca)
8014 Grand Banc Partie Nord-Est/Grand Bank Northeast Portion (Loran-A)
8014 Grand Banc Partie Nord-Est/Grand Bank Northeast Portion (Loran-C)
8049 St. Michael Bay to Gray Islands (Decca, Loran-A, and Loran-C)



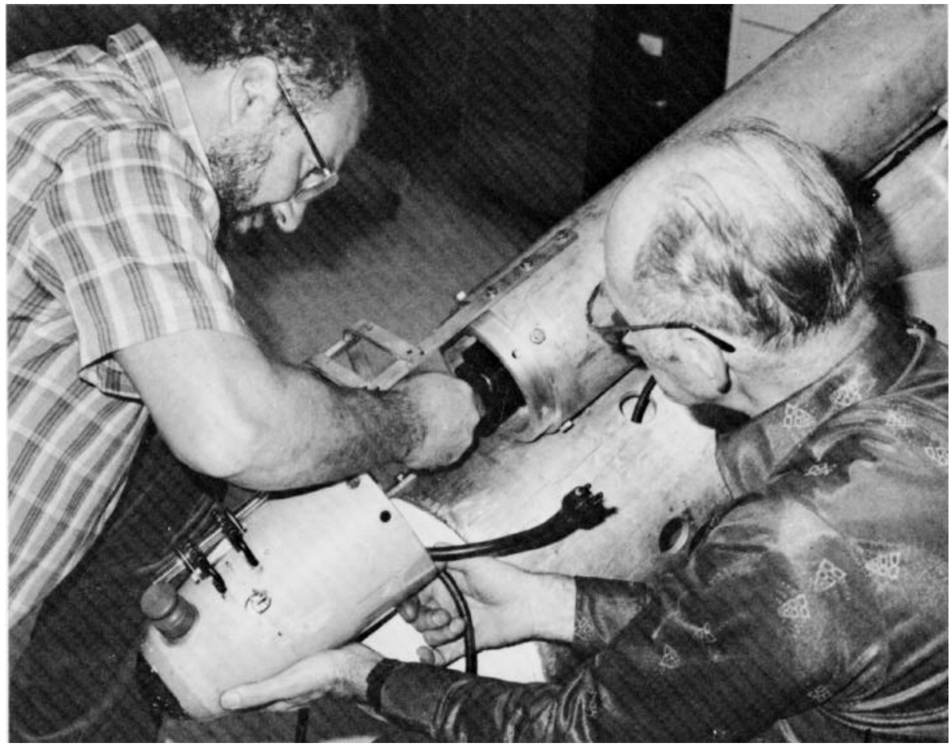
Bylot Island in the eastern Arctic.

Large Corrections (Patches)

4281 Canso Harbour and Inner Approaches
4310 Bedford Basin
4316 Halifax Harbour
4426 Restigouche River
4483 Caribou Harbour
5300 Ungava Bay
4637 The Burgeo Islands
4771 Eclipse Harbour to Cape White Hankerchief
4776 Entrance to Saglek Bay to Button Islands
4647 Fort Harmon and Approaches
5340 Approach to Sorry Harbour
8046 Button Islands to Cod Island
4581 Long Pond
7220 Lancaster Sound, Eastern Approaches /Approches Est
7250 Pond Inlet
7220 Lancaster Sound Eastern Approches

PRIMARY PUBLICATIONS

We present below an alphabetical listing by author of the scientific articles by BIO staff that were published during 1981 in scientific journals, books, conference proceedings, and reports published by other organizations. Technical reports by BIO staff that were published by the Institute and other Canadian government organizations are presented next by series.



Bruce Carson and Bruno Greifeneder.

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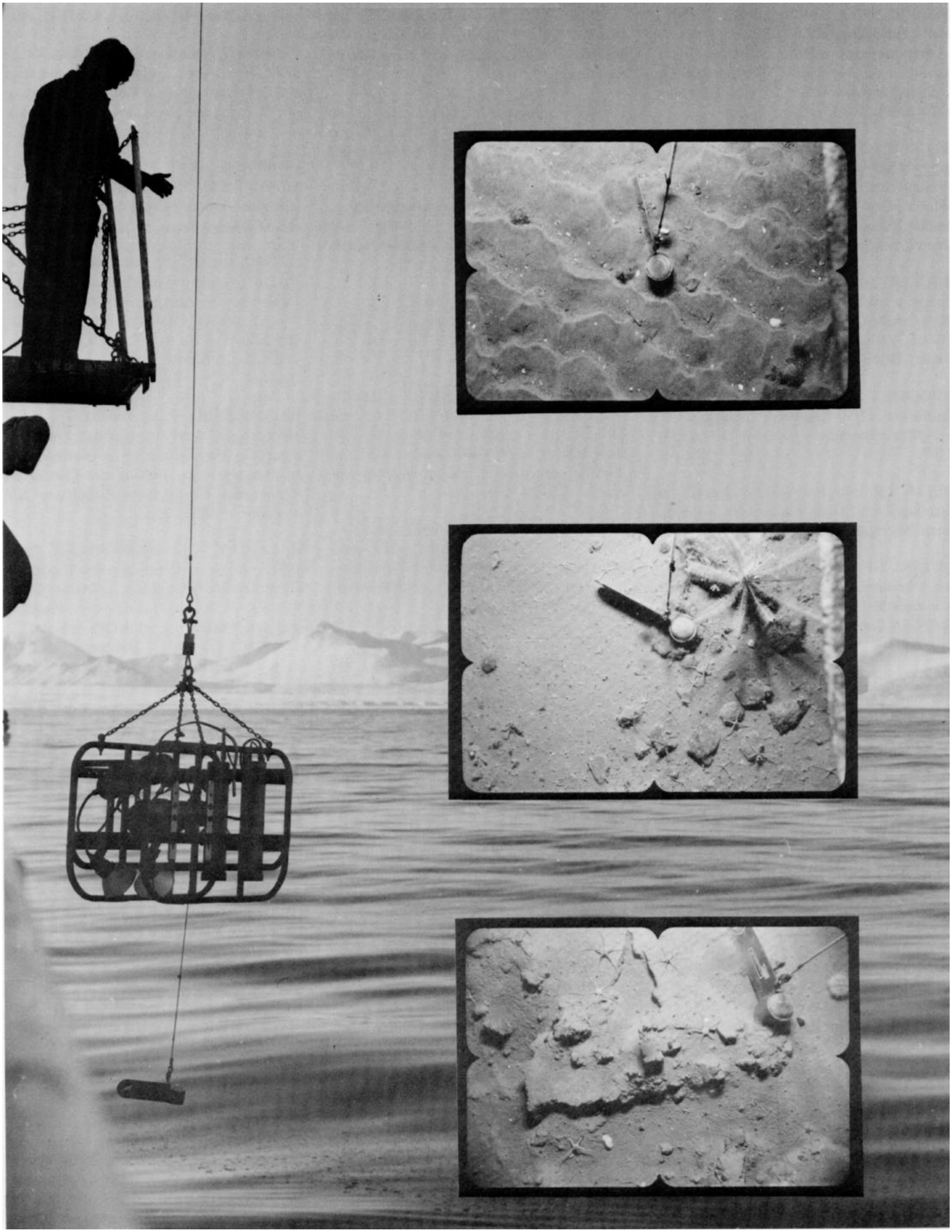

The deep-sea camera system being winched over the side of CSS *Hudson.* insets are sample bottom photographs taken by the camera.

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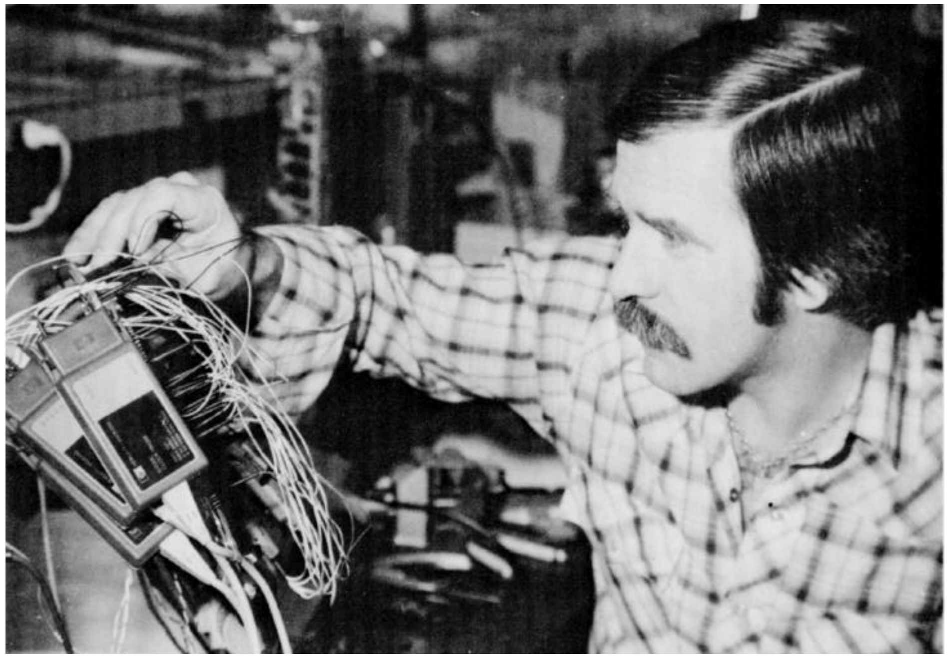

Roger Cassivi.

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This national series of reports is co-ordinated by the Department of Fisheries and Oceans in Ottawa. There are four categories of report in the series: Canadian Technical Reports of Fisheries and Aquatic Science (CTRFAS), Canadian Data Reports of Fisheries and Aquatic Sciences (CDRFAS), Canadian Manuscript Reports of Fisheries and Aquatic Sciences (CMRFAS), and Canadian Industry Reports of Fisheries and Aquatic Sciences (CIRFAS). Below, 1981 contributions to the series by the Marine Ecology Laboratory and the Marine Fish Division are listed. These reports are produced by the Bedford Institute of Oceanography, and information and copies of the reports can be obtained by writing to the Institute.

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ICCAT - International Commission for the Conservation of Atlantic Tunas
ICES - International Council for the Exploration of the Sea
NAFO - Northwest Atlantic Fisheries Organization

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GRADSTEIN, F.M. and WILLIAMS, G.L. 1981. Stratigraphic charts of the Labrador and Newfoundland shelves. GSC, Open File 826: 5 pp., 4 figs., 1 table.

KING, L.H. and FADER, G.B. 1981. Seabed conditions east of the Avalon Peninsula to the Virgin Rocks. GSC, Open File 723.

SHIH, K.G., MACNAB, R.F., and HALLIDAY, D. 1981. Multiparameter survey data from the Scotian margin. GSC, Open File 750.

View of Devil's Island at the entrance to Halifax Harbour.

chapter 5

Cruises of 1981*

C.S.S. HUDSON

- The C.S.S. *Hudson* is a diesel-electric driven ship designed and used for multidisciplinary oceanographic research
- Principal Statistics - Lloyds Ice Class I hull . . . built in 1963 . . . 90.4 m overall length . . . 15.3 m overall beam . . . 6.3 m maximum draft . . . 4870 tonne displacement . . . 3721 gross registered tons . . . 17 knot full speed . . . 13.5 knot cruising speed in Sea State 3 . . . 50 day endurance and 15,000 n. mile range at cruising speed . . . scientific complement of 25 . . . 204 m^2 of space in four laboratories . . . two HP1000 computer systems . . . heliport and hangar . . . twin screws and bow thruster for position holding . . . one landing barge, three survey launches
- 245 days at sea and 34,034 n. miles steamed in 1981

CRUISE YEAR - NUMBER	CRUISE DATES	OFFICER IN CHARGE	AREA OF OPERATION	CRUISE OBJECTIVES
81-001	Feb. 27 to Mar. 16	R. Pocklington, AOL	BIO to Colon. Panama	Multidisciplinary investigations
81-002	Mar. 19 to Apr. 8	T.C. Platt, MEL	Balboa, Panama. to Puntarenas, Costa Rica	BIOSTAT project
81-003	Apr. 9 to May 10	C.S. Wong, IOS	Puntarenas, Costa Rica, to Sidney, British Columbia	Multidisciplinary investigations
81-017	May 16 to 30	R.L. Chase, UBC	Juan de Fuca Ridge and Explorer Seamount off Vancouver Island	Geological and geochemical studies and drilling of basalt cores
81-021	May 30 to Jun. 10	C.J. Yorath, PGC	Hecate Strait and Queen Charlotte Sound off British Columbia	Geological sampling and profiling
81-022	Jun. 10 to 21	R.D. Hyndman, PGC	Queen Charlotte Sound	Geophysical study of Sound and Queen Charlotte fault zone
81-027	Jul. 6 to Oct. 1	A.D. O'Connor, Pacific Region, CHS	Beaufort Sea, Lancaster Sound	Hydrographic surveying and charting
81-045	Oct. 1 to Nov. 4	C.F.M. Lewis, AGC	Eastern Arctic, Grand Bank area	Geological and geophysical studies
81-046	Nov. 6 to 14	R.F. Reiniger, AOL	Newfoundland Basin	Mooring recovery; evaluation of NAVSTAR navigation system

*Abbreviations used here include: *AGC* Atlantic Geoscience Centre: *AOL* Atlantic Oceanographic Laboratory: *CHS* Canadian Hydrographic Service; *INRS* Institut National pour la Recherche Scientifique; *IOS* Institute of Ocean Sciences: *MEL* Marine Ecology Laboratory; *MFD* Marine Fish Division; NAFO Northwest Atlantic Fisheries Organization; n. Nautical; *NSRF Nova Scotia* Research Foundation; OSS Ocean Science and Surveys (Dept. Fisheries and Oceans); *PGC* Pacific Geoscience Centre; *RSD* Resource Services Directorate (Dept. Fisheries and Oceans): *UBC* University of British Columbia; *UQAR* Université de Québec à Rimouski.

C.S.S. BAFFIN

- The C.S.S. *Baffin* is a diesel driven ship designed for hydrographic surveying but also used for general oceanography
- Principal Statistics - Lloyds Ice Class 1 hull . . . built in 1956 . . . 87 m overall length . . . 15 m moulded beam . . . 5.7 m maximum draft . . . 4420 ton displacement . . . 3460 gross registered tons . . . 15.5 knot full speed . . . 13 knot cruising speed in Sea State 3 . . . 45 day endurance and 14,000 n. mile range at cruising speed . . . complement of 29 hydrographic staff . . . drafting, plotting, and laboratory spaces provided . . . two HP1000 computer systems . . . heliport and hangar . . . twin screws and bow thruster for position holding . . . five survey launches
- 211 days at sea and 22,281 n. miles steamed in 1981

CRUISE YEAR - NUMBER	CRUISE DATES	OFFICER IN CHARGE	AREA OF OPERATION	CRUISE OBJECTIVES
81-007	Apr. 8 to May 18	A.R. Clarke, AOL	Newfoundland Basin, Hibernia area	Mooring recovery/deployment; hydrographic station work; equipment trials
81-012	May 22 to 28	C.F.M. Lewis, AGC	Grand Bank	Geological and geophysical studies
81-019	Jun. 5 to Oct. 31	G. W. Henderson, Atlantic Region, CHS	Off Nova Scotia, Newfoundland, and Labrador, and Fury and Hecla Straits	Hydrographic surveying and charting
81-035	Jul. 28 to Nov. 1	G.W. Henderson, Atlantic Region, CHS	Sable Island, Labrador coast, Foxe Basin, Hamilton Bank	Hydrographic charting (including some recovery and deployment of oceanographic moorings)

C.S.S. DAWSON

- The C.S.S. *Dawson* is a diesel-driven ship designed and used for multidisciplinary oceanographic research, hydrographic surveying, and handling of moorings in deep and shallow water.
- Principal Statistics - built in 1967 . . . 64.5 m overall length . . . 12 m moulded beam . . . 4.9 maximum draft . . . 2006 displacement . . . 1311 gross registered tons . . . 15.5 knot full speed . . . 13 knot cruising speed in Sea State 3 . . . 45 days endurance and 12,000 n. mile range at cruising speed . . . scientific complement of 13 . . . 87.3 m^2 of space in four laboratories computer suite provided . . . twin screws and bow trhruster for position holding . . . one survey launch.
- 228 days at sea and 36,635 n. miles steamed in 1981.

