ICE DISTRIBUTION IN THE GULF OF ST. LAWRENCE DURING THE BREAKUP SEASON

by

CHARLES NELSON FORWARD

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

in the Department

of

Geology and Geography

We accept this thesis as conforming to the standard required from candidates for the degree of MASTER OF ARTS.

Members of the Department of

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THE UNIVERSITY OF BRITISH COLUMBIA

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The Gulf of St. Lawrence is closed to commercial navigation for nearly five months each year due to ice conditions. In order to lengthen the shipping season, greater knowledge of the behaviour of the ice is necessary. A step in this direction was the inauguration in 1940 of aerial ice surveys in the gulf during the breakup season. The surveys have continued annually for the past thirteen years.

Based primarily on the data provided by these surveys, maps were drawn showing the limits of the main ice areas in each breakup season. Although the maps enabled the isolation of several distinct patterns and rates of breakup, they revealed that the behaviour of the ice was extremely variable. The factors influencing ice conditions, including tides, ocean currents, temperature, and wind, were examined with the aim of discovering the causes of the breakup patterns. A number of factors were found to be important in determining the fundamental behaviour of the ice, but the meteorological factors of temperature and wind appeared to be the chief agents in causing the variable behaviour from year to year.

In spite of these variations, it was possible to trace average conditions throughout the ice season. The chief characteristics of the ice season may be stated briefly. The Gulf of St. Lawrence is never completely covered with ice, but rather, it is partly covered with fields of shifting pack ice between which lie broad stretches of open water. The southern part of the gulf is an area of accumulation where ice conditions are most serious. The clearing of ice from

the gulf begins slowly in January and February and becomes accelerated in March and April. The bulk of the ice moves through Cabot Strait to the open Atlantic rather than remaining inside the gulf until it melts. Generally, the ice either withdraws from west to east, passing through Cabot Strait directly, or it stagnates in the southern part of the gulf toward the end of the season. By the first of May the gulf is usually clear of ice which constitutes a hinderance to navigation.

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CHAPTER I

INTRODUCTION

THE PROBLEM

The fundamental aim of the present study is to discover the distribution of ice in the breakup season and to trace its behaviour throughout the months of March, April, and May. With this distribution and behaviour established, it is proposed to determine the relative influences on the ice of the physical factors of the environment. Finally, it is intended that a picture of average conditions throughout the ice season should be presented.

Ice distribution in the Gulf of St. Lawrence is of utmost importance to shipping. All ships entering the Great Lakes-St. Lawrence system must pass through the gulf. The whole system is blocked to navigation for nearly five months of the year due to ice conditions. The conditions in the river can be readily evaluated by direct observation from the land, but the Gulf of St. Lawrence presents a different situation. The area of the gulf is approximately equal to the combined areas of the four maritime provinces. It is impossible, therefore, to ascertain the ice conditions over such a large area from observations taken along shore. At the beginning of the ice season the last vessels remaining in the gulf are able to keep each other posted concerning the ice conditions in their respective vicinities. On the other hand, because no

ships are operating in the gulf during the winter other observational arrangements must be made in order to determine when navigation can safely begin during the breakup season.

Until 1940 this estimate of ice conditions during the breakup depended chiefly on the reports of the government icebreakers operating in the gulf. The information obtained was so scattered and incomplete, because there were so few vessels, that it proved inadequate for the purpose. Consequently, with the aim of declaring the gulf open to navigation as early as ice conditions in a given area would permit, an aerial ice survey was inaugurated in 1940 by the Department of Transport. The survey has continued every spring since that time. The reports of this survey provide a wealth of information which simply did not exist previously.

SOURCES OF INFORMATION

The Gulf of St. Lawrence Pilot[1] is probably the most authoritative source of published information on ice conditions in the gulf. The treatment is very brief, however, and does not deal specifically with the breakup season. Another government publication, Arctic Ice on Our Eastern Coast,[2] by A. G. Huntsman, contains a short section concerning the Gulf of St. Lawrence, but the evaluation of ice conditions is un-

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[1]Department of Mines and Resources, Gulf of St. Lawrence Pilot, Third Edition. Ottawa, 1946.

[2]Huntsman, A. G., Arctic Ice on Our Eastern Coast, Bulletin No. 13, Biological Board of Canada. Toronto, January, 1930.

sound and abbreviated. The Ice Atlas of the Northern Hemisphere,[3] published by the U. S. Navy, includes maps of the average limits of ice for each month of the year in the gulf area, however, these are highly generalized. Occasionally, reports of ice conditions in the gulf appear in the annual publication of the International Ice Observation and Ice Patrol Service in the North Atlantic Ocean,[4] although no interpretation is attempted. Mr. J.G.G. Kerry has written a number of articles dealing with ice in the gulf and the St. Lawrence River (see bibliography, page 95). Again, his estimate is incomplete, especially in regard to the breakup season. These few works constitute the main sources of published information in respect to ice conditions.

Extraction of ice information from all these sources and from additional unpublished and published material was carried out by the author during the months from May to November, 1951, in connection with the Canadian Ice Distribution Survey. This survey is a project of the Geographical Branch, Department of Mines and Technical Surveys, Ottawa, and the author was engaged in this work of extraction while in the employ of the Branch. The main sources, besides the aer-

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[3] U. S. Navy, Hydrographic Office, Ice Atlas of the Northern Hemisphere, First Edition. Washington, 1946.

[4] U. S. Treasury Department, Coast Guard, International Ice Observation and Ice Patrol Service in the North Atlantic Ocean, Washington, 1941-1949.

ial ice survey reports,[5] from which extracts were taken were the reports of the International Ice Patrol Service,[6] and the files of the Canadian Hydrographic Service.[7] All the extracts were classified according to a regional division of the gulf.

Until recently the lack of data sufficiently detailed to support conclusions has prevented the furtherance of investigation in this field, but the appearance of the aerial ice survey reports provides an almost unprecedented opportunity for a detailed study of ice conditions in the breakup season. The present study is based primarily on these data. Unfortunately, the flight routes were confined to that part of the gulf south of a line from Heath Point, Anticosti to the Bay of Islands, Newfoundland. As a result, the ice conditions in the northern portion of the gulf, including the Strait of Belle Isle, are not considered in detail. Similarly, ice conditions in harbours and small estuaries are not treated in detail because the ice reports refer chiefly to the open areas of the gulf.

The normal procedure of the aerial observers was to make several flights during March to ascertain the quantity

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[5]Department of Transport, "Reports of Aerial Ice Surveys in the Gulf of St. Lawrence," File No. 8262-3, 8 Vols. Ottawa, 1940-1952.

[6]U. S. Treasury Department, op. cit.

[7]Department of Mines and Resources, Hydrographic Service, "General Correspondence on Ice Conditions," File No. 634, Vol. 3. Ottawa, 1922-1951. Department of Mines and Resources, Hydrographic Service, "Questionnaire, Re: Ice Conditions in the Gulf of St. Lawrence," File No. 634, Vol. 1. Ottawa, 1937.

and extent of ice in the gulf before beginning daily flights, weather permitting, toward the end of the month. These daily flights were generally continued as long as ice remained in the gulf, even if this necessitated making several flights in May. The routes followed were often varied from day to day in order to give a complete coverage every few days of the section of the gulf within the bounds of the survey. The reports were summarized and broadcast over the Maritime radio stations for the immediate warning of vessels in the area. To indicate the type of information contained in these reports an excerpt from the Canadian Ice Distribution Survey file is presented below. These data refer to region 10 CD, Magdalen-St. George, in the file.

> April 4, 1942. "From 48.30 N., 62.00 W., over steamer track to Cape Bay open water, from 23 miles southwest of Cape Ray ice extends southeastward and to the Cape Breton Coast."
> April 9, 1942. "Large field sighted, southern limits 48.30 N., 61.00 W.
> April 23, 1942. "No ice between St. Paul Island and Bird Rocks."
> April 24, 1942. "On a line from Cape St. George, Newfoundland, to Heath Point two small growlers 48.40 N., 59.40 W., 48.40 N., 60.00 W. West coast of Newfoundland clear to vicinity of Bay of Islands, strings and patches forty miles off Heath Point north and south of this line, then large fields ten miles off Heath Point extending to Table Head, then southwestward to 48.20 N., 62.40 W., to 48.30 N., 63.30 W., to 48.55 N., 63.15 W., to South Point."[8]

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[8]Department of Mines and Technical Surveys, Geographical Branch, "Canadian Ice Distribution Survey File," Ottawa, 1951.

PROCEDURES

Such detailed information provided the basis for a series of maps depicting the ice conditions at ten-day intervals. An interval of this length was necessary because of the blanks in the record which occurred as a result of adverse flying conditions or incomplete coverage of the area. The dates chosen were March 15, March 25, April 5, April 15, April 25, May 1, and May 5. The mapping at five-day intervals after April 25 was made possible by the more accurate reports later in the season. Greater accuracy at this time might be expected because the ice areas are so reduced that it is easy to carry out complete observations.

The maps were designed to show the type of ice-cover at these dates with the use of suitable symbols. Considerable interpolation was necessary in the construction of these maps, in order that a complete picture of the probable ice conditions on each date might be achieved. In spite of this necessity, the maps are considered as reasonably accurate. Supplementary notes pointing out the changes in ice conditions which occurred between the dates were written to accompany the maps. The total number of maps produced was sixty-two. Some years required more maps than others, depending on the amount of information available and the date of final clearing of the gulf. These maps were too numerous, however, to facilitate ready comparison of separate years with a view toward determining the patterns and rates of breakup.

A procedure was established to reduce the material to more manageable proportions without losing valuable detail. Upon inspection of the series of maps for each year and examination of the supplementary notes, ice conditions were described in detail.[9] At the same time, a new map was drawn for each season incorporating the main features of the basic maps. This map showed the limits of the main ice areas at each date. While it gave no indication of the percentage or type of ice-cover, it depicted more graphically the changes in position of the ice fields as the season progressed. Copies of these maps may be found in the Appendix.

Ice conditions during the breakup in these thirteen seasons were related to the determining physical factors of the environment. The correlation with the meteorological factors was effected through the use of statistics published by the Meteorological Division, Department of Transport. Mainly government publications were consulted in the examination of the other factors.

The description of average winter conditions was based chiefly on the data extracted from the Canadian Hydrographic Service files[10] and from the reports of the International Ice

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[9]These descriptions are included in the complete report on ice distribution in the Gulf of St. Lawrence during the breakup season which was submitted to the Geographical Branch, Department of Mines and Technical Surveys, Ottawa, in September, 1952.

[10]Department of Mines and Resources, op. cit.

Patrol Service.[11] The files contain the replies to a questionnaire which was sent to skippers of vessels, light-keepers, and other persons who might be expected to possess knowledge of ice conditions. The reports of the International Ice Patrol Service occasionally contain references to the Gulf of St. Lawrence. This information, together with that from other sources, was sifted and cross-checked in order to achieve an evaluation of winter ice conditions which was reasonably accurate. The accuracy of the description of spring ice conditions was better still because it was based on the aerial survey reports as well as on the Hydrographic Service files.

TERMINOLOGY

A number of terms appear throughout the study which require definitions. Several of these terms have a special meaning in this context which may not coincide with their meaning elsewhere, while others are accepted terms for ice types. Included in the first group are the terms "gulf," "breakup," "ice season," "light ice conditions," and "heavy ice conditions." While "gulf" is an abbreviated form for "Gulf of St. Lawrence," it generally does not apply to the whole gulf in this study, but rather to that part south of a line from Heath Point, Anticosti to the Bay of Islands, Newfoundland, for which area detailed ice information is available. When it applies to the whole Gulf of St. Lawrence the context makes that apparent. The word "breakup" is used

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[11] U. S. Treasury Department, op. cit.

in the following study in a wide sense. Not only the actual breaking up of ice sheets is implied, but also the clearing of ice from the gulf. "Ice season" is understood as the period from November to May when ice is present in the gulf. The term "light ice conditions" is relative, indicating that the ice in the gulf is less extensive than in other areas and mostly under two feet thick. Conversely, the term "heavy ice conditions" indicates that the ice is relatively extensive and thicker than two feet.

The list of ice terms which follows is adapted with modifications from a U. S. Hydrographic Office publication on ice terminology.[12] Some of the ice types are illustrated by the photographs on pages 11, 12, and 13.

Brash ice - Small ice fragments less than six feet across; the wreckage of other forms of ice.

Close pack - Pack composed of floes mostly in contact. It is generally unnavigable to ordinary ships.

Drift ice - Loose, very open pack, where water predominates over ice. The floes are usually smaller than in close or open pack with much rotten ice, and vessels can usually pass through it without altering course or speed.

Fast ice or landfast ice - Sea ice which remains fast in the position of growth, found along coasts where it is attached to the shore, or over shoals where it may be held in position by islands or grounded icebergs.

Field - The largest of ice areas, greater than five miles across.

Floe - A piece of sea ice other than fast ice, large or small.

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[12]U. S. Navy, Hydrographic Office, "A Functional Glossary of Ice Terminology," Study No. 103, Provisional, May, 1948.

Growler - A small piece of glacier ice, usually greenish in colour and barely showing above the water.

Heavy ice - Any thick flat ice.

Lead - A passage through pack ice. Leads may form either by the widening of a crack or by a general loosening of the floes. A shore-lead is a stretch of navigable open water formed when pack ice moves away from the fast ice under the influence of wind or tide.

Light ice - Ice of medium thickness, less than two feet.

Open pack - Pack composed of floes which for the most part do not touch. Belts are usually narrow with many leads and pools. Easily navigable but speed is slow and changes of course continually necessary.

Pack ice - Sea ice which has drifted from its original position.

Pool - Any enclosed sea-water in the pack, other than a lead.

Sheet ice - A large piece of floe ice that drifts to sea unbroken.

ORGANIZATION

The physical geography of the Gulf of St. Lawrence, including the subaerial and submarine morphology, the movements and physical characteristics of the water, and the climate, is examined in general detail. Average winter ice conditions are then discussed by months. With this background, the actual observed ice distribution during the break-up seasons of 1940 to 1952, inclusive, is presented, together with an indication of the air temperatures which prevailed throughout the ice season. Maps of ice limits at specified dates in April and temperature graphs accompany this presentation of data. Based on this data, the patterns and rates

Photos. 1 and 2. Strings of brash ice off the north coast of Gaspé Peninsula, March 20, 1952 (courtesy of Miss I. M. Dunbar).

Photo. 3. Edge of brash ice off the mouth of Miramichi Bay, March 20, 1952 (courtesy of Miss I. M. Dunbar).

Photos. 4 and 5. Landfast ice, shore leads, and open pack ice along the north coast of Prince Edward Island, March 20, 1952 (courtesy of Miss I. M. Dunbar and Miss M. R. Montgomery).

Photos. 6 and 7. Pack ice of varying sized floes off Miramichi Bay, March 20, 1952 (courtesy of Miss I. M. Dunbar and Miss M. R. Montgomery).

Photo. 8. Sheets of ice breaking up off the New Brunswick coast south of the Baie de Chaleur, March 20, 1952 (courtesy of Miss I. M. Dunbar).

Photo. 9. A field of close pack ice off the New Brunswick coast south of the Baie de Chaleur, March 20, 1952 (courtesy of Miss I. M. Dunbar).

of breakup are isolated and classified. Then the physical factors discussed at the beginning are re-examined with the aim of relating them to the distribution and behaviour of the ice and determining their influence. Finally, the general conclusions are stated and the average ice conditions during March and April are described. This description complements the statement of winter ice conditions, thereby giving the entire picture of the ice season. The map following page 14 shows the locations of places mentioned in the text.

MAP 1

GULF OF ST. LAWRENCE

PLACE NAMES

SCALE IN MILES

20 10 0 20 40

Map 1 (to follow page 14).

CHAPTER II

PHYSICAL GEOGRAPHY

SUBAERIAL AND SUBMARINE MORPHOLOGY

The Gulf of St. Lawrence lies on the boundary between two physiographic provinces. On the north the gulf is bounded by the Precambrian rocks of the Canadian Shield and on the west, south, and east chiefly by the Palaeozoic rocks, greatly folded and faulted, of the Appalachian Highlands Province.[13] Two main ranges of the Appalachian system are traceable in the region. These are the Shickshock Range of Gaspé peninsula and the highlands of Nova Scotia, which continue northeastward as the Long Range of Newfoundland. The fold mountains of Gaspé curve southeastward toward the Nova Scotia range before disappearing below the waters of the gulf, while the southern range maintains its northeast-southwest trend, thereby enclosing the gulf.

