C. J. Stevenson

Canada

GEOGRAPHICAL PAPER No. 23

Gulf of St. Lawrence Ice Survey, Winter, 1959

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79589-8—1

The shores of the St. Lawrence River converging toward the Quebec bridge, provide a funnel effect, constricting the ice as it passes under the bridge. This is an area of frequent ice jams. Landfast ice, bordered by massive pressure ridges, extends from the shores. Ice coverage of above 9/10 consists of new, young and winter ice forms. (Altitude 1,800 feet, March 8, 1959).

PREFACE

The Gulf of St. Lawrence ice survey, winter 1959, is a study resulting from the fourth winter aerial ice survey conducted over the Gulf of St. Lawrence region. In addition, a survey of the St. Lawrence River between Quebec and Montreal is included.

It is hoped that this report may bring about a clearer understanding of the nature, extent and distribution of the ice and thus contribute to the solution of problems associated with winter navigation of the St. Lawrence River and the Gulf of St. Lawrence.

N. L. Nicholson
Director
Geographical Branch

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GULF OF ST. LAWRENCE ICE SURVEY, WINTER 1959

INTRODUCTION AND ACKNOWLEDGEMENTS

The aerial survey of sea ice conditions in the Gulf of St. Lawrence from January to April, 1959 is a continuation of the survey first undertaken by the Branch in the winter of 1956.* The primary purpose of the survey was to observe and map the coverage and distribution of the various types of ice and to relate ice conditions to climatic factors.

The ice survey was conducted by the Geographical Branch with the cooperation of Air Transport Command R.C.A.F., and was coordinated by the Geophysical Research Section of the Defence Research Board. Specific acknowledgements are made to T.A. Harwood, Geophysical Research Section; W/C W.H. MacDonell of 408 (R) Squadron and C.C. Boughner, Climatological Division. The writer wishes to acknowledge the excellent cooperation received from the R.C.A.F. officers and crews responsible for the flights.

The operation was planned to begin about mid-January, two weeks earlier than in 1958, and to continue until mid-April. Owing to adverse weather conditions, the survey began on January 19 and was completed on April 29. Lancaster aircraft and crews were provided by R.C.A.F. Station, Rockcliffe, the base of operations. R.C.A.F. Station Summerside and R.C.N. Station Shearwater were used as advanced bases for the operation. Air Transport Command organised nine flights at approximately 10-day intervals. These were made from Rockcliffe on the following dates: January 19 and 29; February 11 and 20; March 5 and 17; and April 1, 14 and 28. The average duration of each operation was $3\frac{1}{2}$ days. Aircraft used in the survey were generally flown from 1,000 to 4,000 feet altitude, depending on local visibility conditions.

The aerial reconnaissance was conducted so that the St. Lawrence River from Montreal to the Saguenay River was surveyed during the outward and return flights. The Strait of Belle Isle formed the eastern limit of the survey. To obtain as complete a picture of ice conditions in this area, the gulf was crossed east to west and north to south in 3 flights each. Flight patterns were varied to permit the greatest possible observation of ice conditions and to avoid unfavourable local weather conditions. The flight tracks along the coastline permitted observation of ice in the harbours and bays.

In conjunction with the ice survey a photographic record of ice conditions was made; the photo-

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*For an account of previous ice surveys see Bibliography graphs included are by courtesy of the Royal Canadian Air Force.

The principal sections of the report are: weather conditions, ice distribution and ice coverage in the Gulf of St. Lawrence region; factors affecting ice distribution and ice coverage in the St. Lawrence River, and a photographic record of ice coverage. The section on weather conditions and ice distribution is mainly concerned with the relationship of ice cover to the prevailing climatic conditions; ice coverage and the photographic record provide a graphic presentation of the ice forms, their concentration and distribution. The symbols and main outline of ice classification used are based on those followed by the United States Hydrographic Office in reporting ice.

The method developed in Geographical Paper No. 19 of graphic and quantitative classification to include new, young and winter ice forms is followed in this report. The amount of winter ice in the distribution is considered to be the critical element in ice coverage. Wherever winter ice occurs in amounts of 3/10 or more in association with new or young ice forms, a close graphic pattern to represent winter ice is used. An open, graphic pattern to represent young ice is used to show an ice distribution that consists of 3/10 or more young ice in association with new ice forms. An open pattern of graphic presentation is used to show new ice forms that include such ice as grease, slush, frazil, very young ice and the early stages of sludge or slob ice. By this method of ice reporting, a fuller appreciation of ice conditions as they exist in the winter months may be provided.

PART I

THE GULF OF ST. LAWRENCE

WEATHER CONDITIONS

The winter of 1958-59 was unusually cold in the Gulf of St. Lawrence region, and was favourable for the formation of sea ice.

Mean monthly temperatures for the gulf region for November were normal, but well below the seasonal temperatures for the winter months; December recorded temperatures of -8, January +2, February -6, and March -5 degrees from the normal (Table 1)*

Regional variations in mean temperatures are evident from Table I. The northern gulf areas tended to have lower mean temperatures in the early stages of winter. The Strait of Belle Isle experienced substantially higher temperatures until February. Temperatures for the St. Lawrence River region in

*All degrees are in Fahrenheit

March tended to be similar to those of the southern gulf. North Shore temperatures in April were almost 30°; in the southern gulf temperatures ranged from 35° to 40°.

TABLE I

Average mean and normal monthly temperatures (Fahrenheit) for the gulf region from December, 1958 to March, 1959

	DECEMBER		JANUARY		FEBRUARY		MARCH	
	Mean	Normal	Mean	Normal	Mean	Normal	Mean	Normal
St. Lawrence R.	7	17	12	12	7	12	20	23
North Shore	6	14	14	7	2	9	15	19
St. of Belle Isle	16	19	20	11	5	11	14	19
Gaspé-Chaleur	9	20	15	13	8	15	16	24
Eastern gulf	21	28	22	22	9	21	18	26
Central gulf	20	26	20	19	12	16	22	23
Southern gulf	13	24	18	18	13	18	25	27
Cabot Strait	22	29	22	24	13	21	24	28
Av. Temp.	14	22	18	16	9	15	19	24

Generally, temperatures in the northwest region of the gulf in December tended to be similar to temperature conditions that existed in February; whereas, those in the remainder of the gulf tended to be similar to temperature conditions in January. Thus, at the end of December winter temperatures were from one to two months ahead of normal. The mean monthly temperatures for the gulf region for March (19°) was similar to January (18°), and also these temperatures tended to be similar to the normal mean January temperatures. The effect of these unusually low temperature conditions resulted in an extensive ice coverage that dominated the gulf in February, and that, by March, extended well to seaward from Cabot Strait.

In the gulf region, the mean isotherms for the winter months of 1958-59 (Figure 1A) trend in a general northeast-southwest direction. They show the southeastern gulf area for December as having temperatures 10° to 15° warmer than the North Shore; 5° to 10° warmer in January; 15° warmer in February, and 10° in March and 5° to 8° in April. Usually the normal winter isotherms show the North Shore to have temperatures 10° colder than the southern gulf area, and in March to be 6° colder. The pronounced range and persistent presence of low temperatures emphasize the widespread uniformity of ice-forming conditions that pervaded the gulf region during the winter months.

The departure from the normal isotherms (Figure 1B) show the extent to which various parts of

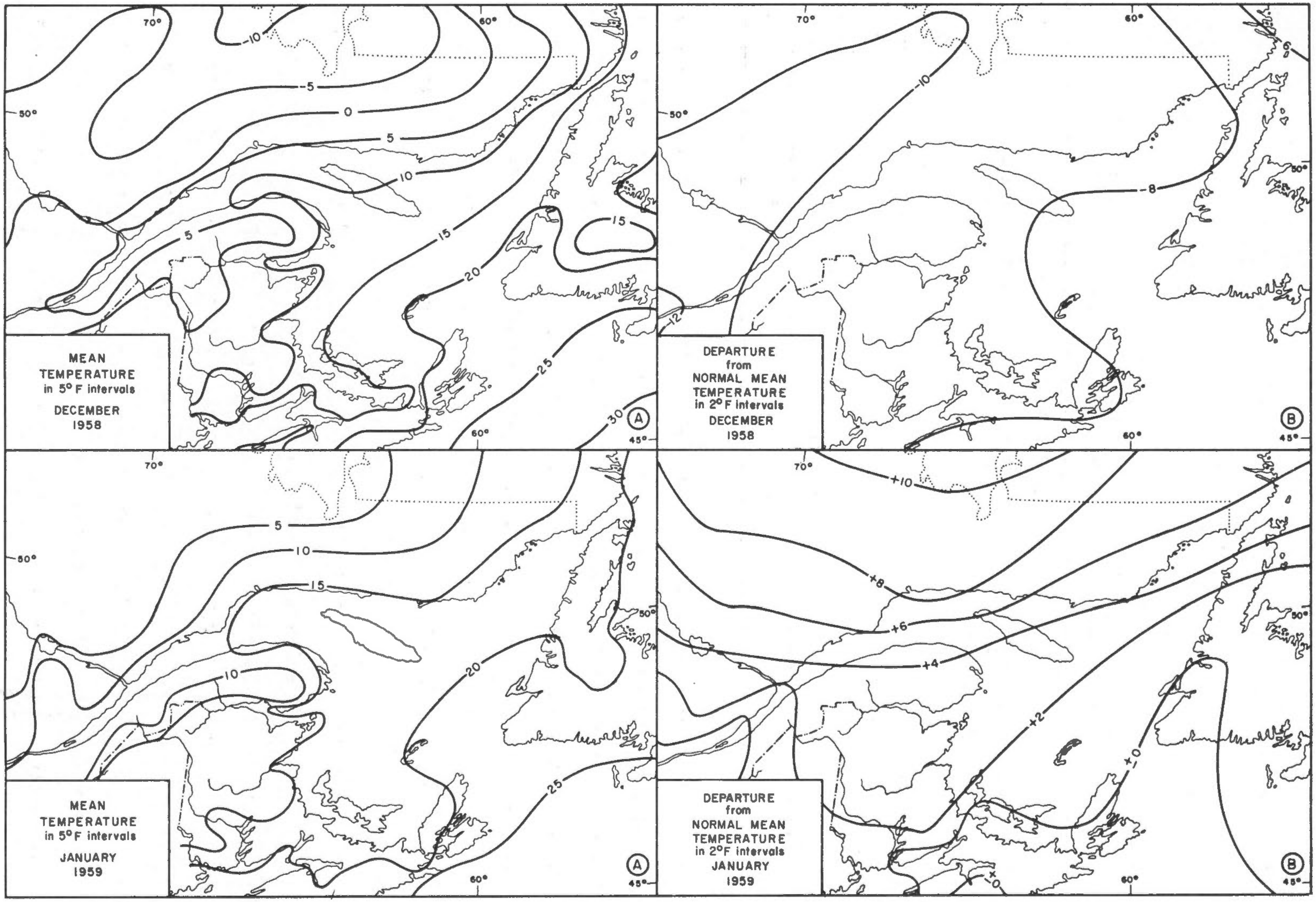

Figure (1A). Mean temperatures, December 1958 to March 1959.

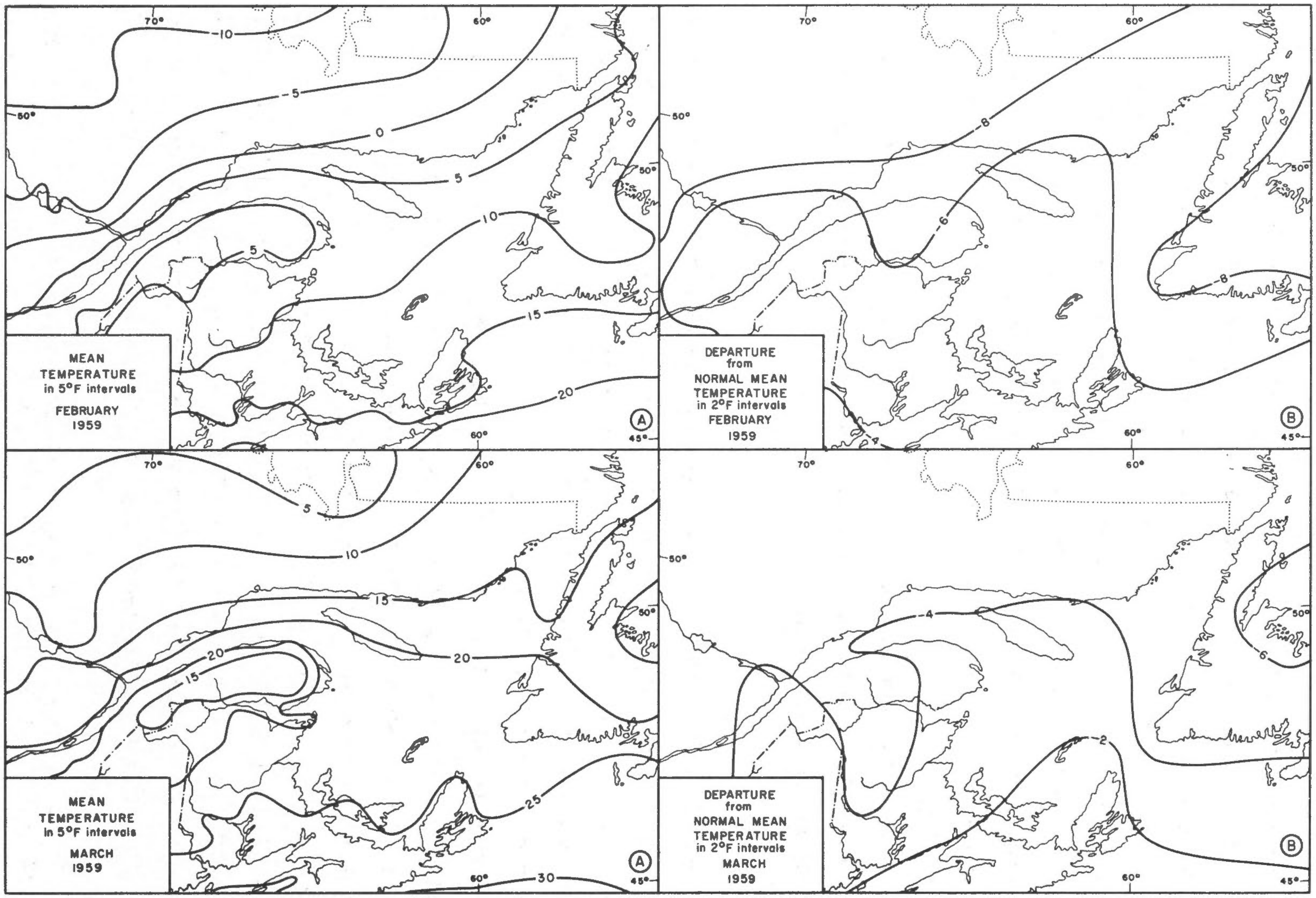

Figure 1(B). Departure from normal mean temperature, December 1958 to March 1959.

the gulf differed from normal winter conditions. The area of below normal temperatures in December extended from Cabot Strait to the St. Lawrence River valley from 7° below normal in Cabot Strait to 12° below normal above Quebec. The December of 1958 was the coldest December in most parts of the Maritime Provinces since.1933. (See Monthly Weather Map, December 1958. p. 1). In January, an above normal temperature anomoly centered over Ungava, stretched across the gulf region to provide seasonal temperatures in Cabot Strait and temperatures 4° to 8° above normal in the northern parts of the gulf. February temperatures were from 6° to 8° below normal, March 2° to 5° below normal, and April temperatures were 2° above the seasonal values for the gulf region. In the northeast arm and the Strait of Belle Isle, temperatures were normal in May.

As a result of the presence of abnormally low temperature conditions, air temperatures favourable for the formation of ice at 29 degrees* in gulf waters prevailed over the entire gulf region and extended over Cabot Strait from December to March.

Winds

Prevailing winds in winter blow, on the average, from the west and northwest. They are generally northwesterly along the north shore of the gulf and westerly over the southern gulf region. The winds tend to blow the ice from the north towards the south shore of the St. Lawrence River, from the north shore to Anticosti Island, and from the western gulf to Cabot Strait (Figure 1A). These winds also tend to cause ice congestion in Northumberland Strait.

During December 1958 when arctic air covered the gulf region, many low pressure air masses crossed the gulf with winds blowing mainly from southwest to northwest. Easterly sector winds were weak. By January, 1959, west and southwest winds prevailed over the St. Lawrence River, western and southern gulf areas; west to north winds prevailed over the remainder of the gulf. With the westward movement of continental air masses over the region during February, winds from the westerly sector were predominant, particularly west and northwest winds. March was marked by surges of continental and maritime air masses crossing the gulf region; S-SW-W sector winds were most prevalent. The prevailing April winds were from a similar direction. The effect of such winds was mainly to drive the gulf ice seaward through Cabot Strait. The frequency of changes in wind direction for various parts of the gulf is shown in Figure 2A.

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*The temperature is based on the general distribution of surface salivity of 30.00 to 32.00 (S°/oo). See Lauzier, L.M. A Preliminary Report of...1956. Figure 4).

Winds in December for the gulf region averaged from 10 to 27 m.p.h. Winds of fresh breeze-type (17 to 21 m.p.h.) were prevalent in the northeast arm of the gulf and the Strait of Belle Isle. Strong breeze-type winds (27 m.p.h.), that were approaching moderate gale force, were general in the central gulf region. Elsewhere in the gulf average wind velocities were from 10 to 15 m.p.h.

January winds varied from 10 to 25 m.p.h. There was an increase in wind velocity in the St. Lawrence River and a decrease of wind speed in the Cabot Strait area. Elsewhere January wind speeds were generally similar to those of December. The central gulf region experienced the strongest winds, averaging 25 m.p.h.

February wind speeds varied from 11 to 25 m.p.h. over various parts of the gulf. The central gulf area again reported the highest wind velocities with average speeds of 25 m.p.h. Winds in the Strait of Belle Isle averaged 20 m.p.h.

Wind speeds continued high for March with velocities ranging from 12 to 23 m.p.h., and were highest in the central gulf region.

Ice Drift

Wind direction and velocity, and sustained wind mileage are important additional factors affecting the surface distribution of ice. Generally, wind mileage and wind frequency tend to coincide. During this survey winds from the westerly and northerly sectors were usually the strongest, and together with mileage distance, caused a steady southeastward movement of the gulf ice toward Cabot Strait (Figure 2B)*. Shuleykin's (Armstrong, 1955) ratio of ice drift speed to wind speed (1:25) indicates that during January westerly winds provided a free daily drift of 10 miles, winds from other sectors provided the least, varying from 1.7 to 3.7 miles per day. Westerly winds in February maintained a higher rate of drift, of 12 miles per day, with support from northerly winds; drift from easterly and southerly winds were the least .9 to 3.7 miles per day. March experienced a weakening of westerly winds that was paralleled by an increase from other wind sectors, and therefore, a reduction in the rate of eastward ice drift. The free driving force of the winds from the westerly sector is about three times that of northerly winds and about five times that of easterly and southerly winds. The actual number of miles the ice drifts is found by deducting the ice-drift miles from the opposing wind sector; it provides the actual mileage of effective ice drift. Winds from an

*A number of places in Figure 2B are not in their proper geographic locations these have been shifted to accommodate the roses within the map.

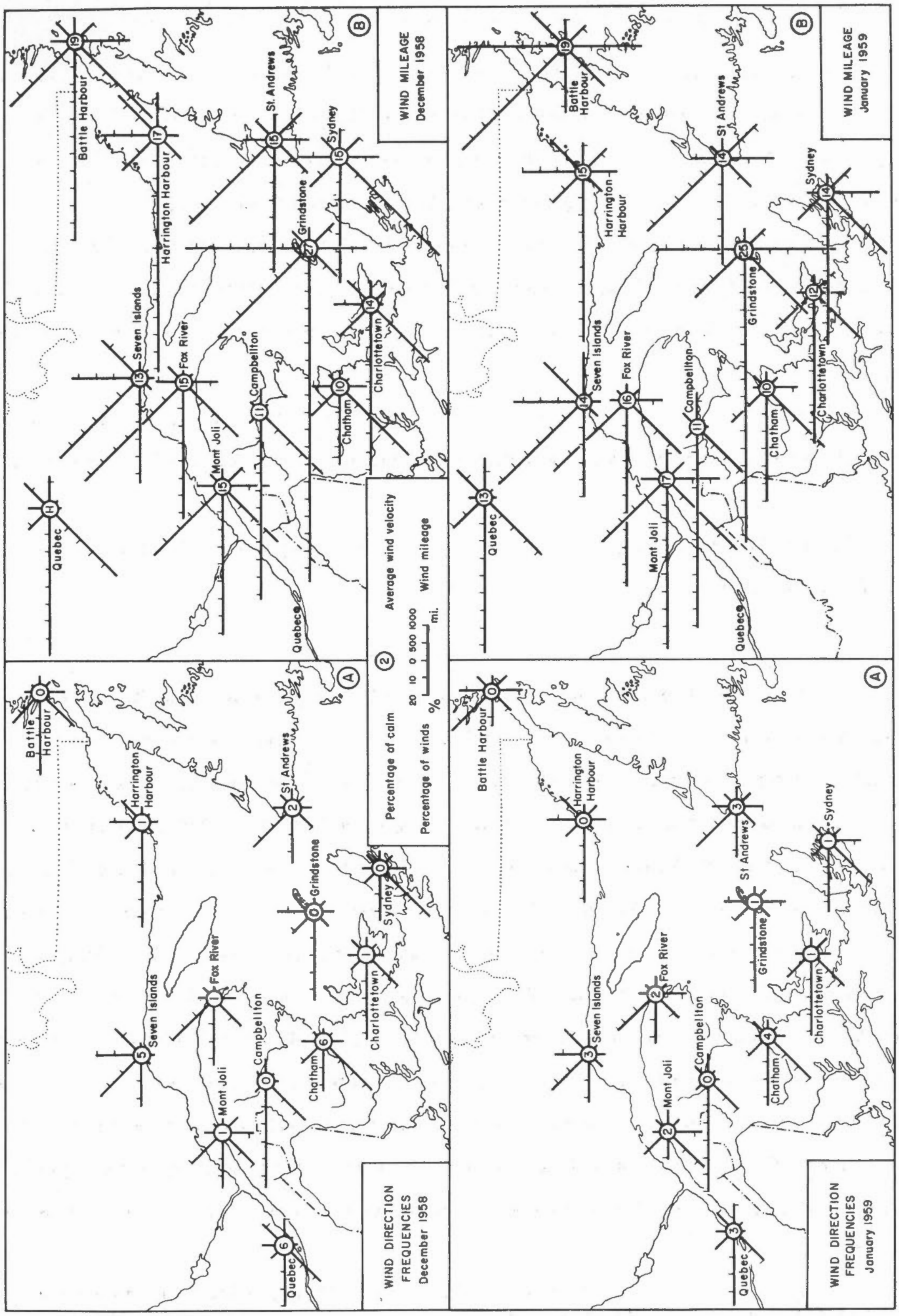


Figure 2(A). Wind direction frequencies, December 1958 to March 1959.