CRUISE YEAR - NUMBER	CRUISE DATES	OFFICER IN CHARGE	AREA OF OPERATION	CRUISE OBJECTIVES
81-004	Mar. 2 to 12	T.R. Foote, AOL	Southeast of Cape Sable, NS, and Georges Bank area	Recovery and replacement of current meter moorings
81-005	Mar. 13 to 19	R.O. Fournier. Dalhousie University	Halifax Section out to Gulf Stream	Biological studies
81-006	Mar. 24 to Apr. 3	D.E.T. Bidgood, NSRF	Nova Scotia coast	Geological studies
81-008	Apr. 7 to 17	E.M. Levy, AOL	Grand Bank (at Hibernia and South Tempest sites)	Preliminary survey of existing levels of petroleum residues, and other chemical oceanographic studies
81-013	Apr. 22 to May 1	B.T. Hargrave, MEL	Continental shelf and slope water southeast of Halifax to Canso and St. Georges Bay	Biological studies

81-014	May 4 to 8	P.C. Smith, AOL	Southwest Nova Scotia (Scotian rise)	Recover and replace portion of current mooring array
81-016	May 12 to 19	F.S. Medioli, Dalhousie University	Scotian Shelf and Slope	Geological studies
81-020	Jun. 2 to 23	C.E. Keen, AGC	Continental margin off eastern USA near New Jersey	Cruise conducted with 3 other oceanographic institutes (4 ships altogether). Investigate the development and use of multi-ship, multi-channel seismic techniques to study the deep structure of continental margins.
81-025	Jun. 25 to Jul. 9	B. Sundby, UQAR	Off Nova Scotia, and estuary of the St. Lawrence	Studies of the benthic boundary layer
81-026	Jul. 9 to 15	R.O. Fournier, Dalhousie University	Southwest coast of Nova Scotia	Study of phytoplankton dynamics
81-036	Jul. 17 to 25	G.C.H. Harding, MEL	Southeastern Gulf of St. Lawrence, eastern Northumberland Strait, St. Georges Bay	Ecological studies and surveys
81-037	Jul. 31 to Aug. 2	B.D. Loncarevic, AGC	Halifax Section	Initial test of KSS-30 gravimeter
81-038	Aug. 6 to Sep. 30	S.T. Grant, Atlantic Region, CHS	Davis Strait	Hydrographic surveying
81-039	Oct. 8 to 19	D.D. Sameoto, MEL	Scotian Shelf	Study phytoplankton and zoo-plankton vertical distributions
81-040	Oct. 22 to 31	P.C. Smith, AOL	Southwestern Scotian Shelf and Rise	Recover mooring array and replace extended moorings of Cape Sable Experiment
81-041	Nov. 3 to 10	D.L. McKeown, AOL	Jordan Basin to Cumberland Basin, Bay of Fundy	CTD survey, equipment trials, other experiments
81-042	Nov. 13 to 24	J.A. Elliott, AOL	Edge of Scotian Shelf	Studies of the internal tide
81-043	Nov. 27 to Dec. 3	G.L. Bugden, AOL	Gulf of St. Lawrence	Ice forecasting
81-044	Dec. 3 to 15	D.J.W. Piper, AGC	Scotian Slope and uppermost Laurentian Fan	Geological studies

C.S.S. MAXWELL

- The C.S.S. *Maxwell* is a diesel-driven ship designed and used for inshore hydrographic surveying
- Principal statistics - built in 1962 . . . 35 m overall length . . . 7.6 m moulded beam . . . 2.4 m maximum draft . . . 280 tonne displacement . . . 262 gross registered tons . . . 12.6 knot full speed . . . 10 knot cruising speed in Sea State 2 . . . 15 day endurance and 2700 n. mile range at cruising speed . . . scientific complement of 7 . . . drafting and plotting facilities . . . two survey launches
- 188 days at sea and 8530 n. miles steamed in 1981

CRUISE YEAR - NUMBER	CRUISE DATES	OFFICER IN CHARGE	AREA OF OPERATION	CRUISE OBJECTIVES
81-009	May 11 to Jun. 26	R.M. Cameron, Atlantic Region, CHS	Southwest coast of Nova Scotia, Bay of Fundy	Hydrographic charting
81-028	Jul. 6 to Oct. 30	E.J. Comeau, Atlantic Region, CHS	Strait of Belle Isle, Labrador coast, west Newfoundland coast	Hydrographic charting
81-048	Nov. 5 to 30	E.J. Comeau, Atlantic Region, CHS	Southwest coast of Nova Scotia, Bay of Fundy	Hydrographic charting of shoal areas

PANDORA II

- The *Pandora II,* a privately owned ship equipped with facilities for handling submersibles, is chartered by the Department of Fisheries and Oceans and used for multidisciplinary oceanographic research
- Principal Statistics - built in 1974 . . . 58.2 m overall length . . . 4.6 m beam . . . 1377 gross registered tons . . . 13 knot full speed . . . 10.5 knot cruising speed . . . 100 day endurance at cruising speed . . . A-frame aft for handling submersibles . . . submersible tracking facilities . . . complete mechanical. electronic, and battery workshops for submersibles

Pandora II: inset - the *Pisces IV* submersible.

CRUISE YEAR - NUMBER	CRUISE DATES	OFFICER IN CHARGE	AREA OF OPERATION	CRUISE OBJECTIVES
81-010	Apr. 14 to 22	J.N.B. Smith, AOL	Bay of Fundy	Environmental monitoring of Point Lepreau
81-011	Apr. 23 to 30	G.L. Bugden. AOL	Gulf and estuary of the St. Lawrence	CTD surveys; recovery of moorings
81-015	May 2 to 16	B. Long, INRS - Océanologie	St. Lawrence River	Miscellaneous investigations
81-018	May 16 to 31	S. Peck, OSS Quebec	St. Lawrence River	Baseline data collection in regard to Romaine River regulation for hydroelectric power
81-023	Jun. 2 to 22	W.W. Denncr. Memorial University	Carson Canyon on the Grand Bank	Study of dynamic processes near Canyon
81-024	Jan. 4 to 8	C.K. Ross, AOL	Flemish Cap	Continuation of NAFO Flemish Cap Experiment
81-049	Jul. 16 to 22	B.T. Hargrave, MEL	Scotian Shelf and Slope. and St. Margaret's Bay, NS	Biological studies
81-050	Jul. 25 to Aug. 6	D.J.W. Piper, AGC	Scotian Slope and gully	Geological studies
81-051	Aug. 13 to 17	D. Bezanson, AOL	Scotian Shelf. Northumberland Strait, Chaleur Bay	Geological studies; investigation of an ocean dump site
81-052	Aug. 17 to 22	J. Syvitski. AGC	Laurential Channel. Magdalen Islands	Studies of suspended particulate matter
81-053	Aug. 22 to 27	B. Long, INRS - Océanologie	St. Jean and Natashquan rivers, Quebec	Geological studies
81-054	Aug. 26 to Sep. 8	G.B. Fader. AGC	Placentia Bay. Newfoundland Newfoundland, Shelf	Use of Pisces IV submersible in geological studies of the seabed
81-055	Sep. 9 to 26	B. MacLean. AGC	Davis Strait - Baffin Bay	Geological and geophysical studies
81-056	Sep. 26 to Oct. 13	B. MacLean. AGC, E.M. Levy. AOL	Southeast Baffin Island	To further study Scott Inlet oil seep using *Pisces* IV submersible
81-057	Oct. 13 to 28	H.W. Josenhans. AGC	Labrador Shelf. Strait of Belle Isle	Geological studies of the scabcd using the *Pisces* IV submersible
81-058	Nov. 1 to Dec. 10	P.J.C. Ryall. Dalhousie University	Bermuda area	Geological study of Bermuda pedestal

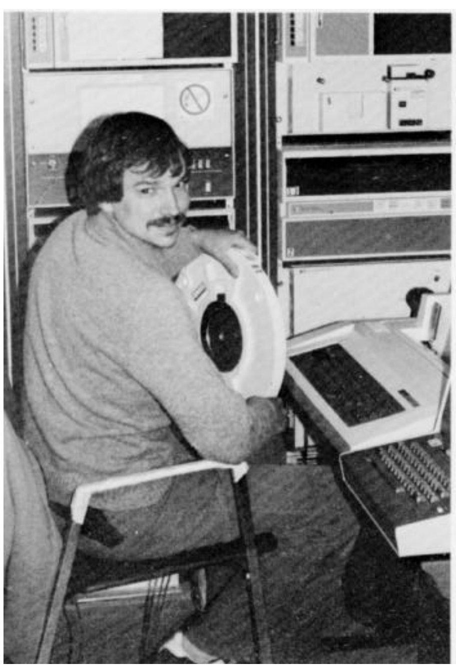
NAVICULA

- The *Navicula* is a wooden-hulled fishing vessel chartered by the Department of Fisheries and Oceans and used for biological oceanography research.
- Principal statistics - built 1968 . . . 19.8 m overall length . . . 5.5 m moulded beam . . . 11- ton displacement . . . 78 gross registered tons

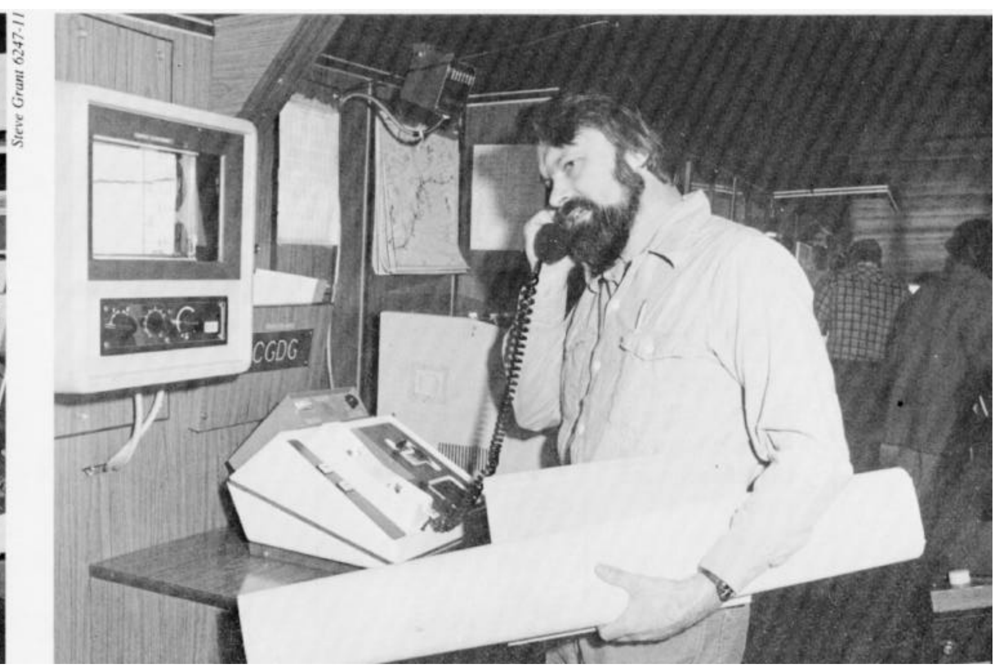
CRUISE YEAR - NUMBER	CRUISE DATES	OFFICER IN CHARGE	AREA OF OPERATION	CRUISE OBJECTIVES
81-030	Apr. 27 to May 7	B.T. Hargrave, MEL	St. Georges Bay	Biological studies
81-031	May 7 to Jun. 3	R.G. Halliday, MFD	Miramichi estuary	Biological studies
81-032	Jun. 3 to Jul. 5	R.M. Eaton, Atlantic Region, CHS	St. Lawrence River	Loran-C calibrations biological studies
81-033	Jul. 5 to Aug. 21	R.W. Sheldon, MEL	St. Georges Bay and Chedabucto Bay	Biological studies
81-034	Aug. 28 to Oct. 30	M.A. Hemphill, Atlantic Region, CHS	Southwest Nova Scotia coast	Hydrographic charting

OTHER CRUISES

CRUISE YEAR - NUMBER	CRUISE DATES	OFFICER IN CHARGE	AREA OF OPERATION	CRUISE OBJECTIVES
81-029 Various Vessels	Jul. 10 to Oct. 8	M.G. Swim, Atlantic Region, CHS	Fury and Hecla straits, Foxe Basin, Northwest Territories	Hydrographic surveying for proposed LNG tanker routes
81-059 M.V. *Polar Circle*	Jul. 18 to Oct. 13	R.M. Cameron, Atlantic Region, CHS	South Wolf Islands, Labrador; Koksoak River, Quebec; Foxe Basin, Northwest Territories	Hydrographic charting



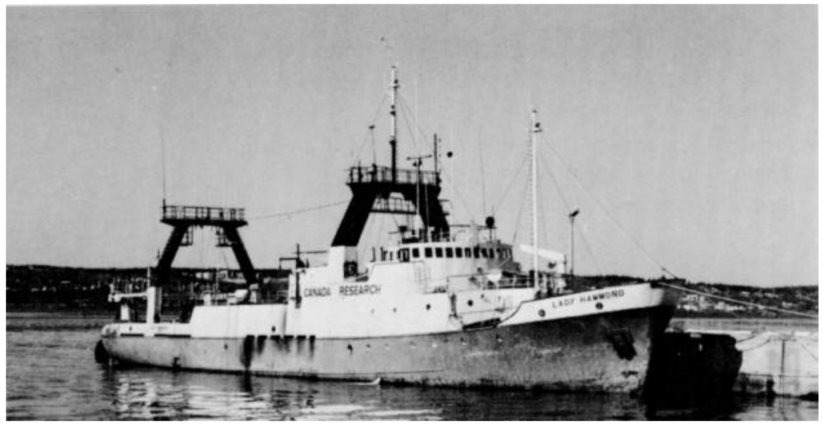
Hart Stoll aboard CSS *Dawson.*



Mike Lewis on the bridge of CSS *Hudson.*

LADY HAMMOND

- The *Lady Hammond.* a converted fishing trawler, is chartered by the Department of Fisheries and Oceans and used specifically for fisheries research. Its main user is the Marine Fish Division, which has components at BIO and in St. Andrews, N.B. Except as otherwise noted below, "officers in charge" are affiliated with the Marine Fish Division.
- Principal Statistics - built in 1972 . . . 54 m overall length . . . 11 m overall beam . . . 5.5 m maximum draft . . . 306 gross registered tons . . . 13.5 knot maximum speed . . . 12 knot cruising speed