The gulf itself is much deeper north of a line from Cape Gaspé to St. Paul Island than south of it (see map following page 15). A submarine canyon, whose bottom depths range from 150 to 300 fathoms below the surface, traverses the gulf from the estuary of the St. Lawrence River past Gaspé, north of the Magdalen Islands, through Cabot Strait and southeastward to the edge of the continental shelf where

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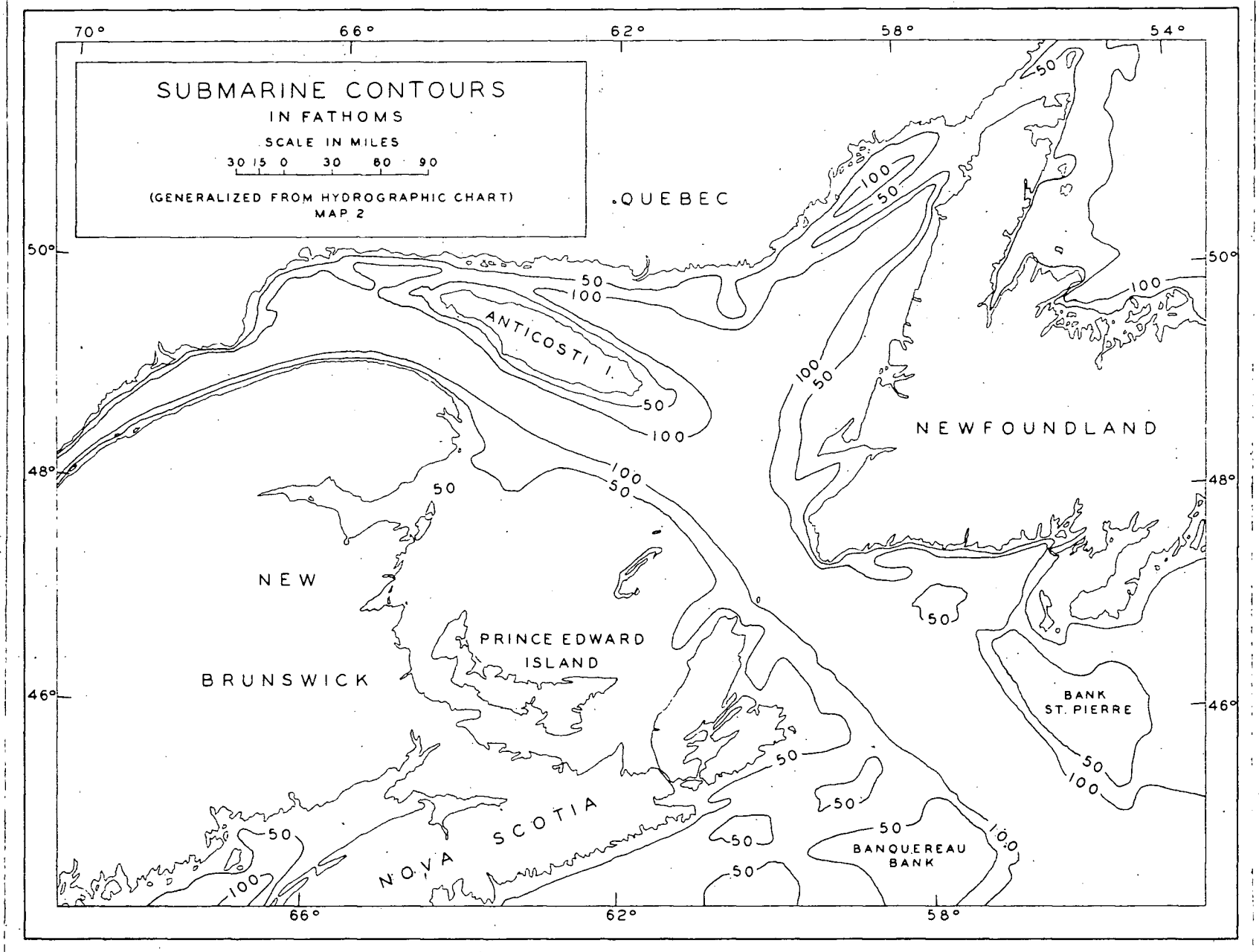
[13]Atwood, W. W., The Physiographic Provinces of North America. Boston: Ginn and Company, 1940, p. 67.



Map 2 (to follow page 15).

it separates Bank St. Pierre from Banquereau Bank. Branches of this canyon extend up the northeast arm of the gulf toward the Strait of Belle Isle and northwestward between Anticosti Island and the Quebec mainland. These steep-walled canyons are 40 to 100 miles broad and occupy much of the northern and eastern sections of the gulf. On the other hand, the floor of the roughly circular area south of the transverse canyon lies less than fifty fathoms below the surface.[14] Ice is more likely to form in shallow areas because there is not so great a body of water which must be cooled before freezing can take place.

Of the three straits connecting the gulf with the open Atlantic, Cabot Strait is the widest. It is apparent that a greater volume of ice will gain exit from the gulf through this strait during the breakup season than through either the Strait of Belle Isle or the Strait of Canso. Because the Strait of Canso is especially narrow, the southern part of the gulf is more confined than the central section and ice movement is restricted. Similarly, the northeast arm is confined, but the Strait of Belle Isle provides a wider link with the open ocean. Anticosti Island, the Magdalen Islands, and Prince Edward Island tend to hinder the free movement of ice over the surface of the gulf.

The shorelines of the Gulf of St. Lawrence area are classified as primary or youthful, their configuration being

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[14]Smith, F.C.G. "Hydrographical Features," Canada Year Book 1947. Ottawa, 1947, p. 7.

due mainly to non-marine erosive forces.[15] These coasts are formed chiefly by the drowning of folded, faulted, and glaciated topography and, as a result, they are diverse in form. The shorelines are characterized throughout by indentations which conform essentially with the alignment and the nature of the rock structure.[16] It is notable that the western and southern shorelines of the gulf have numerous broad, shallow embayments in contrast to the Precambrian shoreline, bounding the gulf on the north, where the bays are small and the water is deep offshore. The broad, shallow bays provide great areas of protected water surface where ice forms more readily and where the breakup is slower than in unprotected regions. The detainment of the ice during the breakup season is particularly noticeable in the Baie de Chaleur because the mouth of the bay is narrowed by Miscou and Shippigan islands. On the other hand, the smooth north coast of Gaspé does not hinder the free drift of ice into the gulf during the breakup.

WATER MOVEMENTS AND PROPERTIES

Within the physiographic framework of the gulf the water movements and properties greatly affect the behaviour of floating ice. Among the factors which cause movement are the tides, tidal currents, and ocean currents.

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[15]Shepard, Francis P., Submarine Geology. New York: Harper and Brothers, 1948, p. 70.

[16]Johnson, Douglas W., The New England-Acadian Shoreline. New York: John Wiley and Sons, 1925, p. 20-23.

Tides and Tidal Currents

Tides are wave motions which involve no appreciable horizontal movement of water, but rather, a vertical raising and lowering of the water in relation to a datum plane. They are generated principally in the open oceans of the world and not in the confined coastal basins where they are most noticeable.[17] The tidal undulation enters the gulf mainly through Cabot Strait and progresses in a counter-clockwise direction around a central point west of the Magdalen Islands.[18] The disturbance of the water surface by tide hinders the formation of large sheets of ice and aids in the breaking up of sheets which have become established. This shattering action is more effective where the tidal ranges are high.

The range of tide in the open ocean is seldom more than 1 metre, but this is amplified along shallow coastlines, in many cases, by tidal components other than those which are gravitational in nature.[19] On the map of tidal ranges in the gulf, following page 19, the lines join places having equal ranges of spring tides.[20] These values, expressed in metres,

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[17] Stewart, John Q., Coasts, Waves and Weather. Boston: Ginn and Company, 1945, p. 207.

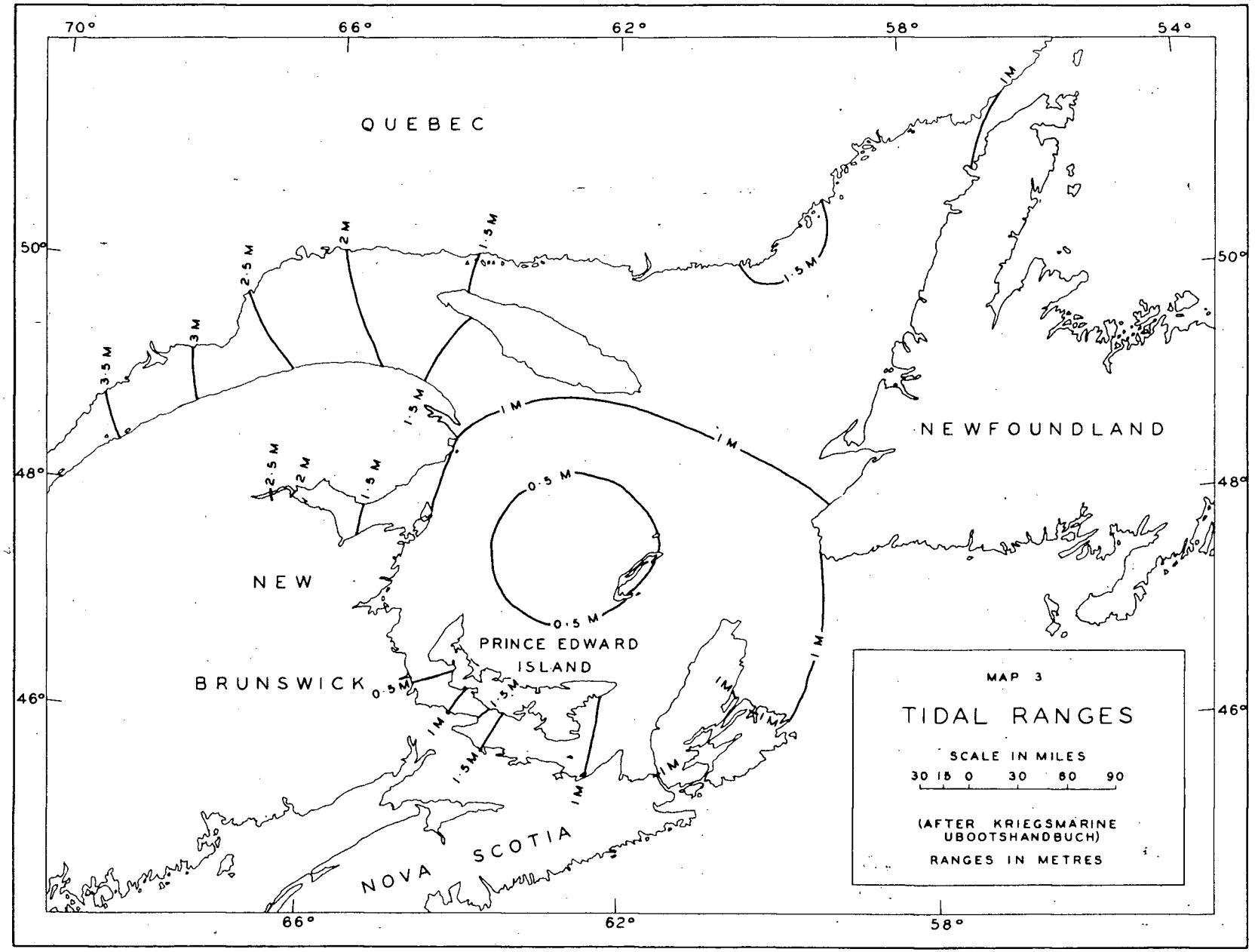
[18] Kriegsmarine, Ubootshandbuch der Ostküste Kanadas (Atlas). Berlin, 1942, p. 166.

[19] Stewart, op. cit., p. 192.

[20] When the gravitational pulls of the sun and moon are combined along the same line, as occurs at new and full moon, the tides produced are both higher and lower than at other times. These are termed spring tides.

are computed from tide tables which do not include the extremes caused by meteorological conditions. Because the readings employed were taken at coastal stations, adjustments were necessarily made in order that average values for the offshore areas might be derived. As a result, figures for some coastal stations may not appear to fit the pattern indicated. Ranges in the gulf are not great, as a rule, but are higher toward the estuary of the St. Lawrence River and in Northumberland Strait than elsewhere. In these areas tidal shattering is most pronounced. From the mouth of the estuary where the range is 1.5 metres the range increases upstream to more than 3 metres above Pointe des Monts. In the vicinity of Cape Tormentine in Northumberland Strait the range is 1.5 metres. Ranges less than 0.5 metres are characteristic of the area west of the Magdalen Islands, consequently, the effect of tides on ice sheets in this area is minimized.

When tidal undulations progress through shallow water an actual horizontal movement of the water takes place. Such horizontal movements are termed tidal currents. These currents seldom coincide with the time of high water, although they are reversed in rhythm with the tides. Their velocities are generally less than 1 knot in open areas, but in the Strait of Canso the tidal currents are decidedly stronger. In Northumberland Strait the currents flow from both entrances meeting in the middle off Baie Verte and their strengths are approximately 1 to 1.5 knots. The Strait of Belle Isle has currents which are tidal in character, but in addition, there is a dominant flow in one direction or the other for periods



Map 3 (to follow page 19).

of a week or more.[21] The velocities in the strait range between 0.5 and over 2 knots. In most other sections of the gulf the tidal currents are weak and ill-defined. Winds are effective in checking or increasing the velocity of tidal currents.

Ocean Currents

Superimposed upon the system of tides and tidal currents is a system of constant ocean currents. In this respect the Gulf of St. Lawrence is characterized by a counter-clockwise circulation (see map following page 21).

Water from the ocean pours into the gulf around Cape Ray and, due to the influence of the earth's rotation, it curves to the right and flows northeastward along the west coast of Newfoundland as far as Point Riche. At Cape Ray the current, a belt near shore ten to fifteen miles in width, has a velocity of a little less than 1 knot. From Cape St. George to the Bay of Islands the movement of the water is hardly appreciable, but northward of this point it is constant at about 1 knot, stronger near land than offshore.[22] The current has the beneficial effect of keeping the southwest and west coasts of Newfoundland free of ice later than other areas within the gulf. Much of the water in this current departs from the stream and spreads out northwestward, heading across

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[21]Although the cause of this dominant flow is not fully known, it is thought to be chiefly meteorological.

[22]Department of Mines and Resources, Gulf of St. Lawrence Pilot, Third Edition. Ottawa, 1946, p. LVI.

the gulf in a weak movement to Anticosti Island. In fact, the preponderance of flow in this whole northern area to a considerable depth is toward the St. Lawrence estuary, although the velocities are low and the direction of movement is readily affected by the wind. Nevertheless, a great quantity of ice is carried southward and westward from the Strait of Belle Isle area. The currents in the strait itself are entirely tidal in character.

At the mouth of the St. Lawrence River water from the northern part of the gulf combines with that from the river to generate the Gaspé Current. The current begins at Cap Chat and, deflected to the right, it hugs the Gaspé coast as it flows eastward. Although it is constant at an average velocity of 2 knots, the tides do cause variations in speed, in spite of the fact that they cannot reverse or completely check the flow. The approximate width of the current is twelve miles and it seldom extends further than fourteen miles offshore.[23] A large amount of ice formed in the St. Lawrence river and estuary is deposited in the gulf by the Gaspé Current.

Leaving Cape Gaspé the current flows southeastward, but the velocity is much reduced and it spreads over a wide area, filling up the central part of the gulf. The predominant drift in this central section is eastward across to the Magdalen Islands and Cape Breton. The velocity, however, is only 0.5 to 1 knot and there is no constant current

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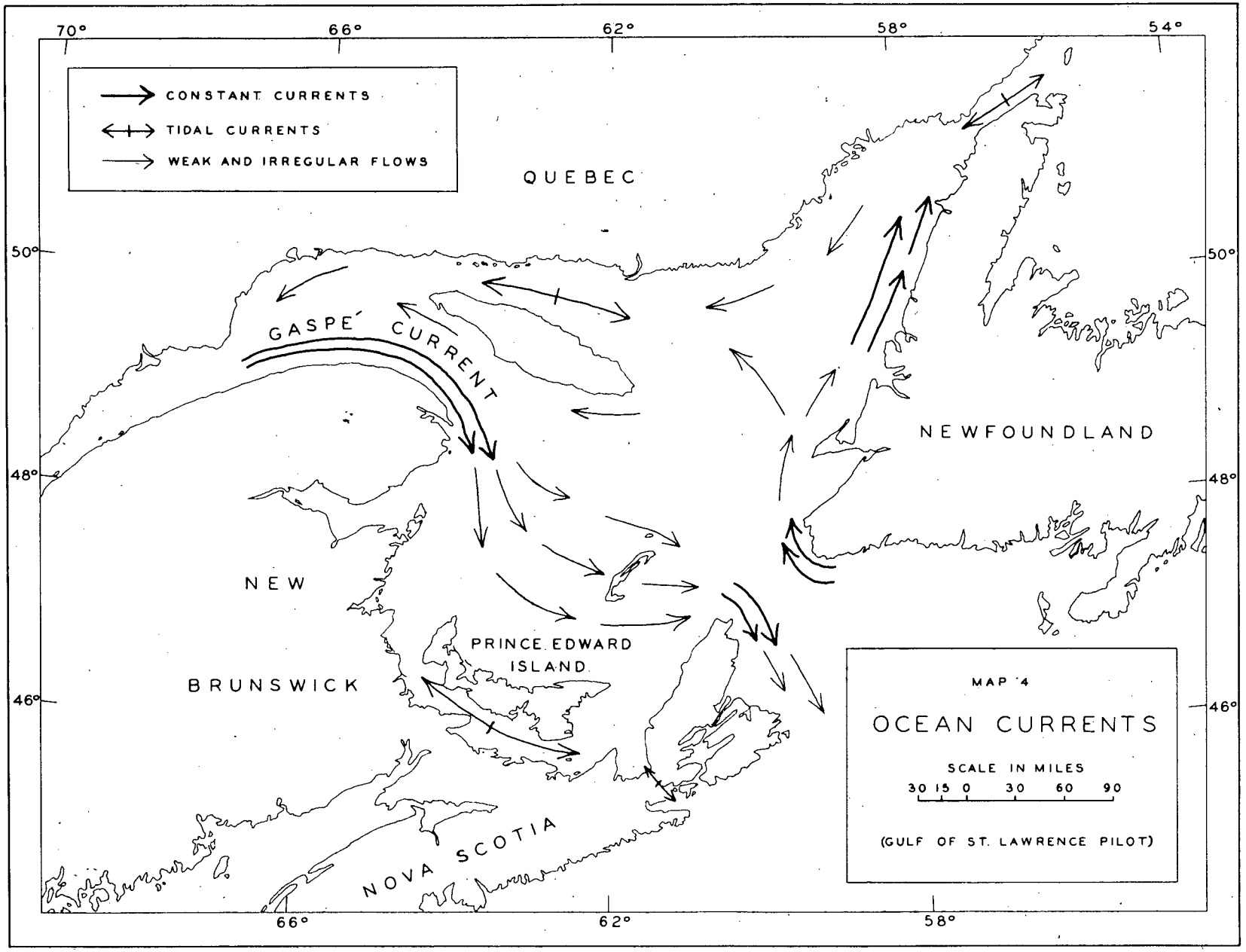
[23] Ibid., p. LIX.



Map 4 (to follow page 21).

discernible.[24] In the southern part of the gulf, particularly in Northumberland Strait, the currents are tidal in character. The lack of constant currents in this section of the gulf permits the accumulation and stagnation of ice in this area on some occasions.