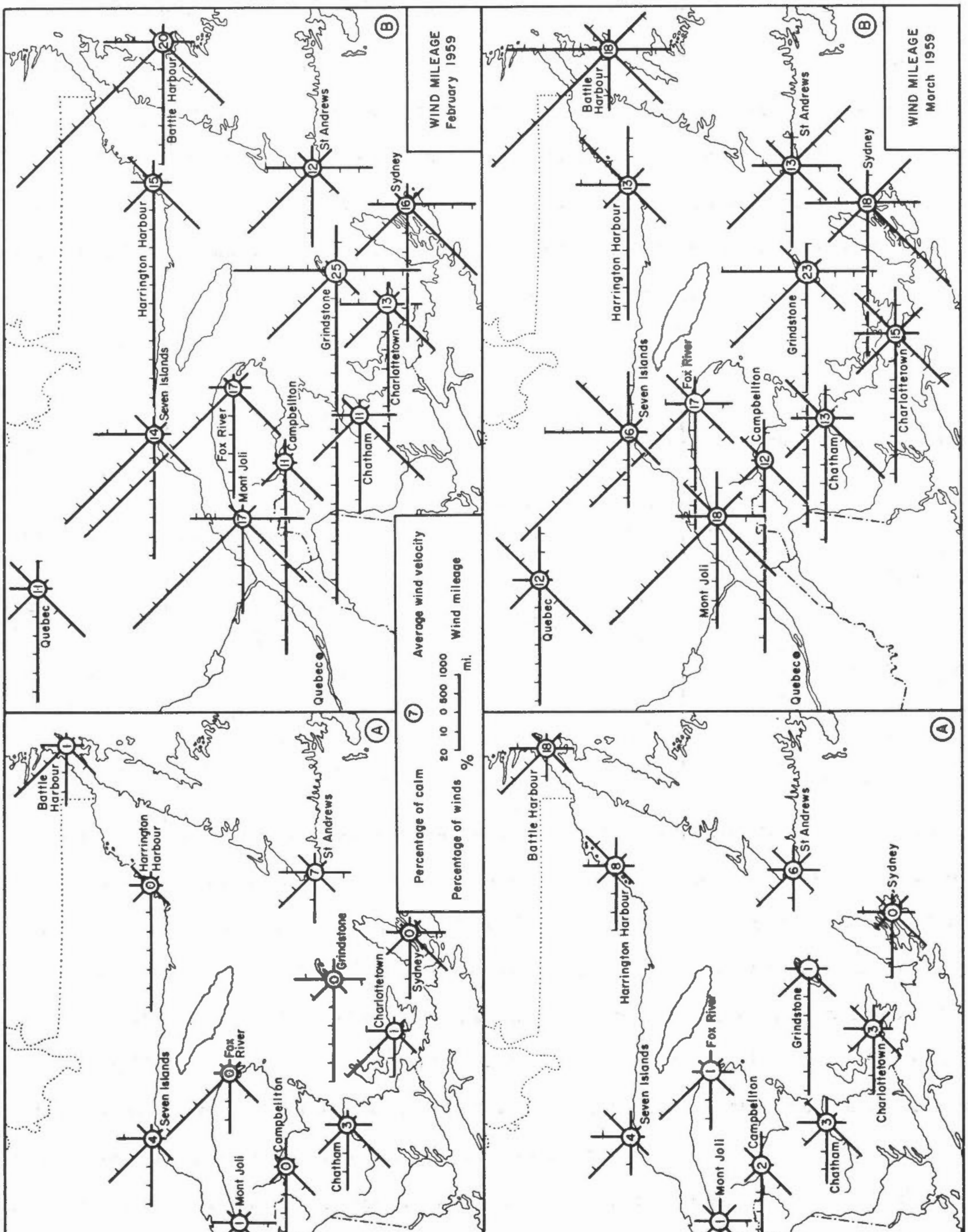


Figure 2(B). Wind mileage, December 1958 to March 1959.

adjacent sector may hinder or assist in the movement of the ice. In the St. Lawrence River for January, westerly winds tended to drive the ice diagonally across to the south shore at a drift speed of 11 miles per day; northerly winds tended to hold the ice against the shore at a drift speed of 3 miles a day; southerly winds tended to drive the ice off the shore at 4 miles a day. This general condition resulted in a strong downstream drift of ice at about 9 miles per day; however, as the current of the lower St. Lawrence flows at 1 m.p.h., the daily ice drift amounted to 31 miles per day.

TABLE II

Free ice drift per day in miles by sector, January, February and March 1959

AREA	WEST (SW - W - NW) Jan: Feb: Mar.	NORTH (NW - N - NE) Jan: Feb: Mar.	EAST (NE - E - SE) Jan: Feb: Mar.	SOUTH (SE - S - SW) Jan: Feb: Mar.
St. Lawrence R.	11 : 10 : 10	3 : 5 : 6	2 : 1 : 4	4 : 4 : 4
North Shore	8 : 11 : 8	7 : 5 : 8	3 : 1 : 5	2 : 2 : 2
Str. of Belle Isle	8 : 17 : 10	5 : 7 : 10	2 : 1 : 3	3 : 4 : 5
Western gulf	9 : 11 : 9	1 : 4 : 3	1 : .6 : 3	3 : 3 : 3
Northumberland Str.	9 : 9 : 9	2 : 4 : 5	1 : .8 : 4	4 : 4 : 4
Central gulf	16 : 17 : 15	5 : 7 : 7	1 : 1 : 3	7 : 4 : 6
Cabot Strait	9 : 9 : 9	3 : 4 : 5	2 : 1 : 4	5 : 5 : 7
Av. drift	10 : 12 : 10	3.7 : 5.1 : 6.3	1.7 : 0.9 : 3.7	2.8 : 3.7 : 4.4

January drift values indicate that westerly winds provided a strong, daily rate of ice drift to the east, that varied from 5 to 9 miles per day after retarding effects of easterly winds are deducted. In the central gulf area eastward drift of the ice was particularly strong. Northumberland Strait, which frequently became ice congested when winds from an east to north quadrant were prevalent, experienced conditions that kept the ice moving eastward. The effective eastward drift was 8 miles per day, with a supporting effective drift from the south sector of 2 miles per day. On the north shore of the gulf free eastward ice drift was 8 miles per day. Drift effectiveness of northerly winds was offset by opposing southerly winds; however the effective ice drift to the southeast was 5 miles per day, and was probably assisted by the south-east flow of the gulf current that paralleled the north and south coasts of Anticosti Island. In the northeast arm of the gulf daily effective eastward ice drift was 8 miles a day and was supported by an effective daily southward drift of $2\frac{1}{2}$ miles. The main effect of this was to drive the ice against the western coast of Newfoundland.

The effectiveness of westerly winds in moving the ice eastward was sustained throughout February and March. Such drift values explain in part the tendency for open water or for new ice forms to develop on the leeward shores of the land areas where the prevailing wind is effective in driving the ice seaward. The dominance of strong westerly winds and the attendant high daily rate of ice drift provide an explanation for the large proportion of pressure-ridged ice that was observed on the west coast of Cape Breton Island and particularly off the west coast of Newfoundland where pressure ridges varied from 4/10 to 8/10 of the ice surface. Extensive fields of heavy ice tended to be concentrated in the eastern part of the gulf under the eastward-driving influence of westerly winds. With the advance of spring conditions, the area of gulf ice diminished. There was a corresponding increase in the area of open water that began in the western part of the gulf, expanded eastward to Cabot Strait, and through April and May, extended northeast to the Strait of Belle Isle.

ICE DISTRIBUTION

The extent of ice coverage depends on the severity of the winter. The winter of 1958-59, compared with normal winter conditions, was unusually severe with air temperatures particularly favourable for the development and preservation of the icefields (Table III). As a result, ice formation and growth was a rapid process.

TABLE III

Mean Monthly Degree-days of Frost, 1958-1959

AREA	NOV.	DEC.	JAN.	FEB.	MARCH	Cum. D-d
St. Lawrence R.	-2	22	17	22	7	66
North Shore	1	23	15	27	14	80
St. of Belle Isle	1	13	9	24	15	62
Gaspé-Chaleur	-2	20	14	21	13	46
Eastern gulf	-6	8	7	20	11	40
Central gulf	-1	9	9	17	7	41
Southern gulf	-6	16	11	16	4	41
Cabot Strait	-8	7	7	16	5	27
Av. for gulf area	-2.9	14.7	11.1	20.4	9.5	50.4

Considering air temperatures over the gulf from November to March as an ice-forming factor, the month of November was unfavourable for the production of an ice cover. Ice-forming conditions were most effective from December to February. In December the most favourable ice-forming conditions prevailed over the northern half of the Gulf of St. Lawrence extending from the St. Lawrence River to the

Strait of Belle Isle. February, with a range of 16 degree-days* in the southern gulf and 27 degree-days in the northern gulf provided conditions highly favourable for the growth and expansion of the ice cover. Although there was a gradual lessening in the number of degree-days for March, the number favourable for the growth of ice was only 1.6 degree-days less than January.

April temperatures in the southern parts of the gulf were unfavourable for the maintenance of ice-fields in this area in May resulted mainly from oceanographic conditions rather than from climatic influences.

The expansion of the ice surface to cover the Gulf of St. Lawrence in the winter of 1958-59 was marked by a persistent advance of the ice front (Figure 3). By the third week of December, ice covered the St. Lawrence estuary and the southwestern gulf region; by mid-January the southern two-thirds of the gulf was ice covered and the St. Lawrence estuary was mainly ice-free below the Saguenay River except for ice that paralleled the Gaspé coast. On January 23, ice in the northeast arm of the gulf and in the Strait of Belle Isle bordered the north coast and was gradually extending eastward and southward. By the end of January the gulf ice had extended to the Newfoundland coast and southeastward through Cabot Strait.

A number of phases are evident in the advance of the gulf ice. In the early winter phase the St. Lawrence estuary was ice covered, but by mid-January the open water area of the estuary extended from the Saguenay River to Anticosti Island. A rapid expansion of the ice surface followed. By mid-February, open water was again limited to an area in the vicinity of the Saguenay River. In March there was a gradual increase in area of open water in the upper estuary and intermittent advance and retreat of new and young ice forms in the lower estuary. From March 25 to 28 the open water area of the lower St. Lawrence estuary extended eastward of Anticosti Island. In the eastern parts of the gulf during February and March there was a persistent similarity in ice conditions. After the passing of a continental high pressure air mass, there was usually an extension of new and young ice areas on the leeward side of the coasts, and a consolidation of floes within the icefields. With the passing of a low pressure air mass, the ice surface relaxed followed by a fracturing of the icefields. The shattering of the icefields into block and small floes was particularly marked in the Cabot Strait area, and into block and brash at the western end of Strait of Belle Isle. In the latter area tides and currents contributed to the "working over" of the icefields. The shattering of young ice into slob and pancake ice was a persistent characteristic in the St. Lawrence estuary after the passing of low pressure air masses. Wherever the free forward movement of the ice was blocked by land,

*A degree-day of frost is defined as a day with a mean temperature one Fahrenheit degree below the freezing point of sea water (29°).

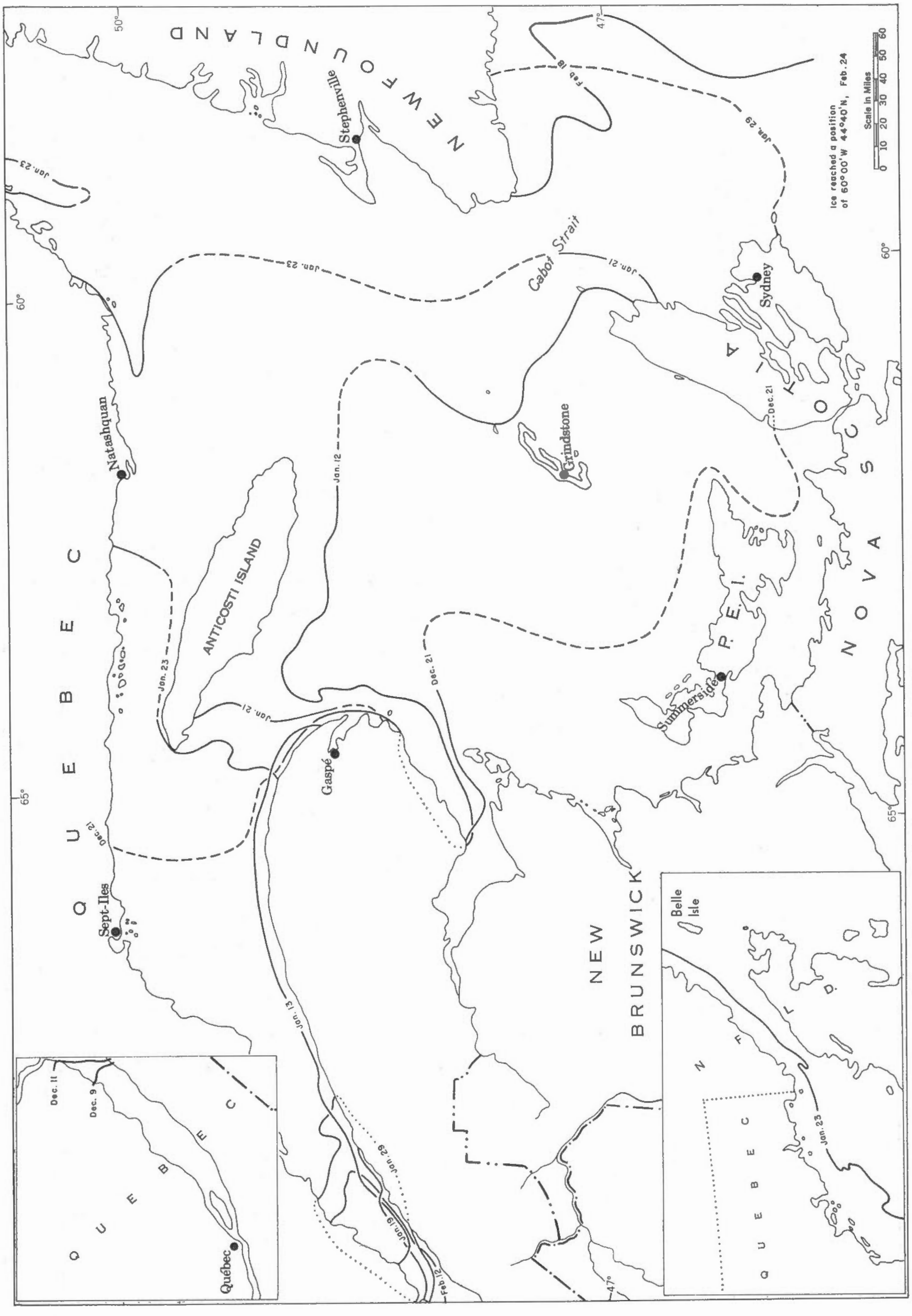


Figure 3. Advance of the ice fronts in the Gulf of St. Lawrence, Winter 1959.

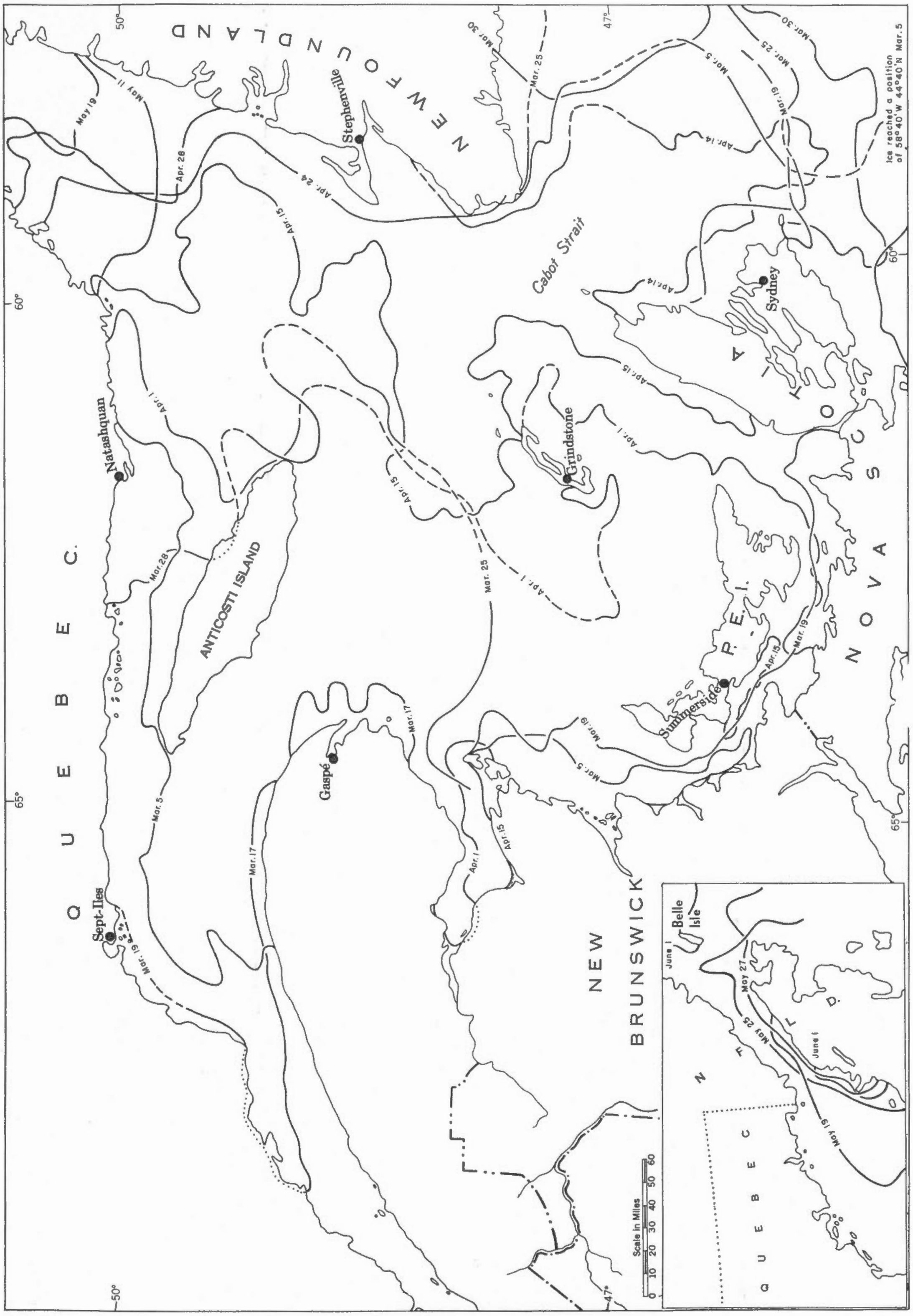


Figure 4. Retreat of the ice fronts in the Gulf of St. Lawrence, Spring 1959.

severe pressure ridging was present in the older ice forms and intensive shelving was usually present in new and young ice. In the Cabot Strait area the icefields were generally marked by alternating areas of close and open ice concentrations.

The retreat of the ice (Figure 4) was marked by an expanding water area in the western gulf region as the ice continued to drift eastward through Cabot Strait. The ice maintained a relatively stable position in the central gulf area from March 25 to April 15, whereas rapid retreat of the ice continued to the north and south of the area. After April 19, the ice in this central area rapidly disappeared and by April 22 Cabot Strait was ice-free.

The movement of the ice through Cabot Strait was marked by an eastward drift toward Saint-Pierre and Miquelon islands and a southeastward drift along the coast of Nova Scotia. In its southwestward drift the ice reached $60^{o}00'$ W. and $44^{o}40'$ N. on February 24; in its eastern drift extended beyond Saint-Pierre and Miquelon by February 25. Until the ice disappeared from the area on April 22, the ice front was marked by irregular advances and retreats.

The ice from the northeast arm of the gulf ceased feeding into Cabot Strait about April 24. At this time its edge extended north from Cape Ray to Harrington Harbour. After this date there was a steady retreat of the southern front in the area. In the northeastern part of the arm, the ice drift was to the northeast along the southern side of the Strait of Belle Isle. The eastern entrance of the strait had been remarkably free of Labrador ice during the winter months as the prevailing winds had held the ice off the coast. A sustained change in wind direction brought the ice on the coast, jamming into the strait about April 25.

The retreat of the ice from the western gulf area after March 19, isolated several icefields in Northumberland Strait. The fields gradually merged, and driven back and forth by the wind, survived until April 24.

At the beginning of the season new ice forms dominated the ice cover. By the end of January, new ice forms were dominant in the western gulf area and young ice in the eastern parts of the gulf. By mid-February winter ice was predominant in the eastern parts of the gulf, young ice in the central gulf area, and ice in the western gulf. Before the end of February winter ice had expanded to occupy two-thirds of the gulf; young ice occupied the western and northwestern parts of the gulf, and new ice was limited mainly to leeward shores. This general pattern of ice coverage continued to dominate the gulf until after mid-March. By the end of March, the ice cover was mainly restricted to the eastern third of the gulf and consisted principally of winter ice; new and young ice forms were unimportant elements in the cover. Thereafter, winter ice was the principal cover.

Ice coverage in the early part of the season and on the leeward coasts of the gulf consisted mainly of new ice forms such as slush, sludge (slob) and very young ice. In the latter, ice shelving varied widely from <1/10 to 8/10. As the ice moved eastward, new ice merged into young ice first through shelving and later through rafting, giving rise to extensive areas of winter ice. This ice surface, expanding more rapidly than it could be driven through Cabot Strait, extending eastward across the gulf. Against windward shores, the winter ice varied from 9/10 to 10/10 in coverage and consisted of concentrations of giant floes and fields (009 to 0010), with surface pressure ridges varying from 4/10 to 8/10. Elsewhere pressure ridges in winter ice varied from <1/10 to 1/10. Restricted channels, such as Northumberland Strait, usually indicated moderate ridging, 2/10 to 5/10 of the surface ice. In Cabot Strait, severe pressure resulted in ice wreckage being piled up around the edges of winter floes.

Bergy bits and growlers, the diagnostic elements that mark the southward drift of arctic ice along the Labrador coast, were first observed in the Strait of Belle Isle on April 28. Between Cape Norman and Belle Isle 18 bergy bits were sighted; by May 6, such ice had drifted halfway through the Strait. After May 12, polar ice contributed from 1/10 to 4/10 of the ice cover.

The icefield in the northeast arm shifted position continually in early June and its area gradually shrank toward the northeast. Sustained westerly and southerly winds held the icefields against the northwestern coast of Newfoundland so that the ice fed slowly eastward following the south side of the Strait of Belle Isle. Except for ice lying adjacent to Belle Isle, the only ice remaining in gulf waters on June 1 was a narrow belt lying off Newfoundland in the vicinity of Flowers Cove. Puddling, a feature of decaying ice, was first observed in early May, and reached 6/10 in some ice concentrations toward the end of the month.