CRUISE NUMBER	CRUISE DATES	OFFICER IN CHARGE	AREA OF OPERATION	CRUISE OBJECTIVES
H046	Jan. 5 to 16	P. Koeller	Scotian Shelf	Silver hake distribution study
H047	Jan. 19 to Feb. 3	J. Reid	Scotian Shelf	Standard ichthyoplankton survey
H048	Feb. 23 to Mar. 6	K. Waiwood	Western Bank - Bay of Fundy	Standard groundfish survey
H049	Mar. 9 to 19	A.C. Kohler	Western Bank - Laurentian Channel and Sydney Bight	Standard groundfish survey
H050	Mar. 23 to Apr. 2	J. M. McGlade	Banquereau Bank - Brown's Bank	Standard ichthyoplankton survey
	Apr. 7 to 14	B. Wood	Scotian Shelf	Standard ichthyoplankton survey
HO51	Apr. 21 to 24	P. Koeller	Emerald Bank	IYGPT Gear trials
H052	Apr. 27 to May 5	W. Smith	NAFO Subdivision 4VS	Groundfish tagging and species interaction survey
H054	May 11 to 14	D. Waldron	Scotian Shelf	Silver hake collection
H055	May 21 to 29	J.S. Scott	Scotian Shelf	Juvenile groundfish distribution survey
H056	Jun. 15 to 24	R. O'Boyle	Scotian Shelf	Standard ichthyoplankton survey
H057	Jun. 29 to 30	J. Cornick, RSD	Emerald Bank	Collection of samples for fish disease study
H058	Jul. 2	J. Cornick, RSD	Chebucto Head	Collection of samples for fish disease study
H059	Jul. 4 to 12	A.C. Kohler	Scotian Shelf - Bay of Fundy	Summer groundfish survey and comparative fishing trials with the A. T. *Cameron*
H060	Jul. 16 to 25	K. Waiwood	Scotian Shelf - Bay of Fundy	Summer groundfish survey and comparative fishing trials with A. T. *Cameron*
H061	Jul. 29 to Aug. 10	K. Howse	Bay of Fundy	Larval herring survey; equipment trials
H062	Sep. 8 to 15	W. Smith	Western Bank	Tagging of cod in NAFO Division 4W; sample groundfish collection.
H063	Sep. 18 to 25	D. Waldron	Scotian Shelf	Silver hake survey
H064	Sep. 20 to Oct. 8	K. Waiwood	Scotian Shelf	Fall groundfish survey
H065	Oct. 13 to 22	J. Hunt	Scotian Shelf	Fall groundfish survey
H066	Oct. 26 to Nov. 13	P. Koeller	NAFO Division 4WX	Juvenile silver hake survey; comparative fishing with USSR vessel *Ekliptika*
H067	Nov. 17 to 28	B.D. Loncarevic, AGC	Scotian Shelf	Gravimeter sea trials
H068	Dec. 1 to 5	D. Beanlands	Scotian Shelf	Pollock collection

E.E. PRINCE

- The E.E. *Prince* is a steel stern trawler used for fisheries research and experimental and exploratory fishing
- Principal Statistics - built in 1966 . . . 39.9 m overall length . . . 8.2 m overall beam . . . 3.6 m maximum draft . . . 421 ton displacement . . . 406 gross registered tons

CRUISE NUMBER	CRUISE DATES	OFFICER IN CHARGE	AREA OF OPERATION	CRUISE OBJECTIVES
249	Feb. 16 to 26	R. Shotton, MEL	Bay of Fundy	Survey of winter distribution of herring
250	Mar. 2 to 13	K. Howse	Bay of Fundy	Larval herring and zooplankton abundance survey
251	Mar. 30 to Apr. 11	B. Mohn. RSD	Scotian Shelf	Shrimp survey
252	Apr. 21 to 24	C. Morrison, RSD	Chebucto Bank, Emerald Bank	Marine fish disease study
253	Apr. 30 to May 18	B. Nakashima	NAFO Division 4RS	Capelin survey
254	May 21 to 26	S. Labonte	Gaspe area	
255	Jun. 15 to 16	G. Young	Gulf of St. Lawrence	Mackerel egg production
256	Jul. 11 to 24	M. Sinclair	Southwest Nova Scotia	Adult herring survey
257	Jul. 27 to 31	J. Robert, RSD	Georges Bank	Scallop survey
258	Jul. 31 to Aug. 7	J. Robert, RSD	Scotian Shelf	Scallop survey
259	Aug. 12 to 20	J. Robert, RSD	Georges Bank	Scallop survey
260	Sep. 2 to 21	S. Smith, P. Koeller	Gulf of St. Lawrence	Groundfish inventory
261	Sep. 24 to Oct. 21	P. Koeller	NAFO Division 4WD	Shrimp survey
262	Oct. 24 to 30	S. Labonte	Northwest Gulf of St. Lawrence	Capelin study
263	Nov. 9 to 27	G. Black	Bay of Fundy	Herring larval survey

CO-OPERATIVE CRUISES

The Marine Fish Division participated in co-operative cruises during 1981 aboard the USSR's research vessel *Ekliptika* (abbreviated EK).

CRUISE NUMBER	CRUISE DATES	OFFICER IN CHARGE	AREA OF OPERATION	CRUISE OBJECTIVES
EK0l	Aug. 26 to Sep. 1, Sep. 1 to 14	B. Wood, J. Reid	Scotian Shelf	Ichthyoplankton survey (annual)
EK02	Sep. 15 to 28, Sept. 28 to Oct. 13	J. Simon, J. Reid	Scotian Shelf	Ichthyoplankton survey (annual)
EK03	Oct. 14 to Nov. 3, Nov. 3 to 15	B. Wood, P. Perley	Scotian Shelf	Ichthyoplankton survey (annual)

chapter 6

Organization and Staff

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

BIO also houses the offices of the Northwest Atlantic Fisheries Organization (Executive Secretary - Captain J.C.E. Cardoso); the analytical laboratories of the Department of the Environment's (DOE) Environmental Protection Service (Dr. H.S. Samant); and the Atlantic regional office of the Canada Oil and Gas Lands Administration of the Department of Energy, Mines and Resources (DEMR) (Mr. T.W. Dexter). In leased accommodation at BIO are the following marine-science related private companies: Huntec Ltd., Wycove Systems Ltd., and Franklin Computers Ltd.

We present below the major groups at BIO together with their managers and a list of Institute staff as at January 1982. Telephone numbers are included in the first list: note that Nova Scotia's area code is 902 and the BIO exchange is 426. The group or division for which an individual works is given in abbreviated form following his/her name: the abbreviations used are defined in the list of major groups immediately below.

OCEAN SCIENCE AND SURVEYS, ATLANTIC (DFO)

A.R. Longhurst
DG - Director-General 3492

C.E. Murray, Public Relations 3251
H.B. Nicholls, Program Anal/Co-ord . . 3246

MS - Management Services
G.C. Bowdridge, Manager 6166
Administrative Services
M.C. Bond, Chief. 6166
Financial Services
N.T. LeBlanc, Chief 7060
Materiel Management Services
A.R. Mason, Chief 3487

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

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

CHS - Canadian Hydrographic Service (Atlantic Region)
A.J. Kerr, Director 3497
CHS - 1. Field Surveys
T.B. Smith, Head 2432
CHS - 2. Chart Production
B.E. McCorriston, A/Head 7286
CHS - 3. Hydrographic Development
R.G. Burke, Head 3657
CHS - 4. Navigation
R.M. Eaton, Head 2572
CHS - 5. Planning and Records
R.C. Lewis, Head 2477
CHS - 6. Tidal
D.L. DeWolfe, Head 3846

MEL - Marine Ecology Laboratory
K.H. Mann, Director 3696
MEL - 1. Biological Oceanography
T.C. Platt, Head 3793
MEL - 2. Environmental Quality
R.F. Addison, Head 3279
MEL - 3. Fisheries Oceanography
R.W. Sheldon, Head 3270

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

ATLANTIC FISHERIES SERVICE, MARITIMES (DFO)

MFD - Marine Fish Division
T.D. Iles, Chief 8390
Canadian Atlantic Fisheries Scientific Advisory Committee - Secretariat
D.Geddes 8390

CANADIAN WILDLIFE SERVICE (DOE)

SRU - Seabird Research Unit 3274

GEOLOGICAL SURVEY OF CANADA (DEMR)

AGC - Atlantic Geoscience Centre
M.J. Keen, Director 2367
AGC - 1. Administration
P.G. Stewart, Head 2111
AGC - 2. Eastern Petroleum Geology
G.L. Williams, Head 2730
AGC - 3. Environmental Marine Geology
D.J.W. Piper, Head 7730
AGC - 4. Program Support
K.S. Manchester, Head 3411
AGC - 5. Regional Reconnaissance
R.T. Haworth, Head 3448

ABERNETHY, Scott *MEL-2*
ABOU DEBS, Chantal *MEL-3*
ABRIEL, James *AOL-1*
ACKER, Queenie *MS*
ADAMS, Al *IF-1*
ADDISON, Richard *MEL-2*
AHERN, Patrick *MEL-2*
ALLEN, Lorraine *MEL-3*
AMERO, Roy *CHS-1*
AMIRAULT, Byron *AOL-1*
AMOS, Carl *AGC-3*
ANDERSON, Bob *AOL-4*
ANDERSON, Carl *AOL-2*
ANDERSON, Debbie *MS*
ANDERSON, George *MS*
ANGELIDIS, Steve *MEL-1*
ANNAND, Christine *MFD*
ARCHER, Barbara *DG*
ARMITAGE, Fred *IF-2*
ARMSTRONG, Nancy *MFD*
ASCOLI, Piero *AGC-2*
ASPREY, Ken *AGC-3*
ATKINSON, Karen *AOL-2*
ATKINSON, Tony *AGC-4*
AVERY, Mike *AGC-2*
AVEY, David *Baffin*
AWALT, Garon *IF-2*
BACHMAN, Earl *Dawson*
BAILEY, Bill *AOL-2*
BAKER, Lloyd *IF-1*
BARRON, John *AOL-1*
BARSS, Sedley *AGC-2*
BASDEN, Kelly *IF-1*
BASTIEN, Robert *IF-3*
BEALS, Carol *CHS*
BEANLANDS, Brian *AOL-3*
BEANLANDS, Diane *MFD*
BEAVER, Darrell *AGC-4*
BECK, Brian *MFD*
BECK, Vince *IF-3*
BEHAN, Chris *MS*
BELANGER, Roger *IF-5*
BELL, Bill *Dawson*
BELLEFONTAINE, Larry *AOL-4*
BELLEFONTAINE, Linda *MS*
BELLEMARE, Paul *CHS-1*
BENNETT, Andrew *AOL-3*
BENNETT, Rick *Navicula*
BERKELEY, Tom *CHS-3*
BEST, Neville *Hudson*
BETLEM, Jan *AOL-1*
BEWERS, Michael *AOL-1*
BEZANSON, Don *AOL-2*
BISHOP, Jeffrey *AOL-1*
BLAKENEY, Claudia *AGC-3*
BLANCHARD, Elaine *MS*
BLANEY, Dave *CHS-1*
BLASCO, Steve *AGC-3*
BONANG, Faye *MS*
BONANG, Linda *MS*
BOND, Murray *MS*
BOUDREAU, Henri *CHS-1*
BOUDREAU, Paul *MEL-3*
BOUTILIER, Gary *MFD*
BOWDRIDGE, Gordon *MS*
BOWEN, Eileen *MS*
BOWMAN, Garnet *CHS-1*
BOWSER, Mike *IF-2*
BOYCE, Rick *AOL-2*
BOYCE, William *AGC-4*
BRANTON, Bob *MFD*
BRINE, Doug *IF-3*
BRODIE, Paul *MEL-3*
BROUSSARD, Joan *MS*
BROWN, Dick *SRU*
BUCKLEY, Dale *AGC-3*
BUGDEN, Gary *AOL-2*
BUJAK, Jonathan *AGC-2*
BURGESS, Frank *CHS-1*
BURHOE, Meg *MS*
BURKE, Robert *CHS-3*
BURKE, Walter *CHS-1*
CALDWELL, Glen *IF-2*
CAMERON, Ralph *CHS-1*
CAMERON, Rose *MS*
CARR, Judy *MFD*
CARSON, Bruce *AOL-4*
CASEY, Deborah *IF-3*
CASHIN, Elmo *IF-1*
CASSIVI, Roger *AOL-3*
CAVERHILL, Carla *MEL-1*
CHAMBERLAIN, Duncan *IF-1*
CHAPMAN, Borden *AGC-4*
CHAREST, Janet *IF-4*
CHARLETON, Beverley *MFD*
CHENIER, Marcel *CHS-2*
CHIN-YEE, Mark *IF-2*
CLARKE, Allyn *AOL-4*
CLARKE, Tom *IF-2*
CLATTENBURG, Donald *AGC-3*
CLIFF, John *Baffin*
CLOTHIER, Rodney *Baffin*
COCHRANE, Norman *AOL-3*
COLE, Flona *AGC-3*
COLFORD, Brian *MS*
COLLIER, Kathie *AOL-3*
COLLINS, Gary *IF-3*
COMEAU, Ernest *CHS-1*
CONNOLLY, Gerald *AOL-3*
CONOVER, Bob *MEL-1*
CONRAD, Bruce *Hudson*
CONRAD, David *AOL-1*
COOK, Gary *AGC-2*
COOKE, Gary *IF-2*
COOTE, Art *AOL-1*
COSGROVE, Art *IF-5*
COSTELLO, Gerard *CHS-1*
COTE, Brenda *MEL-3*
COURNOYER, Jean *IF-2*
COX, Brian *Baffin*
CRAIG, Dale *MS*
CRANFORD, Peter *MEL-2*
CRANSTON, Ray *AGC-3*
CRAWFORD, Keith *CHS-2*
CREWE, Norman *AOL-1*
CRILLEY, Bernard *AGC-2*
CROWE, Hubert *Hudson*
CRUX-COOK, Elizabeth *CHS-2*
CULLEN, John *MEL-1*
CUNNINGHAM, Carl *AOL-1*
CURRIE, Randy *IF-3*
CUTHBERT, Jim *IF-3*
DAGNALL, Joyce *SRU*
DALE, Carla *MFD*
DALE, Jackie *MEL*
DALZIEL, John *AOL-1*
DANIELS, Marilyn *IF-4*
D'APOLLONIA, Steve *AGC-3*
DAS, Paddy *Baffin*
DAVIES, Ed *AGC-2*
DAWE, Jane *AGC-5*
DEASE, Ann *MS*

Judy Hildebrandt,

Catherine Schipilow.

Betty Sutherland.

Patricia Stoffyn

DEASE, Gerry *IF-2*
DeLONG, Bob *IF-2*
DE MESTRAL, Jacqueline *MFD*
DEMONT, Leaman *IF-2*
DENMAN, Richard *MEL-3*
DENMAN, Shirley *AGC-1*
DENNIS, Pat *AGC-1*
D'ENTREMONT, Paul *AOL-2*
DEONARINE, Bhan *AGC-3*
DESCHENES, Mary Jean *IF-3*
DESSUREAULT, Jean-Guy *AOL-3*
DEWOLFE, David *CHS-5*
DICKIE, Lloyd *MEL-3*
DICKIE, Paul *MEL-1*
DICKINSON, Ross *Dawson*
DICKSON, Mary Lynn *MFD*
DINN, Donald *IF-2*
DOBSON, Des *AOL-2*
DOBSON, Fred *AOL-4*
DOLLIMOUNT, Ray *Hudson*
DOWD, Dick *MEL-3*
DRINKWATER, Ken *Mel-3*
DUFFY, Sean *CHS-1*
DUGAS, Theresa *MFD*
DUNBRACK, Stu *CHS-1*
DURVASULA, Rao *MEL-1*
EATON, Mike *CHS-4*
EDMONDS, Roy *MEL-3*
EDWARDS, Bob *P*
EISENER, Don *IF-2*
ELLIOTT, Jim *AOL-4*
ELLIS, Kathy *AOL-1*
ETTER, Jim *IF-2*
FADER, Gordon *AGC-5*
FAHIE, Ted *IF-2*
FAULKNER, Pat *MS*
FEETHAM, Jim *P*
FENERTY, Norman *IF-5*
FENN, Guy *AGC-4*
FERGUSON, Carol *IF-1*
FERGUSON, John *CHS-1*
FINDLEY, Bill *IF-1*
FITZGERALD, Bob *AGC-3*
FLEMING, Dave *CHS-2*
FODA, Azmeralda *MEL-2*
FOOTE, Tom *AOL-2*
FORBES, Donald *AGC-3*
FORBES, Steve *CHS-3*
FOWLER, George *AOL-2*
FOWLER, Mark *MFD*
FRASER, Brian *MEL-1*
FRASER, Jack *Maxwell*
FREEMAN, KEN *MEL-3*
FRICKER, Aubrey *AGC-4*
FRIIS, Mike *MS*
FRIZZLE, Doug *CHS-2*
FROBEL, David *AGC-3*
FROST, Jim *MEL-1*
FU, Tianbao *AOL-1*
FULLERTON, Anne *MEL-3*
GAGNE, Jacques *MFD*
GALLANT, Celesta *MS*
GALLANT, Roger *IF-2*
GALLIOTT, Jim *AOL-2*
GAMMON, Gary *MS*
GAUDET, Cathy *MS*
GAUDET, Victor *CHS-1*
GAY, Tommy *IF-1*
GEDDES, Dianne *MFD*
GEIDER, Richard *MEL-1*
GIDNEY, Betty *IF-5*