The Gaspé Current is rejuvenated in its continuation by the constriction of Cabot Strait. An 18-mile-wide current comparable in constancy with the Gaspé Current flows along the Cape Breton coast a few miles off Cape North. Fed chiefly by a dominant flow of water southeastward from the northern end of the Magdalen Islands to Cape North, its velocity at times reaches 2 knots.[25] The Cape Breton current extends as a weak flow along the coast, often as far as Scatari Island. This current is of great importance in transporting ice from the gulf, especially during the breakup.

Most of the rivers which flow into the gulf, except the St. Lawrence, are too small to give rise to significant currents. In addition, their effect on the clearing of ice from the gulf is minor because the bulk of the ice in the gulf discharges through Cabot Strait before the rivers break up.

Physical Properties

As part of the Atlantic Ocean, the Gulf of St. Lawrence is filled with salt water slightly modified in

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[24]Department of the Naval Service, The Currents in the Gulf of St. Lawrence. Ottawa, 1913, p. 11.

[25]Department of Mines and Resources, op. cit., p. LVI.

certain sections by the addition of fresh water. Investigations have determined that in the southwestern half of the gulf, south of a line from Gaspé to St. Paul Island, the water is warmer and of lower density than in the northeastern half. The density in this northeastern section is much the same as in the open Atlantic. The Gaspé and Cape Breton currents are comparable in having decidedly lower densities than the waters outside the currents.[26]

The temperature characteristics are not well known, but it is established that a cold layer of water lying at a depth of about 50 fathoms is constantly at a temperature near the freezing point and that it separates warmer layers both above and below. The water above 30 fathoms is influenced by the temperature of the air in contact with it.[27] Regarding surface temperatures, which have the greatest bearing on the ice formation process, it is definite that in most sections of the gulf the surface water temperatures do fall below the freezing point of salt water. Ice formation is especially pronounced around the Magdalen Islands and in the shallow bays and straits, including the Baie de Chaleur and Northumberland Strait. Throughout the open gulf, however, ice is

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[26]Department of the Naval Service, op. cit., p. 36.

[27]Department of the Naval Service, Temperatures and Densities of the Waters of Eastern Canada. Ottawa, 1922, p. 7.

not formed on a large scale due to agitation of the water and the greater depths.[28]

CLIMATE

The climate of the Gulf of St. Lawrence region is not so marine in character as might be expected, considering its location. Lying in the belt of Westerly Winds, the area is mainly under the influence of air which moves from land to sea. The path of the most frequent cyclonic storms passes directly across the central part of the gulf. This continental air is modified to a certain extent, resulting in more moderate conditions than those which are experienced inland. Because the meteorological records are taken on land it is necessary to generalize concerning the conditions over the gulf. The temperature will be more moderate over the water and the precipitation lower, as a rule. Winds may achieve greater velocity in view of the fact that obstructions are lacking.

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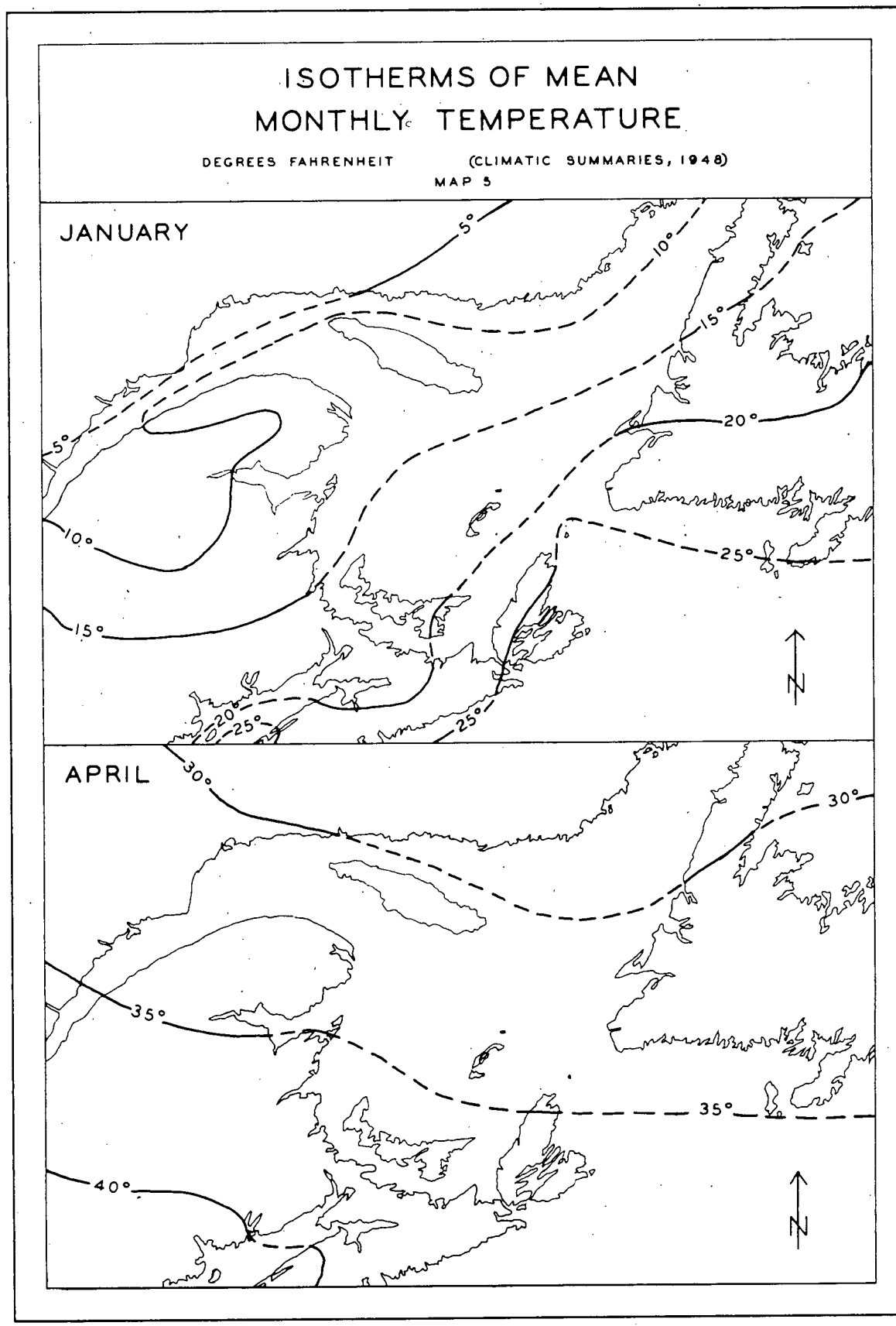
[28]Salt water does not behave in the same manner as fresh water when it is cooled. The maximum density of fresh water is at 4°C. When a body of water has been cooled to this temperature, from top to bottom, further cooling at the surface will not perpetuate the convection currents, but will lead to more rapid cooling and eventual ice formation at 0°C. Salt water reaches its condition of greatest density at -2°C, which is slightly below its freezing point (-1.8°C). As a result, convection currents are generated that keep replacing the surface water until, and if conditions permit, even after it reaches its freezing point. The freezing of salt water is thus retarded by its physical properties. In addition, the disturbance and mixing of the water by winds, tides, and currents plays an important role in the ice formation process.

Temperature

During the winter the isotherms tend to run northeast-southwest across the gulf (see map following page 25). The Cabot Strait region experiences temperatures about ten degrees Fahrenheit higher than those of the Quebec north shore because of the moderating influence of the open Atlantic. This difference in temperature is reflected in the dates of closing of navigation in harbours throughout the gulf (see map following page 32). The harbours in the southeastern part of the gulf freeze later than those in the northwestern part.

The accompanying table, page 26, indicates that average monthly temperatures throughout the gulf drop below the freezing point in December and remain there until April. It is apparent that the air temperature is low enough to give rise to ice formation even on salt water if other factors combine to make it possible. In the event that ice does not form, temperature conditions are such as to preserve ice which may have formed elsewhere and drifted into the gulf. Temperatures are still near freezing during April when the breakup is well advanced.

The variability of ice season temperatures is high. In a given year the difference from average of the mean monthly temperature might be five or ten degrees at many stations in the gulf area. Frequently, several consecutive months in one season experience temperatures somewhat higher or lower than average. The severity of ice conditions is largely dependent on these year to year fluctuations of



Map 5 (to follow page 25).

TABLE I

MONTHLY AVERAGES OF DAILY MEAN TEMPERATURE

Meteorological Station*	November	December	January	February	March	April
Bersimis	27	14	2	8	20	33
Father Point	29	17	9	11	22	34
Clarke City	26	11	2	6	18	31
Natashquan	27	13	6	6	17	30
Harrington Harbour	28	13	8	9	20	30
Cap Chat	32	19	13	15	22	35
Cap Magdalen	31	18	11	14	21	32
Ellis Bay	30	18	13	12	20	31
Anticosti (S.W.Pt.)	30	20	12	12	21	31
Gaspé	30	17	10	11	22	33
Port Daniel	31	19	12	12	27	34
Bathurst	32	18	10	11	24	36
Chatham	33	19	12	12	25	37
Rexton	36	30	15	14	25	33
Summerside	36	24	18	18	26	37
Charlottetown	36	25	18	17	26	36
Alliston	38	26	20	20	28	37
Antigonish	38	27	20	18	28	37
Cheticamp	39	29	22	20	27	36
Baddeck	38	27	27	20	26	37
Sydney	38	29	29	20	27	36
Grindstone Island	36	25	19	16	23	32
St. Paul Island	37	27	27	18	25	32
Burgeo	35	29	23	21	26	33
Channel	36	28	22	21	25	33
St. Georges	35	28	21	16	24	33
Corner Brook	34	25	18	18	25	35

* For locations of meteorological stations see map following page 40.

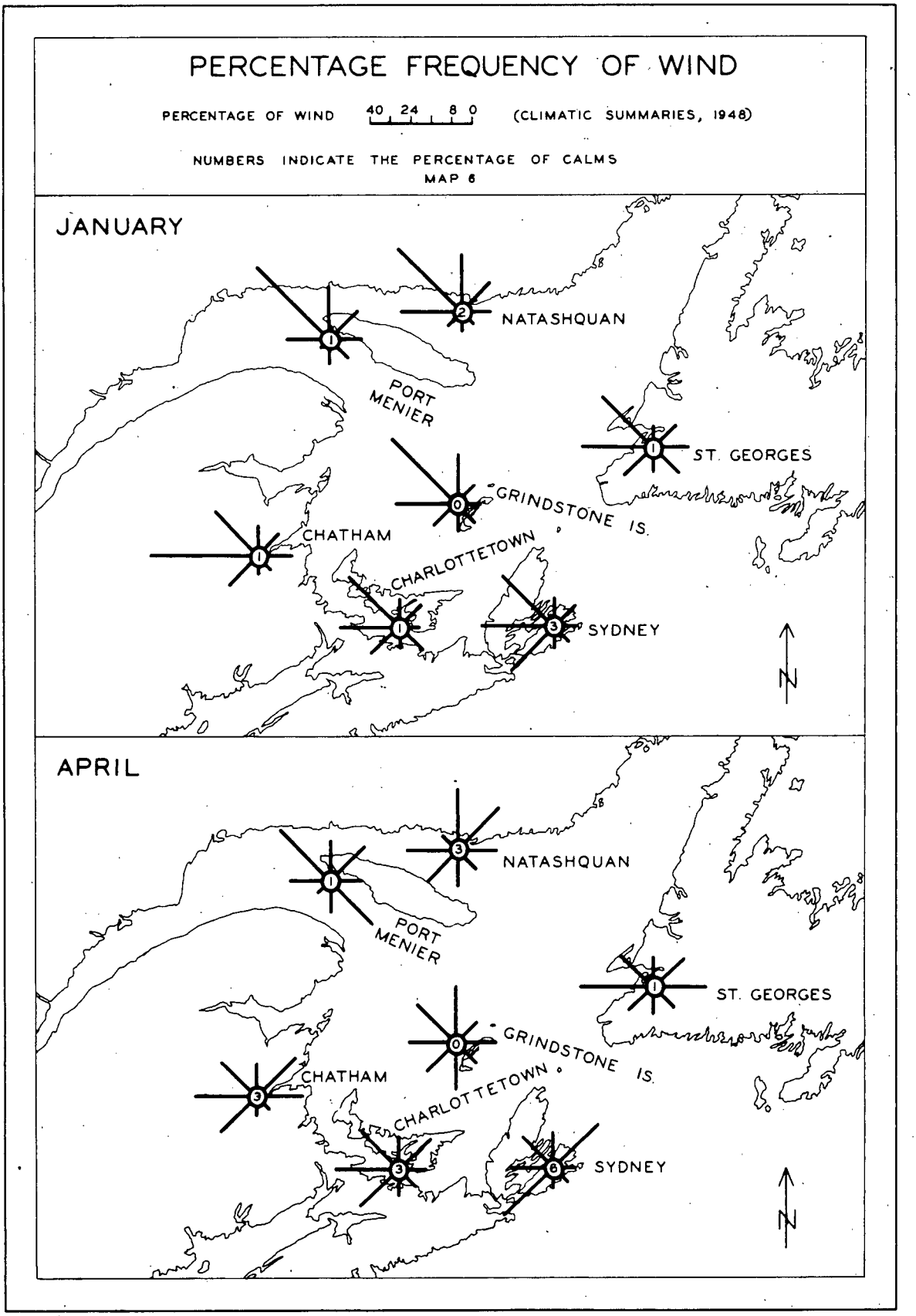
temperature. Consequently, in the examination of ice conditions during a thirteen-year period, it is desirable to relate the results to the observed temperatures of each year as well as to the average temperatures.

Precipitation

Abundant precipitation which is evenly distributed throughout the year is characteristic of the Gulf of St. Lawrence area. Most stations receive more than 40 inches a year. There is a slight summer maximum in the more continental northwestern part of the gulf and a winter maximum in the more maritime southeastern part. Snowfall is fairly high in the gulf area, ranging from 60 to over 200 inches. The higher totals are recorded along the north shore and the lower totals in the southeastern section. The effect of precipitation on ice formation and breakup in the gulf is minor compared to that of temperature or wind.

Wind

The wind roses (see maps following page 27) illustrate the percentage frequencies of wind by direction for January and April, which months represent the period when ice is found in the Gulf of St. Lawrence. Winds of a westerly component prevail throughout most of the year, although in spring and summer their prominence is less noticeable. At this latter time of year the winds are more variable in direction and easterly winds occur more frequently than at other seasons. Changes in direction, even complete reversals, may be expected



Map 6 (to follow page 27).

within very short periods of time due to the circulation of the mid-latitude depressions which move across the area in an almost constant procession in winter. It is this feature, typical of the belt of Westerly Winds, which is responsible for the highly variable weather conditions of the gulf region.

The wind is effective in continually shifting the pack ice which covers most of the gulf in winter. Due to the rotation of the earth, the drift of floating pack ice in the northern hemisphere is about thirty degrees to the right of the wind direction. In general terms, however, the prevailing westerly winds carry the ice eastward toward Cabot Strait, while northerly winds tend to pack the ice in the southern part of the gulf. Southerly winds usually accelerate the clearing of ice, but easterly winds hold the ice in the gulf. The sudden changes of wind direction which are typical of the region cause local changes in the position of pack ice, such as the opening or closing of leads and pools.

SUMMARY

Tides disengage landfast ice and break up sheets of ice formed in shallow water. Much of this ice is carried into the open gulf by tidal and ocean currents, adding to the supply of ice which is largely retained in the gulf by the confined nature of the basin. The air temperatures are low enough to preserve this ice and to encourage local ice formation throughout the season. During this time the factors

causing ice movement, principally winds and currents, keep much of the ice shifting and carry some of it to the open ocean through Cabot Strait.

CHAPTER III

WINTER ICE CONDITIONS

Ice conditions in the Gulf of St. Lawrence during the months from November to March are not well known. No regular aerial survey has been carried out and few records taken aboard ship have been preserved. Much of the information which is available, for example, reports of skippers, light-keepers, and other shore observers, refers to very limited areas and may not be highly reliable. The following discussion constitutes an attempt to present the general picture as indicated by observations which can be substantiated. Although conditions vary greatly from year to year, only average conditions are implied.

The island of Newfoundland acts as a barrier separating the Gulf of St. Lawrence ice from the Arctic ice. The Strait of Belle Isle admits a quantity of ice which is sufficient to fill the northeast arm. Most of this is pack ice which originated as landfast ice along the coast of Labrador. Icebergs seldom gain entrance to the gulf; they drift southward in the main stream of the Labrador Current. Consequently, pack ice constitutes the bulk of the Gulf of St. Lawrence ice.

Winter navigation in the gulf is restricted. The Clarke Steamship Company operates a winter service with ice-breaking vessels from Tadoussac to Seven Islands and sometimes as far east as Havre St. Pierre. This is made possible

by the fact that frequent northwest winds push the ice offshore. In Northumberland Strait an ice-breaking ferry connects Prince Edward Island with the mainland, and a ferry operates between Cape Breton Island and Newfoundland. In addition to these regular services, navigation is carried on by Canadian Government ice-breakers and by small sealing vessels. The ice-breakers, two or three in number, assist those ships attempting navigation and cross the gulf occasionally while en route from the Cape Breton area to the St. Lawrence River.

On the whole, commercial navigation ceases in most sections of the gulf about the middle of December, or earlier. The map following page 32 indicates the average date of the closing of navigation at various harbours in the gulf. In keeping with the characteristics of climate, it is apparent that the harbours nearest the open Atlantic freeze later than those which are more removed from the marine influence.