When landfast ice was first observed in the harbours and bays of the southern gulf region on January 19, it consisted mainly of young ice. By February 1, the bays were mainly covered by landfast winter ice. In the spring break-up the southern harbours of Northumberland Strait were ice-free by mid-April. The bays of Prince Edward Island and New Brunswick were almost entirely ice-free by the end of April. On the west coast of Newfoundland the freeze over of the bays began in the northern part of the coast about mid-January and progressed to the southern parts of the coast toward the end of the month. The direction was reversed at the spring break-up, beginning at the end of April in the south, and about mid-May in the north. The harbours of the North Shore became covered with landfast ice before the end of January and were mainly ice-free by the first of March except where the ice lay behind a protective island or headland. In the northeast arm of the gulf, landfast ice covered all the bays by mid-January. The seaward growth of the landfast ice was frequently interrupted by large masses breaking off. The ice cover began to disappear from the harbours in the southern part of the coast by the end of April and became free of landfast ice by mid-May. In the lower estuary of the St. Lawrence River, from the Saguenay to Point des Monts, landfast ice was mainly limited to protected bays and shoals; the harbours were largely ice-free by the first week of March.

ICE COVERAGE

The various features of the gulf ice coverage that have been discussed are shown graphically in Figures 5 to 18. These maps cover a period from mid-January to June 1. As the icefields in May were limited to the northeast arm of the gulf, six insets were selected to show the deterioration of the ice in this area (Figure 18).

Explanation of Terms

Block: A fragment of sea ice ranging in size from 6 to 30 feet across.

Brash: Fragments of floating ice, less than 6 feet across, resulting from the wreckage of other forms of ice.

Consolidated ice: Ice of different sizes that is compacted into larger ice forms.

Floe: A piece of sea ice. A small floe is from 30 to 600 feet across; a medium floe is 600 to 3,000 feet; a large, or giant floe is 3,000 feet to 5 miles, and an icefield is an area of sea ice greater than 5 miles across.

Ice concentration: The ratio of the areal extent of ice present to the total combined extent of the ice and water surface. Concentration is usually measured in tenths; for example $\frac{9}{621}$ concentration indicates 6/10 brash and block, 2/10 small to medium floes and 1/10 giant floes and field; total surface of ice coverage 9/10.

Landfast ice: Any type of ice attached to the shore, beached, stranded in shoal water, or attached to the bottom of shoal areas. It is also known as shorefast ice.

New ice: New ice includes such forms as grease, slush, frazil, very young ice and the early stage of sludge.

Pressure ridge: A ridge of ice. Wherever a substantial area of the ice is in the form of pressure ridges, coverage may be expressed in tenths; for example, $\frac{PR}{3}$ denotes 3/10 of the area of the ice surface is in the form of pressure ridges. This is also a measure of surface roughness.

Rafting: In this study, rafting denotes the overriding of one floe by another floe of winter ice.

Shelving: Shelving refers to the interlocking rectangular pattern of young ice.

Sludge: An accumulation of small pieces of soft ice mixed with slush. The surface of the sludge is usually hardened into an ice crust. Slob ice is a dense form of sludge. Sludge coverage may be expressed in tenths: thus $\frac{Sg}{4}$ - 4/10 of sludge.

Slush: An accumulation of ice crystals such as would result from snow that has fallen into water at approximately freezing temperature. Slush forms a thick soupy mass in the water. The coverage of slush may be expressed in tenths; thus $\frac{Sl}{5}$ - 5/10 of slush.

Very young ice: Ice that is recently formed in calm water. Coverage is expressed in tenths; thus $\frac{VY}{6}$ - 6/10 of very young ice.

Winter ice: Ice produced during the current winter, usually ridged and capable of maintaining a snow cover without the snow becoming grey from water seepage through the ice. Coverage is expressed in tenths; thus $\frac{W}{5}$ - 5/10 of winter ice.

Young ice: Newly formed ice that is generally grey in appearance and varying from 2 to 6 inches thick. Coverage is expressed in tenths; thus $\frac{Y}{7}$ - 7/10 of young ice.

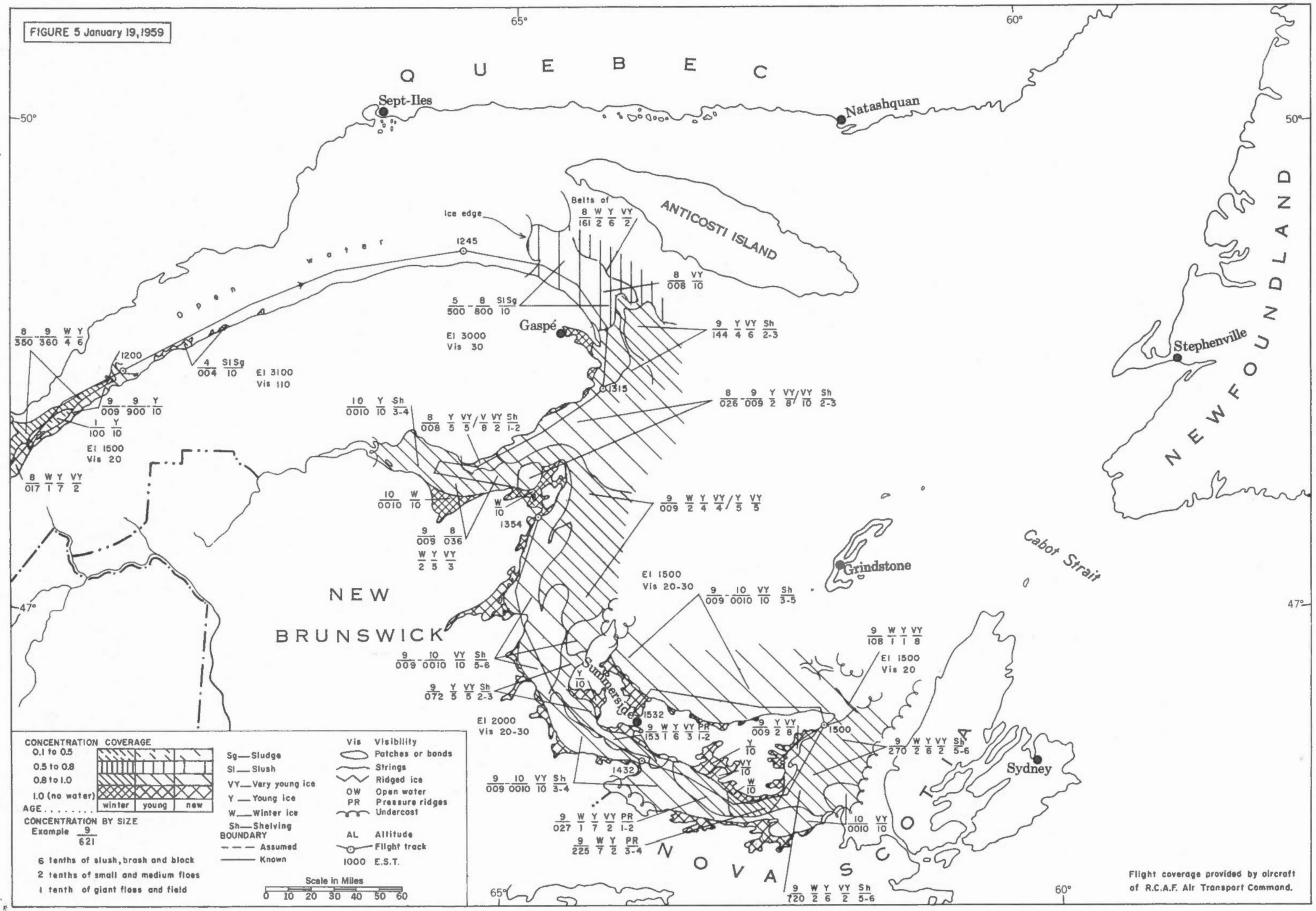


Figure 5. Ice distribution, Gulf of St. Lawrence, January 19, 1959.

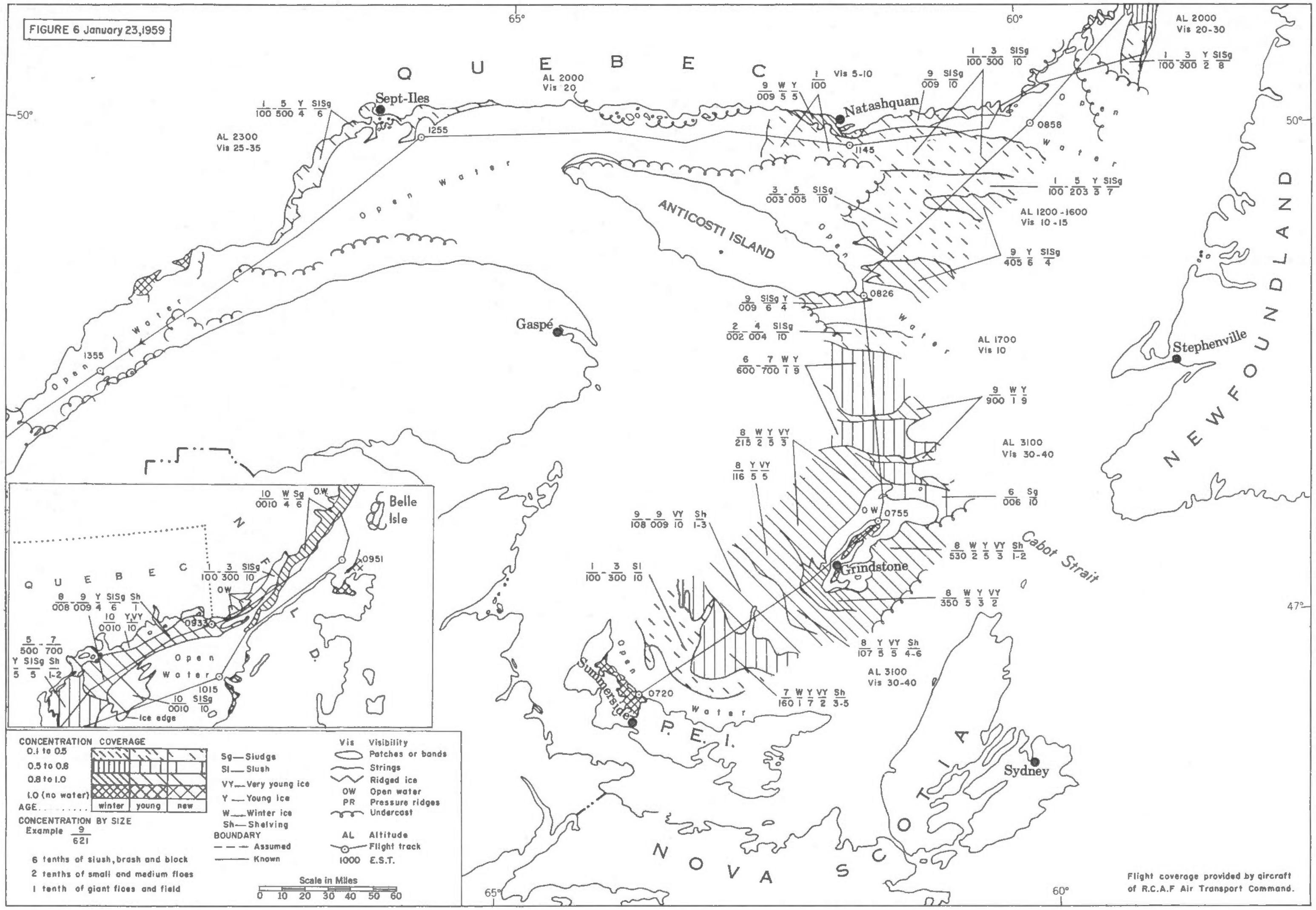


Figure 6. Ice distribution, Gulf of St. Lawrence, January 23, 1959.

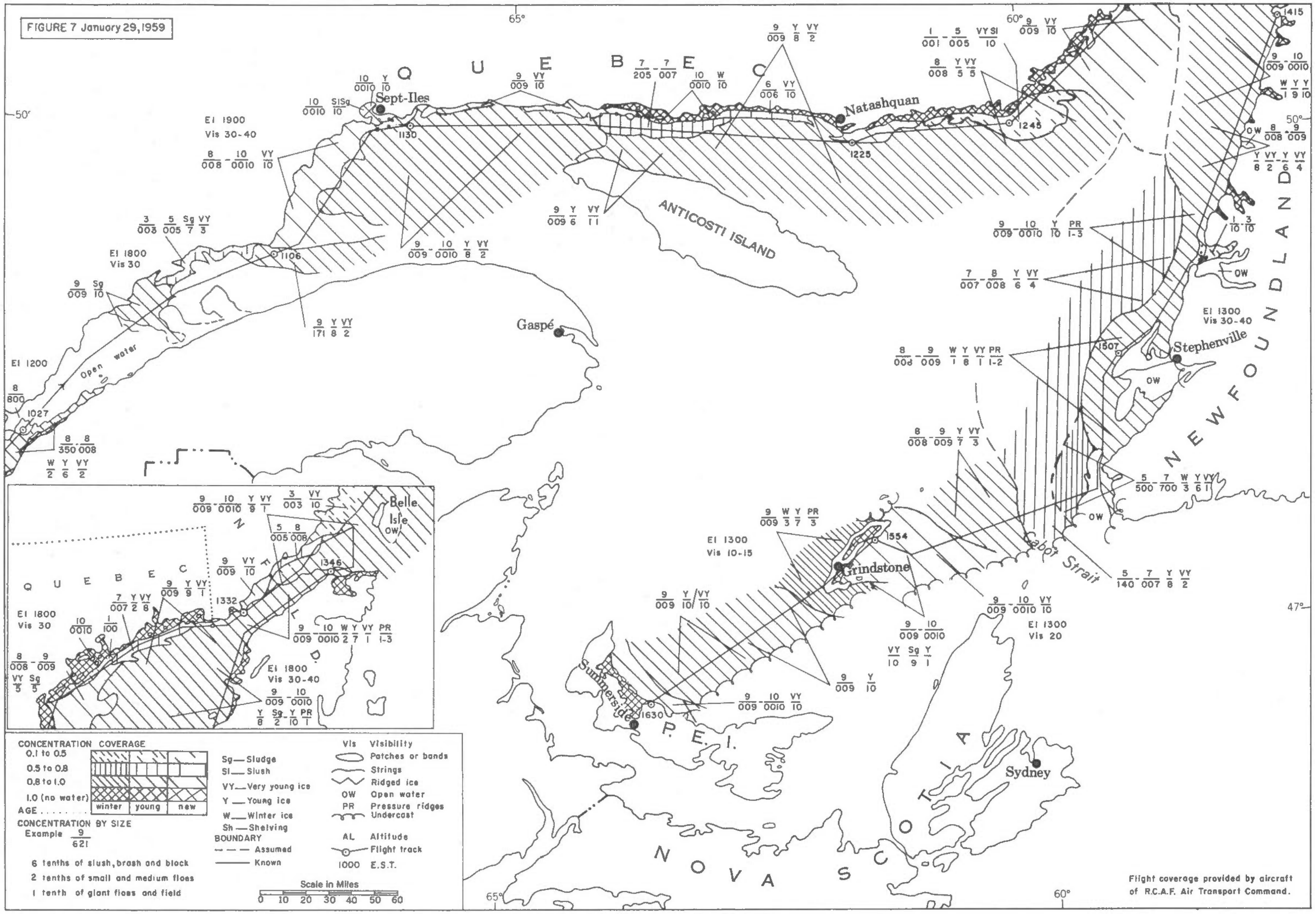


Figure 7. Ice distribution, Gulf of St. Lawrence, January 29, 1959.

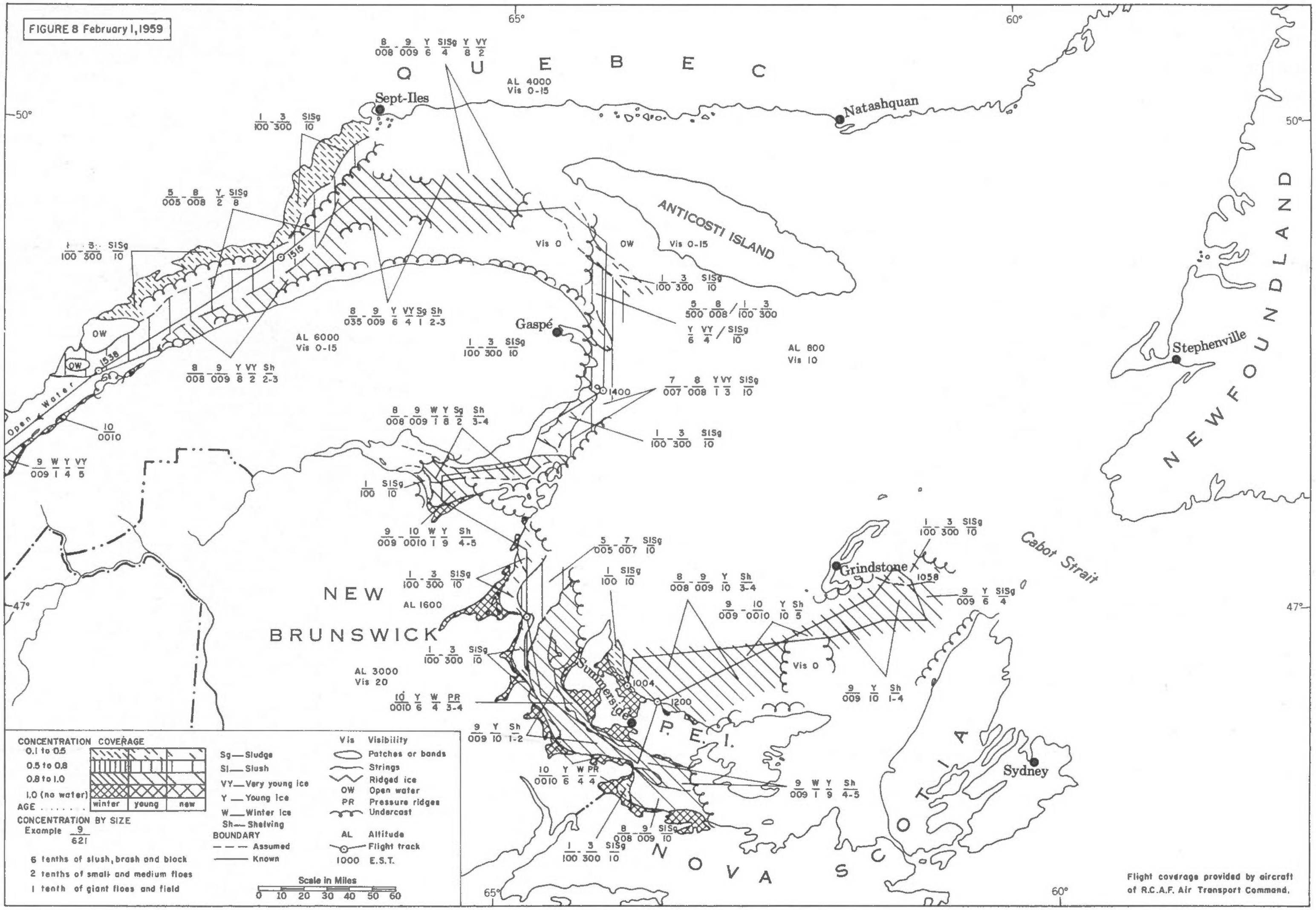
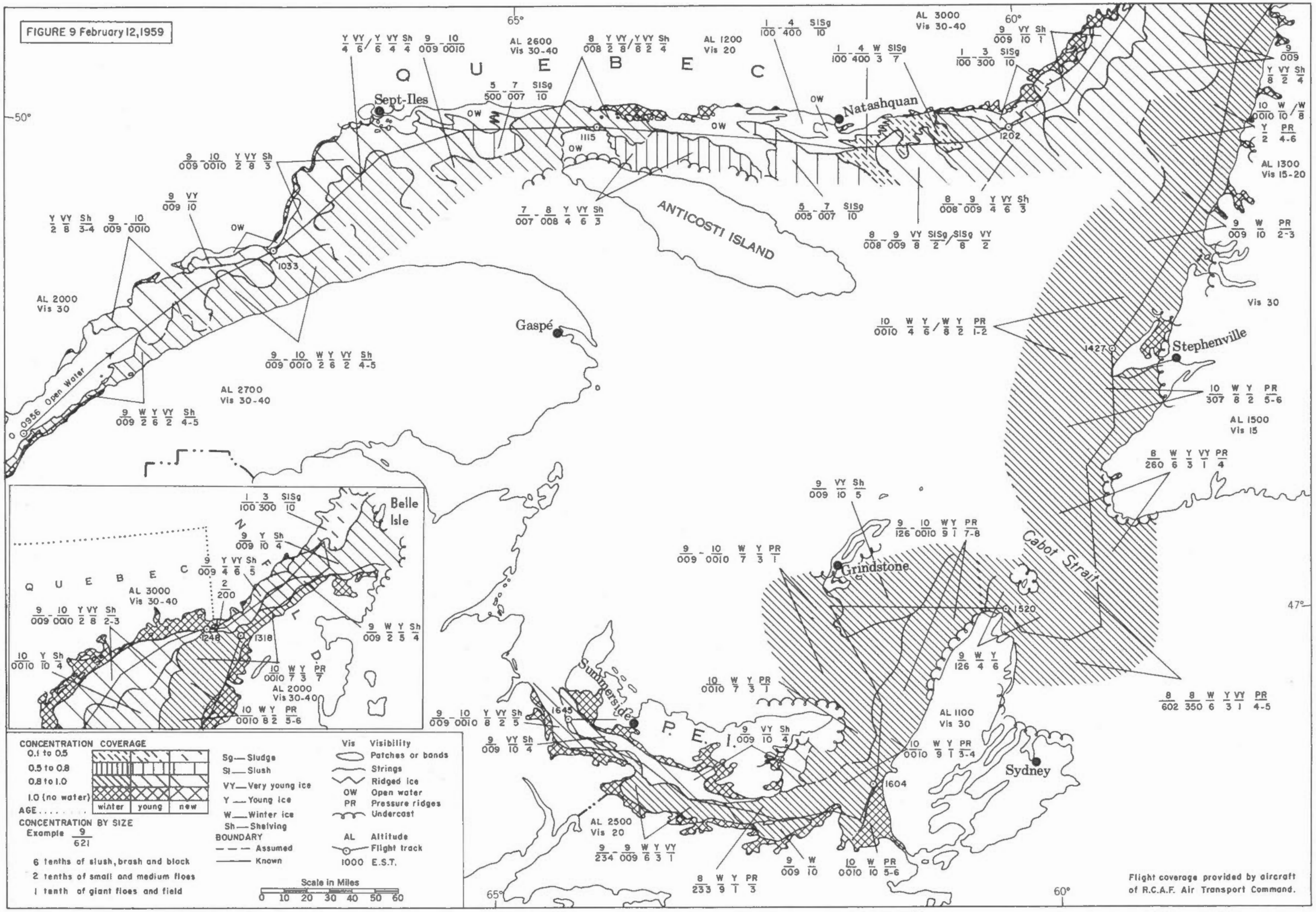


Figure 8. Ice distribution, Gulf of St. Lawrence, February 1, 1959.