GILBERT, Reg *IF*
GILROY, Dave *IF-2*
GIROUARD, Paul *AGC-5*
GLAZEBROOK, Sherman *AOL-4*
GOODWIN, Winston *IF-2*
GOODYEAR, Julien *CHS-1*
GORDON, Don *MEL-2*
GORVEATT, Mike *AGC-4*
GRADSTEIN, Felix *AGC-2*
GRANT, Al *AGC-1*
GRANT, Gary *AGC-2*
GRANT, Steve *CHS-4*
GREENBERG, David *AOL-2*
GREGORY, Doug *AOL-2*
GREIFENEDER, Bruno *AOL-4*
GUILDERSON, Joan *DG*
GUILBAULT, Jean-Pierre *AGC-3*

HAASE, Bob *CHS-1*
HACQUEBARD, Peter *AGC-2*
HALE, Ken *IF-5*
HALLIDAY, James *IF-1*
HALLIDAY, Ralph *MFD*
HALLIDAY, Steve *AOL-4*
HALVERSON, George *IF-2*
HAMILTON, Phyllis *CHS-6*
HANTZIS, Alex *CHS-2*
HARDING, Gareth *MEL-2*
HARDY, Iris *AGC-5*
HARGRAVE, Barry *MEL-2*
HARKINSON. Doug *Baffin*
HARMES, Bob *AGC-3*
HARRIS, Cynthia *MFD*
HARRIS, Jerry *Dawson*
HARRIS, Leslie *MEL-1*
HARRISON, Glen *MEL-1*
HARRISON, Liz *AGC-1*
HARTLING, Bert *AOL-2*
HARVEY, David *AOL-3*
HAWORTH, Richard *AGC-5*
HAYES, Terry *AGC-1*
HEAD, Erica *MEL-1*
HEFFLER, Dave *AGC-4*
HEMPHILL, Milt *CHS-1*
HENDERSON, Gary *CHS-1*
HENDERSON, Terry *AGC-1*
HENDRY, Ross *AOL-4*
HENDSBEE, Dave *AOL-4*
HENNEBERRY, Andy *MEL-2*
HEPWORTH, Deborah *CHS-2*
HERMAN, Alex *AOL-3*
HILDEBRANDT, Judy *P*
HILL, Phil *AGC-3*
HILTZ, Ray *AOL-1*
HILTZ, Sharon *MS*
HINDS, Jim *Hudson*
HODGSON, Mark *MEL-1*
HOFFER, Darrell *AGC-5*
HOGANSON, Joan *MS*
HOLLAND, Len *Dawson*
HOLMES, Wayne *IF-2*
HORNE, *Ed MEL-1*
HORNE, Jack *IF-2*
HOWIE, Bob *AGC-2*
HUBLEY, Susan *AGC4*
HUGHES, David *CHS-1*
HUGHES, Mike *AGC-4*
HUH, Mia *AOL-1*
HUNTER, Leamond *CHS-2*
ILES, Derrick *MFD*
IRWIN, Brian *MEL-1*

JACKSON, Art *AGC-2*
JACKSON, Ruth *AGC-5*
JAMIESON, Steve *P*
JANSA, Lubomir *AGC-2*
JARVIS, Lawrence *Hudson*
JAY, Malcolm *CHS-2*
JENNEX, Rita *MS*
JODREY, Fred *AGC-4*
JOHN, Paulette *MS*
JOHNSON, Sue *SRU*
JOHNSTON, Larry *AGC-4*
JOLLIMORE, Roy *MS*
JOLLIMORE, Shirley *IF-4*
JOLY. Giles *P*
JONES, Peter *AOL-1*
JONES, Roger *CHS-2*
JORDAN, Francis *AOL-2*
JOSENHANS, Heiner *AGC-5*
JULIEN, Diane *MS*

KARG, Marlene *IF-3*
KAVANAUGH, Anita *IF-4*
KEARNEY, Carl *Dawson*
KEDDY, Lil *MS*
KEEN, Charlotte *AGC-5*
KEEN, Mike *AGC*
KEENAN, Pat *AOL-2*
KEIZER, Paul *MEL-2*
KELLER, Jim *AOL-3*
KELLY, Bruce *IF-2*
KENCHINGTON, Trevor *MFD*
KERR, Adam *CHS*
KERR, Steve *MEL-3*
KIERSTEAD, Linda *SRU*
KING, Donna *MFD*
KING, Graeme *CHS-5*
KING, Lewis *AGC-5*
KING, Rollie *IF-1*
KINGSTON, Peter *AOL-3*
KNOX, Don *AOL-3*
KRANCK, Kate *AOL-2*

LAKE, Diana MS
LAKE, Paul *AGC-2*
LAMBERT, Tim *MEL-3*
LAMPLUGH, Mike *CHS-1*
LANDRY, Gary *CHS-1*
LANDRY, Marilyn *MEL-1*
LANGILLE, Neil *Navicula*
LAPIERRE, Mike *IF-2*
LAPIERRE, Richard *IF-1*
LAROSE, Jim *CHS-2*
LARSEN, Einar *MEL-2*
LATREMOUILLE, Michael *IF-5*
LAWRENCE, Don *AOL-2*
LAZIER, John *AOL-4*
LeBLANC, Bill *AGC-3*
LEBLANC, Cliff *Maxwell*
LeBLANC, Neil *MS*
LEBLANC, Paul *IF-2*
LEFAIVRE, Denis *AOL-4*
LEJEUNE, Hans *Dawson*
LEONARD, Jim *AOL-Z*
LEVERMAN, Brian *MFD*
LEVY, Eric *AOL-1*
LEWIS, Marlon *MEL-1*
LEWIS, Mary *MEL-1*
LEWIS, Mike *AGC-3*
LEWIS, Reg *CHS-5*
LI, Bill *MEL-1*
LINDLEY, Pat *MEL-1*
LISCHENSKI, Ed *CHS-2*
LITTLE, Betty *P*
LIVELY, Bob *AOL-2*

Ron Trites.


Gerald Connolly.

LOCK, Stan *Baffin*
LOCK, Tony *SRU*
LOCKE, Don *AGC-4*
LOCKE, Evan *AOL4*
LOCKYER, Roy *Hudson*
LODER, John *AOL-4*
LONCAREVIC, Bosko *AGC-5*
LONGHURST, Alan *DG*
LORD, Gabriel *AOL-1*
LORING, Douglas *MEL-2*
LOVETT, Bill *MS*
LUTLEY, Judy *MS*
MacDONALD, Al *MEL-1*
MacDONALD, Barry *MS*
MacDONALD, Gerry *IF-2*
MacDONALD, Kirk *CHS-5*
MacDONALD, Rose *CHS-2*
MacGOWAN, Bruce *CHS-1*
MacHATTIE, George *IF-2*
MacHATTIE, Sheila *P*
MacISAAC, Mary *MFD*
MacKAY, Bob *Hudson*
MacLAREN, Florence *P*
MacLAREN, Oswald *AOL-3*
MacLAUGHLIN, John *IF-2*
MacLEAN, Brian *AGC-5*
MacLEAN, Carleton *Baffin*
MacLEOD, Grant *CHS-2*
MacMILLAN, Bill *AGC-2*
MACNAB, Ron *AGC-5*
MacPHERSON, Paul *MEL-2*
MAGUIRE, J-Jacques *MFD*
MAHON, Robin *MFD*
MALLET, Andre *MEL*
MALONE, Kent *CHS-1*
MANCHESTER, Keith AGC4
MANN, Ken *MEL*

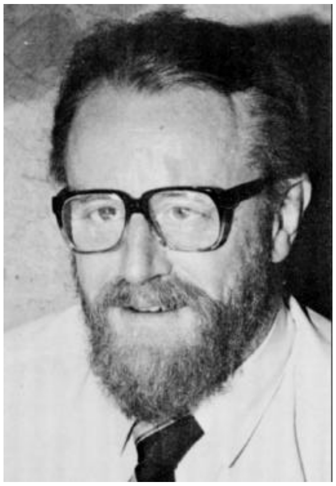

Diana Lake.

MARTELL, Jim *MS*
MARTIN, Bud *MS*
MARTIN, Harold *Dawson*
MASON, Clive *AOL-2*
MASON, Ralph *MS*
MATTHEWS, Benny *Dawson*
MATTHEWS, Gordon *Hudson*
MAUGER, Fred *Hudson*
MAZERALL, Anne *IF-4*
McCARTHY, Cathy *AGC-2*
McCARTHY, Paul *CHS-1*
McCORRISTON, Bert *CHS-2*
McGINN, Pete *CHS-6*
McGLADE, Jackie *MFD*
McKEOWN, Dave *AOL-3*
McMILLAN, Jim *MFD*
McNEIL, Beverley *CHS*
McRUER, Jeff *MEL-3*
MEHLMAN, Rick *CHS-1*
MEIN, John *Baffin*
MEISNER, Patsy *CHS-2*
MELBOURNE, Ron *CHS-2*
MESSIEH, Shoukry *MFD*
METUZALS, Kaija *MFD*
MIDDLETON, Cecilia *AGC-3*
MILLER, Bob *AGC-5*
MILLER, Frank *CHS-2*
MILLETI', David *Baffin*
MILLIGAN, Tim *AOL-2*
MILNE, Mary *AGC-2*
MILTON, Randy *SRU*
MITCHELL, Carol *AGC-2*
MITCHELL, Michel *AOL-3*
MOFFATT, John *AOL-1*
MOORE, Bill *IF-1*
MORAN, Kate *AGC-3*
MORTON, Pete *CHS-2*
MUDIE, Peta *AGC-3*
MUISE, Fred *IF-2*
MUISE, Laura *MS*
MURPHY, Bob *AGC-4*
MURRAY, Ed *DG*
MYRA, Valerie *MFD*
MYERS, Steven *IF-1*

NEEDLER, George *AOL*
METTLESHIP, David *SRU*
NEU, Hans *AOL-2*
NICHOLLS, Brian *DG*
NICHOLS, Brian *AGC-5*
NICKERSON, Bruce *AOL-3*

Ken Drinkwater.

NICKERSON, Carol MS
NICOLL, Michael *IF-1*
NIELSEN, Jes *AGC-4*
NORTON, Neil *Baffin*
OAKEY, Neil *AOL-4*
O'BOYLE, Bob *MFD*
O'REILLY, Charles CHS-6
O'ROURKE, Mike *IF-2*
ORR, Ann *MEL-3*
PALMER, Nick *CHS-2*
PALMER, Richard *CHS-1*
PARANJAPE, Madhu *MEL-1*
PARSONS, Art *IF-2*
PATON, Jim *MS*
PEER, Don *MEL-2*
PELLERINE, Danny *IF-1*
PEMPKOWIAK, Janusz *AOL-1*
PENNELL, Charles *Hudson*
PETERSON, Carl *IF-2*
PETRIE, Brian *AOL-2*
PETRIE, Liam *MEL-3*
PETTIPAS, Roger *AOL-4*
PHILLIPS, Georgina *MEL-2*
PHILLIPS, Ted *AOL-3*
PIETRZAK, Robert *CHS-5*
PIPER, David *AGC-3*
PLATT, Trevor *MEL-1*
POCKLINGTON, Roger *AOL-1*
POLSON, Carl *IF-2*
PORTEOUS, Dave *IF-3*
PORTER, Cathy *AOL-4*
POTTIE, Dennis *AOL-1*
POTTIE, Ed *MS*
POWROZ, William *Dawson*
POZDNEKOFF, Peter *AOL-4*
PRITCHARD, John *AOL-2*
PROCTOR, Wally *AOL-3*
PROUSE, Nick *MEL-2*
PURDY, Phil *MS*
QUINLAN, Garry *AGC-5*
QUON, Charlie *AOL-4*
RACINE, Carol *AGC-1*
RADCLIFFE, Mark *AOL-4*
RAFUSE, Phil *Baffin*
RAIT, Sue *MS*
RASHID, Mohammed *AGC-3*
REED, Barry *Dawson*
REID, Ian *AGC-5*



Dale Buckley.

REID, Jim *MFD*
REIMER, Dwight *MEL-3*
REINHARD, Harry *MS*
REINIGER, Bob *AOL-4*
REYNOLDS, Bill *Hudson*
RICHARD, Wayne *IF-3*
RIPPEY, Helen *AOL-2*
RIPPEY, Jim *Hudson*
RITCEY, Jack *Baffin*
ROACH, Marilyn *MS*
ROBERTSON, Kevin *AGC-3*
ROCKWELL, Gary *CHS-1*
RODGER, Glen *CHS-1*
ROOP, David *CHS-1*
ROSE, Charlie *IF-2*
ROSS, Charles *AOL-4*
ROSS, Jim *CHS-2*
ROSSE, Ray *MS*
ROZON, Chris *CHS-1*
RUDDERHAM, Dave *MEL-1*
RUMLEY, Betty *AOL-2*
RUSHTON, Laurie *MEL-1*
RUSHTON, Terry *MEL-3*
RUXTON, Michael *CHS-I*
SABOWITZ, Norman *IF-4*
SADI, Jorge *Baffin*
SAMEOTO, Doug *MEL-1*
SANDSTROM, Hal *AOL-4*
SAUNDERS, Jo-Anne *IF-4*
SCHAFER, Charles *AGC-3*
SCHIPILOW, Catherine *CHS-2*
SCHUTZENMEIER, Marion *AOL-2*
SCHWARTZ, Bernie *IF-2*
SCHWINGHAMER, Peter *MEL-2*
SCOTNEY, Murray *AOL-2*
SEIBERT, Gerald *AOL-2*
SHATFORD, Lester *AOL-3*
SHAY, Juanita *IF-2*
SHELDON, Ray *MEL-3*
SHERIN, Andy *AGC-4*
SHIH, Stone *AGC-5*
SHOTTON, Ross *MEL-3*
SHUNAMON, Sherry *AOL-2*
SILVERT, Bill *MEL-3*
SIMMONS, *Carol MEL-2*
SIMMS Judy *AOL-1*
SIMON, Jim *MFD*
SIMPSON, Pat *MFD*
SINCLAIR, Allan *MFD*
SISK, Perry *MFD*
SLADE, Harvey *IF-5*

SMITH, Alan *CHS-2*
SMITH, Bert *CHS-1*
SMITH, Bill *MFD*
SMITH, Fred *IF-1*
SMITH, John *AOL-1*
SMITH, John *MEL-1*
SMITH, Peter *AOL-2*
SMITH, Ralph *MEL-1*
SMITH, Steve *MFD*
SMITH, Stu *AOL-4*
SMITH, Sylvia *MEL*
SMITH, Ted *IF-1*
SPARKES, Roy *AGC-4*
SPENCER, Sid *IF-2*
SPRY, Jeff *MEL-1*
SRIVASTAVA, Shiri *AGC-5*
STEAD, Gordon *CHS-2*
STEELE, Trudi *AOL-4*
STEEVES, George *IF-2*
STEPANCZAK, Mike *AOL-3*
STEWART, Pat *AGC-1*
STILO, Carlos *Baffin*
STIRLING, Charles *CHS-1*
STOBO, Wayne *MFD*
STODDART, Stan *Hudson*
STOFFYN, Mark *AGC-3*
STOFFYN, Patricia *AGC-3*
STOLL, Hartmut *IF-2*
STRAIN, Peter *AOL-1*
STRUM, Loran *Hudson*
STUART, Al *IF-2*
STUIFBERGEN, Nick *CHS-4*
SUTHERLAND, Betty *IF-4*
SUTHERLAND, Harry *IF-2*
SVETLIK, Susan *IF-4*
SWIM, Minard *CHS-1*
SWYERS, Bert *AOL-2*
SYMES, Jane *P*
SYVITSKI, James *AGC-3*
TAN, Francis *AOL-1*
TANG, Charles *AOL-2*
TAYLOR, Bill *IF-3*
TAYLOR, Bob *AGC-3*
TAYLOR, George *MEL-3*
TEE, Kim Tai *AOL4*
THOMAS, Frank *AGC-2*
TILLMAN, Betty *P*
TOLLIVER, Deloros *AGC-1*
TOPLISS, Brenda *AOL-2*
TOTTEN, Gary *IF-1*
TRITES, Ron *MEL-3*
UNDERWOOD, Bob *IF-2*
VALDRON, Linda *MFD*
VANDAL, Bob *IF-2*
VANDERMEULEN, John *MEL-2*
VARBEFF, Boris *IF-2*
VARMA, Herman *CHS-1*
VASS, Peter *MEL-2*
VAUGHAN, Betty *IF-2*
VERGE, Ed *AOL-2*
VETESE, Barb *AGC-1*
VEZINA, Guy *IF-2*
VILKS, Gus *AGC-3*
VINE, Dick *IF-2*
WADE, John *AGC-2*
WAGNER, Frances *AGC-3*
WALDRON, Don *MFD*
WALKER, Bob *AOL-2*
WANG, Rong *MEL-2*
WARD, Brian *IF-2*
WARDROPE, Dick *IF-2*

John Woodside.