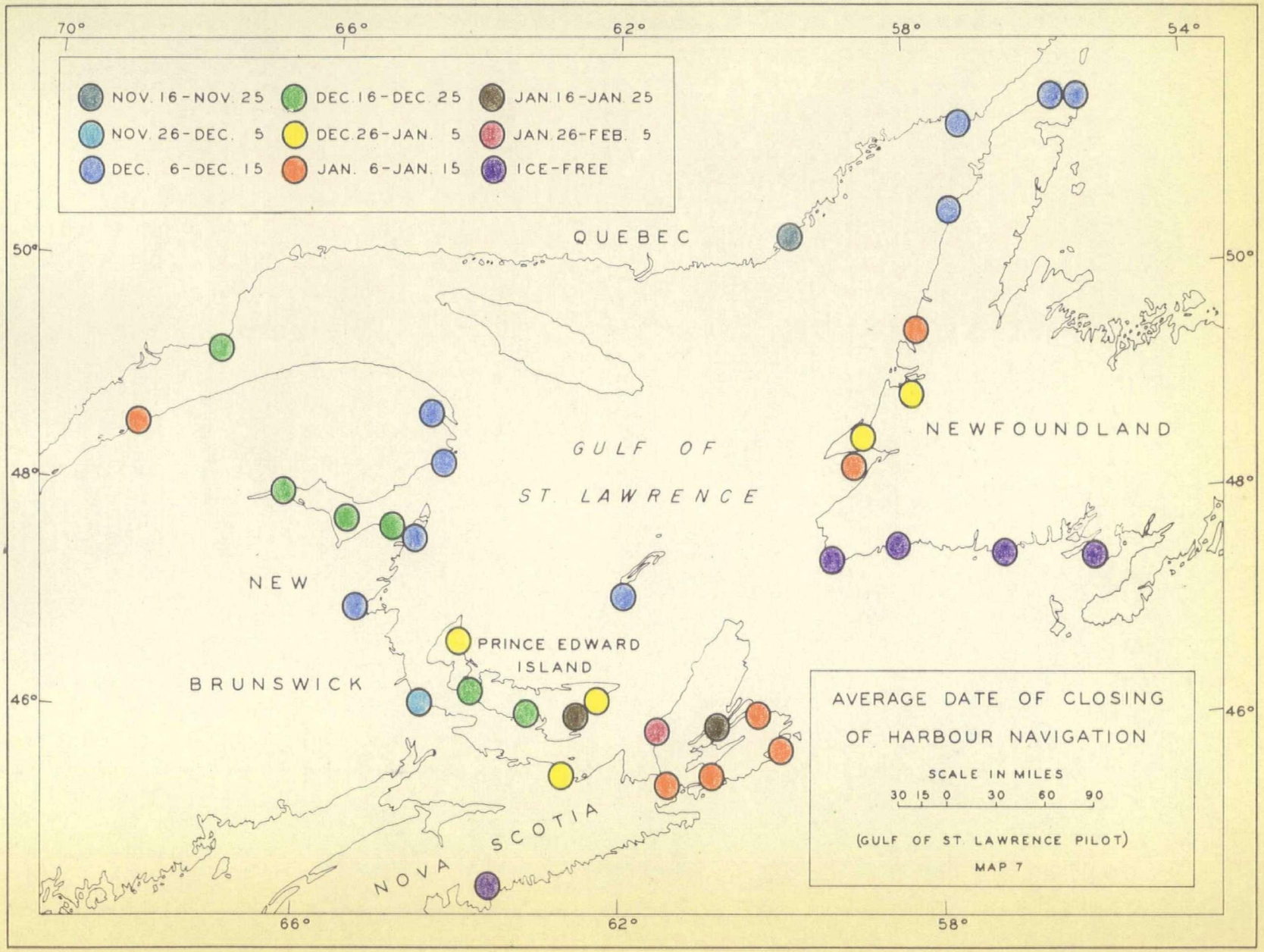
DECEMBER

When the surface water temperatures in the northern part of the gulf drop below freezing point during late November, ice begins to form in the northeast arm, especially in the shallow bays and confined stretches of water. This ice is very light and no appreciable amount forms until December. In addition to ice produced by local freezing, heavy pack ice begins to enter the gulf through the Strait of Belle Isle late in December. In spite of the fact that ice

conditions are not serious in the Strait of Belle Isle throughout most of this month, navigation generally ceases about December 1.

Ice forms fairly early in the lower St. Lawrence River and estuary and along the north shore of the gulf because these areas are removed from the moderating influence of the open Atlantic. Large sheets of ice seldom develop until January, however. Such factors as wind, tide, and current churn the water, breaking up the young ice sheets before they have grown to a thickness which will resist these attacks. A large quantity of ice broken by tidal action in the St. Lawrence estuary is carried into the gulf by the Gaspé Current. This process begins in late December after the upper reaches of the river have already contributed ice to the gulf.

Corresponding closely with the advent of low air temperatures throughout the gulf, the freezing of harbours occurs later in the southern and southeastern areas. Even here navigation is not customary after the end of the first week in December. Although the Baie de Chaleur does not freeze until the latter half of the month, due to the great size of the body of water, the smaller bays and harbours along the western side of the gulf freeze before December 15. Ice originating in the St. Lawrence River is carried into the gulf by the Gaspé Current and by westerly winds and spreads out in southern areas where constant currents are lacking, filling Northumberland Strait by the beginning of January.



Map 7 (to follow page 32).

The route through the Strait of Canso is closed to navigation about January 1, due to the blocking of the northern entrance by ice, although the section south of Mulgrave remains open. Many of the harbours situated along the Nova Scotia and Prince Edward Island coasts do not freeze until late December, or in some cases, until late January. Cabot Strait remains clear throughout December.

JANUARY

By January the water temperatures have been lowered sufficiently to give rise to a large-scale production of ice. Pack ice formed in the gulf usually attains a thickness of two to four feet. Because of lower temperatures and a longer ice season, Labrador pack ice is thicker, sometimes up to seven feet. The growlers which enter the gulf may be considerably thicker. Occasionally, a sheet of ice is buckled into ridges as a result of pressure caused mainly by powerful winds. Several thicknesses of ice may be piled one above the other forming a mass as thick as twelve or fifteen feet. Such ridges occur most frequently in the vicinity of headlands.

Large sheets form in the Strait of Belle Isle and the northeast arm of the gulf and, together with heavy ice which enters the strait from the Labrador coast, chokes up the whole region. The amount of ice which drifts into the gulf through the strait is largely controlled by the tidal currents. When the dominance of flow is inward for a few days, more ice enters the gulf than at other times, but the actual amount is far less than it would be if there were a

constant inward current. Some of this pack ice drifts southward in the weak flow to other sections of the gulf where it may be incorporated into a large ice field or shifted about at the command of wind and wave throughout the winter. Frequent northerly winds aid in driving the ice southward. A few small icebergs and growlers, which have strayed from the Labrador Current, may find their way into the gulf through the strait before it becomes plugged with pack ice. The west coast of Newfoundland receives the full benefit of the moderating influence of the Gulf of St. Lawrence. Consequently, the harbours along this coast do not freeze until January. St. George Bay fills with river ice which seldom becomes cemented into a field, but rather, the floes remain in motion all winter. Offshore, the northward-flowing current is effective in defending the coastal area against the invasion of ice from the north until February. The north shore of the gulf remains fairly clear of pack ice throughout the winter, because of the prevailing northwest winds which continually push the ice offshore, and risky navigation is possible.

The central part of the gulf is covered with pack ice which shifts about constantly. Leads are readily discovered between the floes, but few ships other than ice-breakers attempt navigation. The general movement of the ice in the central gulf is from west to east, under the influence of the prevailing winds and water currents. Conditions are never static because the St. Lawrence River continues to discharge ice into the gulf and new ice is forming in many areas.

The ice is more closely packed in the southern part of the gulf because of the decreased current and the confinement of the basin by the land. By the middle of January Northumberland Strait and George Bay are usually filled with close pack ice and the Strait of Canso is blocked at the northern entrance. Such a volume of ice is swept toward the constriction of the strait that it packs solid and freezes into a compact mass which constitutes a "bridge," as it is commonly called. The effect of this bridge is to prevent the ice in George Bay from drifting into the strait. This results in ice-free conditions south of Mulgrave and navigation in this stretch is possible throughout most of the winter.

Pack ice begins to emerge from the gulf through Cabot Strait about the middle of January, but it is usually light and scattered. In a year of severe conditions ice may be found as far east as Miquelon Island in January, as was the case in 1943. On this occasion, January 24, 1943, patches of heavy field ice were reported at a position thirty miles southwest of Miquelon.[29] Conversely, in a year of favourable conditions, such as 1945, there may be no ice in the Cabot Strait area. On the average, Cabot Strait is partly covered with ice streaming out of the gulf, but it is never frozen over from shore to shore. Seldom does the ice extend southward of Flint Island along the east coast of Cape Breton Island.

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[29]U. S. Treasury Department, Coast Guard, International Ice Observation and Ice Patrol Service in the North Atlantic Ocean, Season of 1946, Bulletin No. 32. Washington, 1947, p. 15.

The harbours along the Cape Breton east and south coasts freeze during the second week of January, while those along the south coast of Newfoundland and that of Halifax are usually ice-free throughout the year. These ice-free harbours are so located that they are protected from the invasion of gulf ice, and they are climatically favoured in the retardation of local ice formation.

FEBRUARY

The main exodus of ice from the gulf begins in February. Ice from the central section is the first to move out. While ice is leaving the gulf through Cabot Strait, heavy ice in the northeast arm continues to drift southward, eventually closing on the west coast of Newfoundland as far south as the Bay of Islands. Some of this ice makes its way westward along the north shore. In addition, the St. Lawrence estuary adds ice to the supply. Consequently, the Cabot Strait outflow is partly compensated for by inflows in other areas and by local freezing, but the net result is a loss of ice.

Generally, Cabot Strait is partly covered with ice closely packed on the Cape Breton side and fairly open or scattered on the Newfoundland side. In some years, as occured in 1943, the ice closes in on the Newfoundland coast due to sustained southerly winds, but this is not the usual condition. Eastward of the strait the ice is more open and lighter and scattered strings of ice frequently extend eastward to the 58th meridian and southward to the 46th parallel.

Occasionally, northeast winds cause the ice to move southwestward along the south coast of Nova Scotia, blocking the harbours.

The southern part of the gulf remains packed with ice, much of it shifting, but little departing from the area to stream through Cabot Strait. The bays, including the Baie de Chaleur and George Bay, are frozen over completely or are filled with closely packed ice which has been cemented into large sheets presenting a mosaic appearance. Other areas are covered with ice of a comparable description, except that there are wide leads between the sheets, particularly in Northumberland Strait.

As early as February, therefore, the withdrawal of ice from the gulf is inaugurated on a large scale. This withdrawal is the normal result of the control of winds and currents and does not indicate that the ice is melting or breaking up due to mild weather. It is mainly the central area between Anticosti Island and Cabot Strait which contributes to the initial outflow.

SUMMARY

The Gulf of St. Lawrence receives ice from two main sources, the St. Lawrence River and estuary, and the Labrador coast through the Strait of Belle Isle. This ice from outside mingles with locally formed ice closing the gulf to navigation in winter. The northeast arm and the western and southern sections of the gulf are the first to become ice-covered. Then the central area fills up and the ice closes the open

strip along the west coast of Newfoundland. Eventually, the ice begins to emerge from the gulf through Cabot Strait. Only the fringes of the gulf are frozen solid; most of the area is covered with shifting pack ice. The southern part is the more closely packed, but even here leads and pools of open water are found throughout the winter.

CHAPTER IV

ICE DISTRIBUTION IN THE BREAKUP SEASON DURING THE YEARS 1940-1952 INCLUSIVE

The general ice conditions during the winter months indicate that the clearing of the gulf takes place over a long period of time and that the ice leaves primarily through Cabot Strait. With this background the breakup season is considered. The behaviour of the ice in this season of clearing can be traced with some precision because detailed information is available for most of the gulf, except for the northeast arm. Although information concerning the breakup in the northeast arm is lacking, it is known that the ice north of a line from Natashquan to the Bay of Islands does not discharge through Cabot Strait, but remains in the gulf until it has melted.

The following description of actual ice conditions in March and April of the years 1940 to 1952, inclusive, is based on information obtained by aerial observation. The data employed were incomplete concerning March but were detailed concerning April. This detailed information in April enabled the determination of limits of the main ice areas at specified dates, and these limits are shown on the maps in the Appendix. The main ice areas do not include regions of widely scattered strings and small patches of ice.

The graphs which accompany the maps are designed to reveal the temperature characteristics of the ice seasons. Statistics for the difference from average of the mean

monthly temperature were used to achieve these results.[30] In the case of the years 1940 to 1950, inclusive, figures for twenty-seven meteorological stations were used in construction of the graphs, but in the other two cases, 1951 and 1952, only eighteen stations were used.[31] The abbreviated list published in the Monthly Weather Map[32] was employed instead of that in the Monthly Record for these two years. The twenty-seven stations are indicated on the map following page 40, with additional ones which were used as replacements in the event of blanks in the record. Those stations used for the 1951 and 1952 graphs are underlined.

Because the graphs are intended to show the general temperature characteristics of the season over the water area of the gulf, stations situated on the coast near sea-level were chosen as most representative. As many stations as possible were included in order that deviations from average due to local causes might be minimized in company with other stations. In view of the nature of the ice data available, a breakdown of temperatures in various parts of the gulf was deemed unwarranted, consequently, the stations lose their local identity and represent points in the Gulf of St.

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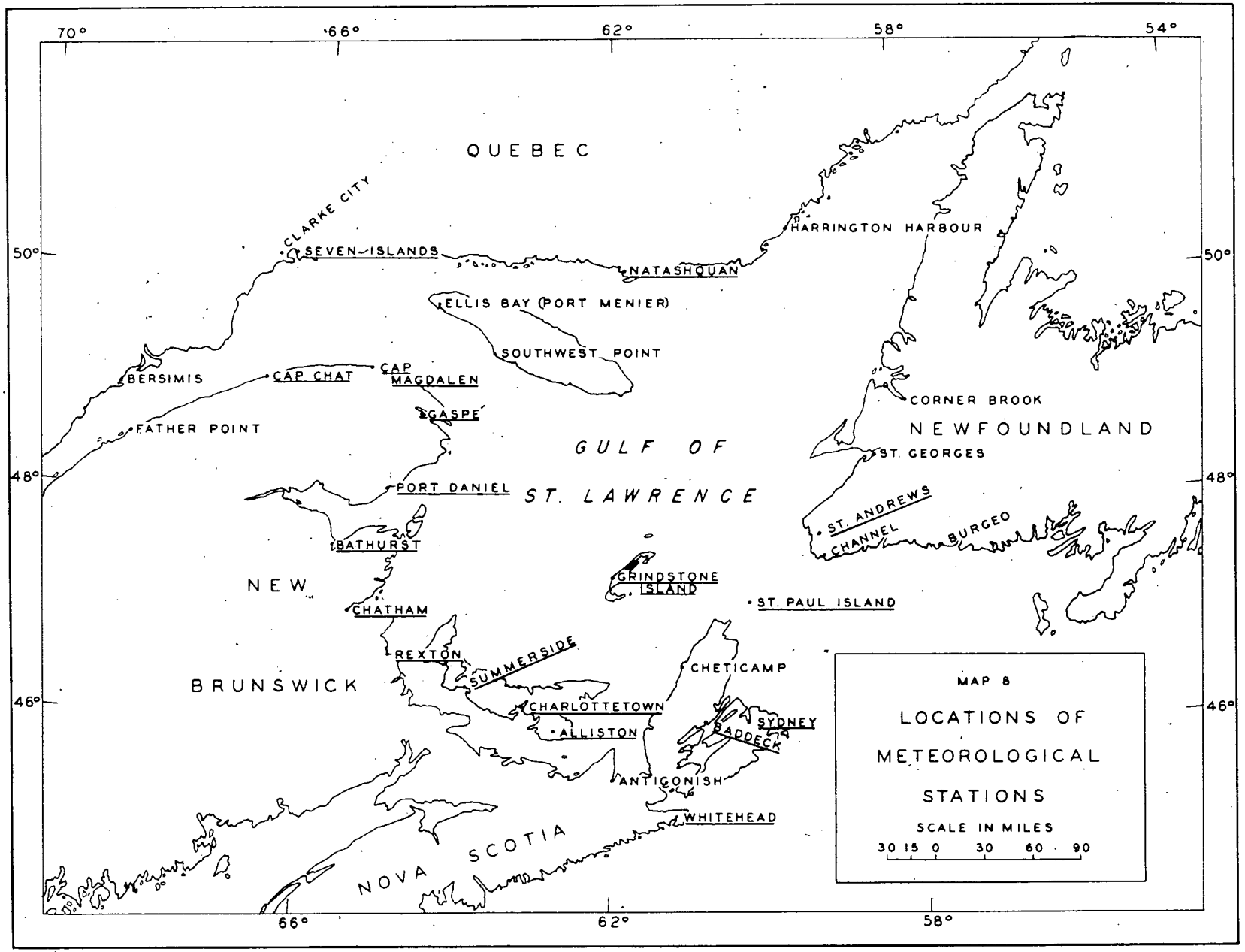
[30] Department of Transport, Meteorological Division, Monthly Record (monthly statistics series). Toronto, 1940-1950.

[31] The reduction in number of stations in these years was necessitated because the Monthly Record had not yet reached the publication stage.

[32] Department of Transport, Meteorological Division, Monthly Weather Map (monthly weather map statistics series). Toronto, 1951-1952.



Map 8 (to follow page 40).

Lawrence area as a whole.

The horizontal axis, zero, is symbolic of the average temperature of every station in the gulf region, although the averages may differ. Each dot represents one station. The difference from average at each station in whole degrees Fahrenheit is found along the vertical axis; each station recording an average monthly temperature which is above its all-time average is located above the zero line, while each one recording a below average temperature is found below the line. If the figure for a station coincides with the average, to the nearest degree, the dot is placed on the zero line.

It must be emphasized that this chapter is primarily a presentation of data. Further interpretation of the material will be found in following sections. The maps for each season are designed to accompany the text and should be consulted in conjunction with it.

SEASON OF 1940

During March there was a considerable area of open water in the gulf, particularly in the central section along the steamer track.[33] A great deal of close pack ice lay in the southern half, although there were pools of open water and numerous leads. The exodus through Cabot Strait was in progress.

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[33]The "steamer track" is the direct route from Cabot Strait to the St. Lawrence estuary south of Anticosti Island which is followed by most ocean vessels.

By early April the ice was melting and breaking up in the western part of the gulf. The open channel along the steamer track had widened, but the passage through Cabot Strait on the Newfoundland side remained constricted. The Baie de Chaleur was clearing along the northern side. Northumberland Strait and the east coast of Prince Edward Island were open; similarly, there was open water in the vicinity of the Magdalen Islands. The ice was confined, essentially, to the eastern half of the gulf at the middle of April.