Figure 9. Ice distribution, Gulf of St. Lawrence, February 12, 1959.



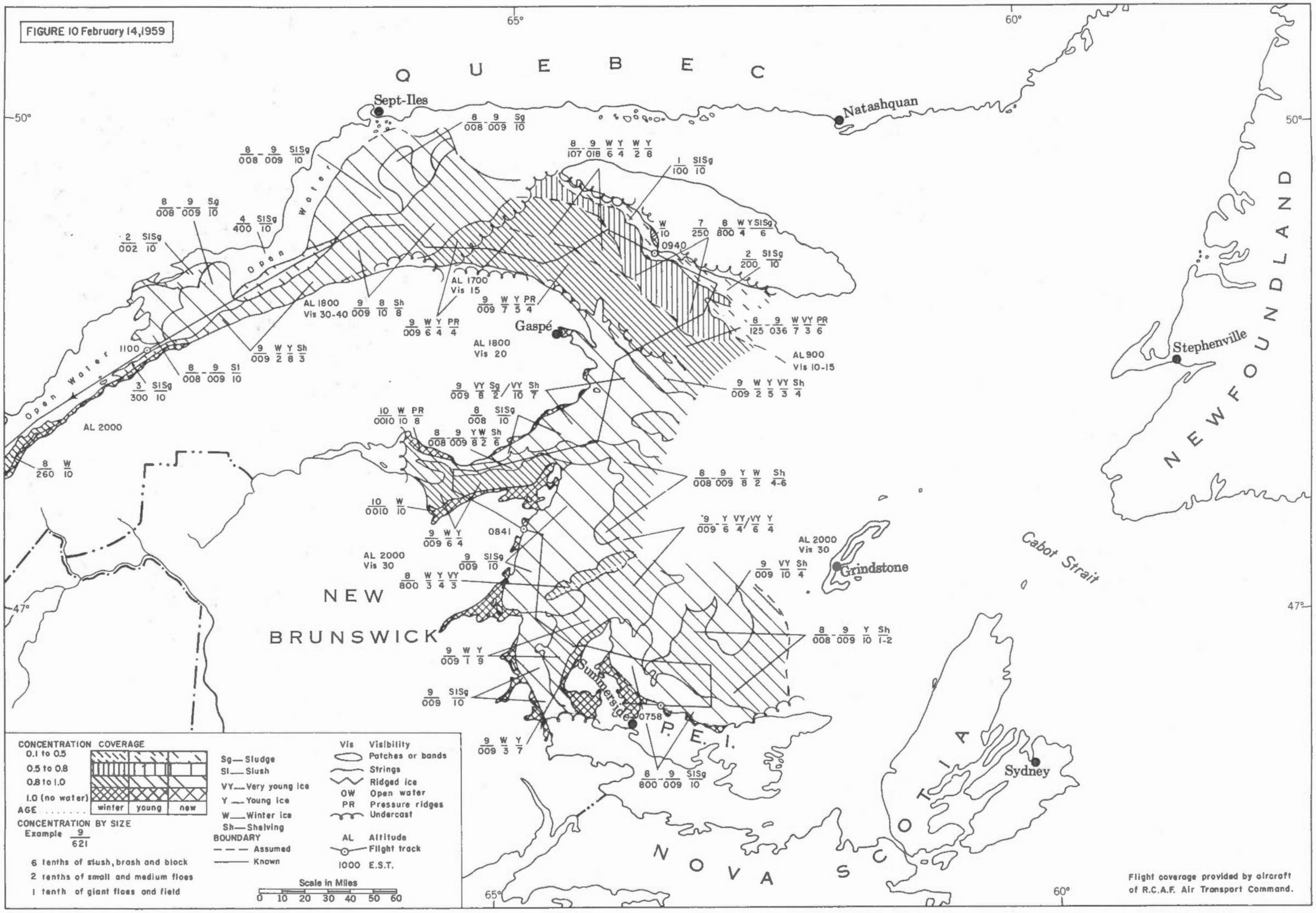


Figure 10. Ice distribution, Gulf of St. Lawrence, February 14, 1959.

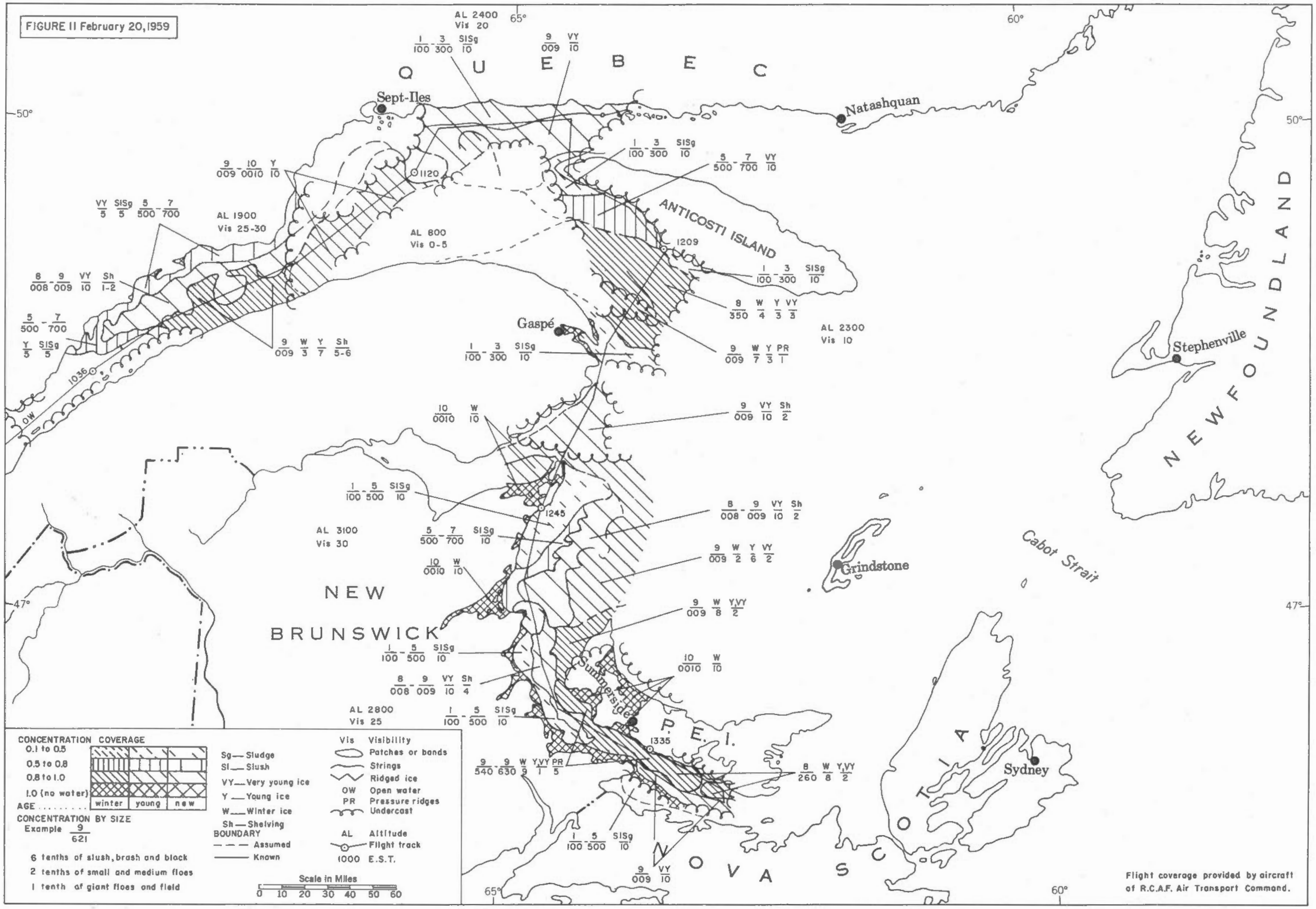


Figure 11. Ice distribution, Gulf of St. Lawrence, February 20, 1959.

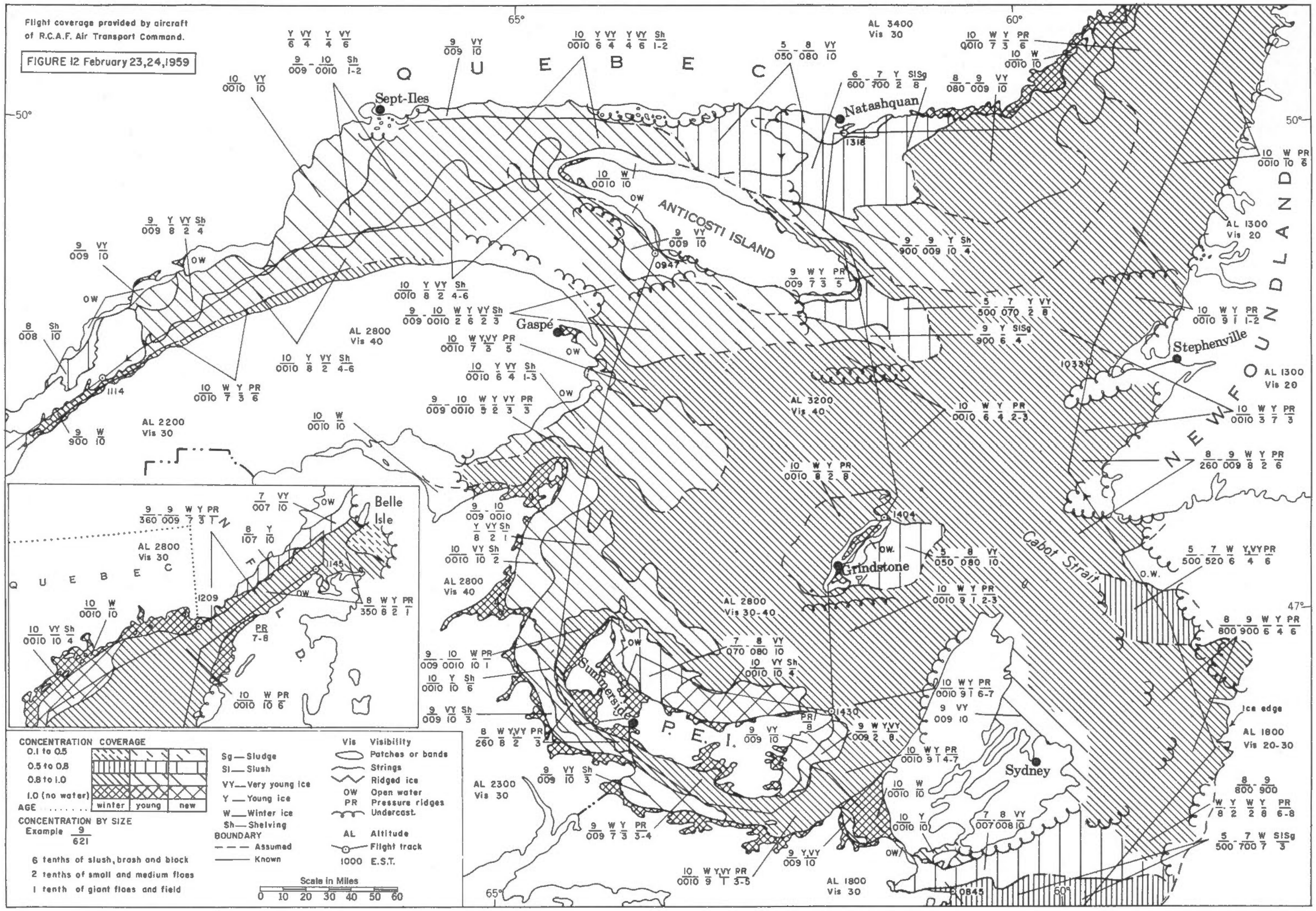


Figure 12. Ice distribution, Gulf of St. Lawrence, February 23, 24, 1959

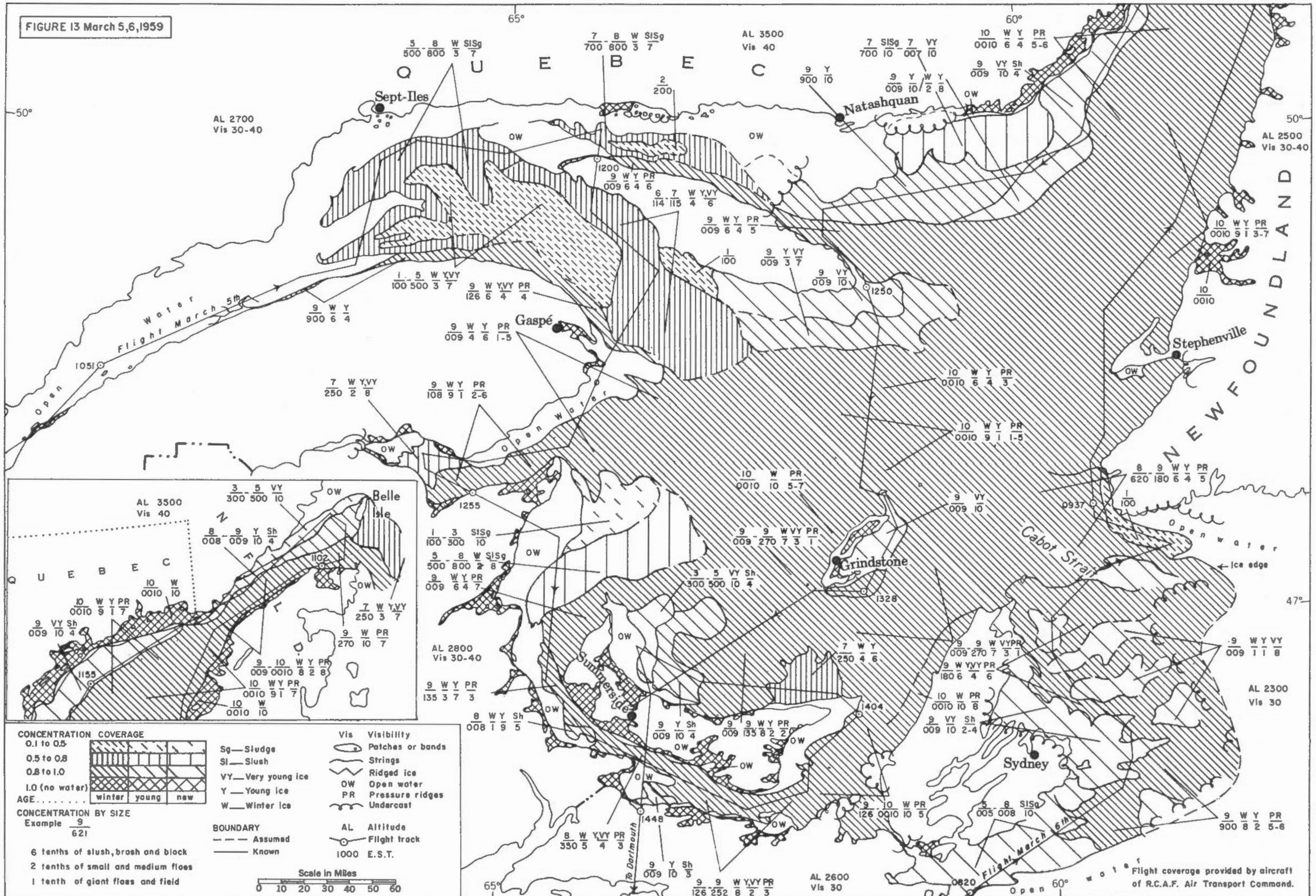


Figure 13. Ice distribution, Gulf of St. Lawrence, March 5, 6, 1959.

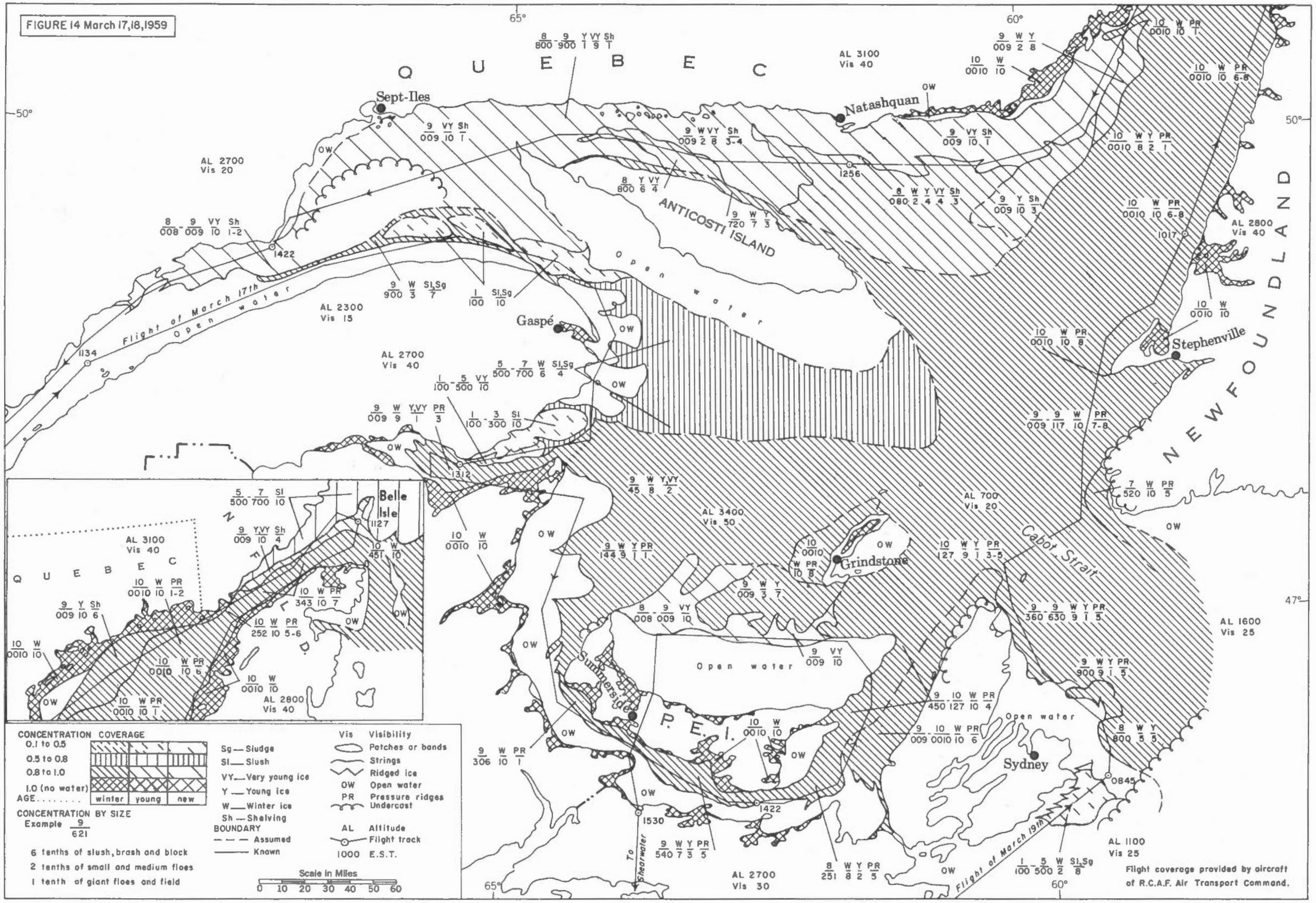


Figure 14. Ice distribution, Gulf of St. Lawrence, March 17, 18, 1959.

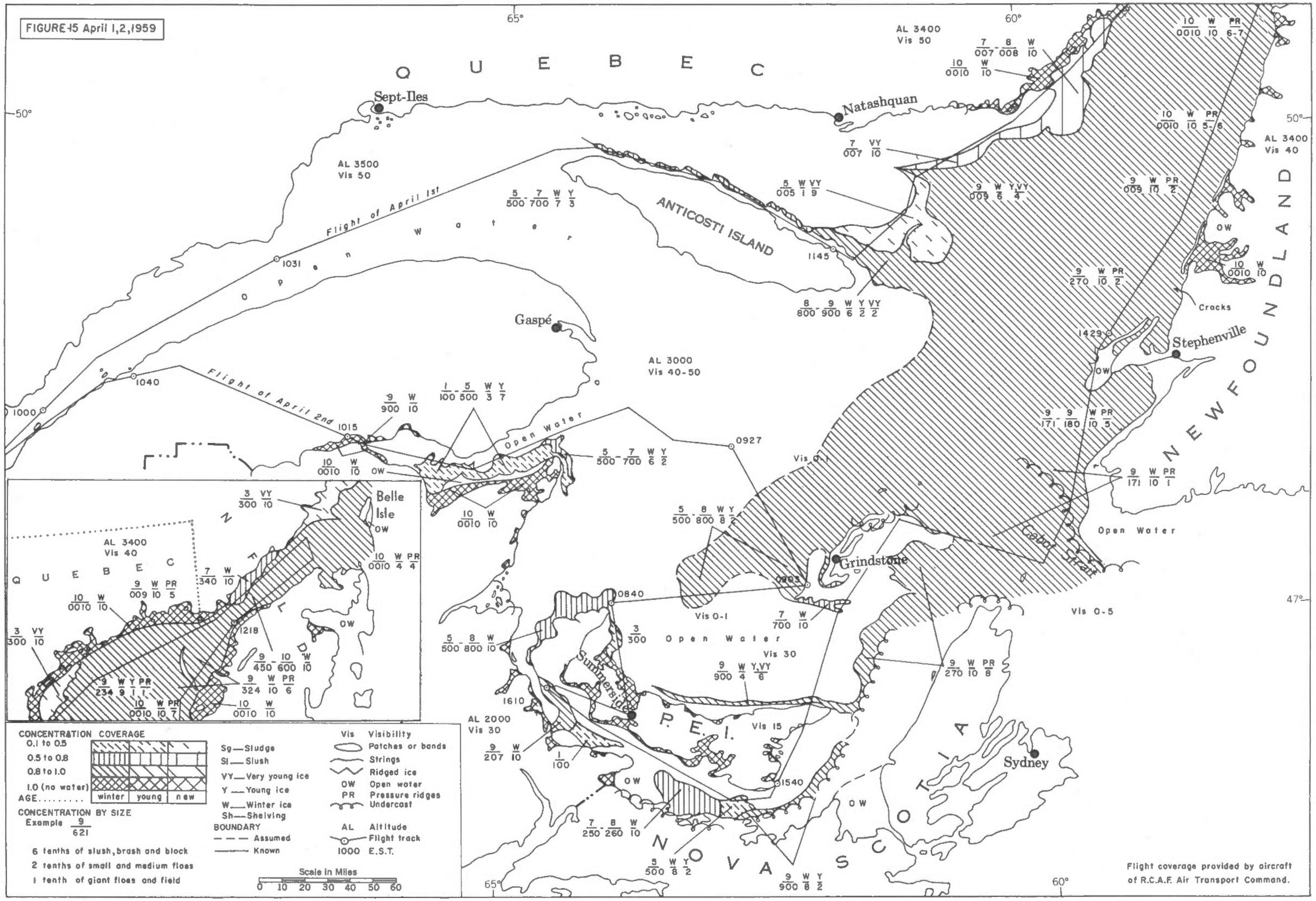


Figure 15. Ice distribution, Gulf of St. Lawrence, April 1, 2, 1959.