WARNELL, Margaret *IF-3*
WEBBER, Shirley *MS*
WELLS, Peter *MEL-2*
WESTHAVER, Don *IF-2*
WESTON, Sandra *CHS-2*
WHITE, George *MFD*
WHITE, Joe *MS*
WHITE, Keith *CHS-3*
WHITEWAY, Bill *AOL-3*
WIECHULA, Marek *IF-3*
WIELE, Heinz *IF-5*
WILLIAMS, Doug *MS*
WILLIAMS, Graham *AGC-2*
WILLIAMS, Pat *AOL*
WILLIS, Doug *MEL-2*
WILSON, George *IF-1*
WILSON, Jim *IF-2*
WINTER, Danny *IF-2*
WINTERS, Gary *AGC-3*
WOOD, Bryan *MFD*
WOODHAMS, Lofty *IF-2*
WOODSIDE, John *AGC-5*
WRIGHT, Dan *AOL-4*
WRIGHT, Morley *IF-2*
WTTEWAAL, Joan *IF-3*
YEATS, Phil *AOL-1*
YOUNG, Gerry *MFD*
YOUNG, Scott *AOL-3*
ZEMLYAK, Frank *AOL-1*
ZINCK, Maurice *MEL-2*
ZWANENBURG, Kees *MFD*

NATIONAL AND INTERNATIONAL COMMITTEES, WORKING GROUPS, AND BOARDS

Because this edition is devoted to basic oceanographic research at BIO, and because individual affiliations of BIO scientists to international organizations do not change so rapidly that an annual update of affiliations is useful, we are this year focussing attention on the role BIO currently plays in a single international research organization, the Scientific Committee on Oceanic Research, or as it is more familiarly known, SCOR. SCOR is one of the 14 scientific committees of ICSU, the International Council of Scientific Unions, itself an international but non-governmental organization working closely with UNESCO and WMO. Membership of SCOR is by National Committee, and presently 35 have adhered and pay membership dues proportional to their activity in international oceanographic research. The Executive Committee of SCOR includes four Canadian members. the others coming individually from: South Africa, the Soviet Union, the United Kingdom, the United States, the Federal Republic of Germany, the Netherlands, Denmark, Switzerland and India. The SCOR office is located in the Oceanography Department at Dalhousie University in Halifax, and is run by Ms. E. Tidmarsh, the Executive Secretary; the President of SCOR is Dr. E. Simpson of the University of Cape Town, and the Secretary is Dr. A.R. Longhurst of the Department of Fisheries and Oceans at BIO.

SCOR performs its work largely through the activities of a shifting population of Working Groups of scientists; these are "normally created to stimulate or focus interest in a particular field of research (especially) when a particular subject will benefit significantly from an international study or when it is desirable to plan a collaborative activity" (SCOR Handbook). The Working Groups of SCOR study both oceanographic problems themselves - how does a particular ocean process really function? - and also methods and standards for observations. Over the history of SCOR about 70 such Working Groups have been established, and currently about 25 are active, with several new proposals in hand.

BIO participation in the Working Groups and other bodies of SCOR is presently as follows: WG 34, Internal Dynamics of the Ocean (Dr. G.T. Needler, AOL); WG 59, Mathematical Models in the Ocean (Dr. K.H. Mann, MEL, Chairman, and Dr. T.C. Platt, MEL); WG 61, Sedimentation Processes at Continental Margins (Dr. D.J.W. Piper, AGC); WG 68, North Atlantic Circulation (Dr. A. Clarke, AOL); Committee on Climate Change in the Ocean (Dr. A.R. Longhurst, OSS Atlantic); Joint Panel on Oceanographic Tables and Standards (Mr. C.K. Ross, AOL).

Further information can be obtained from the SCOR Executive Secretary, Tel.: (902) 424-3558, Telex: 019 21 863, Cables; OCEANOGRAPHY, DALHOUSIE, HALIFAX.

A hydrographic survey launch at Cape White Hankerchief along the Labrador coast.

chapter 7

Project Listing

We present below a listing of the projects (A, B, C, etc.) and individual investigations (1, 2, 3, etc.) being undertaken by staff of the three major research laboratories at BIO: this listing was current at December 1981. For more information on these and the projects of other BIO component laboratories, feel free to write to the directors of the laboratories.

ATLANTIC OCEANOGRAPHIC LABORATORY

A. SURFACE AND MIXED-LAYER OCEANOGRAPHY

1. Sea surface wind stress. heat flux, and evaporation *(S.D. Smith, F.W. Dobson)*
2. Surface heat flux at OWS Bravo *(S.D. Smith, J.R.N. Lazier)*
3. Wave growth studies *(F.W. Dobson)*
4. Wave climate studies *(H.J.A. Neu)*
5. Oil trajectory analysis *(D.J. Lawrence, J.A. Elliott, D.A. Greenberg)*
6. Surface drifters *(D. Bezanson)*
7. Iceberg drift track modelling *(S.D. Smith)*
8. Microstructure in the surface layers (N.S. *Oakey, J.A. Elliott)*
9. Small-scale structure of the frontal zones of warm-core Gulf Stream rings *(C.L. Tang, A.S. Bennett, D.J. Lawrence)*
11. Near-surface velocity measurements (N.S. *Oakey)*
12. Comparison of long-term mean air/sea fluxes from weatherships and ships-of-opportunity *(F.W. Dobson, S.D. Smith)*
13. Ice dynamics during CESAR *(R.J. Anderson, S.D. Smith)*

B. LARGE-SCALE DEEP-SEA OCEANOGRAPHY

1. Labrador Sea Water formation *(R.A. Clarke and others)*
2. Dynamics of the Labrador Sea (C. *Quon)*
3. Age determinations in Baffin Bay bottom water *(E.P. Jones and others)*
4. Tail of the Grand Banks *(R.A. Clarke, R.F. Reiniger)*
5. Local-scale Gulf Stream structure *(R.M. Hendry, R.F. Reiniger)*
6. Gulf Stream extension studies *(R.M. Hendry, R.F. Reiniger)*
7. Newfoundland Basin experiment *(R.A. Clarke and others)*
8. Non-linear dynamics of long waves in the ocean *(H. Sandstrom)*
9. Stability problems in GFD flows (C. *Quon)*
10. Northwest Atlantic atlases *(R.F. Reiniger and others)*
11. Norwegian/Greenland Sea experiment *(R.A. Clarke and others)*
12. Denmark Strait Overflow (C.K. *Ross)*
13. North Atlantic baseline hydrography - 48°N transect *(R. Hendry)*
14. Polar front experiment *(J.R.N. Lazier)*

C. CONTINENTAL SHELF DYNAMICS

1. Cape Sable experiment *(P.C. Smith and others)*
2. Shelf break experiment *(P.C. Smith and others)*
3. Strait of Belle Isle *(B.D. Petrie, C. Garrett)*
4. Shelf dynamics - Avalon Channel experiment *(B.D. Petrie, H. Sandstrom)*
5. Tidally-induced mixing *(J.A. Elliott, H. Sandstrom)*
6. Batfish internal waves *(A.S. Bennett)*

D. CONTINENTAL SHELF AND PASSAGE WATER MASS AND TRANSPORT STUDIES

1. Labrador Shelf and Slope studies *(J.R.N. Lazier)*
2. Flemish Cap experiment (C.K. *Ross)*
3. Impact of fresh water on the water masses of Davis Strait and the Labrador Sea *(H.J.A. Neu)*
4. Long-term monitoring of the Labrador Current at Hamilton Bank *(J.R.N. Lazier)*
5. Long-term temperature monitoring *(B.D. Petrie, P.C. Smith)*
6. Applied studies - EAMES data archiving *(G.H. Seibert)*
7. Long-term surface velocity patterns in Baffin Bay and Davis Strait *(H.J.A. Neu)*
8. Oceanography of the Newfoundland Continental Shelf *(B.D. Petrie)*
9. Development of remote sensing facilities in the Atlantic Oceanographic Laboratory *(C.S. Mason, A.S. Bennett, B. Topliss)*

E. OCEANOGRAPHY OF ESTUARIES AND EMBAYMENTS

1. Saguenay fjord study *(G.H. Seibert)*
2. Northwestern Gulf of St. Lawrence oceanography *(C. Tang, A.S. Bennett)*
3. Gaspé current studies *(C. Tang)*
4. Gulf of St. Lawrence frontal study (C. *Tang, A.S. Bennett)*

From the top: Charles Schafer. Steve d'Apolonia. and Mike Lewis cxaminc sidc-scan sonar records aboard *CSS Hudson* in search of the traces of iceberg tracks.

5 Seasonal and interannual variability in the Gulf of St. Lawrence *(G. Bugden)*
6. Laurentian Channel current measurements *(G. Bugden)*
7. The Gulf of St. Lawrence - numerical modelling studies *(K.T. Tee)*
8. Gulf of St. Lawrence - normal mode studies *(G.H. Seibert)*
9. Tidal and residual currents - 3-D modelling studies *(K.T. Tee)*
10. Bay of Fundy - Gulf of Maine modelling studies *(D.A. Greenberg)*
11. Forced flows in the Strait of Canso *(D.J. Lawrence, D.A. Greenberg)*
12. Physical behaviour of particulate matter and sediments in the natural environment *(K. Kranck)*
13. Laboratory studies of particulate matter *(K. Kranck)*
14. Particulate matter in the Bay of Fundy and Saint John Harbour *(K. Kranck. D. Bezanson)*
15. Bottom drifters *(D. Bezanson)*
16. Residual barotropic circulation in the Bay of Fundy and Gulf of Maine *(D.A. Greenberg)*
17. Suspended sediment modelling *(D.A. Greenberg, C.L. Amos)*
18. Theoretical studies of mean circulation in the Gulf of Maine region *(D. Wright, J.W. Loder)*

F. SENSOR DEVELOPMENT
1. Anemometers for drifting buoys (J.-G. *Dessureault)*
2. CTDs and associated sensors *(A.S. Bennett)*
3. Thermistor chains on drifting buoys *(G.A. Fowler and others)*
4. Towed biological sensors *(A.W. Herman and others)*
5. High productivity and frontal dynamics at the Scotian Shelf Break *(A.W. Herman)*
6. Vertical profiling biological sensors *(A. W. Herman and others)*
7. Zooplankton grazing and phytoplankton production dynamics *(A.W. Herman and others)*
8. Measurements of zooplankton spatial variability *(A.W. Herman, D.D. Sameoto)*
9. Real-time data acquisition *(A.S. Bennett)*
10. Optical instrumentation for suspended-solids measurements *(A.S. Bennett)*
11. CTD sensor time constant measurements *(A.S. Bennett)*
12. Moored fluorometers *(A.W. Herman and others)*

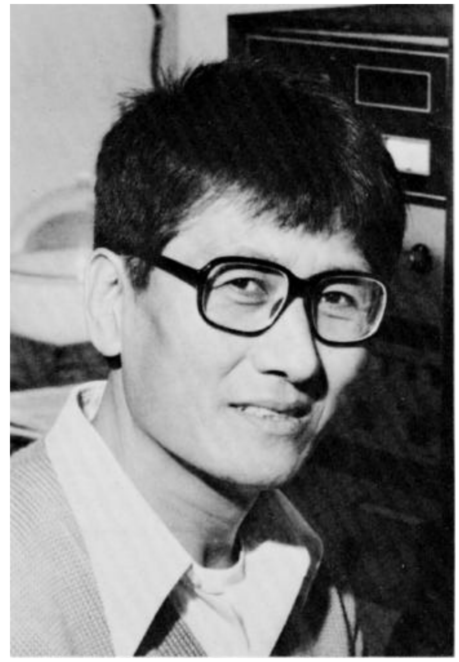
G. SURVEY AND POSITIONING SYSTEM DEVELOPMENT
1. Acoustic current profiler *(D.L. McKeown, R.M. Hendry)*
2. Bottom-referenced acoustic positioning systems *(D.L. McKeown)*
3. Ship-referenced acoustic positioning systems *(D.L. McKeown)*
4. Multifrequency acoustic scanning of water column *(N.A. Cochrane)*
5. Digital echo sounding *(N.A. Cochrane)*
6. Doppler current profiler *(N.A. Cochrane)*

H. OCEANOGRAPHIC INSTRUMENT DEPLOYMENT
1. Engineering studies of the stable platform *(S.D. Smith and others)*
2. Mooring system development *(G.A. Fowler and others)*
3. Handling and operational techniques for instrument/cable systems *(J.-G. Dessureault, R.F. Reiniger)*
4. Drill system improvement *(G.A. Fowler and others)*
5. *In situ* sampling of suspended particulate matter *(P. Kingston)*
6. Measurement of geotechnical properties *(G.A. Fowler)*

I. NEARSHORE AND ESTUARINE GEOCHEMISTRY
1. Nutrient distributions on the Grand Banks and their resupply *(A.R. Coote, E.P. Jones)*
2. Estuarine and coastal trace-metal geochemistry *(P.A. Yeats, J.M. Bewers)*
3. Atmospheric input to the ocean *(E.P. Jones and others)*

A box-type sediment sampler.

4. Sediment geochronology and geochemistry in the Saguenay fjord *(J.N.B. Smith and others)*
5. Sediment transport and bioturbation studies in the Bay of Fundy *(J.N.B. Smith and others)*



Visiting scholar Wang Rong of the Institute of Oceanology (Academia Sinica). People's Republic of China.

