EXPLORATIONS IN LABRADOR

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The purpose of this paper is to set forth certain considerations of the physical geography of Labrador as they apply to the oceanography of the coastal waters and to give an account of the BLUE DOLPHIN studies of physical oceanography.*

Labrador forms the easternmost extension of the North American continent between the Strait of Belle Isle on the south and Hudson Strait on the north. The land is composed almost exclusively of precambrian rocks of the Canadian shield, which forms a more or less rolling plateau from 1200 to 1700 feet in elevation in the interior. Along the coast several mountain blocks rise above the plateau to elevations of 3000 to 5000 feet. The coast is much dissected by fjords, bays, and inlets with many islands lying offshore, particularly in the Nain area where is found a vast archipelago.

Drainage from the land and interior plateau enters these bays and fjords through many streams and rivers. The principal Atlantic drainage from the central plateau area flows into the Hamilton Inlet - Lake Melville estuary which indents the southern Labrador coastline for 150 miles and forms the waterway to Goose Bay airport and air base.

Although Labrador is in the same latitude as the British Isles, its climate is far more severe due to its position along the eastern margin of the North American continent and to the influence of the cold southward flowing Labrador Current. There is a considerable variation in climate from season to season and from the coast to the interior. During the winter months Labrador is under the influences of the Icelandic low and the North American continental high which produces a prevailing airflow from the northwest and low winter temperatures. However the coastal areas often come under the influence of passing cyclones, which with easterly winds off the comparatively warm Labrador Sea provide a moderating influence on the temperatures with a possibility of short periods of near or even above freezing temperatures during any month of winter. During summertime the Icelandic low as well as the continental high dissipate and a weak low appears over Hudson Strait and southern Baffin Island. Thus the prevailing airflow is from the southwest to west which with the continental heat of summer can bring temperatures in Labrador into the 80's and 90's (F). However due to this intense land warming these westerly winds are often replaced along the immediate coastal fringe by a sea breeze that brings in cold air and fog from the ice pack and cold Labrador Current.

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In Labrador the heaviest precipitation occurs in the southern part with an annual total of forty inches near Belle Isle. Amounts of precipitation decrease northward regularly until at Resolution Island there is only a total of about sixteen inches.

The January and July isotherms and precipitation amounts are shown on the accompanying map, figure 1.

The coastal waters of Labrador are under the prevailing influence of the Labrador Current intermixed seasonally with large volumes of fresh water from land drainage and melting ice. The Labrador Current which flows south from Hudson and Davis Straits along the coast of Labrador and Newfoundland represents the southernmost extension in the northern hemisphere of water of Arctic origin. There is in these latitudes a rapid transition both seasonally and geographically from Arctic to subarctic and boreal conditions. For nearly six months of the year the coastal waters are frozen over and the Labrador Current brings south pack ice which blocks the entire coast to navigation and extends south to the Newfoundland shores in March and April to provide the whelping ground and the site of the great western Atlantic seal fishery. During the summer months the pack ice departs, land drainage reaches its maximum, and in the Labrador coastal waters, cod, salmon, and Arctic char form the basis of a summer fishery.

Since 1949 oceanographic studies have been carried out in the coastal waters of Labrador as the principal part of the BLUE DOLPHIN program of research. Oceanography in the broad sense covers all aspects of marine knowledge. The writers principal scientific interest lies in physical oceanography, which in the case of the coastal waters of Labrador is concerned with a study of fjord hydrography and estuary mechanics; and remarks will be confined to this discipline. Aside from the practical importance to economic biology the principal interest in this study is the determination to what extent the water within the fjord is influenced by the ocean water (Labrador Current) outside the fjord, and the processes and relationships of exchange between the fjord and the ocean.