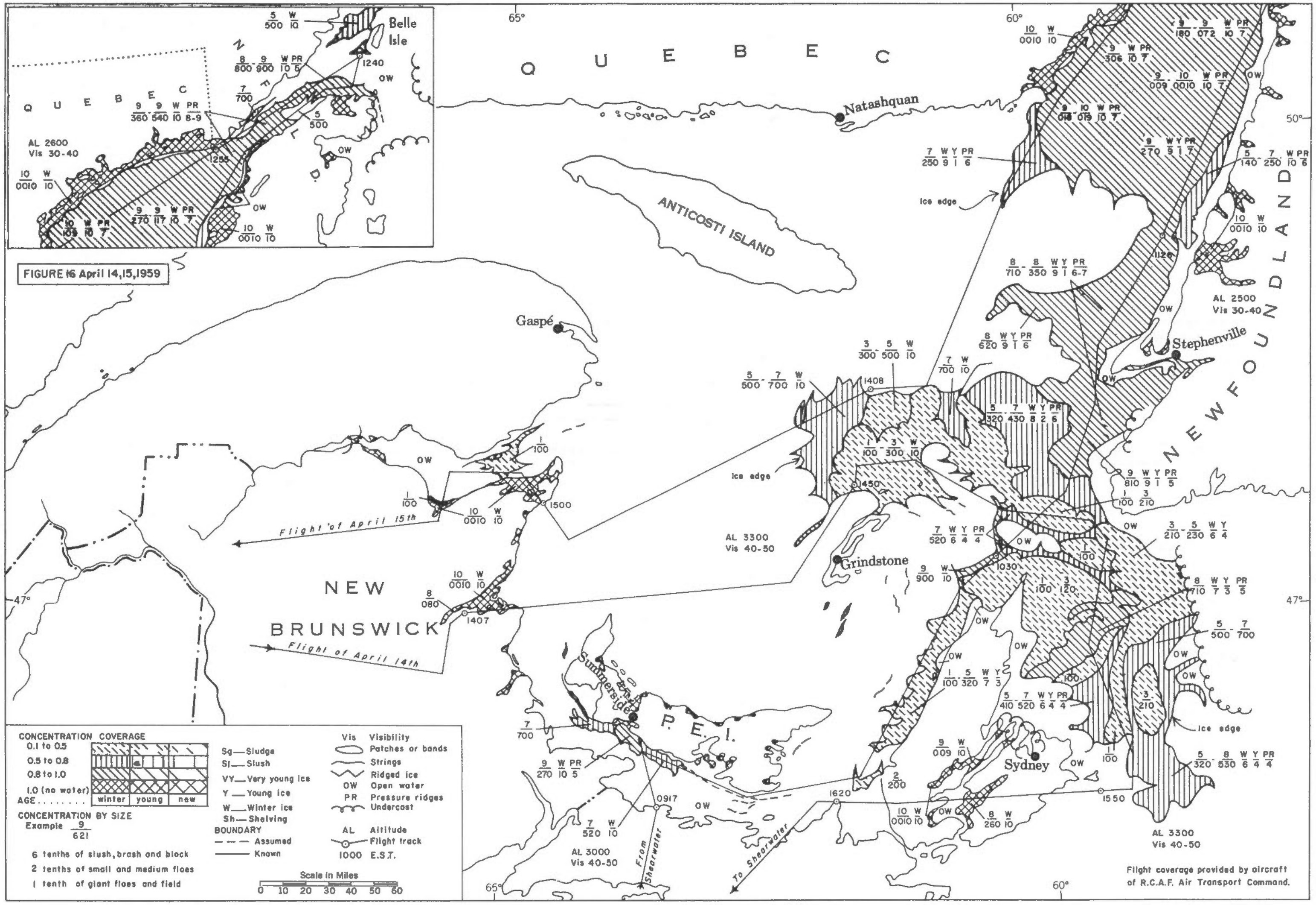


Figure 16. Ice distribution, Gulf of St. Lawrence, April 14, 15, 1959.

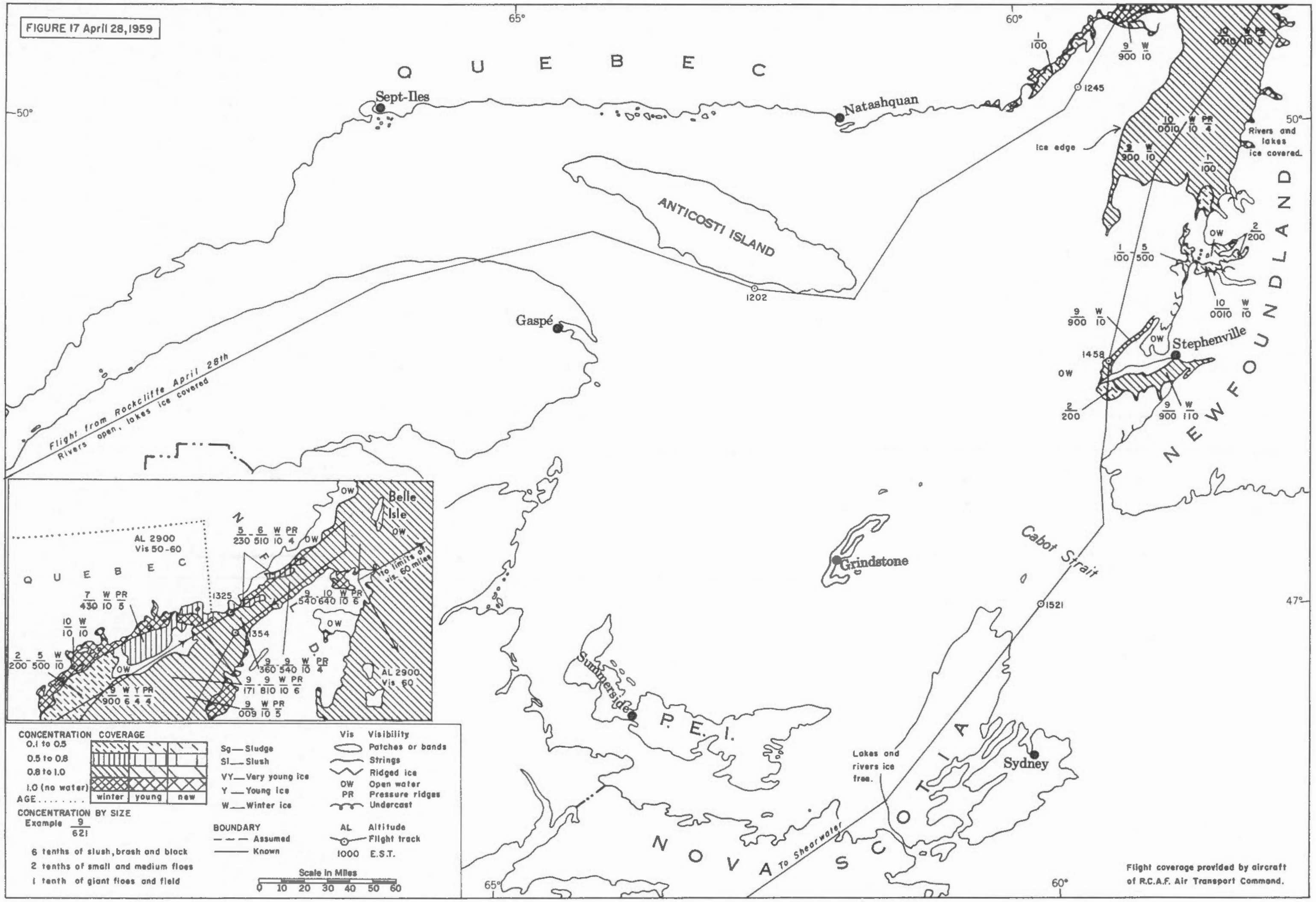


Figure 17. Ice distribution, Gulf of St. Lawrence, April 28, 29, 1959.

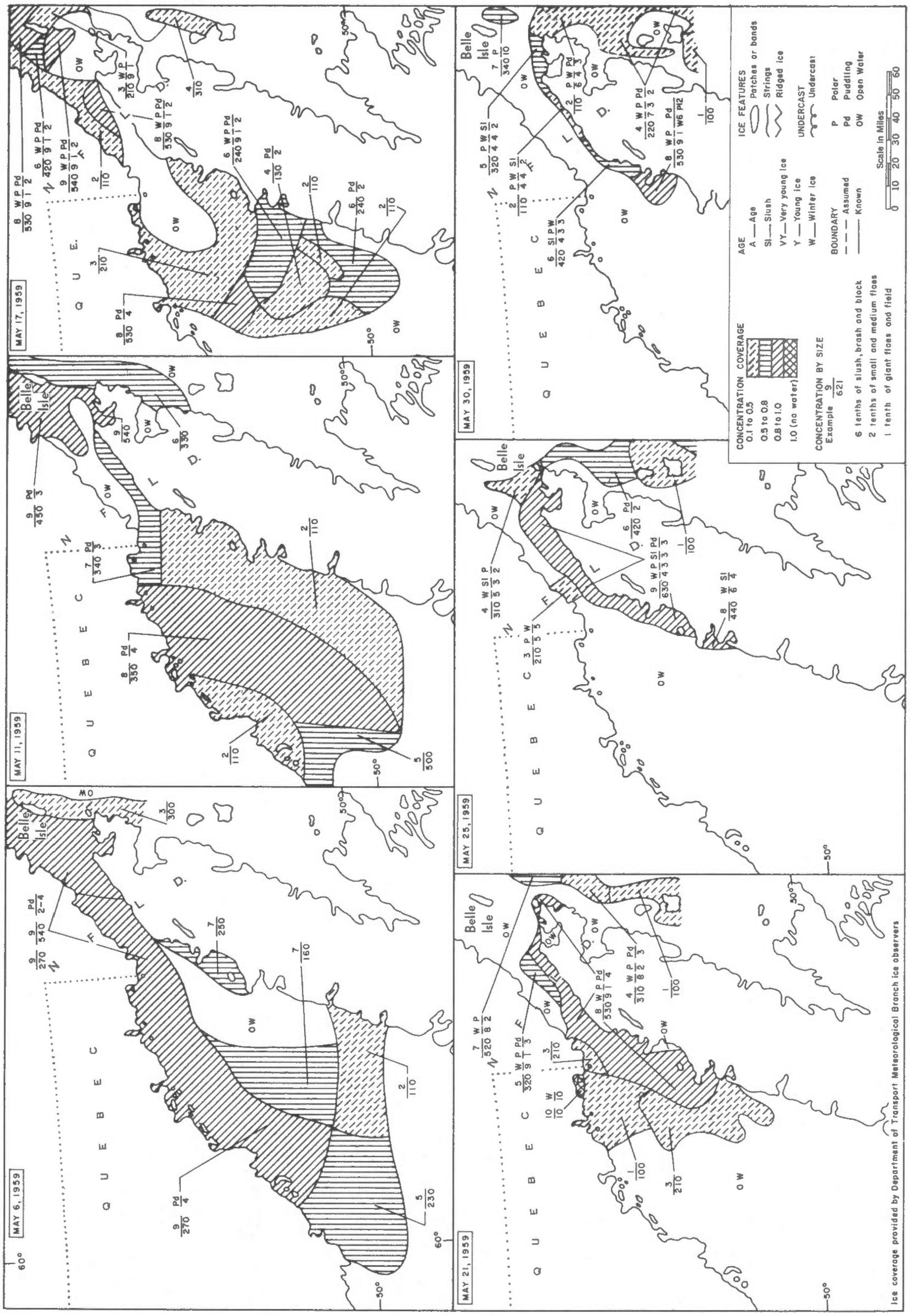


Figure 18. Northeast Arm and the Strait of Belle Isle, May 1959.

PART II

THE ST. LAWRENCE RIVER

The middle St. Lawrence River extends from Lake St. Louis to the Island of Orleans. The lower St. Lawrence River is the broad part of the river that extends from the Island of Orleans eastward to the mouth of the Saguenay River.

WEATHER CONDITIONS

Winter opened in the St. Lawrence valley with an influx of arctic air on November 26, and thereafter, the winter continued cold and severe (Table IV). Mean temperatures in the area for November (31^{o} to 38^{o}) were unfavourable for ice growth. The period from December to February, compared with normal winters, was unusually cold. Mean monthly temperatures for this period ranged from 5 to 11 degrees. December temperatures varied from 10^{o} to 15^{o} below normal, January 0^{o} to 2^{o} below normal, and February 6^{o} below normal. March temperatures were also below normal. In this period temperatures were very favourable for the formation of ice. April, with mean temperatures of 38^{o} to 43^{o}, was a month of rapid removal of the shorefast ice.

TABLE IV

Mean temperature values (F^{o})
(Middle St. Lawrence River area)

	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Mean temperature	35	5	11	7	22	40
Range in temperatures	31 to 38	1 to 11	8 to 14	5 to 12	19 to 26	38 to 43
Difference from normal	2	-10 to -15	0 to -2	-6	-4	2
Excess of temperatures at Montreal over Quebec	5	4	2	3	6	3
Degree-days of frost	-3	27	21	24	10	-8

Ice formation and growth was a rapid process during the winter of 1958-59 as indicated by the degree-days of frost.* The intensity of the cold is evident from the mean temperature for December which

*For the formation of fresh water ice the degree-day is based on $32^{o}F$.

was lower than that for February; the latter is normally the coldest winter month.

Regional variation in temperatures was from 5^{o} to 7^{o}, except for December. The difference between the Montreal and Quebec parts of the river was 2^{o} to 6^{o}. The coldest part tended to centre about Lake St. Peter. The effect of lower temperatures was reflected in the ice cover. The St. Lawrence River, from the eastern entrance of Lake St. Peter to Quebec, usually contained drifting ice. The western part of the river to Montreal East was mainly ice congested. The Montreal harbour front usually contained running ice in a channel several hundred feet wide.

ICE DISTRIBUTION

The low temperatures in December resulted in a rapid expansion of ice coverage in the St. Lawrence River. On December 9 and 11 the ice front had reached the vicinity of the Saguenay River. The ice consisted mainly of young and new ice forms and remained important elements in the drifting ice until the end of March. Landfast ice by December 9 and 11 bordered each shore in a narrow ribbon 100 to 200 feet wide. By January 23, landfast ice had consolidated into heavy winter ice and occupied about two-thirds of the channel below Three Rivers; Lake St. Peter was 9/10 covered with landfast ice; the navigable channel above Sorel was restricted to a width of a few hundred feet.

From the extremely low temperatures experienced in this area in the winter months, landfast ice would be expected to block the entire middle St. Lawrence waterway. That this occurrence was mainly limited to the ship channel above Lake St. Peter was largely because of the strength of the tidal and river currents supported by strong westerly winds. From Lake St. Peter to Quebec these currents flow at a rate of 2 to 5 knots. From Montreal to Lake St. Peter the river flows at a variable rate of about 2 to 4 knots in a much narrower channel. The main effect of such currents is to pile up pressure ridges varying from 5 to 15 feet high and to retard or prohibit the fusion of the landfast ice that borders each shore of the St. Lawrence.

Ice from the landfast edge continued to break off and together with new and young ice forms drifted downstream during the winter months. In the ship channel the ice coverage above Sorel fused to become part of the landfast ice prior to February 12. Because of the river current this ice was compressed into windrows of ice ridges that amounted to as much as 10/10 of the ice surface. It was not until March that the landfast ice covering the ship channel above Sorel was broken up and carried downstream. For the remainder of the winter only small areas of ice congestion, where consolidation with landfast ice had taken place, again occurred in this part of the river. From Three Rivers to Quebec local areas of ice congestion occurred periodically, especially at bends and in narrow constrictions of the river, where the ice-drifting downstream accumulated and consolidated with the landfast ice. The constriction of the river at the Quebec bridge was frequently an area of ice congestion.

Although ice continued to break off from the leading edge of the shore-fast ice, the first observation of a retreat from its maximum extent at the end of February was in the lower St. Lawrence River on March 5. The retreat was observed upstream as far as Portneuf. Removal of the landfast ice in the lower St. Lawrence was almost complete by March 18, but very little progress was made by this date on the middle St. Lawrence River. By April 1 the landfast ice was reduced substantially between Quebec and Three Rivers, but little progress was made in the upstream area. In the interval between April 2 and 15, the landfast ice had almost disappeared from the upper part of the river. The ice that was observed in April on the middle St. Lawrence of the wreckage of landfast ice that was drifting downstream.

The ice area in the lower St. Lawrence was marked by frequent advances and retreats. Generally, ice extended over much of the lower St. Lawrence in January and February. In March the ice surface tended to be relatively stable with the ice limited to the upper half of the lower St. Lawrence. April opened with the ice coverage limited mainly to strings and belts. This ice consisted of the wreckage of landfast ice which had drifted downstream from the middle St. Lawrence. The St. Lawrence River was ice-free by April 21.

ICE COVERAGE

The ice coverage that was observed on the St. Lawrence River from Lake St. Louis to the Saguenay River, is shown on Figures 19 to 24.

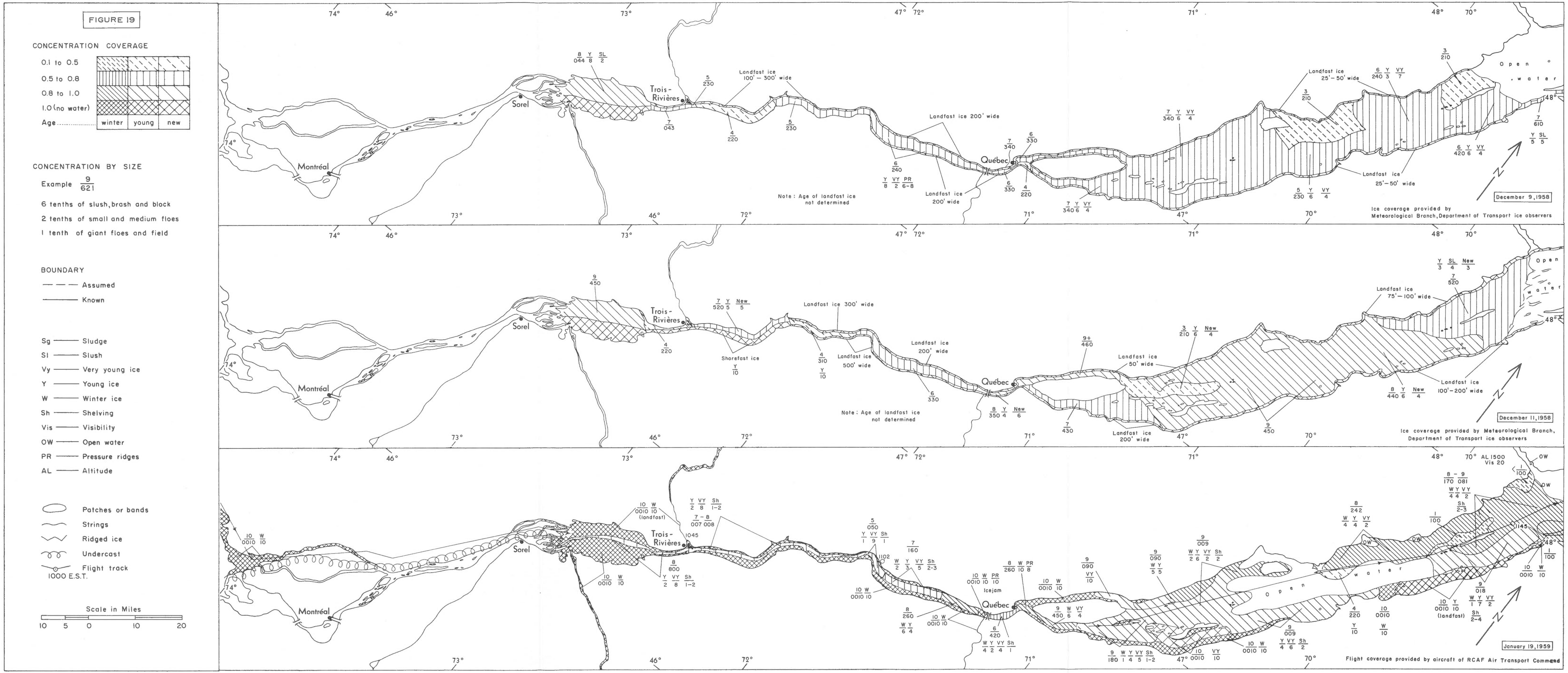


Figure 19. Ice distribution, St. Lawrence River, December 9, 11, 1958 and January 19, 1959.

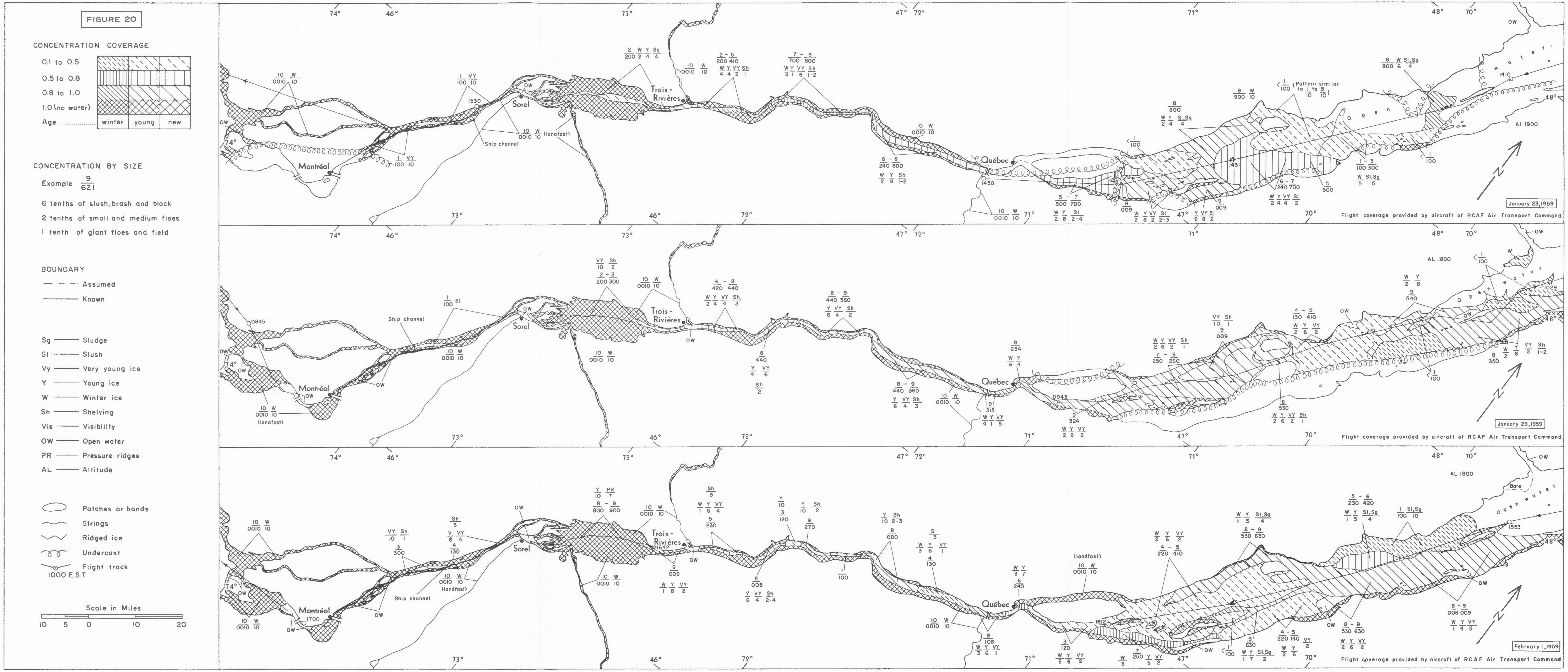


Figure 20. Ice distribution, St. Lawrence River, January 23, 29, and February 1, 1959.