6. Organic matter in estuaries of the St. Lawrence *(F.C. Ton, P.M. Strain)*
7. Sources of organic carbon in the Peck's Cove ecosystem *(F.C. Tan, P.M. Strain)*
8. Composition of organic matter in marginal seas *(R. Pocklington and others)*
9. Organic composition of the St. Lawrence River *(R. Pocklington and others)*
10. Carbon isotope study on Scotian Shelf ecosystems *(E.L. Mills, F.C. Tan)*
11. Geochemical factors controlling the accumulation and dispersal of heavy metals in the Bay of Fundy sediments *(D.H. Loring)*
12. Trace metals in suspended particulate matter in the Bay of Fundy *(D.H. Loring)*
13. Physical-chemical controls of particulate heavy metals in a turbid tidal estuary *(D.H. Loring, A. Morris)*

J. DEEP-OCEAN MARINE CHEMISTRY
1. Nutrient regeneration processes *(A.R. Coote, E.P. Jones)*
2. CO_2 in the ocean *(E.P. Jones and others)*
3. Distribution of sea-ice meltwater in the Arctic *(F.C. Tan, P.M. Strain)*
4. Trace metal geochemistry in the North Atlantic *(P.A. Yeats, J.M. Bewers)*
5. Sediment transport, deposition, and bioturbation studies on the Newfoundland Slope *(J.N.B. Smith and others)*
6. Upwelling and living resources *(R. Pocklington)*
7. Natural marine organic constituents *(R. Pocklington and others)*
8. Particulate organic matter in the North Atlantic *(F.C. Tan, P.M. Strain)*
9. Paleoclimatic studies *(F.C. Tan and*

others)
10. Comparison of vertical distribution of trace metals in the North Atlantic and North Pacific oceans *(P.A. Yeats)*
11. Chemical budgets and tracers in the Arctic Ocean *(E.P. Jones, A.R. Coote*

K. MARINE POLLUTION CHEMISTRY
1. Dissolved low molecular weight hydrocarbons *(E.M. Levy, E.P. Jones)*
2. Petroleum hydrocarbon components *(E.M. Levy, P.M. Strain)*
3. Seabird preen gland chemistry *(E.M. Levy, P.M. Strain)*
4. Petroleum residues in the eastern Canadian Arctic *(E.M. Levy)*
5. Point Lepreau environmental monitoring program *(R. Pocklington and others)*
6. Canadian marine analytical standards program *(P.A. Yeats and others)*
7. Belledune project *(D.H. Loring and others)*
8. Baseline levels of low molecular weight hydrocarbons and petroleum residues on the Grand Banks *(E.M. Levy)*
9. International activities *(J.M. Bewers and others)*
10. Joint Canada/Federal Republic of Germany caisson experiments on metal exchanges between aqueous and sedimentary phases *(D.H. Loring, F. Prosi)*
11. Marine emergencies *(E.M. Levy)*

L. TECHNOLOGY TRANSFER
1. Papa *(J.A. Elliott)*

MARINE ECOLOGY LABORATORY

A. PRIMARY PRODUCTION PROCESSES: PHYTOPLANKTON PHYSIOLOGY AND BIOENERGETICS
1. Mathematical representation and parameterization of phytosynthetic response to changes in light intensity *(T.C. Platt, W.G. Harrison)*
2. Dependence of photosynthesis - light parameters on environmental conditions *(T.C. Platt and others)*
3. Significance and nature of aggregation and dispersion in phytoplankton production processes *(T.C. Platt)*
4. Photosynthetic and respiratory enzymes in phytoplankton assemblages: dynamics and significance for understanding and predicting variations in rate of primary production *(J.C. Smith, T.C. Platt)*
5. Size-fraction of phytoplankton in photosynthesis-light experiments and relative contribution of diatoms to total phytoplankton production *D.V. Subba Rao)*
6. Primary production rates of individual phytoplankton species *(W.G. Harrison)*
7. Growth rates and protein synthesis by phytoplankton in relation to light intensity *(T.C. Platt and others)*
8. Respiration. nutrient uptake, and regeneration in natural plankton populations *(W.G. Harrison, J.C. Smith)*
9. Physical oceanography of selected features in connection with marine ecological studies *(W.H. Horn, T.C. Platt)*
10. Physiology of marine bacteria *(W.K.W. Li, T.C. Platt)*
11. Patterns of phytoplankton photosynthesis assessed by radiocarbon distribution among cellular polymers and metabolites *(W.K.W. Li, T.C. Platt)*
12. Phytoplankton studies during BIOSTAT cruise *(D.V. Subba Rao)*

B. SECONDARY PRODUCTION PROCESSES: TRANSFORMATION OF ORGANIC MATERIAL IN SECONDARY PRODUCTION
1. Carbon and nitrogen utilization and factors controlling secondary production by zooplankton *(R.J. Conover)*
2. Nutrition, metabolism. and overwintering strategies of microzooplankton *(M.A. Paranjape)*
3. Vertical distribution of microzooplankton *(M.A. Paranjape)*
4. Development of profiling equipment for plankton and micronekton *(D.D. Sameoto)*
5. Use of acoustic techniques to measure distribution of plankton and ichtyoplankton *(D.D. Sameoto)*
6. Analysis of microdistribution of ichthyoplankton and zooplankton in upwelling ecosystems *(D.D. Sameoto)*
7. Nature and significance of vertical variability in zooplankton profiles *(A.R. Longhurst)*
8. Investigation of the biochemical composition of particulate organic matter in relation to digestion by zooplankton *(E. Head)*
9. Digestive enzymes of zooplankton in relation to food supply *(E. Head)*
10. BIOSTAT *(D.D. Sameoto)*
11. Feeding studies on zooplankton grown in an algal chemostat *(E. Head, R.J. Conover)*

C. ATLANTIC CONSHELF ECOLOGY: STUDIES OF THE SCOTIAN SHELF AND ADJACENT REGIONS
1. Scotian Shelf resources, ecological composition of CEP/SSIP analysis: data aquisition over large spatial and long temporal scales *(R.J. Conover and others)*
2. Seasonal cycles of abundance and distribution of microzooplankton *(M.A. Paranjape)*
3. Methods of calculation of secondary production estimated from zooplankton population data *(R.J. Conover)*
4. Significance of Yarmouth upwelling plankton production to general productivity of Scotian Shelf fish stocks *(D.D. Sameoto)*
5. Vertical flux of living and nonliving particles in the water column and nutrient-sas exchange across the seawater-sediment boundary on the Scotian Shelf *(B.T. Hargrave, G.C.H. Harding)*
6. Comparative studies of functional structure of pelagic ecosystems *(A.R. Longhurst)*

D. EASTERN ARCTIC ECOLOGICAL STUDIES
1. Physiology. production. and distribution of marine phytoplankton *(T.C. Platt and others)*
2. Distribution. growth. and production, and the role of diapause in Arctic zooplankton communities *(R.J. Conover and others)*
3. Zooplankton and macronekton of the eastern Arctic *(D.D. Sameoto)*
4. Arctic surface water zooplankton *(D.D. Sameoto)*
5. Arctic microzooplankton *(D.D. Sameoto)*
6. Distribution and abundance of microzooplankton in the eastern Arctic *(M.A. Paranjape)*
7. Eco-physiological aspects of marine bacterial processes *(W.K.W. Li, T.C. Platt)*

The nearshorc research vessel *Sigma-T*.

E. POPULATION AND TROPHODYNAMICS: ECOLOGICAL THEORY AND STRUCTURE OF ECOSYSTEMS

1. Acoustic analyses of fish populations and development of survey methods (L.M. *Dickie and others)*
2. Genetic and environmental control of production parameters *(L.M. Dickie, K.R. Freeman)*
3. Geographic variation of production parameters *(L.M. Dickie, K.R. Freeman)*
4. Development of biochemical indicators of metabolism and growth for fish (J.C. *Smith, L.M. Dickie)*
5. Metabolism and growth of fishes *(S.R. Kerr)*
6. Mathematical analysis of fish production systems *(S.R. Kerr, W.L. Silvert)*
7. Parameter estimation and the theory of prediction *(W.L. Silvert)*
8. Size-structure spectrum of fish production *(S.R. Kerr and others)*
9. Optimal foraging and reproductive strategies *(D.M. Ware, W.L. Silvert)*
10. Growth rate in relation to size and temperature *(R.W. Sheldon)*
11. Bioenergetics: marine mammals *(P. Brodie)*
12. Feeding strategy and ecological impact of bivalve larvae *(C. Abou Debs)*
13. Mathematical analysis of fish population interactions *(S.R. Kerr, L.M. Dickie)*
14. Marine mammal - fisheries interactions *(P. Brodie)*

F. ENVIRONMENTAL VARIABILITY EFFECTS: CLIMATE AND ENVIRONMENTAL CONTROL OF FISH POPULATION ABUNDANCE.

1. Residual current patterns on the Canadian Atlantic continental shelf as revealed by drift bottles and seabed drifters *(R.W. Trites)*
2. Water type analyses for the NAFO areas *(R. W. Trites)*
3. Mesoscale variability in current patterns in the southern Gulf of St. Lawrence *(R. W. Trites)*
4. Effects of Hudson Bay outflow on the Labrador Shelf *(W.H. Sutcliffe)*
5. Effects of St. Lawrence River outflow on the populations of fish and invertebrates in the Gulf of St. Lawrence and on the Scotian Shelf *(W.H. Sutclife, K.F. Drinkwater)*
6. Larval herring transport and diffusion studies *(R.W. Trites, D.M. Ware)*
7. Currents and transport in Georges Bank - southwest Nova Scotia in relation to the inshore-offshore lobster problem *(R.W. Trites)*
8. Oil distribution in relation to winds and currents following the break-up of the Kurdistan *(D.J. Lawrence and others)*
9. Halifax section historical data *(K.F. Drinkwater)*
10. Environmental variability - correlations and response scales *(R.W. Trites)*

G. INSHORE ECOLOGY: ECOLOGICAL STUDIES OF COASTAL FISHERIES

1. Steady state model and transient features of the circulation of St. Georges Bay *(K.F. Drinkwater)*
2. Lateral diffusion measurements in coastal areas *(R.W. Trites)*
3. Relation between chlorophyll-a and temperature structure *(K.F. Drinkwater)*
4. Distribution of lobster larvae in relation to water movement *(G.C.H. Harding and others)*
5. The distribution, abundance, and recruitment of lobster larvae in St. Georges Bay and the possible effects of the Canso Causeway on the Chedabucto Bay lobster fishery *(G.C.H. Harding and others)*
6. Seasonal variability of planktonic particle size spectrum *(G.C.H. Harding and others)*
7. Nutrition and growth of micro-, macro-, and ichthyoplankton *(R.W. Sheldon and others)*
8. Vertical movement of plankton, suspended matter, and dissolved nutrients in the water columns of coastal embayments *(G.C.H. Harding and others)*
9. Distribution and ecology of ichtyoplankton *(D.M. Ware)*
10. Spatial relations between demersal fish and sediment parameters *(R.W. Sheldon)*
11. Characterization of water masses by particle spectra *(R.W. Sheldon, R.W. Trites)*
12. Langmuir circulation and small scale distribution of the plankton *(D.M. Ware and others)*
13. Primary production dynamics *(K.F. Drinkwater and others)*
14. Vertical distribution and feeding behaviour of Atlantic mackerel larvae *(B. Cork)*
15. Coupling of pelagic and benthic production systems *(P. Schwinghamer and others)*
16. Instrument development for surveys of particle size distribution *(R.W. Sheldon, J. deMestra1)*
17. Trophic relations in nearshore kelp communities *(K.H. Mann)*

H. SUBLETHAL CONTAMINATION AND EFFECTS: LOW-LEVEL RESPONSES AND PHYSIOLOGICAL STRESS

1. MFO induction by PCBs and PCB replacements *(R.F. Addison)*
2. Organochlorines in Arctic seals *(R.F. Addison)*
3. Fate, metabolism, and effects of petroleum hydrocarbons in marine environments *(J.H. Vandermeulen)*
4. Uptake and clearance of organochlorines by zooplankton by feeding and from water *(G.C.H. Harding and others)*
5. Dynamics of metalloids in marine plankton *(R.F. Addison, J. Wrench)*

I. BAY OF FUNDY ECOLOGICAL STUDIES: MACROTIDAL ECOLOGY AND ENVIRONMENTAL MODIFICATION

1. Ice dynamics in Chignecto Bay *(D.C. Gordon, Jr.)*
2. Water column chemistry and planktonic primary production in the Bay of Fundy *(D.C. Gordon, Jr., and others)*
3. Concentration, distribution, seasonal variation, and flux of inorganic nutrients and organic matter in shallow waters and intertidal sediments in the upper reaches

Leslie Harris.

of the Bay of Fundy *(D.C. Gordon, Jr., and others)*
4. Intertidal primary production and respiration, and the availability of sediment organic matter *(B.T. Hargrave and others)*
5. Microbial ecology of the Bay of Fundy *(L. Cammen, P. Schwinghamer)*
6. Subtidal benthic ecology of the Bay of Fundy (D.L. Peer and P. Schwinghamer)
7. Intertidal benthic ecology of the upper reaches of the Bay of Fundy *(D.L. Peer and others)*
8. Zooplankton studies in Cumberland Basin *(N.J. Prouse)*
9. Production and export of Cumberland Basin salt marshes *(D.C. Gordon, Jr., P. Cranford)*
10. Stable carbon isotope studies of the Pecks Cove mudflat food chain *(P. Schwinghamer and others)*
11. Modelling Bay of Fundy ecosystems *(Entire group)*

J. DEEP OCEAN ECOLOGY
1. Deep ocean ecology *(B.T. Hargrave)*

ATLANTIC GEOSCIENCE CENTRE

A. TECHNOLOGY DEVELOPMENT
1. Seabed Mosaics *(D.E. Heffler, W.A. Boyce)*
2. Huntec SEABED project *(L.H. King)*
3. Sediment dynamics monitor - RALPH *(D.E. Heffler, R.J. Murphy)*
4. Ocean bottom seismometers at the AGC *(D.E. Heffler)*
5. Development of data management system for marine geophysical data - GEOFFREY *(G.B. Martin, A.G. Sherin, D.E. Beaver)*

B. RESOURCE EVALUATION: HYDROCARBONS
1. Hydrocarbon inventory of the sedimentary basins of eastern Canada *(J.A. Wade)*
2. Geophysical interpretation of geophysical data as an aid to basin synthesis and hydrocarbon inventory *(A.C. Grant)*

C. RESOURCE EVALUATION: COAL
1. Rank and petrographic studies of coal and organic matter dispersed in sediment *(P.A. Hacquebard, M.P. Avery)*
2. Geological assistance with provincial coal drilling project in Nova Scotia *(P.A. Hacquebard)*
3. Advice to the Cape Breton Development Corporation on coal geology for its operation in the Sydney coalfield *(P.A. Hacquebard)*

D. REGIONAL GEOLOGY
1. Compilation of geoscience data in the Paleozoic basins of eastern Canada *(R.D. Howie)*
2. Regional subsurface geology of the Mesozoic and Cenozoic rocks of the Atlantic continental margin *(J.A. Wade)*
3. Regional subsurface geology of the continental shelf and slope, offshore Labrador, Baffin Island, and related areas *(D.C. Umpleby)*

E. BIOSTRATIGRAPHY
1. Identification and biostratigraphic interpretation of referred fossils *(Eastern Petroleum Geology Subdivision staff)*
2. Palynological zonation of the Carboniferous interpretation of referred fossils *(Eastern Petroleum Geology Subdivision staff)*
2. Palynological zonation of the Carboniferous and Permian rocks of the Atlantic Provinces, Gulf of St. Lawrence, and northern Canada *(M.S. Barss, W.C. MacMillan)*
3. Biostratigraphic zonation (palynology) of the Mesozoic and Cenozoic rocks of the Atlantic shelf *(G.L. Williams, G.L. Cook)*
4. Biostratigraphic zonation (Foraminifera-Ostracoda) of the Mesozoic and Cenozoic rocks of the Atlantic Shelf *(P. Ascoli)*
5. Classification of dinocysts *(G.L. Williams)*
6. Biostratigraphic history of the Mesozoic-Cenozoic sediments of the Grand Bank, northeast Newfoundland, and Labrador shelves based on Foraminifera and Ostracoda *(F.M. Gradstein, F.C. Thomas)*
7. Biostratigraphy and paleo-ecology (palynology) of the Mesozoic and Cenozoic, Atlantic Shelf *(J.P. Bujak)*
8. Geological Survey of Canada representative on the Steering Committee for the Kremp Palynologic Computer Research Project *(M.S. Barss, B.J. Crilley)*
9. Taxonomy, biostratigraphy, paleoecology, and paleobiogeography of agglutinated foraminifera *(F.M. Gradstein)*
10. Dinoflagellates - origin and evolution *(E.H. Davies)*
11. Vitrinite reflectance of dispersed organic matter *(E.H. Davies)*
12. Mesozoic-Cenozoic palynostratigraphy *(E.H. Davies)*

F. LITHOSTRATIGRAPHY
1. Stratigraphy and sedimentology of the Mesozoic and Tertiary rocks of the Atlantic Continental Margin *(L.F. Jansa, P. Lake)*