Data gathered for this study included seasonal surface and subsurface temperatures, salinities, and in certain cases oxygen and inorganic phosphate determinations, as well as information concerning tides, currents, river flow and runoff. The summer-regime observations were made routinely from small boats or from the research vessel BLUE DOLPHIN, a 100-foot schooner (see figures 2 and 3) equipped with the necessary winches, instruments, and laboratory facilities. The temperature and water samples were taken by means of bathythermograph, deep sea reversing thermometer, and Nansen bottle.

During wintertime, when the coastal waters of Labrador are ice covered and unnavigable, it was necessary to develop new techniques and equipment for the purpose of securing the data. The first consideration was the requirement of providing a shelter with above freezing temperatures, not only for comfort and ease of handling instruments, but also to insure the proper functioning of the instruments and the validity of the samples taken. For this purpose a special pyramidal tent frame, to which could be attached the necessary winch and meter wheel was designed for the lowering of the instruments through the ice (see figure 4). With a tent covering the frame it was possible by means of one or two small stoves to provide quite comfortable working temperatures of 50° to 70°F. while it was zero or below outside. This oceanographic tent with gear detached could also be used for camping. Aircraft were used for transport to and from the local areas of study, while dog teams were used for local transport within the area.

Particular study has been made of the Nain and Hebron areas of northern Labrador and the Hamilton inlet-Lake Melville estuary of southern Labrador. Variations in annual cycles are noted in these three areas and it may be of interest to consider briefly the principal hydrographic features.

Hebron is of the classic fjord type of structure with a sill of 59 meters at its entrance and a deep inner basin of 255 meters. During the winter the fresh water inflow has ceased or becomes neglibible. Equilibrium has then been reached between the waters of the fjord and the immediate coast; isothermal and isohaline conditions with an average temperature of -1.75°C. and salinity of 32.75 °/oo prevail, and winter convectional processes are taking place. The summer season brings into the fjord quantities of fresh water and causes climatic warming. These summer processes establish a stable density gradient, and only very slowly are the effects of freshening and warming transmitted to the bottom waters. Although surface waters may warm to 6° to 10°C., the bottom water at 250 meters in Hebron Fjord at the end of the summer season of 1954 had warmed only from -1.75° to -1.68°C. Thus in the lower levels, below 100 meters, is found a permanent high Arctic marine environment.

The Nain area consists of a vast archipelago of islands extending offshore for more than thirty five miles while Nain Bay reaches into the interior for another twenty miles. Among the islands is found a variety of channels, and the bottom topography forms a series of basins separated by sills of varying depths. Due to the as yet incomplete charting the precise sill depths are not known, but in the approach to Nain it is probably not greater than 20 to 25 meters.

Again during winter we find virtually the same isothermal and isohaline conditions as at Hebron. The large river at the head of Nain Bay probably continues to make a small contribution all winter as a very slight freshening of the surface layers in Nain Bay was noted at the time of observation in March 1954. The summer processes at Nain are quite different. The effects of the tidal currents and associated turbulence over the rough bottom topography overcome the stable density gradient normally found in summer and the effects of summer freshening and warming are carried rapidly to the bottom levels. This begins in June among the islands of the Archipelago and progresses landward finally flushing out the inner part of Nain Bay by October or November. The warming from -1.7°C. to over 4°C. at 100 meters off Nain is of such magnitude that the high Arctic marine environment is completely dissipated during the summer months.

The huge Hamilton Inlet-Lake Melville estuary provides yet another variation of annual cycle. Hamilton Inlet is relatively shallow with very rough bottom topography. It is separated from Lake Melville, a deep tidal lake 200-300 meters deep and 80 miles long, by a sill of 29 meters at the Narrows. Goose Bay, fifteen miles long and 55 meters deep, is a further extension of Lake Melville and separated from it by a 6 meter bar. In the process of exchange through the narrows a dilution of the Hamilton Inlet water of about 4 °/oo takes place so that the highest observed salinity in

Lake Melville has been less than 29.00 °/oo. A further dilution occurs in the exchange between Goose Bay and Lake Melville over the 6 meter bar. During winter a substantial volume of fresh water continues to enter the estuary and a stable density gradient is maintained throughout the annual cycle. Thus the bottom water cannot be renewed by the normal winter convectional processes, but must be renewed by a continual vertical circulation.