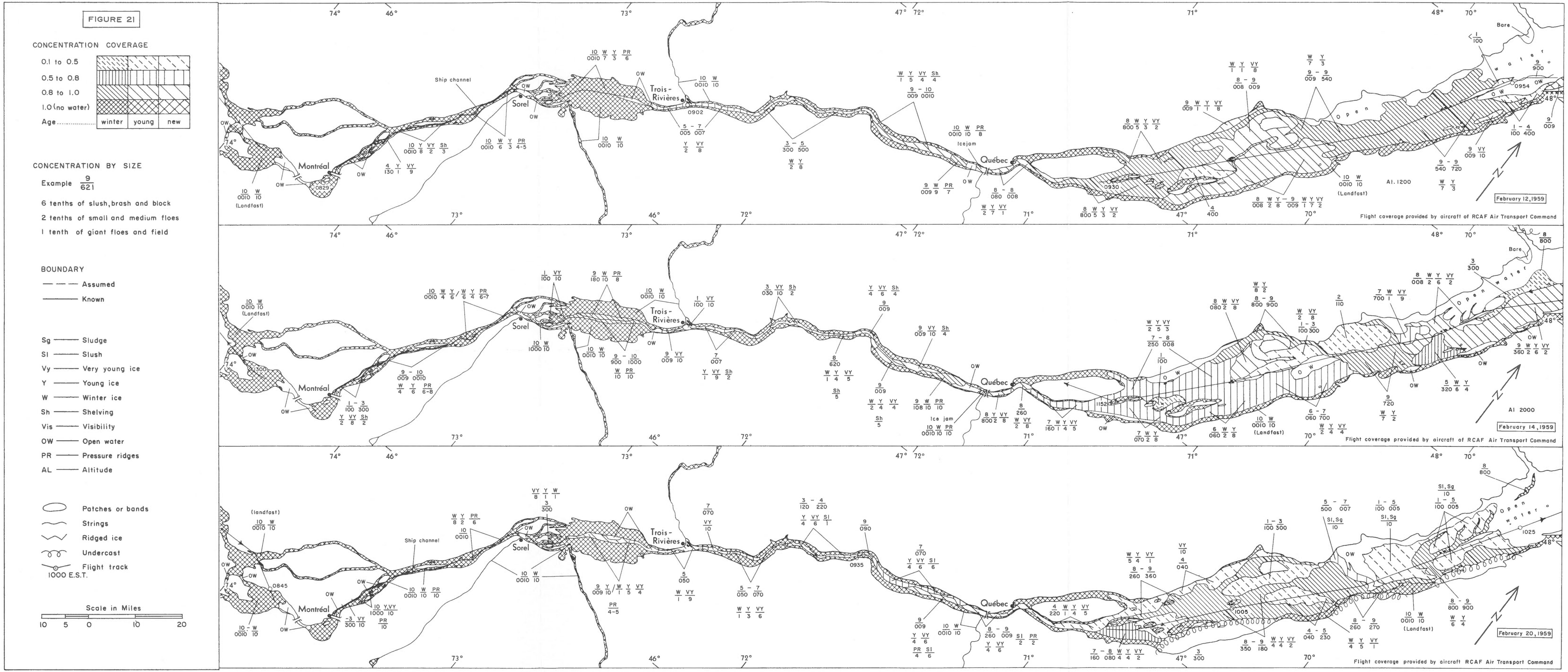


Figure 21. Ice distribution, St. Lawrence River, February 12, 14, 20, 1959.

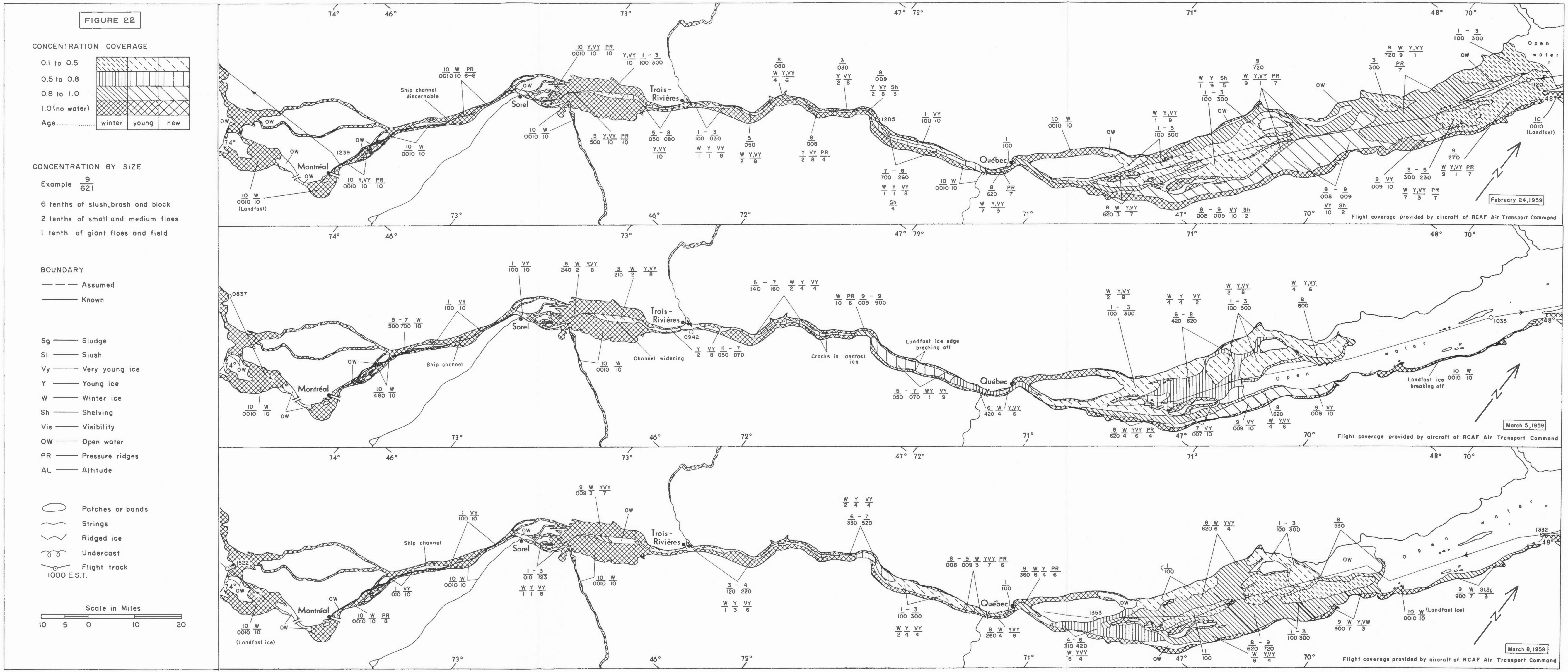


Figure 22. Ice distribution, St. Lawrence River, February 24; March 5, 8, 1959.

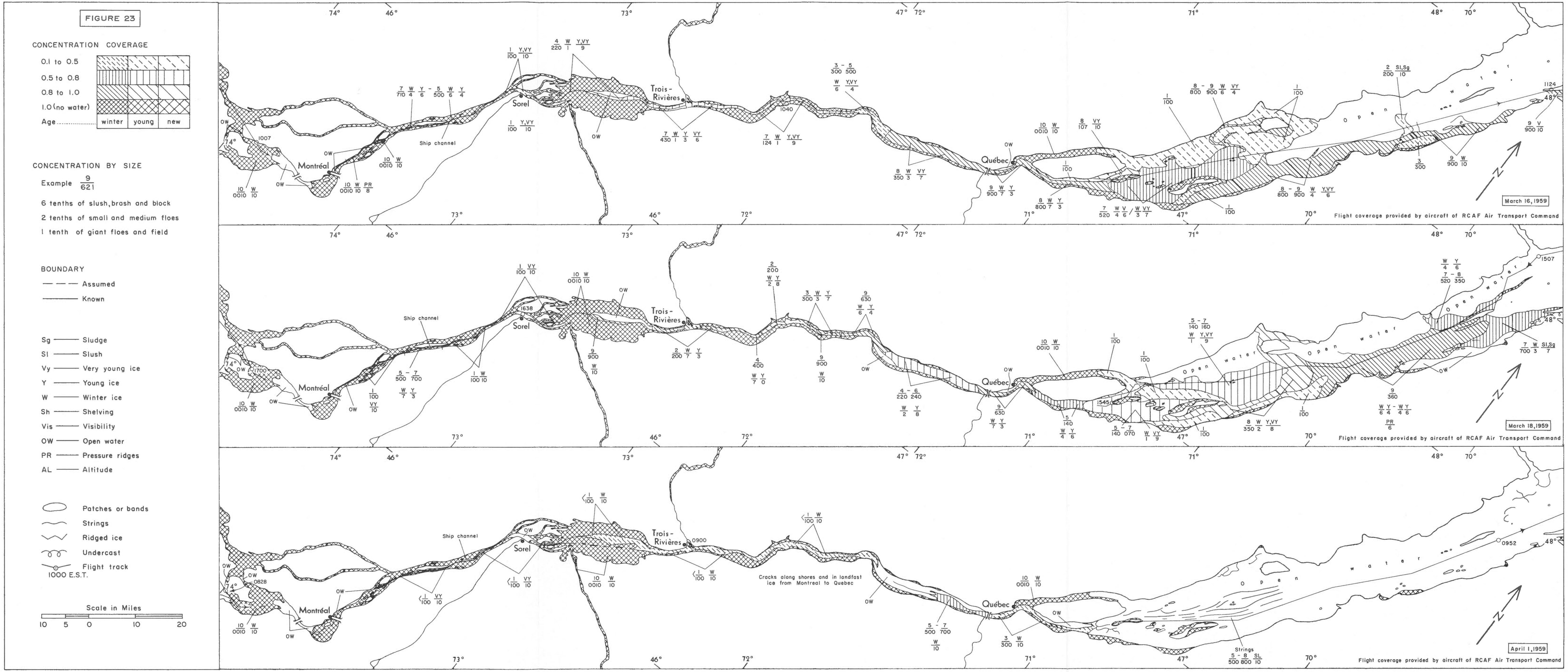


Figure 23. Ice distribution, St. Lawrence River, March 16, 18; April 1, 1959.

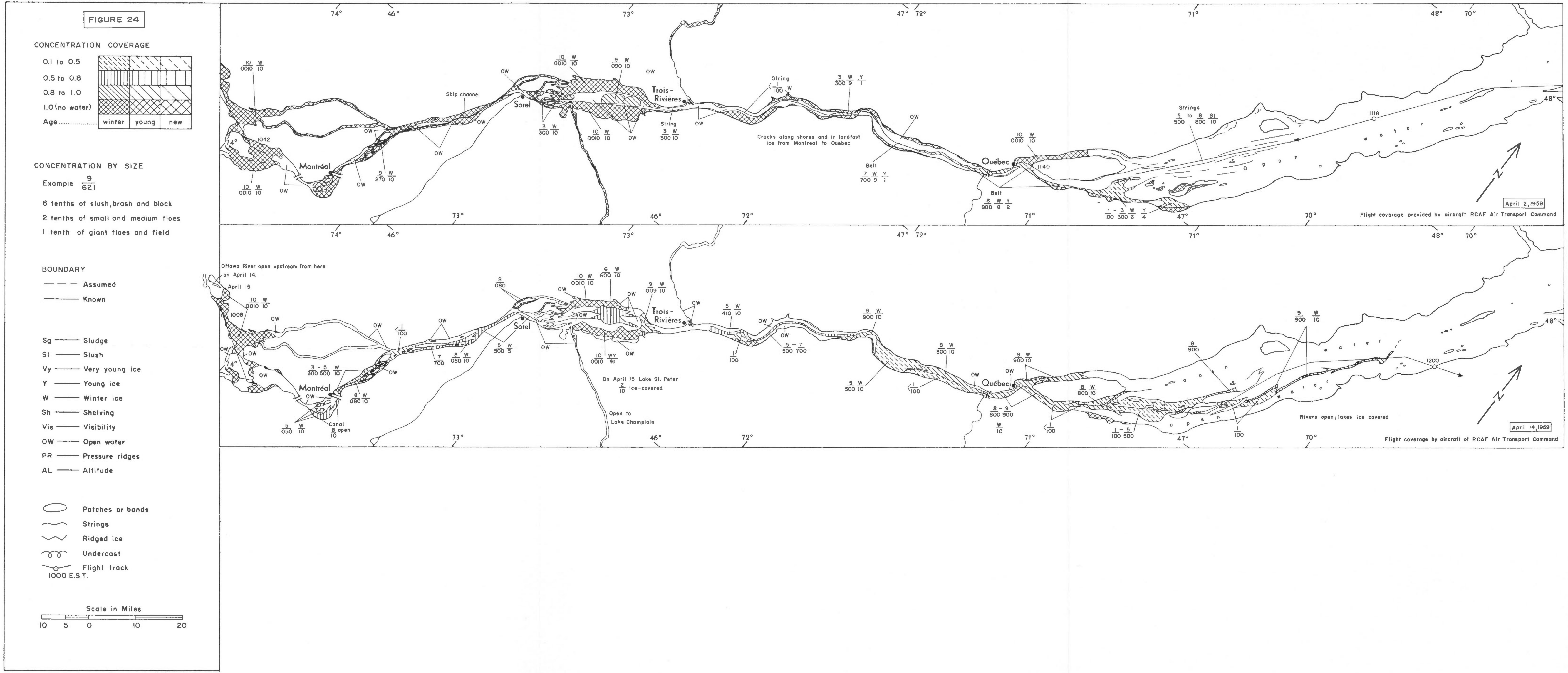


Figure 24. Ice distribution, St. Lawrence River, April 2, 14, 1959.

GULF OF ST. LAWRENCE ICE SURVEY, WINTER 1959

SUMMARY

The aerial ice survey of the winter of 1958-59 showed the Gulf of St. Lawrence to be dominated by an extensive ice coverage. This was mainly related to the abnormally low temperatures that prevailed over the gulf. The mean winter temperatures from December 1958 to March 1959 ranged from 7° to 19° in the northern gulf, from 18° to 26° in the southern gulf, and from 5° to 22° in the middle St. Lawrence River region. Such temperatures were conducive to the formation and maintenance of icefields in the gulf region.

Towards the end of December ice covered the middle and lower St. Lawrence River and the western part of the Gulf of St. Lawrence. By mid-January the central and southern gulf region was ice covered, and by the end of January, the gulf ice was pushing through Cabot Strait on a broad front. The extensive ice coverage prevailed over the gulf until after mid-March. The retreat of the ice from the region progressed in a west to east direction with most of the ice drifting southeastward through Cabot Strait, leaving the estuary and the central gulf region ice-free. The middle St. Lawrence River was almost ice-free by April 15, Cabot Strait by April 22, but the northeast arm of the gulf and the Strait of Belle Isle did not become ice-free until after June 1.

The lightest ice in the gulf, consisting of new ice forms, occupied the western parts of the gulf and the St. Lawrence estuary during most of the winter. The ice became considerably heavier and massive in the eastern parts of the gulf. In these areas, particularly against windward coasts, the ice surface consisted of a jumble of pressure ridges. The Labrador or polar ice was late in arriving on the Strait of Belle Isle, being first observed there on April 28; this ice form constituted a substantial amount of the ice surface that was observed in the northeast area during May.

Winter navigation

The severe ice conditions affected shipping in various parts of the gulf region. Icebreaker operations began with the freeing of lake and ocean shipping in the Montreal area in December. By mid-February, worsening ice conditions in the Gulf of St. Lawrence were reported to have resulted in the heaviest ice barriers in Cabot Strait in over 30 years. The Danish 'ice-working' freighter Helga Dan, the first ocean-going vessel to arrive at Quebec in winter (February 13), received icebreaker support to enter and to leave Cabot Strait. The Cabot Strait ferry, M.V. William Carson, and the Northumberland Strait ferry, M.V. Abegweit, were frequently delayed by ice congestion.

In the Gulf of St. Lawrence-Chaleur Bay area nine ships departed from Dalhousie in December, and seven in January. Because of the severity of ice conditions winter navigation ceased after January 28. Navigation re-opened on April 16; by the end of the month three ships had entered and departed from Dalhousie.

In the lower St. Lawrence River and estuary where ice conditions were relatively light, low-powered vessels operated from Quebec throughout the winter with the assistance of icebreakers. On April 2, relatively light ice in the middle St. Lawrence River permitted the first vessel, the German freighter Volumnia, to dock at Montreal - nine days later than the Valaria the year before.

In the period from December to March, the Department of Transport icebreakers assisted over seventy vessels and broke out approximately twenty-five ports in the St. Lawrence River and gulf region.

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PHOTOGRAPHIC RECORD OF ICE COVERAGE

Because of the importance of the St. Lawrence seaway, most of the photographs selected are concerned with ice conditions that existed at various times in the middle St. Lawrence River. The photos are arranged mainly in chronological order. The purpose of this visual presentation is to provide a clearer understanding of the special problems ice presents to navigation, particularly in the St. Lawrence River waterway.

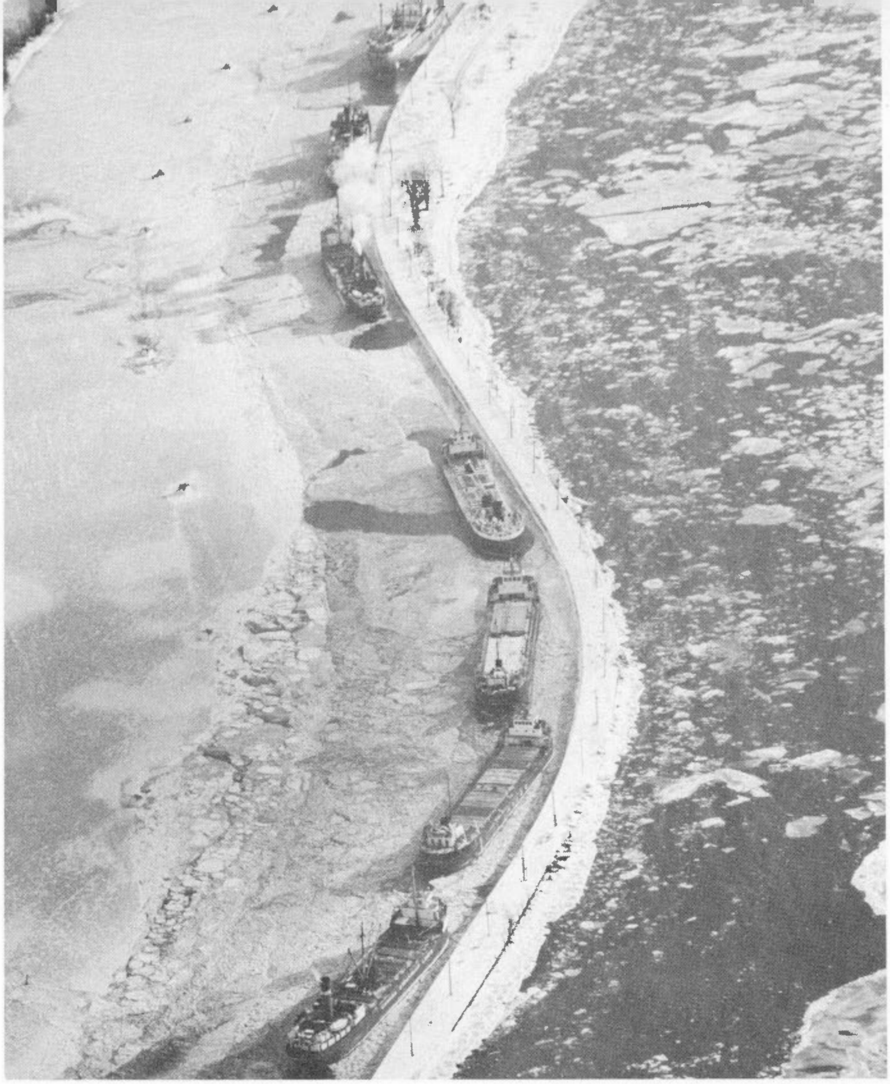


Figure 25. (December 8, 1958). The prolonged period of cold weather that set in on November 26 with zero temperatures resulted in severe and unexpected icing conditions. The photo shows part of the line of 21 ships caught in the ice at the Lake St. Louis entrance to the Lachine Canal. Ice congestion in the canal and ice on the lock gates limited the number of ships passing through to Montreal harbour from 5 to 8 per day. (Photo courtesy *The Montreal Gazette*).

Figure 26. (January 23, 1959). Landfast ice on the south shore converges on the port of Sorel, freezing in the shipping. The mouth of the Richelieu River is kept relatively ice-free by frequent ferry crossings. (Altitude 1,800 feet).