The bulk of the ice had withdrawn from the gulf by April 25 when the main field lay off the east and south coasts of Cape Breton Island. Shortly after the middle of the month the route through the Strait of Canso, George Bay, and via East Point became open. Some scattered ice which constituted a danger to navigation remained in Northumberland Strait until the end of April. The field off the east coast of Cape Breton covered a relatively large area during much of April and reached along the south coast as far as St. Esprit, but it shrank quickly in the last week, revealing open water across the full width of Cabot Strait.

On the whole, ice conditions were not severe during this season of 1940. The breakup was well under way in March and was accelerated during April. The clearing proceeded from west to east and the last remaining ice of any consequence was found off the Cape Breton coast.

The graphs indicate that the season was warmer than average, in spite of the fact that two months, November and

April, were definitely below normal. March was nearer the average than any of the other months. The mild winter assured that ice conditions would not be severe by preventing the ice from becoming unduly thick or extensive.

SEASON OF 1941

Close pack ice covered about half of the gulf in March, 1941, although there were some large patches of open water, especially between Anticosti Island and Gaspé and in the southern part of the gulf. The Cabot Strait region was choked up with close pack ice which extended a great distance southeastward.

The western part of the gulf was mainly clear by April 5, except for ice in the Baie de Chaleur and this ice was moving out quickly. As in 1940, open water was found along the east coast of Prince Edward Island. The ice had moved to the eastern side of the gulf where it covered the steamer track and completely filled Cabot Strait. Eastward and southward of the strait the field was unusually extensive because the quantity of ice in the gulf was great and the clearing took place rapidly. The ice was packed on the Cape Breton east coast.

By the middle of April the ice had receded from the central section, opening a narrow passage through Cabot Strait and along the steamer route. Along the east coast of Cape Breton the ice had moved offshore with westerly winds, but the field remained extensive. Northumberland Strait, George Bay, and the Strait of Canso opened during the third week of

the month, although ice clung to the west coast of Cape Breton until nearly the end of April. The field outside Cabot Strait, which was still offshore, had contracted by April 25 and disappeared shortly after. Between Heath Point and Cape St. George the ice lingered until early May.

The breakup was well advanced by the end of the first week in April in this season and the whole area was practically clear by May 1. Considering the quantity of ice which had to be expelled from the gulf, more than in 1940, the breakup was reasonably swift and followed a normal pattern. The ice made its way from west to east and passed through Cabot Strait in the same manner as it had done in 1940, except that the strait and the steamer track were ice-covered until a later date and the greater volume of ice was spread over a wider area beyond the strait.

Temperatures in the gulf area were near average in November, but were definitely below average in December and January. February temperatures were remarkably high, while those of March and April were nearer normal. The fact that the ice was heavier than in 1940 was probably due to the lower temperatures in December and January.

SEASON OF 1942

The ice was less extensive during March, 1942, than it had been the year before. Frequent northerly winds throughout March and April shifted the ice to the southern part of the gulf. As in previous years, the Baie de Chaleur began opening first along the northern side. It appears

likely that this pattern of clearing is chiefly determined by the islands which narrow the mouth of the bay. Open water extended southward from the Baie de Chaleur into Northumberland Strait. The steamer track was clear, unlike the condition in 1941, and there was an open route through Cabot Strait on the Newfoundland side. Beyond the strait the northerly winds had carried the ice far southward along the south coast of Nova Scotia.

The southerly movement of the ice continued throughout April under the influence of northerly winds. A shore lead along the north coast of Prince Edward Island was pinched out by the middle of the month. The improvement in the southern section where the ice fields had contracted by April 15 was paralleled by the invasion of an extensive field from the north which covered a large part of the steamer track. After the middle of April the ice was slow in rounding Cape North and tended to remain in the region of George Bay.

During late April the field south of Anticosti Island still constituted a hazard. Although George Bay and the Strait of Canso had been clear on April 25, close pack ice was drifted into the bay by winds a few days later, closing navigation until the ice withdrew on May 3 and eventually made its way up the west coast of Cape Breton and around Cape North. The south coast of Cape Breton was clear throughout April because there were no southerly winds powerful enough to push the ice on shore.

At the beginning of April the breakup was sufficiently advanced to indicate an early opening of all navigation routes. Much of the gulf was open and the ice, confined to the southern section, was loosely distributed over a wide area. However, the flow of ice through Cabot Strait was restricted by northerly winds and the ice accumulated along the west coast of Cape Breton. In addition, a large field encroached on the steamer track south of Anticosti Island and dispersed very slowly. As a result, the pattern of breakup differed from that of the previous two years in the fact that the ice did not drift freely from west to east, taking advantage of the full width of Cabot Strait as an exit. Rather, it stagnated in the southern section and clogged the George Bay-Strait of Canso area until early May.

In respect to temperature, November and January were the only months which were distinctly below average. The rest of the months were warmer than normal, March in particular when temperatures ranged from three to ten degrees above average. The December, March, and April temperatures were higher than in 1941 which accounted for the lighter ice conditions experienced early in the season.

SEASON OF 1943

Most of the gulf was ice-covered throughout March. In many areas the ice was closely packed, especially in the Baie de Chaleur, around Cape Breton Island, and in Cabot Strait. Outside the strait the southward and eastward extension of the ice was greater during the latter half of

March than during the first half. This condition was a normal reflection of the acceleration of the clearing during the breakup season. Because westerly winds prevented the ice from closing in on the south coast of Cape Breton, it remained clear.

Early in April there was still a great deal of open pack ice in the gulf. The steamer track was unnavigable, although it was opening south of Anticosti Island. Little improvement had taken place in the Baie de Chaleur. East of the Magdalen Islands the ice was very open, but Cabot Strait was still partly filled with close pack ice. With frequent southerly winds the ice was withdrawing northward from George Bay, leaving the Strait of Canso and the bay open.

This northward movement of the ice continued through April and led to the early clearing of the southeastern section of the gulf. Close pack ice remained in central regions and along the steamer track, however, until late in April. The fact that the ice moved northward blocking the mouth of the Baie de Chaleur was responsible for the retarded breakup of the bay. Cabot Strait began to open first on the Cape Breton side as the ice receded from the coast. This unusual pattern of clearing was caused mainly by southerly winds. The gulf cleared rapidly during the last few days of April and the steamer track was navigable throughout on April 30. Some ice remained until early May in the Baie de Chaleur and off the west coast of Newfoundland.

The 1943 breakup followed quite a different pattern from those of the preceding three years. In this season ice in the main body of the gulf was more abundant. It cleared

first in the area east of Gaspé Peninsula, then in the southeastern part of the gulf, and last of all, in the central section along the steamer route. The main contributing factor in this withdrawal was the frequent occurrence of southerly winds.

In the matter of temperature during the ice season, it is apparent that below normal conditions prevailed in every month except November and February. Only February was decidedly warmer than average, while December, January, March, and April were considerably colder than average. These lower temperatures led to the occurrence in this season of widespread, heavy ice, much of which was closely packed.

SEASON OF 1944

The breakup proceeded with rapidity during March. Although the ice was fairly extensive early in the month, strong northwest and west winds opened up the ice throughout the gulf and carried it eastward to feed a broad stream of ice drifting through Cabot Strait. A narrow passage remained open on the Newfoundland side during most of the month, probably owing to the inward current. The southward and eastward limits of the ice outside the strait approximated those of April 5. In late March the eastern part of the steamer track cleared and the ice receded from the whole west coast of the gulf, except in the Baie de Chaleur. This rapid dispersal may be attributed, chiefly, to sustained northwest winds.

By April 5 the ice had withdrawn to the Cape Breton Island region. Close pack ice in Northumberland Strait and George Bay blocked the route through the Strait of Canso and reached up the west coast of Cape Breton. As in 1940 and 1941, the east coast of Prince Edward Island was open. This evidence supports the conclusion that southeast coastal areas are cleared readily by northwest winds. Cabot Strait remained partly ice-covered and the ice in the dispersal area was unusually extensive as a result of the presence of a large quantity of ice which left the gulf during March. Along the Cape Breton east coast the ice was inshore, filling Sydney harbour.

Northumberland Strait had largely cleared by the middle of April. Southwest winds moved the ice in George Bay northward on April 15, rendering the route navigable, but northerly winds caused it to invade the bay again on April 17, obstructing the passage. In the Baie de Chaleur the ice had opened and was dispersing, in spite of the fact that its limits had changed little since April 5. The field in Cabot Strait and beyond was diminishing and had receded from the Cape Breton coast with southwest winds. As a result, Sydney harbour cleared.

Most of the gulf was clear by April 25 with the exception of ice in George Bay and the Strait of Canso, which prevented navigation until April 27, and along the west coast of Cape Breton. Some fields of ice remained offshore beyond Cabot Strait, but these were disintegrating rapidly.

The pattern of breakup in 1944 resembled that of 1942 in certain respects. There was a wide area of open water on April 5 in each case, but the conditions during March were different. In the one instance, 1942, much open water was visible in March, while in the other, 1944, the ice had been extensive but cleared rapidly. In both cases George Bay was invaded by ice at a late date owing to northerly winds.

The temperatures of the autumn were high enough to retard ice formation. December and January were in contrast; the first was well below average and the second was well above. February temperatures were near normal, but those of March and April were lower. The fact that the ice conditions were not so severe as in the year before would suggest that the temperatures were higher, which was the case.

SEASON OF 1945

The season of 1945 was singular in its paucity of ice, owing to mild winter temperatures. During March the ice which did exist was segregated in the southern part of the gulf. George Bay was filled with close pack ice which extended up the west coast of Cape Breton Island, elsewhere, the ice was fairly open. The flow of ice through Cabot Strait was very limited in amount and was confined to a narrow belt on the Cape Breton side. The strait was never closed during the month. In the dispersal region the ice field reached its greatest extent during early March, then it diminished rapidly during the latter part of the month.

This field was of lesser dimensions than those of previous years. Only on one occasion, at the middle of March, did the ice move onshore along the south coast of Cape Breton in the vicinity of Louisburg, but this incursion, caused by easterly winds, was short-lived.

The gulf was practically clear by the end of the first week in April. The only ice remaining was in the Baie de Chaleur, around the Magdalen Islands, in George Bay, and along the west coast of Cape Breton. Most of this ice moved out quickly, rendering the route through the Strait of Canso navigable by April 8. The field off the Cape Breton east coast had almost completely dissipated and left only a strip of ice near shore.

The whole season of 1945 was characterized by mild ice conditions. Ice was late in forming in the fall and was never very extensive during the winter, consequently, the breakup and final clearing occured remarkably early. The pattern of breakup was similar to that of 1944, although the amount of ice involved was much less. The ice departed from the gulf via a route lying on the southern side of Cabot Strait. Inside the gulf it lingered in three particular areas a little longer than in others, the Baie de Chaleur, the vicinity of the Magdalen Islands, and the George Bay region.

Exceptionally high temperatures throughout the season were mainly responsible for these clement ice conditions. All months, except December, were considerably warmer than average and even December was slightly warmer than normal.

SEASON OF 1946

Little information was available concerning ice conditions in March. It is established that there were wide areas of open water in many sections of the gulf throughout the month. Prevailing northwest winds during March led to the removal of a considerable quantity of ice through Cabot Strait. The steamer track was almost clear at the end of the month.

By April 5 the track was navigable with patches and strings of loose ice and the western part of the gulf was clear. Northumberland Strait was navigable from the western entrance to Pictou Island. The majority of the ice in the gulf lay in the southeastern section along the north coast of Prince Edward Island and the west coast of Cape Breton Island. George Bay and the Strait of Canso were unnavigable. In Cabot Strait a narrow strip of ice was pressed close against the land and the ice was inshore along the Cape Breton east coast. The ice field beyond the strait reached far southward, but its eastward extent was more limited. Frequent northeast winds during April undoubtedly caused this southward drift of the ice.

The fields gradually diminished throughout the rest of April without any drastic alterations of their positions, although in mid-April a tongue of ice was thrust southward along the Nova Scotia south coast by easterly winds. George Bay cleared in the latter half of the month, enabling the

commencement of navigation on that route. It was not until the last week of April that the ice in the field off the west coast of Cape Breton opened up and rounded Cape North to dissipate beyond Cabot Strait. Only a few patches of ice remained by May 1.

During the winter of 1946 a moderate quantity of ice appeared in the gulf, but rapid clearing occurred in March. Throughout April the withdrawal of the ice proceeded more slowly, in a manner similar to its behaviour in 1942. In both cases northeast winds prevailed during April which drove the ice southward and tended to discourage its free movement through Cabot Strait.

The first four months of the 1946 ice season were characterized by temperatures near the average. March temperatures were somewhat higher than normal and April temperatures were slightly lower. The situation with regard to ice was not inconsistent with these data. The near average temperature conditions indicate that this particular season may have experienced near average amounts of ice.

SEASON OF 1947

The ice in the gulf during March was more extensive than it was the year before. Although there were few areas of open water, one of which lay along the east coast of Prince Edward Island, the ice opened up a great deal in March, especially along the steamer track. The flow through Cabot Strait was not excessive and the ice field beyond the strait was unusually contracted.

Early in April a large area in the gulf was still ice-covered, but much of the ice was open and scattered. As was customary in former years, the Baie de Chaleur cleared first along the northern side. The steamer track and a strip in the southwestern part of the gulf, including Northumberland Strait, cleared during the second week of April. The route through the Strait of Canso and George Bay also became navigable at this time. In the dispersal region the field was very limited in extent and a shore lead existed along the northeast coast of Cape Breton. Occasional periods of southerly winds were effective in clearing the southern part of the gulf readily and in maintaining a shore lead along the east coast of Cape Breton.

The central section of the gulf between the Magdalen Islands and Prince Edward Island where the ice was scattered cleared after April 15. Cabot Strait was essentially clear at this time. Toward the end of the month the field off the Cape Breton west coast broke up and began moving rapidly around Cape North. The field off the east coast retreated from shore and the ice dispersed shortly afterwards. North of the steamer track some ice remained until May.

The breakup pattern of 1947 bore a close resemblance to that of 1941. The ice was reasonably extensive and heavy during March. It cleared first in the western part of the gulf, along the steamer route, and in Northumberland Strait and George Bay, then in the central area, and last of all, along the west coast of Cape Breton, north of the steamer track, and in the dispersal region.

A similarity was also evident in the ice season temperatures of the two years. February was unusually warm in both years. The first three months of the 1947 season were colder than normal and April was colder still. March, like February, was above average, although the ice was fairly extensive in spite of it, thus indicating that low early winter temperatures are critical in ice formation.

SEASON OF 1948

At the middle of March the whole gulf was ice-covered. The ice was more closely packed in the southern part, but there was little open water anywhere. Beyond Cabot Strait the ice was spread over a tremendous area. Clearing proceeded rapidly during the latter half of the month with strong westerly winds and several areas opened sufficiently to reveal open water, particularly along the steamer track. A very narrow shore lead existed in Cabot Strait off Cape Ray and Cape Anguille. The limits of the field in the dispersal region had receded to the positions where they remained throughout April.

The speedy withdrawal of the ice from west to east continued in April aided by strong northwesterly gales. Much of the western part of the gulf was clear early in the month, except for the Baie de Chaleur which was closely packed on the southern side. The eastern part of the steamer track was still closed by ice, although the narrow shore lead remained along the Newfoundland coast. Similarly, the Cape Breton east coast was clear throughout the month.

Northumberland Strait and George Bay were opening up, but were not clear until the third week of April. The Strait of Canso which had been clear on April 5 was admitting a flow of scattered ice that impeded navigation.

Toward the end of April the ice was mainly confined to the Cape Breton area. Cabot Strait was largely ice-covered and the field beyond occupied an area as great as that on April 15. The ice, which had been offshore throughout April, was driven on the coast on April 27 by strong northeast winds, leaving Cabot Strait essentially open. Here the field remained until it loosened up and dispersed after May 9 with westerly winds. Sydney harbour was completely blocked until this date.

The large quantity of ice in the gulf early in the breakup season cleared rapidly, gaining exit through Cabot Strait. It occupied most of the strait during March and April. The ice withdrew from west to east in a normal manner and vacated the George Bay area before the Cape Breton north and east coastal areas. However, the ice in this last-mentioned region moved onshore at the end of April and did not clear until the second week of May. Essentially, the breakup resembled that of 1941, except that the Cape Breton region was encased by ice until an exceptionally late date.

Temperatures were above average in November and January, near average in December, and distinctly below average in February, March, and April. Although the early winter temperatures were slightly above average, there was

a great amount of heavy ice in this season. The importance of low early winter temperatures is reduced by this fact.

SEASON OF 1949

In the season of 1949 the ice was somewhat lighter than the year before, nevertheless, it covered a wide area. The majority of the ice was inside the gulf on the March 15; the steamer track east of the Bird Rocks as well as Cabot Strait was clear, and beyond the strait there were a few patches of loose ice only. By March 25 the ice had moved eastward under the influence of northwest winds, covering the steamer track and all but closing Cabot Strait, except for a shore lead around Cape Ray. It had drifted along the Cape Breton east coast to Scatari. Accompanying this movement was a withdrawal of ice from the Gaspé coast. The clearing of the Baie de Chaleur was in progress, with the ice moving out of the northern half. Other parts of the gulf remained ice-covered.

Great improvement had taken place by April 5. The most notable was the retreat of the ice from the western part of the gulf and the opening of the steamer track. Although the steamer route was navigable, there was considerable scattered and open ice in the area. Cabot Strait itself was fairly open, but the field outside the strait had been driven onshore along the east and south coasts of Cape Breton by northerly winds.

By the middle of April the Baie de Chaleur was clear and most of Northumberland Strait was open, while scattered

ice was strewn over the steamer track, although it was navigable. George Bay and the west coast of Cape Breton were still ice-covered, but were swiftly clearing. Along the Cape Breton south coast the ice had moved offshore. All these areas were clear by the end of the third week of April. Finally, northerly gales on April 25 broke up the entire field located off the east coast of Cape Breton and scattered the ice widely.