G. GEOLOGICAL MAPPING
1. Bedrock and surficial geology, Grand Banks *(L.H. King, R.O. Miller)*
2. Eastern Baffin Island Shelf bedrock and surficial geology mapping program *(B. MacLean, P. Girouard)*
3. East coast offshore surveys *(R.F. Macnab, B. Chapman, A. Atkinson)*

H. CRUSTAL PROCESSES
1. Geophysical investigation of the submarine extension of geological zonation of Newfoundland *(R.T. Haworth)*
2. Arctic Ocean: seismic refraction and related geophysical measurements *(H.R. Jackson)*
3. Rift processes and the development of passive continental margins *(C.E. Keen)*
4. Seismic studies of continental margins and ocean basins of the North Atlantic *(C.E. Keen)*
5. Co-crust 1980 *(B.D. Loncarevic)*
6. An earth science atlas of the continental margins of eastern Canada *(S.P. Srivastava)*
7. Comparative studies of the continental margins of the Labrador Sea and of the North Atlantic *(S.P. Srivastava)*

I. PLEISTOCENE
1. Pleistocene-Holocene marine basin sedimentation *(G. Vilks, B. Deonarine)*
2. Regional distribution of marine molluscs (Gastropoda and Pelecypoda), Eastern Canada *(F.J.E. Wagner)*
3. Quantitative Quaternary paleo-ecology, eastern Canada *(P. Mudie)*

J. HOLOCENE CLIMATIC CHANGE
1. The recent paleoclimatic and recent paleoecologic records in fjord sediments *(C.T. Schafer)*

K. DEEP OCEAN ENVIRONMENTAL GEOLOGY
1. Environmental geology of the deep ocean *(G. Vilks, D.E. Buckley, P. Stoffyn)*

L. CONTINENTAL SLOPE
1. Quaternary geologic processes on continental slopes *(D.J.W. Piper, P. Hill)*
2. The Newfoundland continental slope at 49°N to 50°N - nature and magnitude and contemporary marine geologic processes *(C.T. Schafer, F.E. Cole)*

M. BEAUFORT SEA
1. Surficial geology and geomorphology - MacKenzie Bay/Continental Shelf *(S.M. Blasco, F.D. Jodrey)*

N. ORGANIC GEOCHEMISTRY
1. Geochemical transformations and reactions of organic compounds in recent marine sediments *(M.A. Rashid, W. LeBlanc)*

O. ADVICE
1. Ocean dumping consultation and study *(D.E. Buckley)*
2. Consulting advice on conservation and restoration of coastal environments *(R.B. Taylor)*

P. ARCTIC COASTAL RECONNAISSANCE AND PROCESSES

1. Coastal reconnaissance of the Sverdrup Basin *(R.B. Taylor)*
2. Coastal reconnaissance of Bylot and Northeast Baffin Islands *(R.B. Taylor)*
3. Coastal erosion - sedimentation. Northern Somerset Island. NWT *(R.B. Taylor, D. Frobel)*
4. Surficial geology of the Lomonosov Ridge. Arctic Ocean *(S.M. Blasco, P. Hill, R. Harmes)*
5. Arctic coastal reconnaissance development *(D.L. Forbes, A. Fricker)*
6. Sediment dynamics and transgressive processes. Eastern Shore. Nova Scotia *(D.L. Forbes)*

Q. ATLANTIC COASTAL PROCESSES AND MAPPING

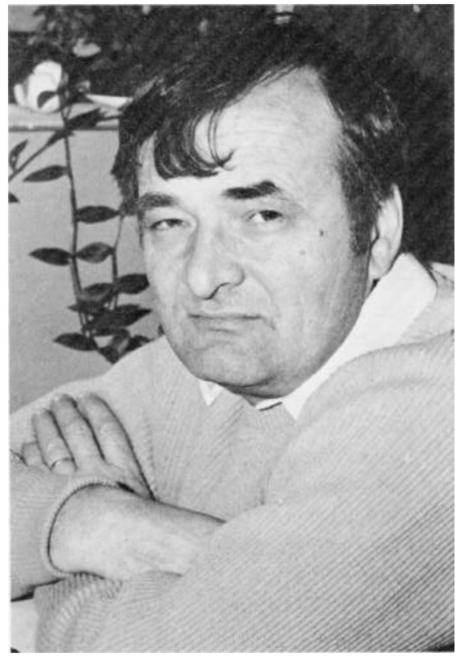
I. Coastal morphology and sediment dynamics. southeast and cast Cape Breton Island, NS *(R.B. Taylor)*
2. Morphology, sedimentology, and dynamics of Newfoundland coast *(D.L. Forbes)*
3. Sediment dynamics at the Head of the Bay of Fundy *(C.L. Amos, K. Asprey)*
4. Landsat calibration for suspended sediment concentration in the marine coastal environment *(C.L. Amos)*

R. SEDIMENTOLOGY OF FJORDS

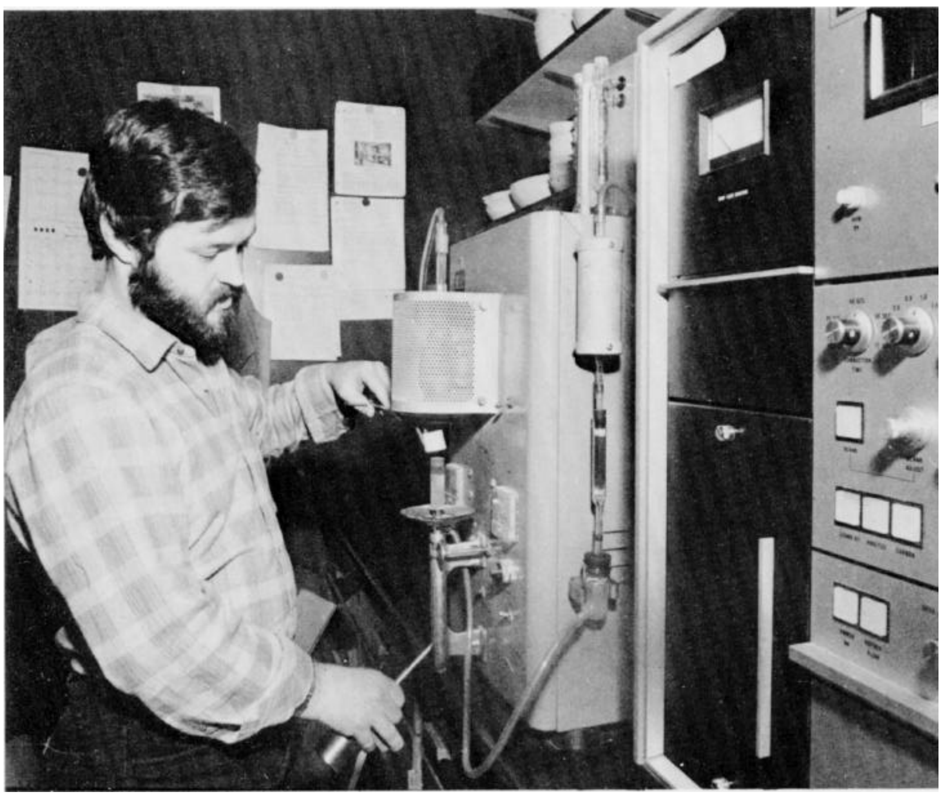
1. Sedimentology of fjord sills *(J.P.M. Syvitski, D. Clatenburg)*
2. The physical behaviour of suspended particulate matter (SPM) in natural aqueous environments *(J.P.M. Syvitski)*

S. SOUTHERN SHELVES

1. Stability and transport of sediments on continental shelves *(C.L. Amos)*
2. Iceberg scouring *(C.F.M. Lewis)*
3. Sedimentology of Arctic fjords *(J.P.M. Syvitski, D. Clattenburg)*
4. Sedimentology of west coast fjords *(J.P.M. Syvitski)*



Gus Vilks.



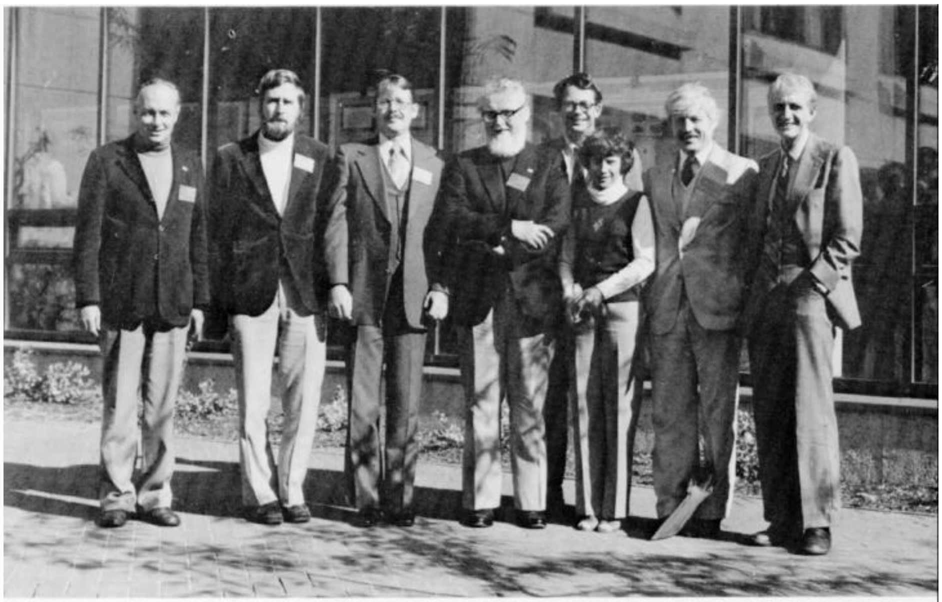
Bill LeBlanc.

chapter 8

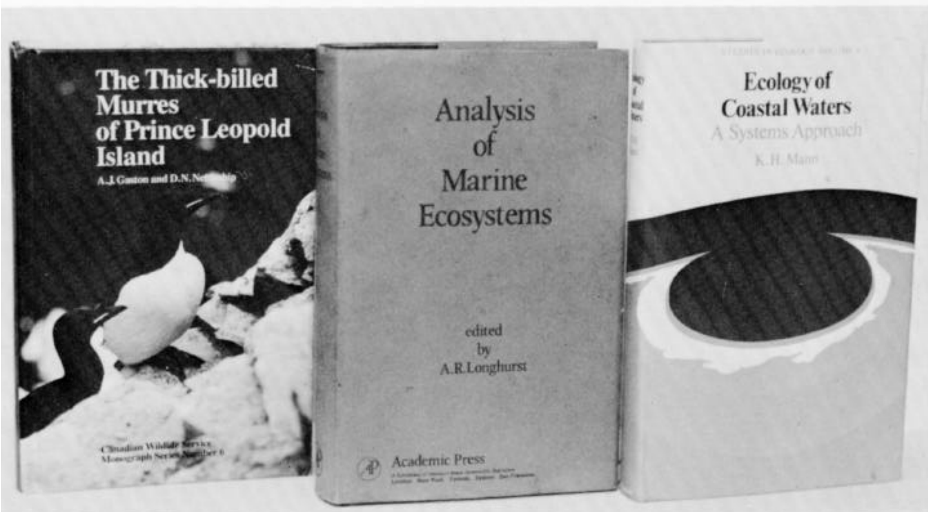
Excerpts from the BIO Log

Dr. J. Tuzo Wilson - outstanding earth scientist, author, educator, explorer, and administrator - was the 1981 recipient of the A.G. Huntsman Award presented annually by BIO to honour excellence in the marine sciences. Dr. Wilson spoke of his recollections of the plate tectonic revolution in earth science in a public lecture at BIO. Here, he folds an envelope to demonstrate graphically how plate tectonic forces have shaped our world.

John Vandermeulen of BIO (right) and Edmund Morris, then Minister of Fisheries for the Province of Nova Scotia, at the 1981 Huntsman Award dinner. John was chief organizer of the event, and one of the principals involved in establishing the award.



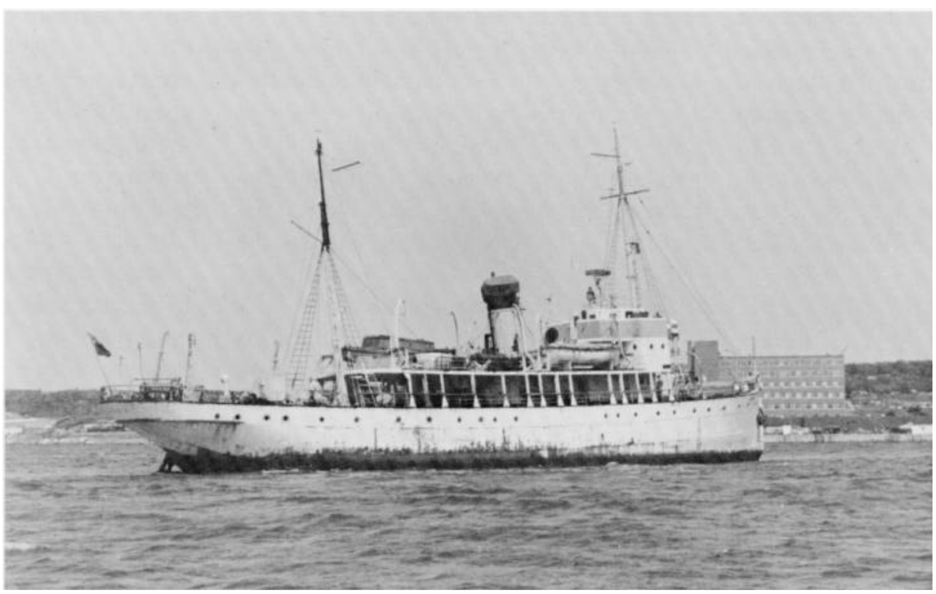
BIO hosted a symposium on "The Dynamics of Turbid Coastal Environments" that was held September 29 to October 2. 1981. Over 150 people participated from many different countries. Session chairmen and symposium organizcrs shown opposite are : from left to right - H. Postma, A.J. Bowen, D.C. Rhoads, P.J. Wangersky, D.C. Gordon, Jr. (Symposium chairman), J. Dale (chairman, Local Arrangements), G. Evans, and A.K. Longhurst.



Three books by BIO staff were recently published.

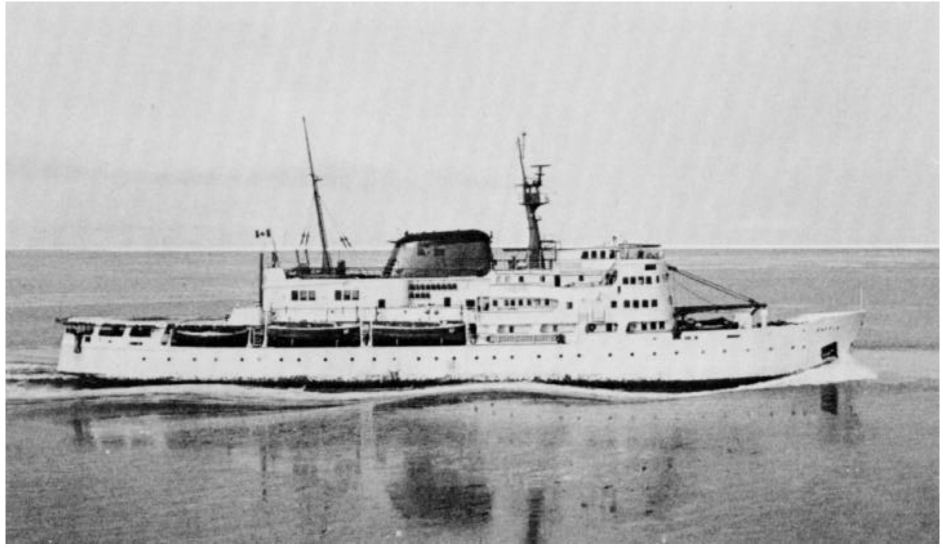
The *Whiting*, a United States survey vessel of the National Oceanic and Atmospheric Administration, from Norfolk, Virginia. visited BIO in May 1981.