Spring thaw, with the melting of the heavy accumulated snowfall of this area, introduces vast amounts of fresh water into the estuary. The effect of this is noted down to about 50 meters, the top ten meters being almost fresh with salinities of less than 5 °/oo. The very bottom layers below 100 meters, except just inside the sill of the Narrows, remain virtually unaffected throughout the annual cycle and maintain a high Arctic marine environment of -1.2°C. to -1.3°C. Of particular interest is that a certain amount of residual summer heat is trapped throughout the winter in the upper layers by the stable density gradient. During the winter of 1952-53 temperatures in Goose Bay remained as high as 2° to 3°C. while a wedge of water of 1°C. extended eastward throughout the main body of Lake Melville between 5 and 25 meters. Goose Bay and the adjacent western part of Lake Melville is the only locality now known in Labrador where the water temperatures remain throughout the annual cycle above 0°C. The water is, however, diluted to approximately 20 °/oo.

In all cases the principal processes of summer are freshening and warming. Although their precise effects vary in magnitude and extent in the various localities, the maximum effect of freshening normally takes place earlier than that of warming. Spring thaw introduces vast quantities of fresh water which first enters at about 0°C. The processes of exchange are rapid enough that shortly after the spring freshet a progressive salting of the coastal waters takes place which continues throughout the summer and fall. On the other hand heat is continually added all summer and gradually conducted downward so that the maximum warming occurs sometime in late September or early October.

Of all the hydrographic phenomena in the coastal waters of Labrador perhaps ice formation during the winter and spring months is of the greatest practical importance. Not only does the ice cover influence the fjord hydrography by contributing to the salting process of fall and winter and the storing of a large volume of fresh water for release during the spring thaw, but it is a controlling factor in local transportation. Ice places an almost complete limitation on water transport for a period of six months, while during this period it is the medium for surface travel and, more recently, for local aircraft landings.

Many variable factors affect the formation and growth of ice in Labrador where exist both deep and shallow fresh water lakes and a transition through the brackish estuaries to the saline waters of the open sea. The essential factor required for the formation of ice, is atmospheric cooling with mean air temperatures below freezing. Other factors being favorable, ice will then form. The effect of fall cooling is to set up thermo-haline convection. The amount of heat that must be abstracted before ice formation can begin is dependent upon the hydrographic structure of the water. With the varying hydrographic conditions noted in the general discussion of hydrography above, a considerable variation in the ice potential along the coast and even within local areas must be expected.

From fall hydrographic observations it is possible to compute the effect of heat abstraction on the thermo-haline structure and determine the depth to which convection must be carried and the quantity of heat that must be abstracted before ice can form. Since actual measurements or precise data are lacking we have assumed that the effective rate of atmospheric heat abstraction is 0.1 $g/cal/cm^2/min$ which is a reasonable order of magnitude for the area concerned and in general agreement with available observations. It is then possible to compute the time and date on which ice formation can be expected. The extreme example of this is in the Goose Bay area where the fresh water inflow maintains a fresh water surface layer and extremely stable density gradient. Consequently practically no convection is possible or necessary for the formation of ice; and this area is known to freeze over, substantially before nearby fresh water Grand Lake and other areas where greater convection is required.

The processes of thermo-haline convection are nicely illustrated by the computations for three stations made at Hebron in the fall of 1954, all within a distance of twenty five miles. The results of these computations are given in the following table.