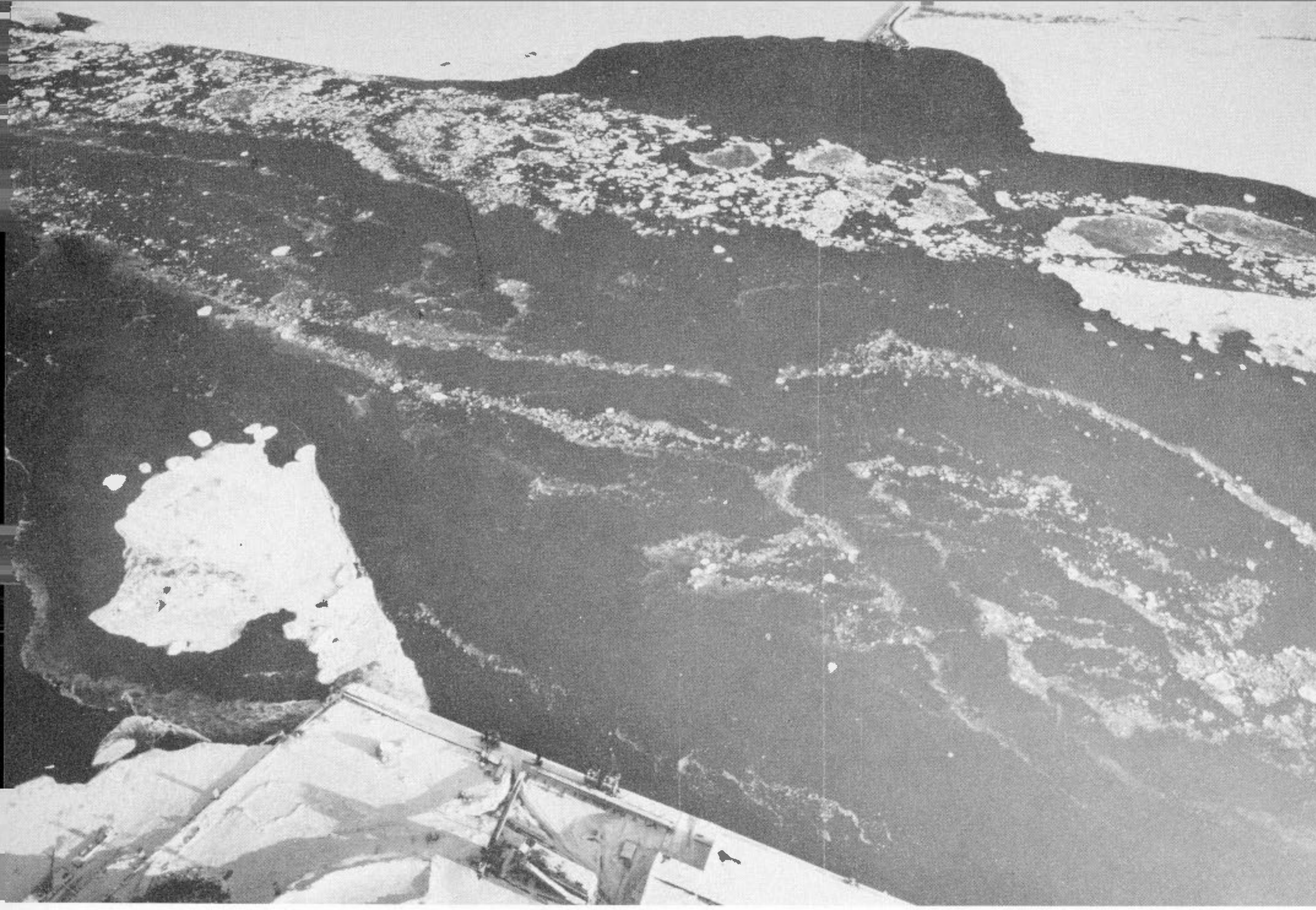
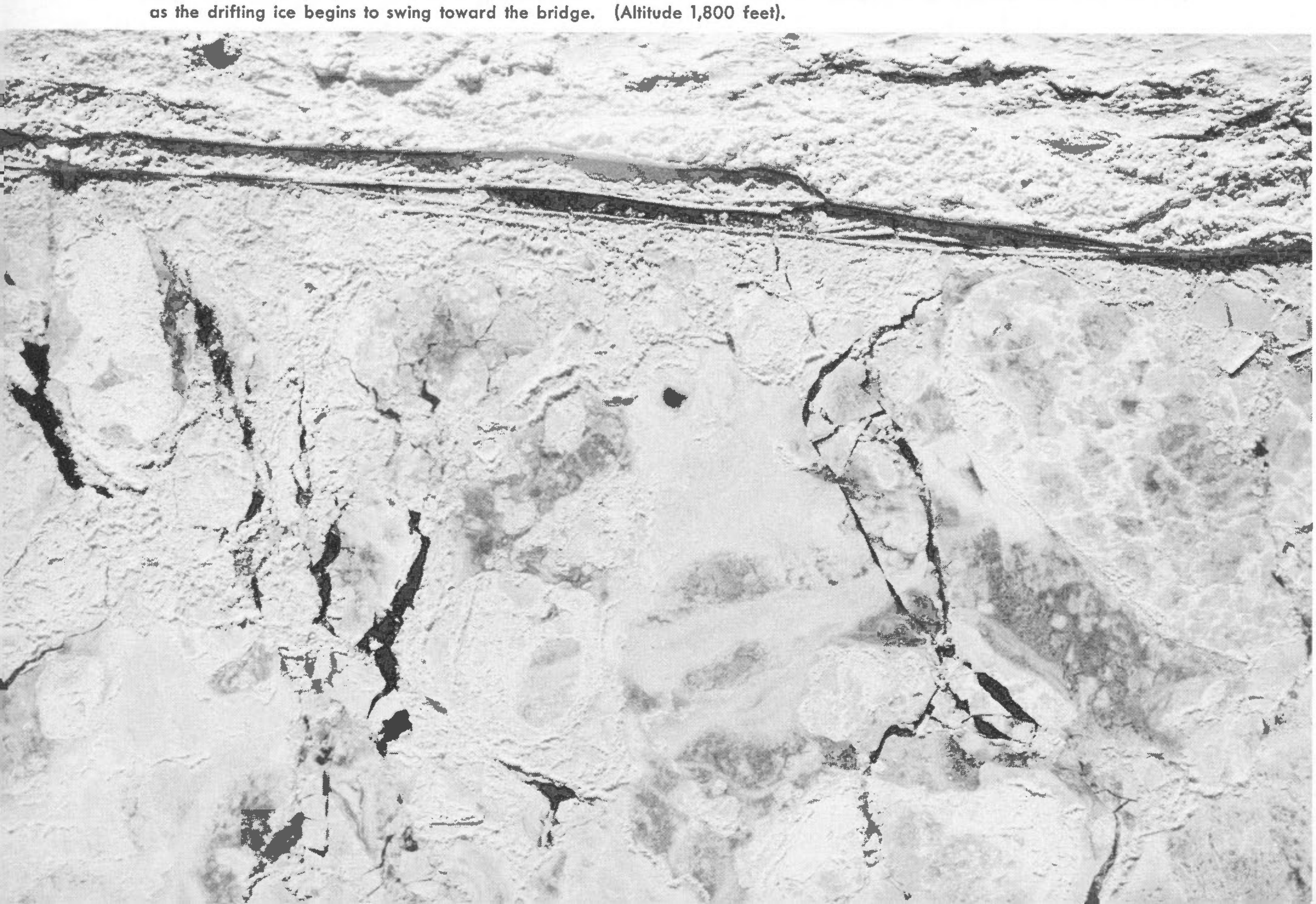


Figure 27. (January 23, 1959). A broad area of landfast ice occupies the south shore of the St. Lawrence River opposite Three Rivers. Through the winter, streams of ice similar to that above were observed drifting down the river. (Altitude 1,800 feet).

Figure 28. (February 20, 1959). Immediately west of the Quebec bridge on the north shore of the river, massive landfast ice shows up in sharp relief. Areas of new and young ice with patches of winter ice having been consolidated, are now fracturing as the drifting ice begins to swing toward the bridge. (Altitude 1,800 feet).



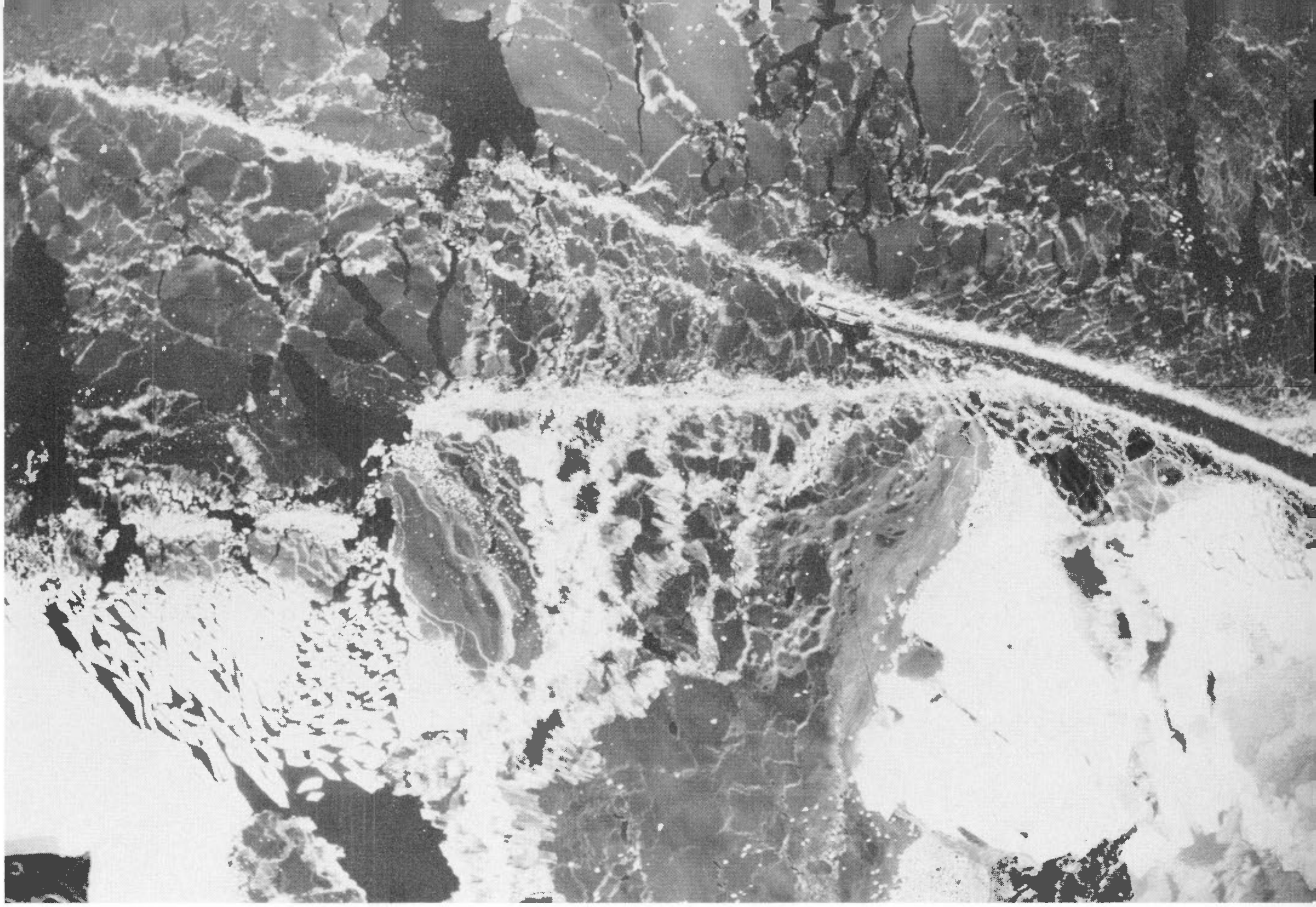


Figure 29. (January 29, 1959). Across this area of new ice, in the lower estuary of the St. Lawrence River south of Seven Islands are the tracks of two ships. A third track made by a passing ship is shown in the centre of the photograph. Very young ice is dark, but through the process of shelving becomes grey in appearance. (Altitude 2,000 feet).

Figure 30. (January 29, 1959). Circular remnants of young ice are discernible within the area of landfast ice. Lines of pressure ridges mark the growth of the landfast ice seaward. Accumulations of ice indicate areas where the ice has been under intense pressure. (Altitude 2,000 feet).

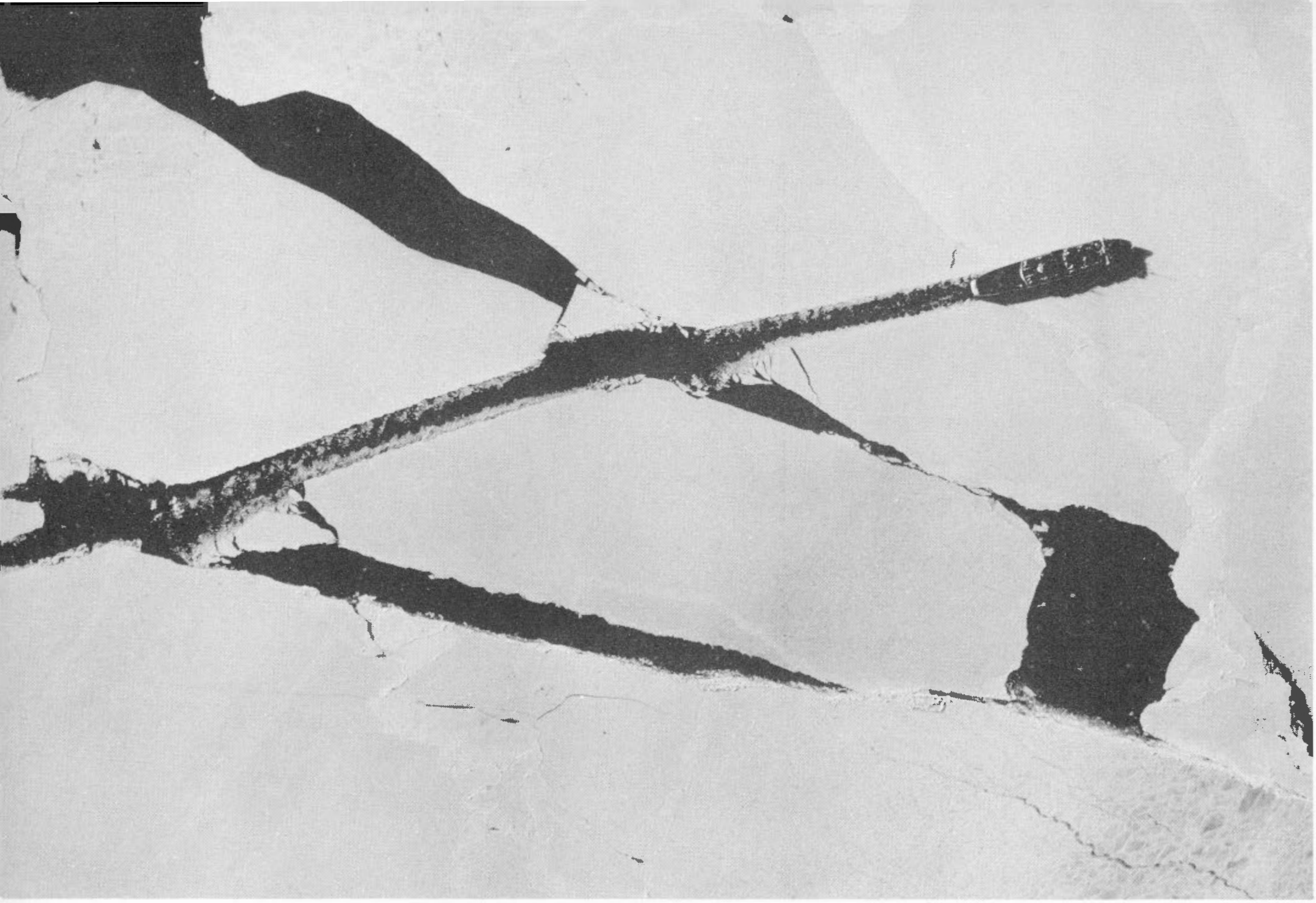


Figure 31. (January 29, 1959). Extensive areas of young ice cover Northumberland Strait. The straight track and small amount of ice wreckage in the wake of the C.G.S. *Abegweit* are characteristic of young ice. (Altitude 2,000 feet).

Figure 32. (February 12, 1959). The Danish ship, *Helga Dan*, passing through young ice near Seven Islands, shows no accumulation of ice about the bow. This ice consisting formerly of very young ice has been subjected to intensive shelving. The ice is grey and opaque, and the cracks in it are sharp. (Altitude 600 feet).

Figure 33. (February 14, 1959). The ice jam at the Quebec bridge indicates the massiveness of the ice. The upper ship C.G.S. *Saurel* is beset, and the lower, the C.G.S. *Montcalm*, is working through the ice in a broad front to free her. The 'worked' ice is consolidating faster than the current can carry it away. (Altitude 1,000 feet).

Figure 34. (February 14, 1959). The St. Lawrence River channel at Levis. A broad arc of landfast ice extending from the Island of Orleans to Quebec harbour encloses the inner harbour at Quebec. Most of this ice floating seaward consists of new and young ice. (Altitude 2,000 feet).

Figure 35. (February 20, 1959). The ship channel near Varennes is clearly marked by the pressure ridges that border the edge of the landfast ice. In the channel small floes of new, young and winter ice have consolidated into a single sheet. At the present stage of consolidation the ice offers no particular resistance to the icebreaker. (Altitude 1,000 feet).

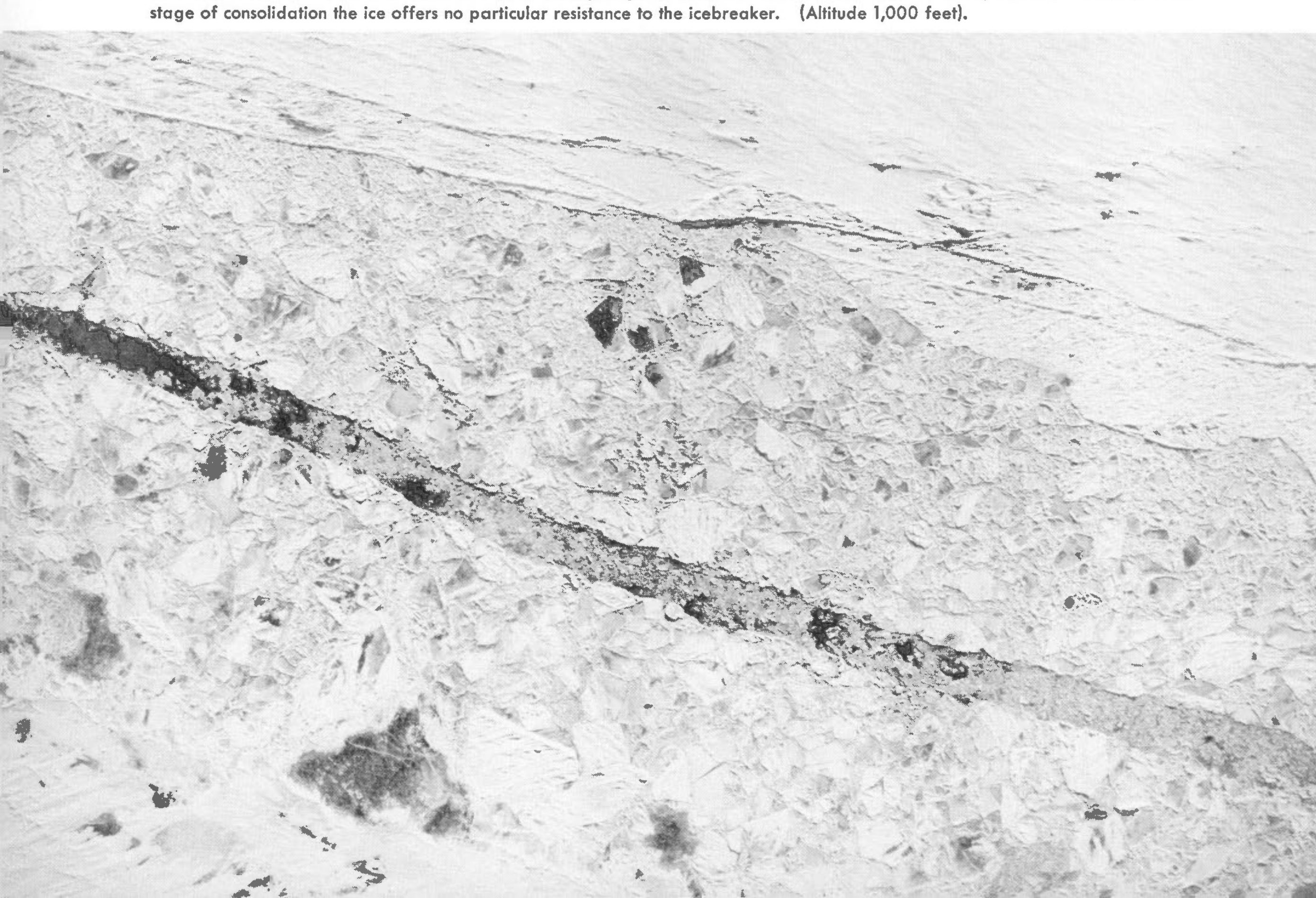
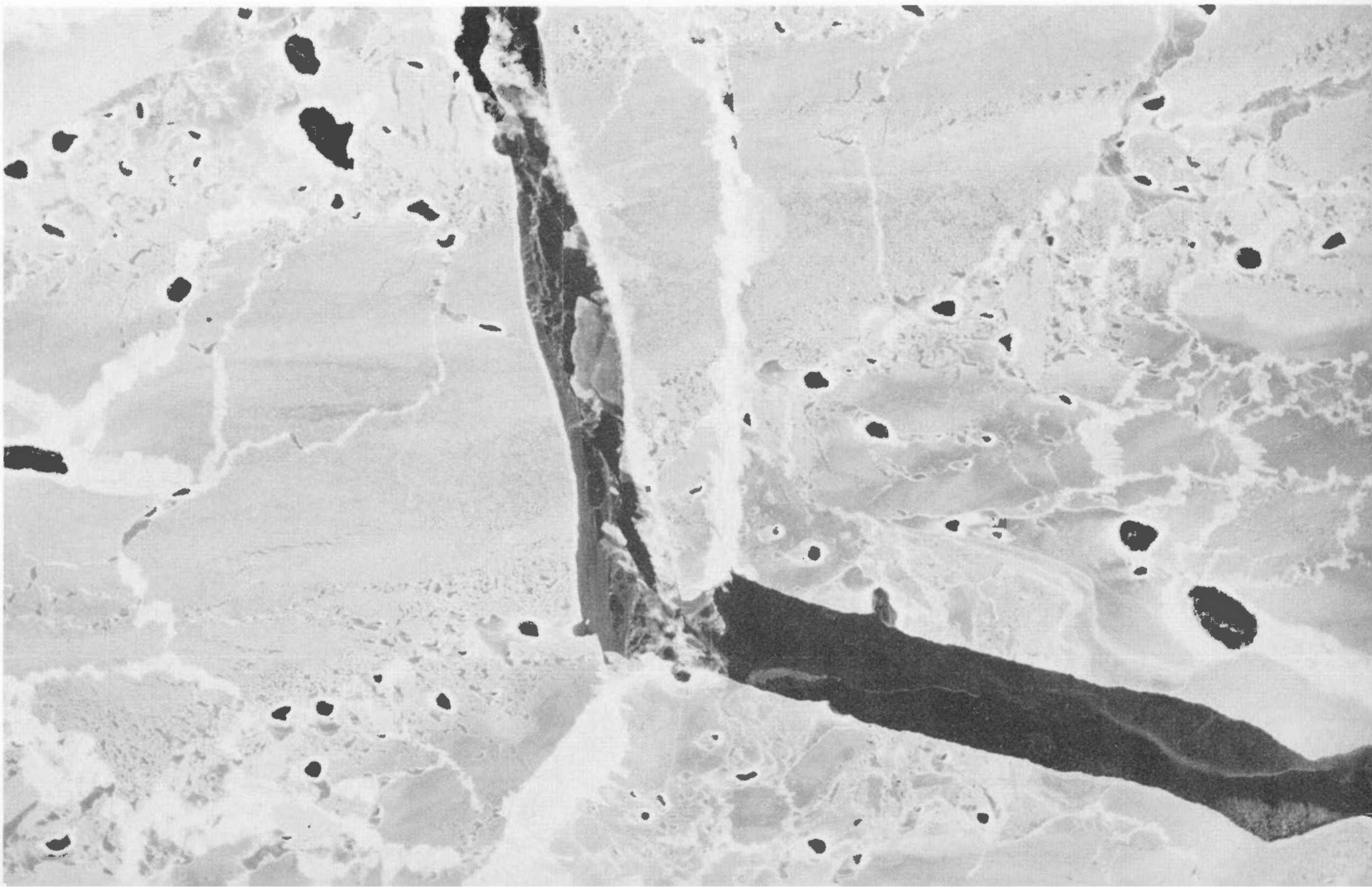


Figure 36. (February 20, 1959). The ship channel in the St. Lawrence in winter is clearly marked as it lies between the encroaching edges of landfast ice. During prolonged cold periods, the floating ice in the channel anchors to the landfast ice, consolidates, and may become a considerable barrier for an icebreaker to crush. The C.G.S. *Ernest Lapointe* is pushing up-river in the vicinity of Verchères. (Altitude 500 feet).