The ice season was not severe in 1949. Once the clearing began in earnest after March 15 it proceeded speedily and in an orderly fashion. Moving from west to east, the ice departed from the gulf through Cabot Strait and left behind few traces after April 25. This season may be compared with 1940, for the breakup followed a similar pattern, although the ice was much lighter in 1949.

The light ice conditions were due, in part, to remarkably high temperatures. All months except February were four or five degrees above average at many stations. February temperatures were nearer average.

SEASON OF 1950

During March, 1950, the flow of ice through Cabot Strait was in considerable volume. Several areas were open toward the end of the month; among them were the western part of the steamer track and the region from the Baie de Chaleur to Northumberland Strait. The rest of the gulf was ice-covered. Cabot Strait was filled with ice and the field outside was unusually extensive because of the abundance of ice and the moderately rapid rate of clearing during March.

The steamer track was essentially clear by April 5, except for a tongue of ice which was thrust across it near Cape Anguille by northerly winds. Frequent northerly winds were packing the ice in the southern part of the gulf. The Baie de Chaleur was opening along the northern side and Northumberland Strait was partly clear. Drift ice was strewn over much of the central section of the gulf. In Cabot Strait the ice occupied only the southern half, but the field in the dispersal region remained extensive. Although the ice had been offshore along the east coast of Cape Breton on April 3, it moved onshore a few days later.

By April 15 the ice was compacted in the southeastern section of the gulf and in the dispersal region, with the exception of a broad band of ice which had been drifted southward across the steamer route by the northerly winds. The Baie de Chaleur had largely cleared and was navigable to Dalhousie. George Bay, however, was full of ice and the Strait of Canso was discharging ice southward into the Atlantic. Close pack ice covered the part of Cabot Strait between Cape North and St. Paul Island. The ice was still close inshore along the east coast of Cape Breton and, in addition, the field had moved a great distance southward and occupied the south coastal area.

Toward the end of the month northerly winds held the ice in the southeastern part of the gulf, restricting the flow around Cape North. The steamer track had cleared and the field beyond Cabot Strait had diminished, but a great deal

of ice remained inside the gulf which must eventually arrive in the area of dispersal. The clearing of the southeastern part of the gulf was gradual; the Strait of Canso was not entirely clear for navigation until May 7 and the ice lingered along the Cape Breton coast until the middle of May. Once around Cape North the ice spread over a wide area, no longer constituting a danger to navigation.

The ice in this season was reasonably extensive and heavy. The pattern of clearing during April was more from north to south than from west to east. Northerly winds were mainly responsible for the accumulation of the ice in the southeastern portion of the gulf. These conditions resembled those of 1942 when the ice seemed to stagnate in this area, but the situation was worse in 1950 because the ice was more abundant and the final clearing was postponed even longer.

Concerning temperature, December and January were the only months which were warmer than average. The latter part of the season was colder, with February and March much colder than average. These conditions approximated those of 1948 and lend weight to the assertion that late winter temperatures which are well below average may lead to an abundance of ice.

SEASON OF 1951

The season of 1951 displayed a most peculiar irregularity. Throughout the season the ice was segregated in the western part of the gulf. At the end of the first week in

March there was practically no ice east of the 62nd meridian. West of this meridian the ice was open in the central section and closely packed near shore. As March progressed the ice dispersed in the offshore areas, while it remained closely packed along the New Brunswick coast, in Northumberland Strait, and along the north shore of Prince Edward Island.

Strong and sustained northeast and east winds through March and April were directly responsible for the accumulation of ice along the west shore of the gulf. By April 5 the field north of Prince Edward Island was disappearing and the Baie de Chaleur was opening along the northern side. Most of Northumberland Strait was clear. A southward movement of the ice took place in the second week of April when the wind became more northerly, leaving the region off the mouth of the Baie de Chaleur clear of ice. On April 16 brisk westerly winds finally loosened up all the ice in the southern part of the gulf and it drifted seaward. By April 25 the only ice obstructing navigation was located in Northumberland Strait, but it dissipated before the end of the month.

The pattern of breakup in 1951 was not paralleled by any of the previous ten seasons. The ice conditions were as lenient in this season as they were in 1945. The main distinction between the seasons lay in the fact that the ice which entered the gulf from the St. Lawrence River was packed along the New Brunswick coast by easterly winds, rather than carried through to Cabot Strait by westerly winds. The concentration of ice along this coast had the additional

effect of retarding the breakup of the Baie de Chaleur. When the ice dispersed it scattered widely and did not hinder navigation in other areas. The routes through Cabot Strait and the Strait of Canso were clear throughout March and April.

The ice season was remarkably mild, perhaps the mildest of the years examined. Temperatures were several degrees above average in every month. A great part of the gulf was ice-free throughout the season, and it is definite that the ice was exceptionally light.

SEASON OF 1952

The whole central section of the gulf was clear by the middle of March and the main ice area was in the southern portion. Much of this area was covered with close pack ice. Northerly winds through February and March drifted the ice southward. The flow of ice through Cabot Strait increased toward the end of March with the strait half covered, but the ice was of limited extent beyond.

In early April the Baie de Chaleur continued to clear along the northern side, and Northumberland Strait and George Bay were beginning to open up. Most of the ice had retreated even further southward. Off the east coast of Cape Breton the ice had spread over a larger area and had moved onshore, also encroaching on the south coast. Because the winds during April were light and variable in direction, they did not shift the ice to other regions or encourage its quick withdrawal from the gulf.

The clearing progressed gradually, resulting in more areas of open water by the middle of the month, especially around Prince Edward Island. Cabot Strait was mainly open and the ice beyond had receded from the Cape Breton coast. By the end of April the ice fields had shrunken, but considerable ice remained as a formidable obstacle to navigation. Close pack ice covered the eastern half of George Bay and much of the Strait of Canso, as well as the Cape Breton west coastal region. The drift ice in the eastern half of Northumberland Strait prevented navigation via this route. Strong northwest winds on April 24 were effective in clearing the east and south coasts of Cape Breton, leaving only a few scattered patches and strings. George Bay and the Strait of Canso were not clear until May 3 and some ice lingered in Northumberland Strait for another week.

The breakup of 1952 was similar to that of 1942, ten years earlier. In both years the gulf began clearing at an early date, but ice remained in the southern sections until early May, blocking the Strait of Canso route. The retardation of the breakup was to be attributed primarily to northerly winds, which packed the ice in the south, and to the lack of sustained periods of southerly or westerly winds, which would have accelerated the exodus.

The records of temperature indicate that the season was above average in this respect. November and December were nearer average than the other four months which were above. The ice was more extensive than in 1951, but the ice season was still lighter than normal.

CHAPTER V

THE NATURE OF THE BREAKUP AND THE DETERMINING FACTORS

PATTERNS AND RATES OF BREAKUP

It is apparent from the examination of the maps of ice conditions in the Gulf of St. Lawrence that the pattern and rate of breakup varies immensely from year to year. Nevertheless, the fundamental drift of the ice is from west to east. Cabot Strait, constituting the main outlet from the gulf, is the destination of most of the ice, except for that in the northeast arm. Deviations of the ice from the most direct route to Cabot Strait, which are caused by numerous factors, are responsible for the different patterns and rates of breakup.

In Most years there are certain areas which become free of ice before others. A triangular region off the south coast of Newfoundland, with the apex at Cape Ray, is generally ice-free throughout the year and a passage around Cape Ray and Cape Anguille is open most of the time. The central part of the gulf northwest of Cabot Strait discharges ice in January or February, but it continues to receive more from other sections and, as a result, it is seldom the first area to become clear, although it clears before the southern part. The stretch south of Anticosti Island appears to open first, then the western section and the steamer route, and finally, the southeastern section and the dispersal region.

While ice remains in the Baie de Chaleur after the area outside is clear, it is usually confined to the southern side. Northumberland Strait clears from west to east and the east coast of Prince Edward Island tends to open earlier than its surroundings. Similarly, the area immediately east of the Magdalen Islands frequently opens early. Chedabucto Bay and the south coast of Cape Breton are encroached upon by ice occasionally only. Although these general features of the breakup are characteristic of most seasons, it is possible to differentiate the seasons on the basis of several recurrent patterns and rates of withdrawal.

The thirteen seasons may be divided roughly into two categories, with two exceptions. The first group comprises the years 1940, 1941, 1945, 1947, 1948, and 1949. During these seasons the ice drifted from west to east and vacated the southern part of the gulf in a normal course of withdrawal. The Baie de Chaleur, Northumberland Strait, George Bay, and the Strait of Canso were clear before the dispersal region, and open water appeared off the coast of Prince Edward Island at an early date. Generally, the steamer track was not clear much in advance of the southern regions. In all but the two seasons of 1940 and 1949, some ice along the west coast of Cape Breton was slow in rounding Cape North, but the delay was not lengthy. Also, in the case of 1941 and 1947, the ice lingered unduly late in the region north of the steamer track. Otherwise, the breakups followed a reasonably consistent pattern.

The rate of clearing was fairly rapid throughout both March and April during these seasons. Of course, the amount of ice present was a deciding factor in determining the date of its complete disappearance. For example, in 1945, the gulf was practically clear by the first of April, while in 1947, it was not clear until early May. In spite of this, the actual rates of breakup were comparable. The breakup of 1948 differed slightly from the rest in that it progressed rapidly until the end of April, then the ice lingered on the west coast of Cape Breton. The movement of the ice in these years was reasonably direct and at a rapid pace, without stagnating in the southern part of the gulf.

The second group includes the ice seasons of 1942, 1944, 1946, 1950, and 1952, which witnessed such stagnation as failed to occur in the years discussed previously. Ice remained along the west coast of Cape Breton until exceptionally late dates. In most cases, the clearing progressed until all but the southeastern section of the gulf was free of ice, then the process of clearing slowed and the ice appeared to stagnate.

Although the steamer track was frequently clear in advance of the southern areas, ice from the north was thrust southward across the route in 1942 and 1950, hindering navigation until after the middle of April. As a rule, the flow of ice through Cabot Strait was restricted in April, leaving the strait partly open. Usually, Northumberland Strait opened before George Bay, but in 1952 it was the last place to clear. The east coast of Prince Edward Island

generally cleared before the Cape Breton side of the strait, but in 1946 it was blocked late in April after being clear most of the month. On the other hand, the north coast of the island was slow in clearing, except in 1944. This season displayed some of the characteristics of the first group, however, it differed from them particularly in its rate of breakup.

In respect to rates of breakup, the ice in these years became sluggish toward the end of the season. Rapid clearing during March followed by gradual withdrawal in April was the experience of the seasons of 1944 and 1946. A similar rate of clearing prevailed in 1942 and in 1950, except that the rate was not so swift in March. The 1952 season differed in the fact that the withdrawal was slow in both months. The ice seasons in this second group, therefore, were characterized by an early spurt of clearing followed by a period of stagnation and accumulation of the ice in the southeastern section of the gulf. The route via the Strait of Canso and George Bay was blocked until long after the steamer track was open.

The two years which were not included in either of these groups follow quite different breakup patterns. In 1943, the ice began clearing in George Bay at the south and off Anticosti Island in the north. The ice in the western part of the gulf retreated from both the north and south to accumulate in the central area. Likewise, around Cape Breton it shifted offshore. During much of April the ice streamed

through Cabot Strait, filling it from shore to shore. As a result, the steamer track was blocked until late in April, but the Strait of Canso route was open remarkably early. The Baie de Chaleur was late in clearing. On the whole, however, the rate of breakup was swift throughout the season, especially in view of the great quantity of ice which lay in the gulf that winter.

The other exceptional year was 1951. In many parts of the gulf which are usually ice-covered during the spring there was virtually no ice. Accumulation had occurred in the western part of the gulf. On the outer fringes of the fields dispersal took place, leading to their contraction, but the main body of the ice remained as if pinned against the western side. During the first half of April the ice moved south and finally disintegrated before the end of the month. Because the clearing proceeded gradually the eastern areas were not invaded by large fields dangerous to navigation, but rather, remained open throughout the breakup. The rate of clearing was slow during both March and April. These conditions which prevailed in 1951 were definitely remarkable, if not unique.

THE DETERMINING FACTORS OF THE BREAKUP

The behaviour of the ice in all phases of its formation and breakup is controlled by the physical factors of the environment. Many of these factors were indicated previously, but it is necessary to re-examine them in the

light of an understanding of the ice conditions. The aim of this discussion shall be to determine the relative influence of each factor.

The Non-Variable Factors

The influence of some of these factors does not vary appreciably from year to year; for this reason they may be termed non-variable. Those which are discussed are the subaerial and submarine morphology, the tides and tidal currents, and the ocean currents.

Subaerial and Submarine Morphology

Because ice formation takes place more readily where the water is shallow, local ice is more likely to originate in the southern part of the gulf than elsewhere. Whether or not ice forms in great quantity in the open gulf is unknown, although it is suspected that it does not. The bays and harbours throughout the gulf do freeze over during the winter, if only for a short time. Where the bays are broad and shallow, as in this southern region, a great quantity of ice is produced. Among the bays which freeze are the Baie de Chaleur, Miramichi Bay, and Gaspé Bay. In the wide-mouthed bays, such as George Bay, it is possible that some ice formed in other areas finds its way into the bays and is cemented into a solid sheet before local ice covers them. Other regions of local ice formation are the shallows in Northumberland Strait and around the Magdalen Islands.

The gulf is so shaped that the southern part acts as a basin of accumulation into which ice is diverted as it moves from west to east. If Cape Breton Island were removed, the gulf would become ice-free much earlier than it does because it is the relative narrowness of the outlet which retards the clearing. The ice tends to pile up along the west coast of Cape Breton and little can escape through the constricted Strait of Canso. The Strait of Belle Isle is also narrow and, in addition, other forces discourage the mass movement of ice toward this opening. On the other hand, conditions would be far worse if Cabot Strait were as narrow as either the Strait of Belle Isle or the Strait of Canso. Its existence makes possible the withdrawal of most of the ice to dissipate in the open Atlantic, otherwise, the ice would remain in the gulf until it melted.

Within the main southern basin are smaller bays and bights which tend to detain the ice. There is the bight of the north coast of Prince Edward Island where the ice is cradled throughout the winter. Again, there is George Bay which serves as an overflow basin for ice in Northumberland Strait even after the bay has cleared. In turn, George Bay often funnels ice into the Strait of Canso. And finally, there is the Baie de Chaleur which always clears first along the northern side, mainly because the mouth on the southern side is obstructed by Shippigan and Miscou islands.

The Magdalen Islands, the Bird Rocks, and Brion Island constitute obstacles in the path of ice movement by splitting

the larger sheets of ice which move toward Cabot Strait. Anticosti Island serves as a partition separating the ice which originates in the St. Lawrence River from that which comes from the northeast arm. Most of this ice from the river drifts along the Gaspé coast and reaches the gulf without suffering detainment because the coast is smooth. During seasons when the ice moves southward Prince Edward Island protects Northumberland Strait with the result that the strait opens earlier than other southern regions.

The controlling influence of the land obviously determines the boundaries within which the ice may move and indicates the routes by which the ice may withdraw. It provides a framework which is non-variable in its function. Within this framework other forces affect the behaviour of the ice.

Tides and Tidal Currents

One of these forces is the tidal force, with its associated tidal current. The disturbance of the water is the most important influence exerted by the tidal undulation, while the tidal currents shift the ice back and forth and are responsible for a certain amount of mass movement.

Landfast ice which forms along shores and over shoals is frequently shattered by the tidal swell and is carried offshore by tidal currents or winds as pack ice. This occurs commonly in the early winter, especially where the range of tide is great. The St. Lawrence estuary, with its

high range of tide, must be the source of large quantities of ice because the tides and currents disengage and carry away the ice as fast as it is produced. This effect is not so pronounced in the vicinity of the Magdalen Islands due to the small range of tide here.

In Northumberland Strait the tidal currents are reasonably strong and the range of tide is higher than in most sections of the gulf. These forces are successful in preventing the formation of a continuous sheet. Nevertheless, here, and elsewhere in the gulf, narrow strips of landfast ice establish themselves along the shores. Outside the strips the ice is kept in motion. In the bays which do freeze over, Miramichi Bay, Baie de Chaleur, and Gaspé Bay, among others, the swell does not enter with effectiveness after the sheet of ice has solidified. During the spring when the ice is decaying, however, the tide regains its dominant position and shatters the ice sheets. The tidal currents in the Strait of Canso flush out the ice before an ice-cover originates.

Transportation of great quantities of ice is effected by tidal currents. When the wind blows in the same direction as the current flows, ice may be carried along at a high velocity. Then, if the wind continues in the same direction when the current is reversed, the velocity may be reduced and only part of the ice will return to its original position. This type of movement occurs frequently in Northumberland Strait, the Strait of Canso, and other areas where tidal currents are reasonably strong. Considerable ice is ushered

into the gulf and expelled from it by the tidal current in the Strait of Belle Isle, because there appears to be a dominant flow one way or the other for extended periods of time. Although the whole northeast arm of the gulf becomes stopped up with ice, the strait does not freeze over completely.

Briefly, the effect of tides and tidal currents in the gulf is to break up the ice sheets into pack ice and to inaugurate movement of the pack. This process often results in the formation of great quantities of ice in favourable areas, thereby increasing the total amount of ice. On the other hand, through agitation of the water the tides retard the formation of ice and prevent widespread consolidation of sheet ice.

Ocean Currents

The system of constant currents in the gulf is definitely a major factor in controlling the movement of ice. An immense volume of ice is carried into the gulf from the St. Lawrence River by the Gaspé current. When the velocity of the current is reduced off the mouth of the Baie de Chaleur the ice is cast free from the stream and spreads out in the southern part of the gulf. A slower drift still prevails which carries some ice toward the Magdalen Islands and Cabot Strait. In spite of this cross-gulf flow, much of the ice finds its way into the southern basin of the gulf which eventually fills up.