	Coastal Waters	Mid Fjord	Inner Fjord
Date of Observation	Oct. 15	Oct. 18	Oct. 26
Heat to be abstracted before ice formation ($Kg/cal/cm^2$)	20.37	6.36	1.93
Depth of convection (meters)	70	20	10
No. of days until ice forms	141	44	13
Date of ice formation	March 6	Dec. 2	Nov. 9

This shows clearly that ice may be expected to form in the inner fjords and bays before it forms in the coastal waters, and this is confirmed by all local knowledge and observation. However the extremely long delay in ice formation in the coastal areas is not borne out by observation; ice here generally begins to form by the late December. It is apparent that an exchange is continually taking place between the Labrador Current and the coastal and fjord waters, so that the hydrographic structure also changes; and as the fall and winter progresses it becomes more favorable for ice formation. In fact the magnitude of exchange is so great that any long term prognosis of ice formation is not accurately possible by an analysis of the thermo-haline convection alone. It can be shown that the exchange is the controlling factor in establishing the actual winter hydrographic structure, and that its influence on ice formation is significant, tending toward an earlier date of freezeup and greater ice thickness.

Snow cover plays an important part in the growth of ice, especially in southern Labrador where the mean annual snowfall is 150-200 inches. Not only does a heavy snow cover serve as an insulating blanket, but often causes the treacherous condition, especially for aircraft or mechanized vehicles, known as "double ice". The weight of snow sinks the ice, the surface floods, and the snow soaks up the water which froze again from the top down forming a layer of ice, a layer of water or slush, and the original layer of ice. This "double ice" is quite probably very weak.

I have only touched on some of the general aspects and problems in physical oceanography and the associated phenomena of ice formation in the coastal waters of Labrador to show the general nature of the BLUE DOLPHIN investigations and the scientific problems of this area. The various factors and phenomena are far more complex than indicated, and much detailed research on a day to day basis must be done before we can gain a practical and adequate understanding of the hydrographic processes.