Wang Ying bids farewell to BIO and Halifax after a three year visit. Ying spent one year at Dalhousie University's Department of Geology and two with BIO's Atlantic Geoscience Centre. She returned to the People's Republic of China in February 1982 to resume her position as Associate Professor of Geography at Nanking University.



Anchor's Aweigh! CSS *Acadia* leaves her berth at BIO's jetty for the last time. Headed for a little restoration at the shipyards, she will then begin a new life as a National Historic Monument. At her home alongside Halifax's Maritime Museum of the Atlantic, the ship will be open to one and all.

The *CSS Acadia* was launched in 1913 and retired in 1969. During her long career, she played a pioneering and active role in Canadian hydrography and oceanography: first ship commissioned especially for hydrographic work, second ship to routinely perform oceanographic work, and a leader in the charting of areas like Hudson Bay, the Labrador coast, and the Gulf of St. Lawrence. Not least of *Acadia's* attractions as a National Historic Monument are her splendid brass, teak, and mahogany fittings, her well preserved boilers and coal-burning engine, and of course the feel of places visited and events witnessed that is in her rigging.



CSS *Baffin* before her refit.

The CSS Baffin's mid-life refit

R.L.G. Gilbert

In 1956, while I was employed in the Gravity Division of Canada's Dominion Observatory, I visited a ship being built in Vickers's yard in Montreal. I scrambled up and down ladders - including an abrupt descent down one ladder, a short section of which had not yet been installed - looking over the ship to evaluate its potential use for the measurement of gravity at sea. That was my first contact with CSS *Baffin.*

Conventional wisdom has it that a ship's life expectancy is about 20 years. In *Baffin's* case, however, she appeared to be in good condition even after 20 years of surveying in areas ranging from the Bay of Fundy to Baffin Bay, over and occasionally on hard rocks and soft muds. A detailed survey of the ship was carried out and, as a result, it was decided to undertake a major mid-life refit of the vessel.

There were four objectives to the refit: the ship was to be brought up to modern standards as far as general facilities and accommodations were concerned; steps were to be taken to ensure that the ship could be operated for the next 20 years and that machinery could be maintained over that period; the capability of the ship for hydrographic surveying was to be at least maintained at the present level and preferably improved substantially; and the ship was to be outfitted so that, when not required for hydrographic missions, she could be used for oceanographic research.

The refit is now essentially complete and the few remaining items will be finished very soon. The photographs show that there have been substantial changes to her outward appearance and the interior changes have been equally substantial. The accommodation for both crew and research and survey staff has been renovated. In many cases cabins have been completely stripped and then rebuilt from scratch; they are now fully equipped to today's standards. The ship's recreational facilities have been improved according to the wishes of those serving onboard. The galley facilities have been renovated to a fully modern standard. The engine room equipment has been checked throughout and steps are being taken to ensure a further 20-year life for each unit; in some cases, spares have been purchased so that the units can be maintained over the rest of the ship's life, while in other cases it was more economical or more feasible to replace the old unit with a new unit that will be maintainable for the next 20 years.

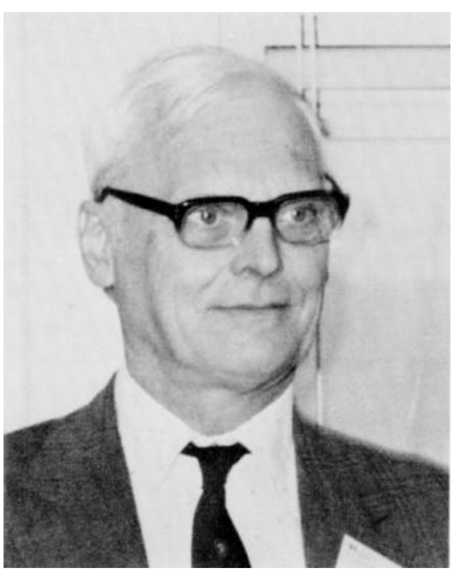
Perhaps the biggest interior change has been associated with the work facilities, laboratories, and drawing offices. Virtually the entire working area has been completely rearranged and rebuilt. As a result, the ship now has a dedicated computer room, which houses the shipboard computer whether on hydrographic or on oceanographic missions. Adjacent to the computer room is a dry laboratory; on hydrographic missions this will be used as an extension of the computer room, while on oceanographic missions it will be used as a conventional dry laboratory. Adjacent to the dry lab is a wet laboratory and enclosed winch room (on the port side of the ship). It will enable oceanographic sampling to be carried out under extreme weather conditions, and transfer and analysis of samples to be carried out in a convenient and clean environment. The main hydrographic drawing office has been transferred to the old flying bridge deck, and it can be seen from the photograph that the ship's superstructure has been substantially enlarged for this purpose. As a result, the drawing office and precision navigation equipment are closely associated and this is expected to lead to an appreciable improvement in convenience. Finally, a laboratory has been provided adjacent to the afterdeck of the ship that will be of major benefit to researchers who use towed equipment.

The ship has been outfitted with equipment to enable her to be handled, operated, and navigated conveniently and accurately. A tunnel bow-thruster enables her to hold station under adverse operating conditions; revised engine couplings allow

CSS *Baffin* after her refit.

her to hold a station without wear on the mechanical clutches; a transducer ram improves sounding capabilities in bad weather; new positioning systems enable her to navigate with greater precision and reliability than ever before; and the data-processing equipment is superior to anything previously installed.

One of the major changes to the ship relates to launches. As can be seen, the arrangement of launches and their davits has been completely changed. Baffin can now carry six launches, four 9.45-m long and two 12.2-m long. The 9.45-m launches are mounted on gravity davits while the 12.2-m launches are on power-operated luffing davits. The ship will benefit both from having large launches available - since these can carry more extensive and more sophisticated equipment and also operate under somewhat rougher weather than the 9.45-m launches - and from the increased number of launches. The design and construction of the new launches is presently underway. They are intended to have higher speeds than the present launches while fully retaining the latter's qualities of seaworthiness. Other external changes include an A-frame at the stem to enable equipment to be towed from the ship in a convenient and efficient manner; the replacement of the old cargo booms on the foredeck with an articulated hydraulic crane; and relatively minor changes such as the elimination of the forward deep sea mooring anchor and removal of the aftermast.



Reg Gilbert.

Now that the refit has been essentially completed, what are the end results? Perhaps the biggest change relates to the scientific capabilities of the ship. Her primary role continues to be hydrographic surveying, but she has now acquired a very substantial capability to carry out oceanographic research operations during most of the day and night, so long as she is present when launches are to be deployed or picked up. In addition to this combined operation, there will be times (especially during winter) when conditions preclude hydrographic surveys, but some specific oceanographic surveys may be possible; the ship will then be used for purely oceanographic purposes.

Hydrographic operations aboard the refitted Baffin will be greatly improved. The new davits will enable the launches to be deployed and recovered rapidly, safely, and with a minimum of manpower. It is anticipated that six launches will be operated regularly, but that only one hydrographer and one crew member will be required on each launch - so that the total operational complement will not increase, whilst the work output will grow considerably. New high-speed launches will also increase the output further. The data will be gathered automatically in digital format, and the data-processing system onboard ship will immediately process that information and present it to the hydrographers in a suitable form so that they can check the day's work before starting on the next section.

Last, but not least, the accommodations provided for all staff aboard the ship have been substantially improved. Comfortable and well-outfitted cabins, friendly dining areas supplied from well-equipped kitchens, and a range of recreational facilities combine to create an atmosphere in which surveyors, scientists, and ship's staff can comfortably relax after a vigorous day's work.

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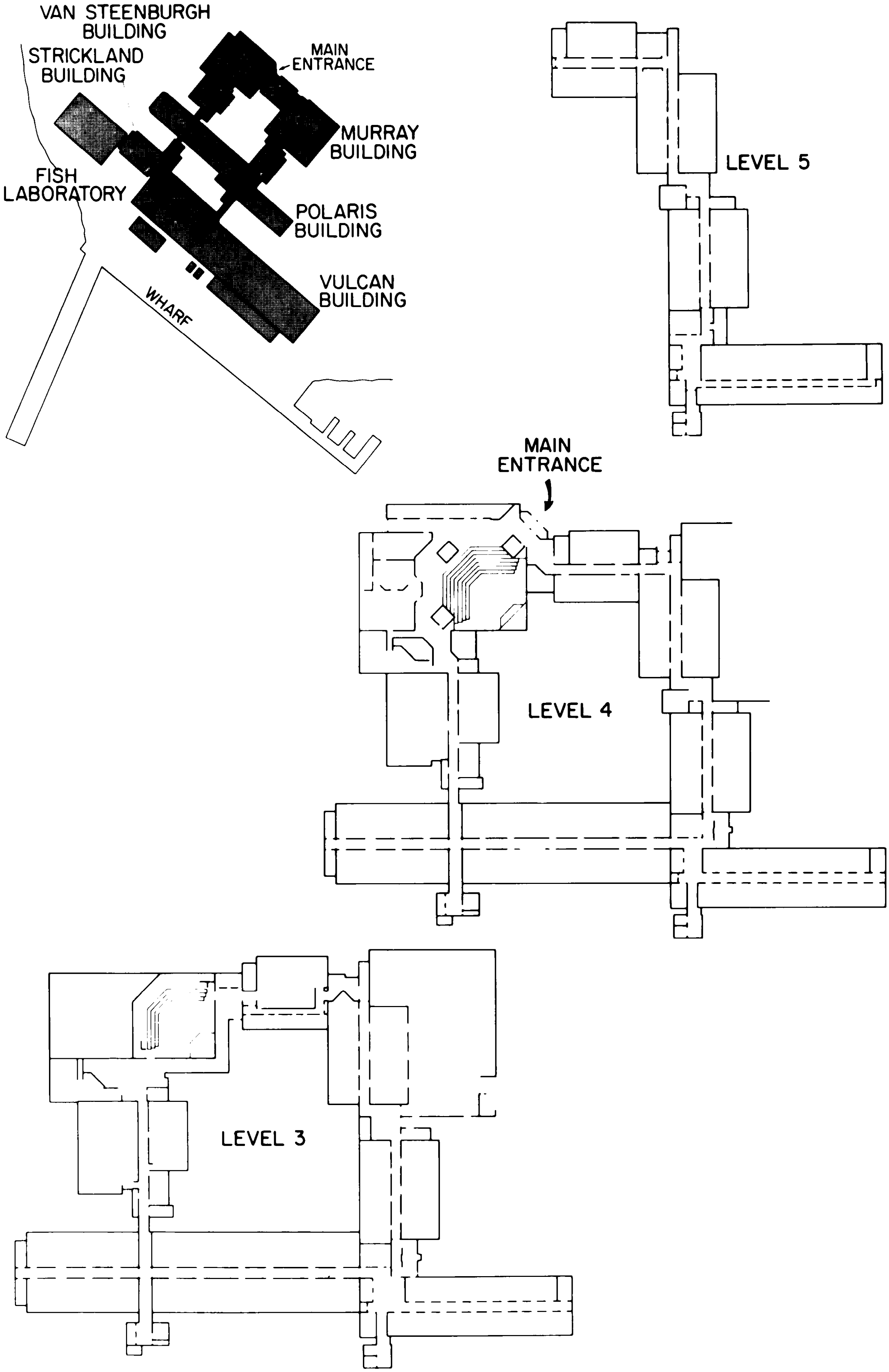
The BIOMAIL Office

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

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

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

CONTACT: BIOMAIL
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
B2Y 4A2 CANADA
***Phone:* (902) 426-3698**
***Telex:* 019-31552**


VAN STEENBURGH BUILDING
STRICKLAND BUILDING
MAIN ENTRANCE
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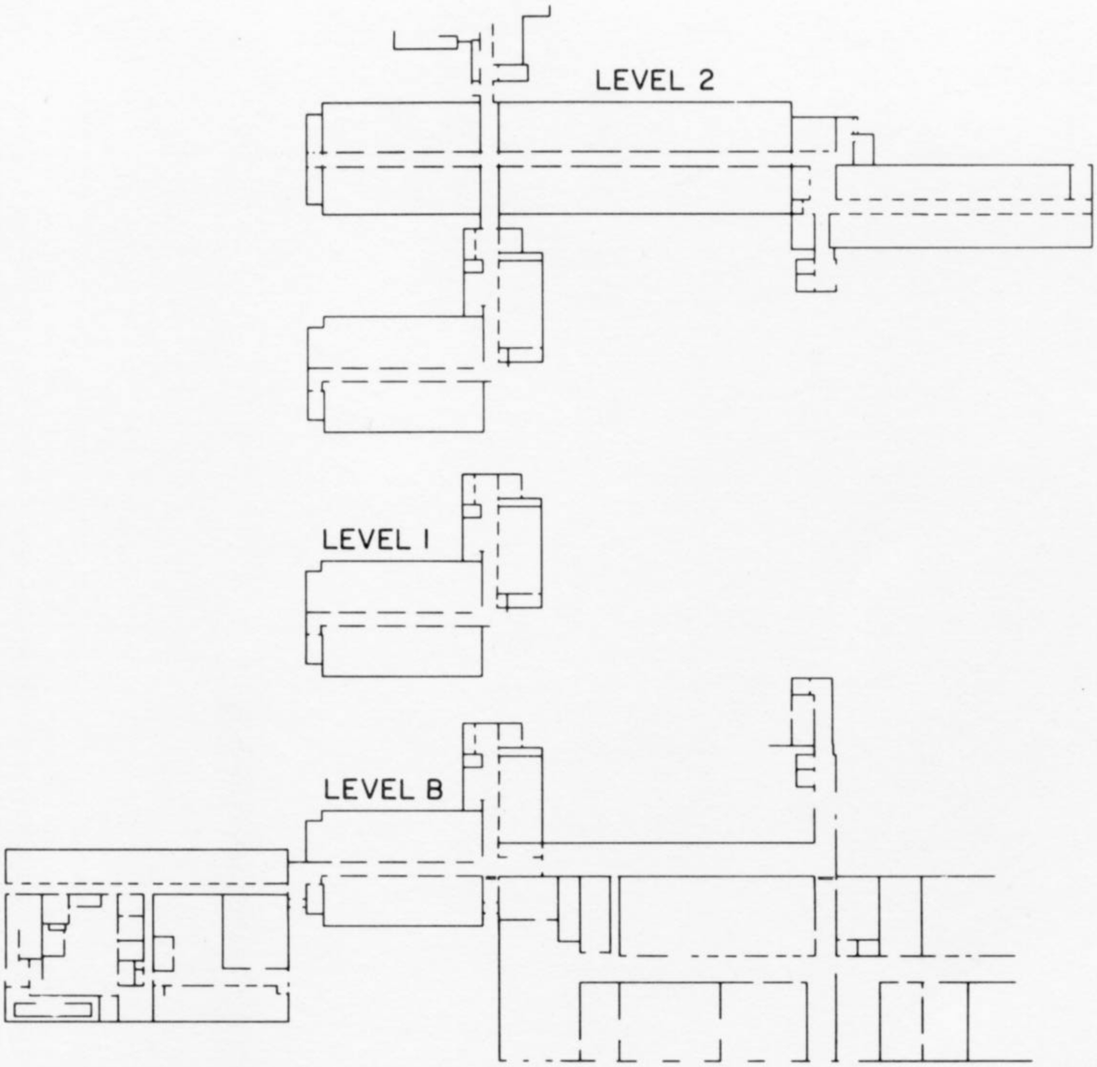
FISH LABORATORY
POLARIS BUILDING
VULCAN BUILDING
WHARF
LEVEL 5
MAIN ENTRANCE
LEVEL 4
LEVEL 3


LEVEL 2
LEVEL 1
LEVEL B

Fisheries and Oceans

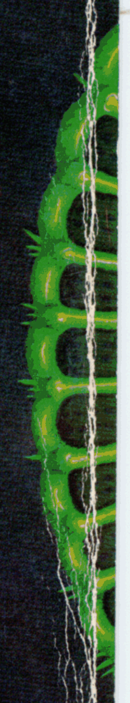
Pêches et Océans

Energy, Mines and Resources

Energie, Mines et Ressources

Environment

Environnement



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