A constant current off Cape North dismisses ice from the gulf, but its power is largely wasted during the early

winter because it is not supplied with ice in any great quantity until that from the west reaches Cabot Strait. If there were a current of comparable velocity joining the Gaspé and Cape Breton currents the ice from the river would be conducted directly into the Atlantic, but such is not the case. On the Newfoundland side of Cabot Strait the current flows into the gulf. The general westward drift along the south coast of Newfoundland and the inward flow around Cape Ray tend to repel the invasion of ice from the north and west. As a result, these areas are frequently clear throughout the season.

Similarly, the northward drift and current along the west coast of Newfoundland keeps that coast open later in the fall and clears it earlier in the spring than the area offshore. In the northern part of the gulf the currents are ill-defined and of low velocity, although there appears to be a general westward movement. This drift aids the spreading of ice from the northeast arm.

Within the physiographic framework of the gulf the constant currents and general movements further define the directions in which the ice may move and indicate the areas where the ice may stagnate.

Variable Factors

The factors treated in this section are characterized by annual variability. The physical properties of the water and the meteorological factors of temperature, precipitation and wind are discussed.

Physical Properties of the Water

As was pointed out previously, the surface temperatures of the water in many parts of the gulf reach a point which is favourable to the ice formation process, but due to other factors ice formation is not as widespread as might be expected. The presence of imported ice in a given area will have the effect of reducing surface temperatures in that vicinity. This undoubtedly occurs in the gulf and may account for ice formation in an area where ice would not originate otherwise. But on the whole, although surface temperatures are not well known, it is suspected that they do not vary appreciably from year to year as a result of influences other than those which are meteorological in nature. The surface water temperature is raised by the same meteorological factors which cause the breakup of the ice. The relationship between these factors of water temperatures and weather conditions is close enough to permit the disregard of surface water temperatures in view of the lack of information. While the meteorological factors exert their influence indirectly in respect to ice formation, they exert it directly on the ice in the breakup.

Meteorological Factors

It is the meteorological factors of the environment which are the main cause of annual variation in ice conditions. The climate, which represents the average of the meteorological conditions, can be justly compared only with average ice conditions. Therefore, an investigation of the

actual weather conditions which prevailed in the thirteen years is necessary in order to determine the causes of the variation in these ice seasons. Such an investigation properly requires a detailed examination of the daily synoptic charts over a four-month period in each of the thirteen years, together with a careful study of the station records which are kept on file at the Meteorological Division offices in Toronto. This task was not undertaken in connection with the present study.

The aim of the investigations that were carried out was to establish a general relationship between ice conditions in the breakup season and the main features of weather, namely, temperature, precipitation and wind. The study was confined to the use of published statistics, except in the case of the examination of synoptic charts to determine wind directions and forces. The effects of sunshine, cloudiness, frequency of depressions or other air mass phenomena were not investigated. Nevertheless, the following evaluation should establish a general relationship which might form the basis for a more exhaustive and detailed study.

Temperature. The relationships between the mean monthly temperatures at a number of stations in the Gulf of St. Lawrence area during the ice season and the ice distribution during the breakup were indicated for each year previously. Considering all the years examined, as a group, a definite relationship can be established. The following discussion considers temperature in relation to the pattern

of breakup, the rate of breakup, the time of final clearing, and the quantity and extent of ice.

To facilitate comparison with the ice conditions it is advantageous to divide the seasons into groups on the basis of their temperature characteristics (see Table II, page 88). Four main groups can be isolated. The first group, made up of the years 1940, 1945, 1949, 1951, and 1952, is characterized by above average temperatures in the ice season. The second is defined on the basis of the fact that the first three months, essentially, are colder than the last three, and includes the years 1941, 1942, 1946, and 1947. The third group is just the opposite in that the first three months are warmer than the last three. The years which have this feature in common are 1944, 1948, and 1950. Finally, the fourth group has only one representative in the year 1943. In this case the temperatures of the ice season were below average. Within these main groups there are subdivisions which indicate more specifically the differences between the years; these are defined on the accompanying table.

The pattern of breakup is reasonably independent of the ice season temperatures. While there are two cases where the pattern of breakup is similar in two years of like temperature conditions, namely, groups 2A and 2B, there is no instance in the first three main groups where all the years of one group witnessed the same pattern of breakup. Nor does the rate of breakup seem to be controlled by temperatures in the ice season. There does not appear to be any consistent relation even within subgroups, although again, in group 2B

the same rate of breakup prevailed in each year. On the other hand, group 1B is characterized by two opposite rates of breakup.

The time of final clearing is understood as representing the time when all the ice, except for scattered strings and patches which do not constitute a hinderance to navigation, has melted or departed from the gulf. It can only be roughly estimated because the information available will not permit the determination of actual dates (see Table II). The relationship with temperature is closer than in the case of either the pattern or the rate of breakup, but it is not close enough to establish temperature as the main control in this respect. In spite of the fact that the year of earliest clearing, 1945, had unusually high temperatures, the year 1951 was later in clearing and had even higher temperatures. However, two of the colder than average seasons, 1948 and 1950, were the latest in clearing. Low late winter and early spring temperatures appear to retard the clearing more than low fall and early winter temperatures.

The best correlation is discovered between the temperatures of the ice season and the quantity and extent of ice.[34] Due to the lack of reliable data concerning winter ice conditions, this estimation of the severity of each season is based primarily on the conditions existing in March (see Table II). The terms used to describe these conditions,

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[34]By "quantity" is meant the total volume of ice and by "extent" is meant the area which is ice-covered.

light, moderate to light, moderate, moderate to heavy, and heavy, are relative only; each of the thirteen seasons is compared with the rest. The term "light" indicates that the ice was less extensive and appeared in smaller quantities than in the other years, while "heavy" is taken to represent a more extensive and abundant occurrence of ice. The other terms define intermediate conditions.

The seasons of high temperatures coincide with those of light ice conditions and the seasons of low temperatures with those of heavy ice conditions. Between these extremes the other years fit the pattern reasonably well. It may appear that lower temperatures in the last three months cause more severe ice conditions than lower temperatures in the first three, as is suggested in the case of 1948 and 1950. However, the lower temperatures may have retarded early spring clearing which led to a misjudgment of the severity of the ice conditions. In view of this possibility and considering the nature of the information available, the assumption is not justified.

According to G. A. Mackay,[35] the ice clearance date in Hudson Bay is dependent mainly on the spring temperatures, and the winter temperatures have little influence on the breakup. This assertion was prompted by his investigations of air temperatures over Hudson Bay, particularly at Churchill. He was dealing mainly with landfast sheet ice and

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[35]Mackay, G. A., "The Effect of Protracted Spring Thaws on Ice Conditions in Hudson Bay," Bulletin of the American Meteorological Society, 33: 106, March, 1952.

not with shifting pack ice. Conditions in the Gulf of St. Lawrence differ from those in Hudson Bay in several respects. A good portion of the ice in the gulf does not remain where it is formed, consequently, the amount of ice present may vary considerably according to the temperatures in the season when ice is forming in the producing areas. Most of the ice is constantly shifting pack ice which does not remain in the gulf until temperatures are raised sufficiently to melt it, but rather, it moves toward Cabot Strait and is expelled to the open Atlantic.

Although the breakup of bays and harbours in the gulf may be accelerated by spring thaws, the clearing of the gulf as a whole may or may not respond to this impetus. In 1943, low spring temperatures may have retarded the opening of the Baie de Chaleur, but did not affect the speedy withdrawal of the ice from the gulf. Then in 1951 and 1952, high spring temperatures were not successful in bringing about early withdrawal. George Bay which generally freezes over completely is subject to invasions of ice long after its original ice sheet has disappeared. In 1943, however, George Bay was clear more than a month before the Baie de Chaleur, in spite of the low spring temperatures. The smaller bays and harbours in the gulf were not investigated.

The conclusion in regard to the importance of spring thaws as applied to the conditions in the Gulf of St. Lawrence must be that their primary effect is in decaying and breaking up ice sheets and in contributing to the clearing

process. As a factor in clearing, however, spring thaws are not predominant outside the small bays. On the other hand, the winter temperatures do influence the breakup in that they are partly responsible for the quantity and extent of ice to be cleared away.

The air temperature is definitely of fundamental importance in respect to ice conditions. It is the cooling of the atmosphere, in turn cooling the water, which produces ice in the first place. On the average, mean monthly temperatures are below freezing for four months of the year, providing a suitable climate for ice formation. Air temperature is such a variable factor that the temperatures of one ice season may be quite different from those of another. These differences are reflected primarily in the amount and the extent of ice which exists in the gulf during that season. When mean monthly temperatures are above average the ice will be less abundant and will cover a smaller area than when temperatures are below average. In spring the higher temperatures cause melting of ice and the breaking up of large ice sheets into pack ice. Temperature does not appear, however, to be the most important factor determining the movements of the ice, the rate of withdrawal, or the time of final clearing.

Precipitation. An examination of the figures for the difference from average of the mean monthly precipitation and the monthly total of snowfall in inches suggests that the influence of precipitation on ice conditions in the gulf is

slight.[36] In this investigation the same stations were used as in the case of temperature.

The main effect of precipitation seems to be the retardation of freezing by a snow-cover. A heavy blanket of snow lying on the ice throughout the winter months helps to retain heat. This limits the thickness of the ice because it is chiefly through conduction of heat upward that the ice sheet is able to build downward on the under side. In those years when the ice was heavy, as in 1943, 1948, and 1950, the tendency was toward lower than average snowfalls. On the other hand, when the ice was lighter, as in 1945 and 1946, the tendency was toward higher than average snowfalls. The correlation is by no means close, however.

Whether or not this influence is important, heavy snowfall is responsible for the formation of slush. When low temperatures follow a snowfall the slush frequently provides a mortar which aids in cementing pack ice into large sheets. During the breakup the effect of precipitation is relatively insignificant. Throughout the ice season, as a whole, it is likely that precipitation performs a minor role in determining the ice conditions in the gulf.

Wind. The wind is definitely the most important factor in determining the deviation from the expected pattern and rate of withdrawal of the ice as dictated by the non-

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[36]Department of Transport, Meteorological Division, Monthly Record (monthly statistics series). Toronto, 1940-1950.

variable factors. As was indicated by the wind roses (following page 27), prevailing winds throughout the winter and spring have a westerly component, but in spring this dominance is less pronounced. Although the drift of floating ice is approximately thirty degrees to the right of the wind direction, due to the earth's rotation, it varies according to the closeness of the pack. In any case, it is possible to deal with the effect of wind in the general terms, northerly, easterly, southerly, and westerly without specifying actual directions. There is no doubt that westerly winds are a potent factor, combining with the currents, in causing the ice to move toward Cabot Strait.

In order to discover the influence on the ice of the annual variation of the wind, the statistics for the total mileage of wind by directions were examined at twelve stations.[37] These figures indicate the prevailing direction for each month as determined by the total velocity of the wind, rather than by the total hours of wind. In addition, daily synoptic charts for the months of March and April were scanned in the case of the years 1944, 1945, 1948, 1951, and 1952. These observations proved that the winds during February, March, and April are the primary control of the pattern and rate of breakup, as well as of the time of final clearing.

A short period of strong wind from one direction tends to have a greater effect on ice movement than a long period

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[37] Ibid., 1940-1950.

of weak wind. This is logical because the wind must overcome the forces of friction before the ice can be moved appreciably. Therefore, gales exert an influence quite out of proportion to the length of time they blow. Strong winds are able to overpower water currents in some instances. Only the constant currents in the gulf are never checked by the wind; the weak flows and the tidal currents are all susceptible to the power of wind, especially when loose ice is present. The ice floes present the wind with a rougher surface that is easier to grip. Not only does the wind aid or hamper the normal water current flow, but also it generates currents which may continue to flow even after the wind has abated.

In view of the great transporting power of wind, it is obvious that a period of several days with sustained strong wind from one direction can redistribute tremendous quantities of pack ice in the gulf. The frequency of such periods of wind from the same direction during February, March, and April is of utmost importance. For example, in 1952, strong northerly winds prevailed for several periods of a week or more in February and March, resulting in accumulation of the ice in the southern part of the gulf (see Table II, page 88). The same process occurred in 1951, except that the winds were more easterly and continued until the middle of April, driving the ice toward the western section. In 1943, sustained southerly winds were responsible for pushing the ice northward where it found its way out of the gulf readily.

These cases are extreme; the more likely occurrence is the cancelling of the work of one period by that of another. That is to say, if the winds are strong easterly for a few days, they may be strong westerly in the next period. Often the periods are short and cause only minor diversions of the ice. A period of very light variable winds may create a stagnation of the ice as occurred in late April, 1952.

These influences of the wind are reflected, as has been pointed out, in the pattern of breakup. Those years in which the ice tended to stagnate in the southern part of the gulf were characterized by excessive strong northerly wind at some time during the season or lack of sufficient southerly wind. In some cases there was an actual accumulation of ice in the south, as in 1952, while in others the ice present simply did not withdraw readily, as in 1944. The season of 1952 serves as an example of stagnation throughout April due to weak and variable winds as well as one of southern accumulation.

On the other hand, the years in which the ice withdrew more readily from west to east experienced a favourable combination of wind throughout the spring season. Short periods of southerly winds followed by longer periods of westerly appear to assure the withdrawal of the ice from the south. If strong winds occur frequently, as in 1945, the exodus is accelerated. The other patterns, that of 1943, when the ice moved northward during April, and that of 1951, when the ice lingered in the western part of the gulf, were caused by southerly and easterly winds respectively.

The influence of the wind on the rate of breakup is apparent because the wind is a vital factor in moving the ice. Should the wind combine forces with the water currents in driving ice through Cabot Strait and in feeding this stream with ice from the bays and bights of the more confined sections of the gulf, the clearing would progress rapidly. But on the contrary, should the wind oppose the water currents and other forces tending to clear the gulf, the clearing would be retarded. This adverse effect occurs most severely with northeast winds which, considering the deviation in the drift of the ice, drive the ice southward. The case of 1952 is witness to this effect. Of course, the rate of breakup may be rapid through part of the season and then be slowed by northerly or easterly winds for a short period of time. The season of 1948 was subject to north and northeast winds of a high velocity toward the end of April which forced the ice onshore along the east coast of Cape Breton, although it had been offshore throughout most of the month.

Similarly, the time of final clearing is mainly determined by the wind. In retarding the withdrawal of ice by causing stagnation in the southern section, the wind is directly responsible for ice remaining unduly late in the gulf. In several instances when there was a direct withdrawal, the ice was held onshore in the dispersal region by easterly winds.

The quantity and extent of ice are also affected by the wind. When ice formation is in progress the wind aids the tides and tidal currents in disengaging ice from the land

and from shoals in the producing areas and carrying it away to add to the shifting pack. The extent of ice may be reduced materially by accumulation in one particular area as a result of wind. In this manner the wind is often responsible for the closeness of pack ice.

Most of the shifting in position of pack ice is caused directly by the wind. Northerly winds brought ice southward blocking the steamer track in mid-April in the seasons of 1942 and 1950. In 1948, southerly winds pushed the ice to the north side of Northumberland Strait about the middle of April and kept the ice off the Cape Breton east coast. Likewise, in 1952, the ice was shifted from one side of the strait to the other around April 25. Westerly winds generally clear southeast coastal areas readily. This effect may be noticed along the north side of the Baie de Chaleur, the southeast coasts of Prince Edward Island, the Magdalen Islands, and Cape Breton Island. The northward movement of ice in 1943, occasioned by southerly winds, effectively blocked the mouth of the Baie de Chaleur which greatly retarded its clearing.

The wind is of utmost importance in the clearing of ice from the gulf. On the average, the prevailing westerly winds during the ice season assure that most of the ice will eventually depart from the gulf through Cabot Strait. The loss of dominance by westerly winds for varying periods of time results in a different behaviour of the ice. Periods of sustained northerly or easterly winds cause accumulation of ice in the southern part of the gulf and slow the rate of

TABLE II

RELATIONSHIPS BETWEEN TEMPERATURE, WIND, AND ICE CONDITIONS

Group		Temperatures	Year	Winds	Pattern of Breakup	Rate of Breakup	Time of Final Clearing	Quantity and Extent of Ice
1. above average temperatures	A.	every month well above average	1945	strong westerly	west to east, direct withdrawal	rapid in March and April	early April	light
			1951	strong easterly and northerly	west side accumulation	slow in March and April	late April	light
	B.	most months well above average	1949	northerly and westerly	west to east, direct withdrawal	rapid in March and April	late April	moderate to light
			1952	strong northerly and light, variable	stagnation in south	slow in March and April	early May	moderate to light
	C.	most months above average or near average	1940	(insufficient data)	west to east, direct withdrawal	moderate in March, rapid in April	early May	moderate to light
2. first 3 months colder than last 3	A.	first three months near average, last three months higher than average	1942	strong northerly	stagnation in south	moderate in March, slow in April	early May	moderate to light
			1946	strong westerly followed by northerly and easterly	stagnation in south	rapid in March slow in April	early May	moderate
	B.	first three months lower than average, last three higher than average	1941	(insufficient data)	west to east, direct withdrawal	rapid in March and April	late April	moderate to heavy
			1947	westerly and southerly	west to east, direct withdrawal	rapid in March and April	early May	moderate to heavy
3. first 3 months warmer than last 3	A.	first three months above average, last three months below average	1948	strong westerly followed by strong northerly and easterly	west to east, direct withdrawal	rapid in March and April	middle of May	heavy
			1950	strong northerly	stagnation in south	moderate in March slow in April	middle of May	heavy
	B.	Two of first three months above average last three below average	1944	strong westerly and northerly	stagnation in south	rapid in March slow in April	late April	moderate to heavy
4. below average temperatures		four months well below average	1943	strong southerly and westerly	south to north, direct withdrawal	rapid in March and April	early May	heavy

clearing. Westerly and southerly winds in combination lead to the prompt withdrawal of ice through Cabot Strait. As a result, wind is the major factor in determining the pattern and rate of breakup as well as the time of final clearing, and it is responsible for many of the minor changes in position of the pack ice.