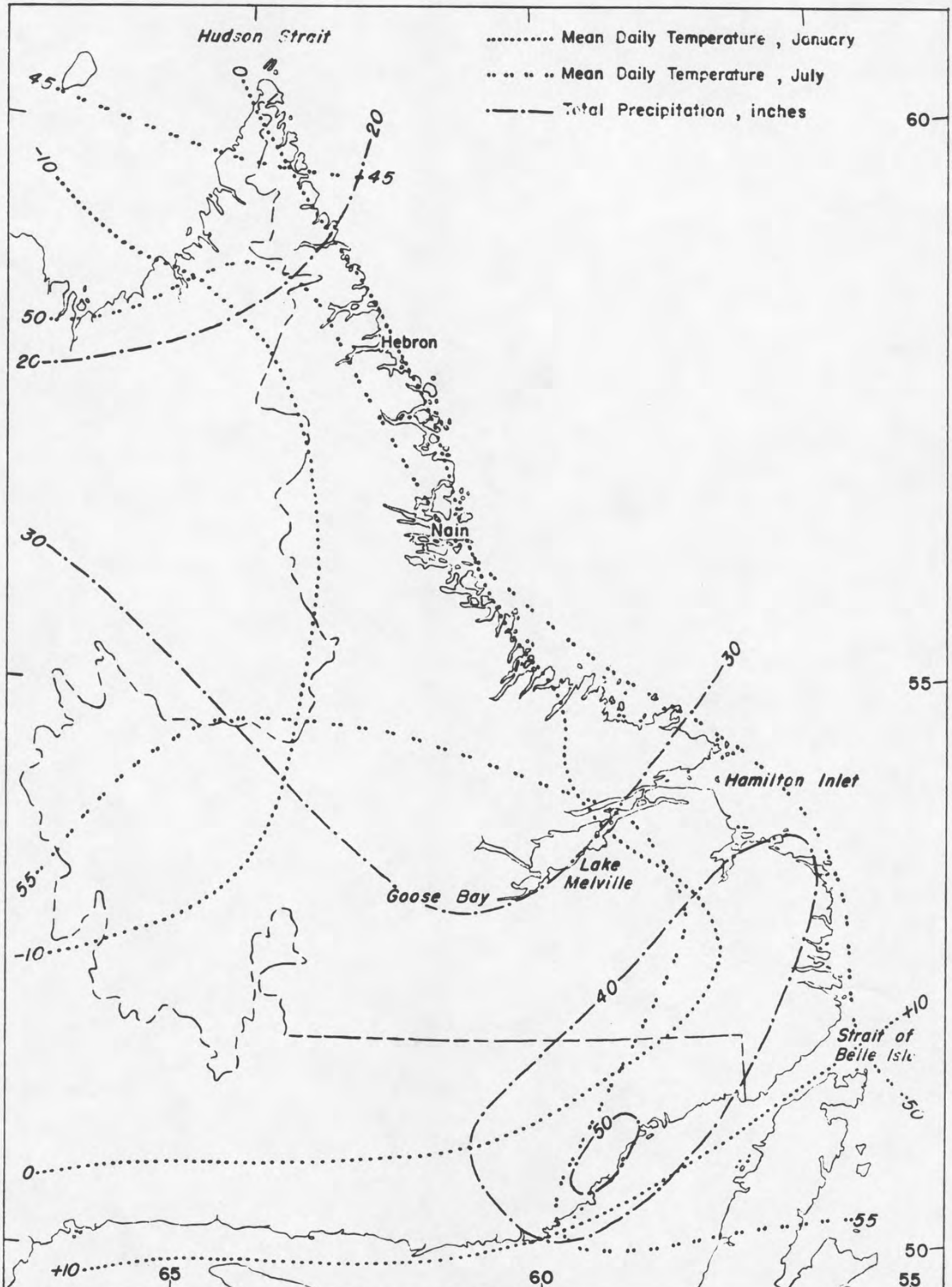

Figure I. LABRADOR

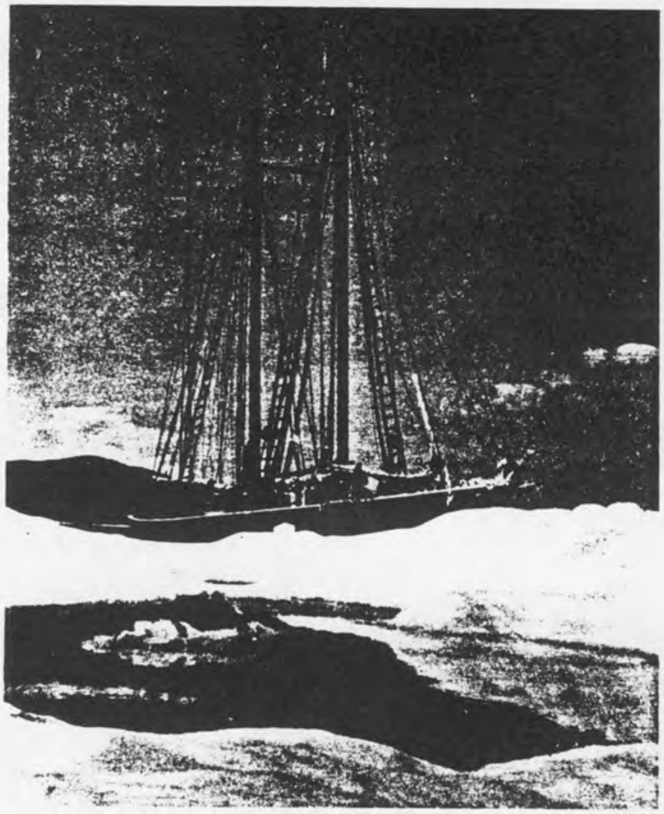

FIGURE 2

FIGURE 3

FIGURE 4.

FIGURE 2

Research Vessel BLUE DOLPHIN moored to ice floe, Hebron Fjord, July 1954.

FIGURE 3

Pack ice off the Northern Labrador coast, July 1954.

FIGURE 4

Oceanographic tent frame with winch, meter wheel, and Nansen bottles used to make observations of the winter hydrographic structure through the ice. Normally the frame is covered by a tent which provides above freezing temperatures for the proper functioning and handling of the instruments.