SUMMARY

The process of ice formation and melting is directly caused by temperature. Because data is lacking concerning water temperatures, only air temperatures are used as an index of the influence of this factor. The fact that the temperatures do become low enough in winter to cause formation of ice and high enough in spring to cause melting establishes temperature as the primary factor in determining ice conditions. Beyond the bounds of average conditions, annual variations of temperature largely determine the quantity and extent of ice and to a certain degree the time of final clearing. With the temperature favourable to ice formation, it is partly the shallowness of some areas that induces ice to originate and it is the physiographic framework which is responsible for obstructing the free movement of ice to the open ocean. The bays and bights detain the ice and offshore islands constitute obstacles in the path of movement.

Assuming the existence of ice within this framework, the factors of movement exert their influence. The tides are effective in breaking ice sheets which have formed along the

shore or over shoals and winds and tidal currents keep the ice in motion in many sections of the gulf throughout the winter. In this manner the total ice supply is augmented. Constant ocean currents provide a system of transportation which carries ice into the gulf from the St. Lawrence estuary and also conducts ice outside through Cabot Strait. The lack of constant currents in the southern part of the gulf to aid in the removal of ice is partly responsible for the stagnations which frequently occur in that area.

But these factors of movement cannot explain the remarkable variety of behaviour patterns of the ice. Instrumental in causing these variations is the wind. It appears to be the predominant factor in determining the pattern and rate of breakup and, to a certain degree, the time of final clearing and the quantity and extent of ice. The continual fluctuation of pack ice in relation to the land is essentially due to the wind's influence. While there are numerous other factors which influence the ice during the breakup season, it is suggested that these are the major ones.

CHAPTER VI

CONCLUSION

The investigation of the distribution of ice in the Gulf of St. Lawrence during thirteen breakup seasons yields the fact that the behaviour of the ice is extremely variable, although it follows certain patterns. Examination of environmental factors which exert an influence on the ice reveals distinct correlations with the behaviour of the ice. These factors, both non-variable and variable in function, act in combination to determine the ice behaviour, but it is the variable factors, mainly meteorological, which are chiefly responsible for the year to year differences.

In view of the variable behaviour of the ice due to these factors, the determination of average conditions is rendered difficult. The thirteen-year period examined is hardly long enough to achieve valid averages. It is established that many of these years were distinctly above average in respect to temperature, while few were below average. This fact serves to indicate that the ice conditions of this period, as a whole, were less severe than those which might be expected in a future period. Nevertheless, certain generalizations can be made with justification.

The Gulf of St. Lawrence is never completely ice-covered; there are always areas of open water because much of the ice is shifting pack ice, especially in the central part. The southern section is an area of accumulation and there are

usually large ice sheets in this region as well as considerable close pack ice. In most parts of the gulf the ice does not remain in the spring until it melts, but rather, it drifts into the open Atlantic primarily through Cabot Strait.

The discharge of ice is commonly in progress during February, but it is accelerated in March. Cabot Strait is seldom completely blocked for more than a few days at a time, in spite of the statement which appears in the Gulf of St. Lawrence Pilot[38] to the effect that it is blocked solid with ice nearly every year, often for three weeks at a time. The ice field in the dispersal region generally extends eastward past 58 degrees west and southward past 45 degrees north. Occasionally, the ice moves onshore along the south coast of Cape Breton under the influence of easterly winds, but seldom encroaches on the area off the south coast of Newfoundland. Most of the ice which is the first to depart from the gulf comes from the central area between Anticosti Island and Cabot Strait. However, this central region may continue to be ice-covered until late in March or early in April due to invasions of ice from other areas.

Most of the ice in the lower estuary of the St. Lawrence River finds its way into the gulf by the middle of March, leaving the stretch between Pointe des Monts and the gulf clear of ice. Toward the end of March the steamer route opens and allows navigation to commence. Frequently, the passage north of Anticosti Island clears before that south

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[38]Department of Mines and Resources, Gulf of St. Lawrence Pilot, Third Edition. Ottawa, 1946, p. L.

of it. The steamer track is sometimes blocked by ice during April when northerly winds drive ice from the northeast arm across it. Ordinarily, however, the ice north of a line from Cape St. George to Natashquan is not discharged through Cabot Strait but tends to drift northward where it disintegrates and melts.

Early in April the ice withdraws from the western part of the gulf, leaving ice in the Baie de Chaleur, although the bay is clearing along the northern side. Throughout the southern section the larger ice sheets are breaking up, rendering the ice more mobile. In the meantime, the stream of ice through Cabot Strait continues with the bulk of ice confined to the Cape Breton side. The field of ice beyond the strait has receded from its position of greatest extent in March. As the month progresses the ice moves toward Cabot Strait. The region around the Magdalen Islands clears before the southern area and the belt of ice in Cabot Strait becomes narrower. Most of the ice has departed from the Baie de Chaleur by the end of the third week in April. Northumberland Strait clears from its western entrance eastward and the last ice to withdraw from the gulf in late April or early May is that in the southeastern sector along the west coast of Cape Breton. Sometimes the Strait of Canso clears in early April, but it is dependent on the clearing of George Bay and the ice may remain here until the end of the month. Likewise, ice is found in the dispersal region off the Cape Breton east coast until the end of April.

The ice fields are constantly shifting position. Some areas may be clear at certain times and ice-covered at others, depending primarily on the direction of the wind. Such fluctuations are especially noticeable along the east and south coasts of Cape Breton where the ice may be driven alternately onshore and offshore by the wind. As a result of these encroachments, Louisburg harbour is sometimes blocked for a few days in April, but usually there exists a shore lead inside the ice field. The east coast is more susceptible to these invasions because the ice does not clear from this area until the end of April or early May. Consequently, Sydney harbour may be blocked for longer periods and until a later date than Louisburg.

The variability of the ice conditions in the breakup season is well illustrated by the thirteen years examined. With the gulf essentially open by the end of March, the year 1945 probably witnessed one of the earliest clearings which might be expected. On the other hand, the year 1950 saw ice remain in the gulf until May 15. The unusual patterns of breakup which characterized the years 1943 and 1951 may not occur frequently, but it is possible that other patterns, equally distinctive, that are not represented among the years studied may yet occur. On the basis of the thirteen years it appears that, most often, the ice will either withdraw directly from the west to east, passing through Cabot Strait readily, or will tend to stagnate in the southern part of the gulf toward the end of the season.

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Pocket

Charles Nelson Howard

Geology - Geography

APPENDIX

MAPS OF LIMITS OF MAIN ICE AREAS

MAP	
9	Season of 1940
10	Season of 1941
11	Season of 1942
12	Season of 1943
13	Season of 1944
14	Season of 1945
15	Season of 1946
16	Season of 1947
17	Season of 1948
18	Season of 1949
19	Season of 1950
20	Season of 1951
21	Season of 1952

GULF OF ST. LAWRENCE

LIMITS OF MAIN ICE AREAS
BREAKUP SEASON OF 1940

Ice Limits

- April 5 th
- April 15 th
- April 25 th
- May 1st
- May 5 th

Open Water April 5 th

SCALE IN MILES
20 10 0 20 40

MAP 9

66 64 62 60 58

50 48 46 44

QUEBEC

NO DATA

ANTICOSTI

NEWFOUNDLAND

NEW BRUNSWICK

PRINCE EDWARD ISLAND

NOVA SCOTIA

APR 5

APR 15

APR 25

MAY 1

Sable Island

MEAN MONTHLY TEMPERATURE DIFFERENCE FROM AVERAGE (Each dot represents one station)

°F 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14

NOV. 1939 | DEC. 1939 | JAN. 1940 | FEB. 1940 | MAR. 1940 | APR. 1940

GULF OF ST. LAWRENCE

LIMITS OF MAIN ICE AREAS
BREAKUP SEASON OF 1941

Ice Limits

- April 5 th
- April 15 th
- April 25 th
- May 1st
- May 5 th
- Open Water April 5 th

SCALE IN MILES
20 10 0 20 40

MAP 10

QUEBEC

NO DATA

Anticosti I

MAY 1

APR 25

APR 15

APR 5

NEW FOUNDLAND

NEW BRUNSWICK

APR 5

APR 15

PRINCE EDWARD ISLAND

APR 15

APR 5

APR 25

APR 25

APR 25

APR 15

APR 5

NOVA SCOTIA

Sable Island

MEAN MONTHLY TEMPERATURE DIFFERENCE FROM AVERAGE (Each dot represents one station)

°F 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14 °F

NOV. 1940 | DEC. 1940 | JAN. 1941 | FEB. 1941 | MAR. 1941 | APR. 1941

66 64 62 60 58

50 48 46 44

GULF OF ST. LAWRENCE

LIMITS OF MAIN ICE AREAS
BREAKUP SEASON OF 1942

Ice Limits

April 5th — May 1st

April 15th — May 5th

April 25th

Open Water April 5th

SCALE IN MILES

20 10 0 20 40

MAP II

QUEBEC

NO DATA

NEWFOUNDLAND

NEW BRUNSWICK

NOVA SCOTIA

PRINCE EDWARD ISLAND

APR 5

APR 15

APR 25

MAY 1

MAY 5

Sable Island

MEAN MONTHLY TEMPERATURE DIFFERENCE FROM AVERAGE (Each dot represents one station)

°F

14 12 10 8 6 4 2 0 2 4 6 8 10 12 14

NOV. 1941 | DEC. 1941 | JAN. 1942 | FEB. 1942 | MAR. 1942 | APR. 1942

66 64 62 60 58

50 48 46 44

GULF OF ST. LAWRENCE

LIMITS OF MAIN ICE AREAS
BREAKUP SEASON OF 1943

Ice Limits

- April 5 th
- April 15 th
- April 25 th
- May 1st
- May 5 th

Open Water April 5 th

SCALE IN MILES
20 10 0 20 40

MAP 12

QUEBEC

NO DATA

ANTICOSTI I.

APR 5

APR 15

MAY 1

APR 25

APR 25

APR 15

MAY 1

NEW BRUNSWICK

PRINCE EDWARD ISLAND

APR 15

APR 25

APR 15

APR 5

NOVA SCOTIA

NEWFOUNDLAND

Sable Island

MEAN MONTHLY TEMPERATURE DIFFERENCE FROM AVERAGE (Each dot represents one station)

°F 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14 °F

NOV. 1942 | DEC. 1942 | JAN. 1943 | FEB. 1943 | MAR. 1943 | APR. 1943

64 62 60 58

50 48 46 44

66 64 62 60 58

GULF OF ST. LAWRENCE

LIMITS OF MAIN ICE AREAS
BREAKUP SEASON OF 1944

Ice Limits

- April 5 th
- April 15 th
- April 25 th
- May 1st
- May 5 th

Open Water April 5 th

SCALE IN MILES
20 10 0 20 40

MAP 13

QUEBEC

NO DATA

Anticosti I.

APR 5

NEWFOUNDLAND

APR 15

NEW BRUNSWICK

PRINCE EDWARD ISLAND

APR 15
APR 25
APR 5

APR 15
APR 25
APR 5

APR 5

NOVA SCOTIA

APR 25

Sable Island

MEAN MONTHLY TEMPERATURE DIFFERENCE FROM AVERAGE (Each dot represents one station)

°F 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14

NOV. 1943 | DEC. 1943 | JAN. 1944 | FEB. 1944 | MAR. 1944 | APR. 1944

66 64 62 60 58

50 48 46 44

GULF OF ST. LAWRENCE

LIMITS OF MAIN ICE AREAS
BREAKUP SEASON OF 1945

Ice Limits

- April 5 th
- April 15 th
- April 25 th
- May 1st
- May 5 th

Open Water April 5 th

SCALE IN MILES
20 10 0 20 40

MAP 14

QUEBEC

NO DATA

Anticosti I.

NEWFOUNDLAND

APR. 5

APR. 5

NEW BRUNSWICK

PRINCE EDWARD ISLAND

APR. 5

APR. 5

NOVA SCOTIA

Sable Island

MEAN MONTHLY TEMPERATURE DIFFERENCE FROM AVERAGE (Each dot represents one station)

°F 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14

NOV. 1944 | DEC. 1944 | JAN. 1945 | FEB. 1945 | MAR. 1945 | APR. 1945

66 64 62 60 58

50 48 46 44

GULF OF ST. LAWRENCE

LIMITS OF MAIN ICE AREAS
BREAKUP SEASON OF 1946

Ice Limits

- April 5 th
- April 15 th
- April 25 th
- May 1st
- May 5 th

Open Water April 5 th

SCALE IN MILES
20 10 0 20 40

MAP 16

QUEBEC

NO DATA

ANTICOSTI I.

APR. 25

APR. 5

APR. 15

NEWFOUNDLAND

APR. 5

APR. 15

NEW BRUNSWICK

APR. 5

APR. 25

APR. 15

MAY 1

PRINCE EDWARD ISLAND

APR. 25

NOVA SCOTIA

APR. 15

APR. 5

Sable Island

°F MEAN MONTHLY TEMPERATURE DIFFERENCE FROM AVERAGE (Each dot represents one station) °F

14 12 10 8 6 4 2 0 2 4 6 8 10 12 14

NOV. 1945 | DEC. 1945 | JAN. 1946 | FEB. 1946 | MAR. 1946 | APR. 1946

66 64 62 60 58

50 48 46 44

GULF OF ST. LAWRENCE

LIMITS OF MAIN ICE AREAS
BREAKUP SEASON OF 1947

Ice Limits

- April 5th
- April 15th
- April 25th
- May 1st
- May 5th

Open Water April 5th

SCALE IN MILES
20 10 0 20 40

MAP 16

66 64 62 60 58

QUEBEC

NO DATA

ANTICOSTI I.

APR. 5

APR. 15

APR. 25

NEWFOUNDLAND

APR. 15

APR. 25

MAY 1

APR. 25

APR. 15

APR. 5

NEW BRUNSWICK

PRINCE EDWARD ISLAND

NOVA SCOTIA

Sable Island

MEAN MONTHLY TEMPERATURE DIFFERENCE FROM AVERAGE (Each dot represents one station)

°F 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14

NOV. 1946 | DEC. 1946 | JAN. 1947 | FEB. 1947 | MAR. 1947 | APR. 1947

66 64 62 60 58

50 48 46 44

GULF OF ST. LAWRENCE

LIMITS OF MAIN ICE AREAS
BREAKUP SEASON OF 1948

Ice Limits

- April 5 th
- April 15 th
- April 25 th
- May 1st
- May 5 th

Open Water April 5 th

SCALE IN MILES
20 10 0 20 40

MAP 17

QUEBEC

NO DATA

Anticosti I.

NEWFOUNDLAND

NEW BRUNSWICK

NOVA SCOTIA

PRINCE EDWARD ISLAND

APR 5
APR 15
APR 25
MAY 1
MAY 5

Sable Island

66 64 62 60 58

50 48 46 44

MEAN MONTHLY TEMPERATURE DIFFERENCE FROM AVERAGE (Each dot represents one station)

°F 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14

NOV. 1947 | DEC. 1947 | JAN. 1948 | FEB. 1948 | MAR. 1948 | APR. 1948

GULF OF ST. LAWRENCE

LIMITS OF MAIN ICE AREAS
BREAKUP SEASON OF 1949

Ice Limits

- April 5 th
- April 15 th
- April 25 th
- May 1st
- May 5th

Open Water April 5 th

SCALE IN MILES
20 10 0 20 40

MAP 18

QUEBEC

NO DATA

ANTICOSTI I.

NEWFOUNDLAND

NEW BRUNSWICK

PRINCE EDWARD ISLAND

NOVA SCOTIA

APR 5
APR 15
APR 25

Sable Island

MEAN MONTHLY TEMPERATURE DIFFERENCE FROM AVERAGE (Each dot represents one station)

°F

NOV. 1948 | DEC. 1948 | JAN. 1949 | FEB 1949 | MAR 1949 | APR. 1949

66 64 62 60 58

50 48 46 44

GULF OF ST LAWRENCE

LIMITS OF MAIN ICE AREAS
BREAKUP SEASON OF 1950

Ice Limits

- April 5 th
- April 15 th
- April 25 th
- May 1st
- May 5 th

Open Water April 5 th

SCALE IN MILES
20 10 0 20 40

MAP 19

QUEBEC

NO DATA

ANTICOSTI I.

NEWFOUNDLAND

NEW BRUNSWICK

PRINCE EDWARD ISLAND

NOVA SCOTIA

APR 5

APR 15

APR 25

MAY 1

MAY 5

Sable Island

MEAN MONTHLY TEMPERATURE DIFFERENCE FROM AVERAGE (Each dot represents one station)

°F 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14

NOV. 1949 | DEC. 1949 | JAN. 1950 | FEB. 1950 | MAR. 1950 | APR. 1950

66 64 62 60 58

50 48 46 44

GULF OF ST. LAWRENCE

LIMITS OF MAIN ICE AREAS
BREAKUP SEASON OF 1951

Ice Limits

- April 5 th
- April 15 th
- April 25 th
- May 1st
- May 5 th
- Open Water April 5 th

SCALE IN MILES
20 10 0 20 40

MAP 20

66 64 62 60 58

50 48 46 44

QUEBEC

NO DATA

NEWFOUNDLAND

NEW BRUNSWICK

NOVA SCOTIA

APR 5

APR 15

APR 25

Sable Island

MEAN MONTHLY TEMPERATURE DIFFERENCE FROM AVERAGE (Each dot represents one station)

°F 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14

NOV. 1950 | DEC. 1950 | JAN. 1951 | FEB. 1951 | MAR. 1951 | APR. 1951

GULF OF ST. LAWRENCE

LIMITS OF MAIN ICE AREAS
BREAKUP SEASON OF 1952

Ice Limits

- April 5 th
- April 15 th
- April 25 th
- May 1st
- May 5 th

Open Water April 5 th

SCALE IN MILES
20 10 0 20 40

MAP 21

66 64 62 60 58

50 48 46 44

QUEBEC

NO DATA

Anticosti

NEWFOUNDLAND

NEW BRUNSWICK

PRINCE EDWARD ISLAND

NOVA SCOTIA

APR 15
APR 5
APR 25
MAY 1
APR 25
APR 5
APR 15

Sable Island

MEAN MONTHLY TEMPERATURE DIFFERENCE FROM AVERAGE (Each dot represents one station)

°F 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14

NOV. 1951 | DEC. 1951 | JAN. 1952 | FEB. 1952 | MAR. 1952 | APR. 1952