Figure 37. (February 24, 1959). In the early part of winter or on the leeward areas of the gulf new ice formations are prevalent and often reveal an intricate pattern showing the effects of strong drift. This ice consists of consolidated slush and sludge with very young ice. Shelving indicates the ice surface to be under pressure. New and young ice provides no serious problem for ships with adequate power. (Altitude 1,600 feet).



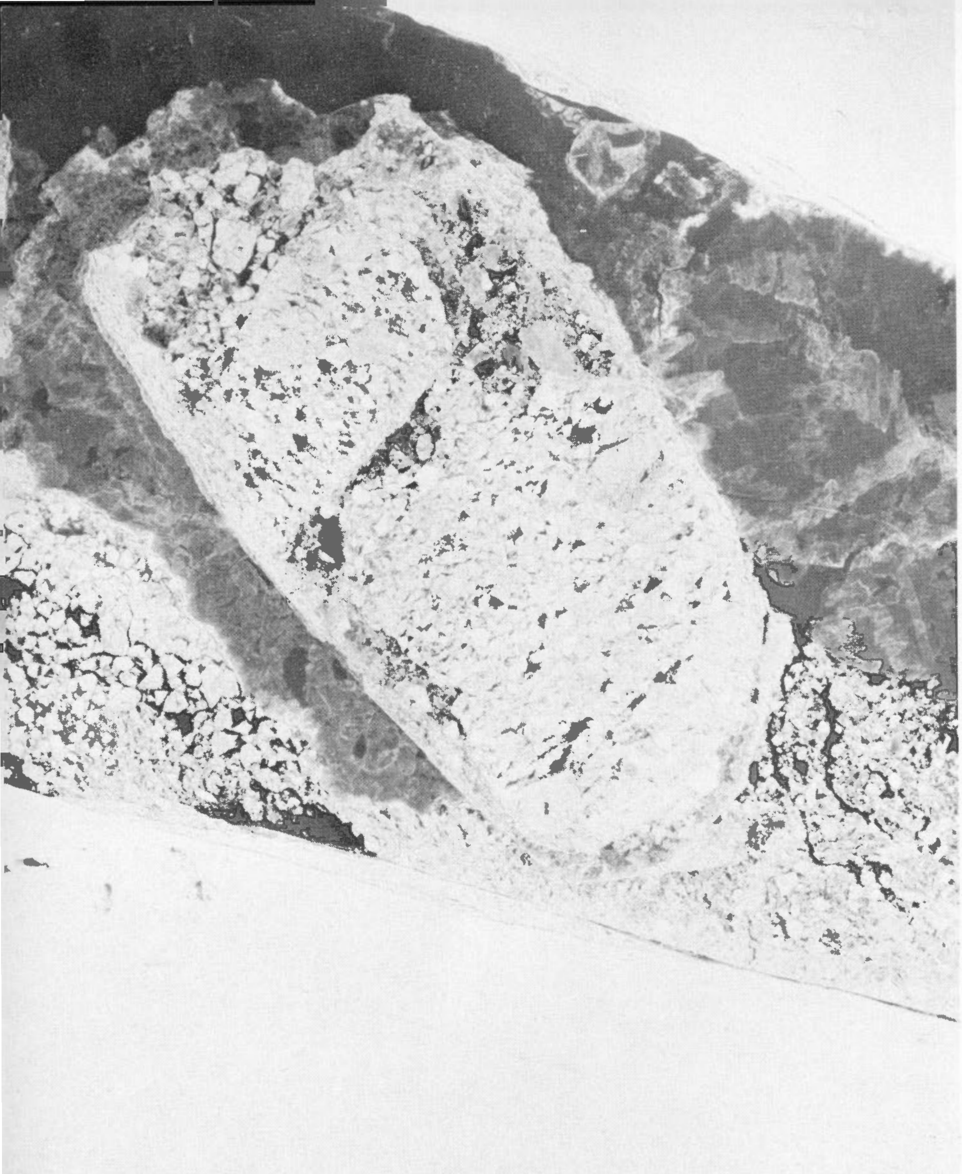


Figure 38
(February 24, 1959). The ship channel bordered by landfast ice is mainly occupied by brash, block and small floes of winter ice, all of which are bonded together by new ice. The shelving of the new ice and fracturing of the larger floes indicate the mass to be under pressure. (Altitude 1,600 feet).

Figure 39
(March 5, 1959). New ice provides no particular problem for the ferries crossing the St. Lawrence at Three Rivers. However, masses of young and winter ice have been known on occasion to carry the St. Lawrence River ferries a considerable distance downstream. (Altitude 1,900 feet).

Figure 40. (March 5, 1959). The ship channel at Three Rivers is bordered by landfast ice. Winter ice broken from the edge of the landfast ice is usually an important constituent of the ice in the ship channel. (Altitude 1,900 feet).

Figure 41. (March 5, 1959). During most of the winter open water bordered the harbour front of Montreal in the vicinity of Victoria bridge. South of the open water channel landfast ice extended to the south shore. (Altitude 1,400 feet).

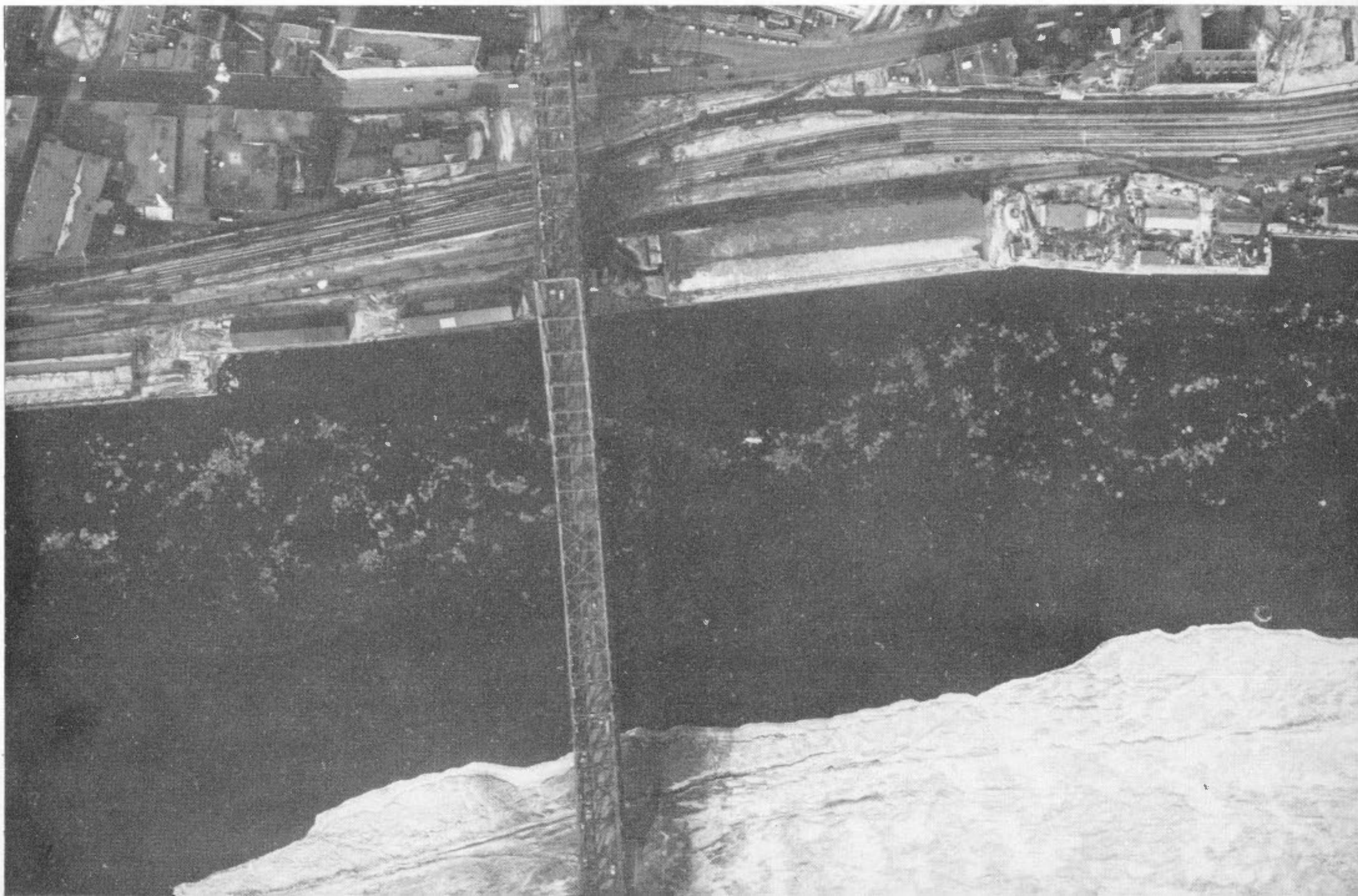
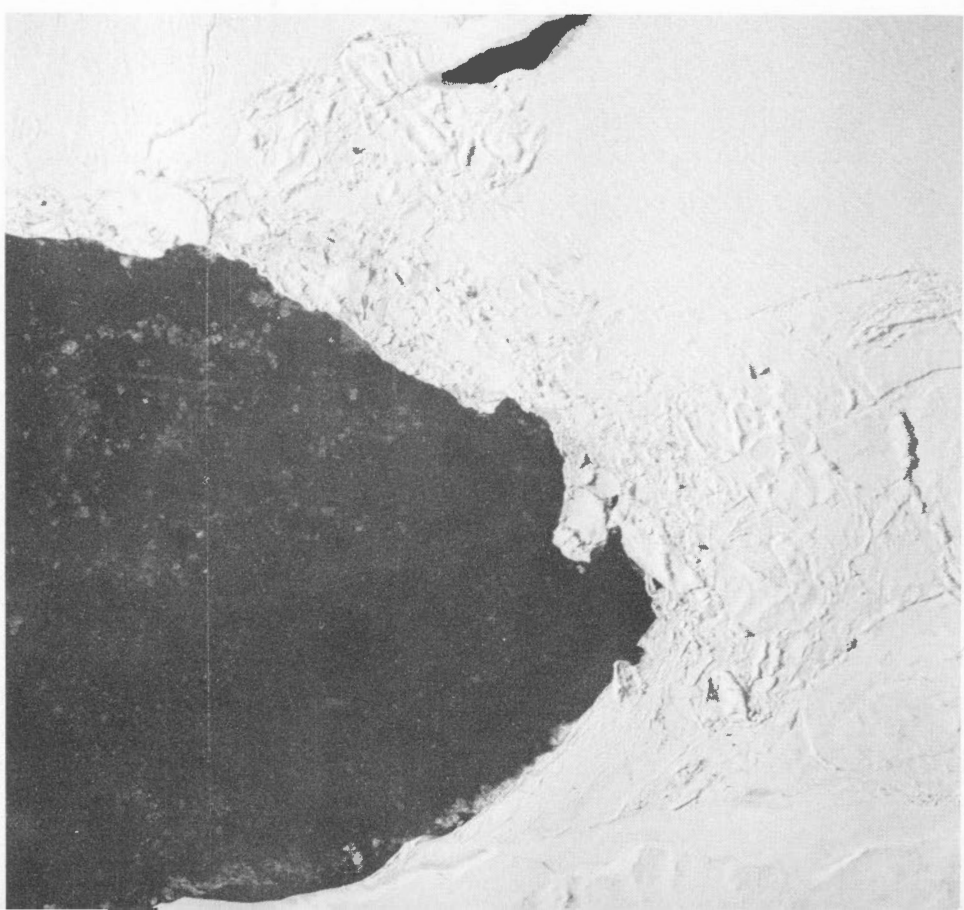


Figure 42
(March 5, 1959). The subdued line of pressure ridges between the ship channel ice and the landfast ice indicates that the landfast ice has almost bridged the channel and is penetrable only by an icebreaker. Such ice conditions result from prolonged periods of very cold weather. The C.G.S *d'Iberville* steams up-channel in the vicinity of Varennes. (Altitude 600 feet).

Figure 43
(March 8, 1959). This photo shows the formation of an ice jam in the ship channel at Montreal East. Some distance downstream from this point the channel ice has anchored to the landfast ice. As drifting ice reaches the barrier it is caught and compressed into windrows. With consolidation this form of ice can be a formidable barrier to an icebreaker. (Altitude 1,800 feet).



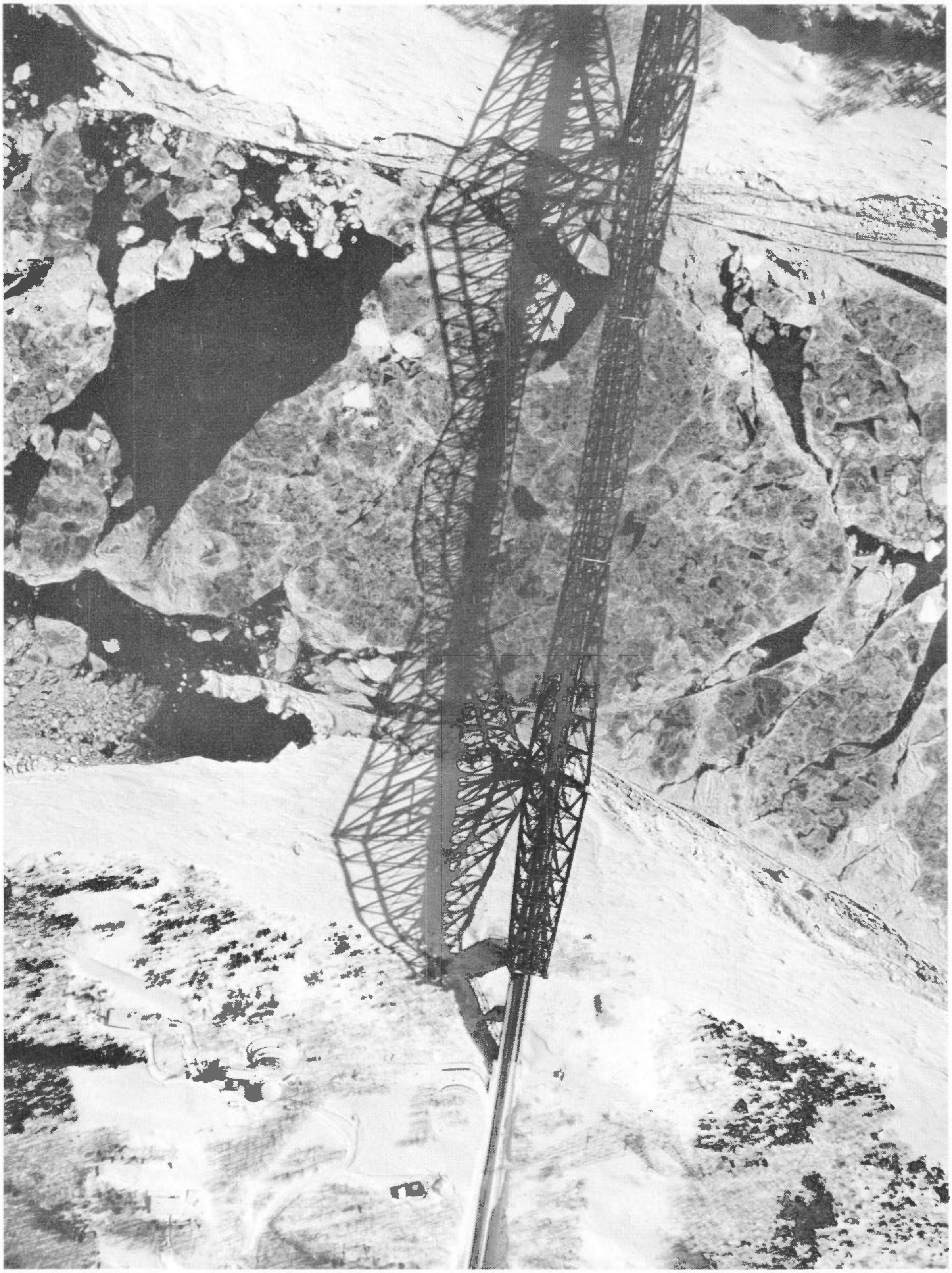


Figure 44. (March 8, 1959). The constriction of the shores of the St. Lawrence River at the Quebec bridge provides an excellent situation for the formation of an ice jam. The edge of the landfast ice is marked with pressure ridges where the ice may be 20 or more feet in thickness. (Altitude 3,000 feet).

Figure 45. (March 8, 1959). This view extends NE across the river from Levis to the landfast ice of the inner harbour of the port of Quebec. The drifting ice, hemmed in between Point Levis and the landfast ice, tends to jam as it rounds the point to enter the Orleans ship channel. Landfast ice along this shore may reach 20 to 30 feet in thickness. The heaviest ice concentrations usually border the Levis shore rather than the Quebec shore. (Altitude 1,800 feet.)

Figure 46. (March 17, 1959). In the area off Cape Tormentine, Northumberland Strait, the ice coverage was 9/10 and consisted mainly of young and winter ice forms. Pressure ridging varied from 1/10 to 5/10 of the ice surface. Because of the combined effect of tides and winds in a restricted channel, the ice in the Strait is usually broken into small floes that offer no special obstacle to the ferry C.G.S. *Abegweit*. (Altitude 1,100 feet).

Figure 47
(March 19, 1959). Regular movements of the icebreakers between Montreal and Quebec help to prevent ice jams on the river by keeping the ice moving downstream in the ship channel. The C.G.S. *Saurel*, facing upstream on Lake St. Peter, is testing the landfast ice on the north side of the ship channel. (Altitude 350 feet).

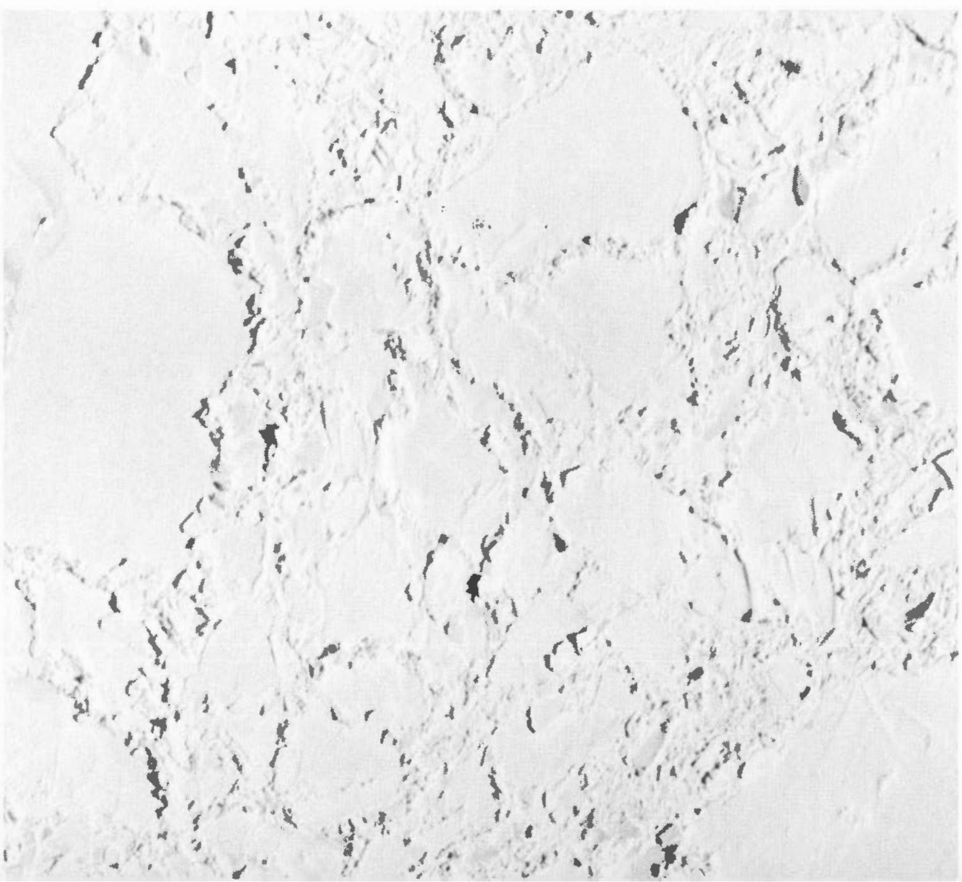


Figure 48
(March 19, 1959). Extensive areas of winter ice with surface coverage of 9/10 to 10/10 and with pressure ridging varying from 5/10 to 8/10 of the ice surface border the windward side of Cape Breton Island, Magdalen Islands, and the west coast of the Island of Newfoundland. Such ice areas would provide a formidable barrier to any ship. (Altitude 1,300 feet).

Figure 49. (April 1, 1959). This freighter, pushing up-river in the vicinity of Donnacona, is steaming through the wreckage of landfast ice that is now drifting downstream. The area of landfast ice bordering the shore has been greatly reduced. (Altitude 1,100 feet).

Figure 50. (April 14, 1959). The eastbound ship in the vicinity of Ste-Anne-de-la-Pérade, has passed through and shattered a large ice floe and is approaching a similar large floe. There are frequently no markings to indicate that these ice masses are rotten. The north shore is free of landfast ice. (Altitude 1,700 feet).

Figure 51. (April 14, 1959). The icebreaker C.G.S. *Ernest Lapointe* is in the process of breaking up a mass of landfast ice that is blocking the eastern entrance to the Seaway canal at Montreal. The ice drifting downstream on the north side of the river provided no obstacles to the freighters that have docked along the Montreal harbour front. (Altitude 1,700 feet).

Figure 52
(April 14, 1959). On this date a mass of ice from Lake St. Peter extended across the eastern entrance of the St. Lawrence River. Although the ice sheet was rotten local areas of hard ice occurred as indicated by the eastbound ship which at the moment is held fast. Shortly after, the ship pushed through the jam to open water. The shores are now relatively free of landfast ice. (Altitude 1,700 feet).

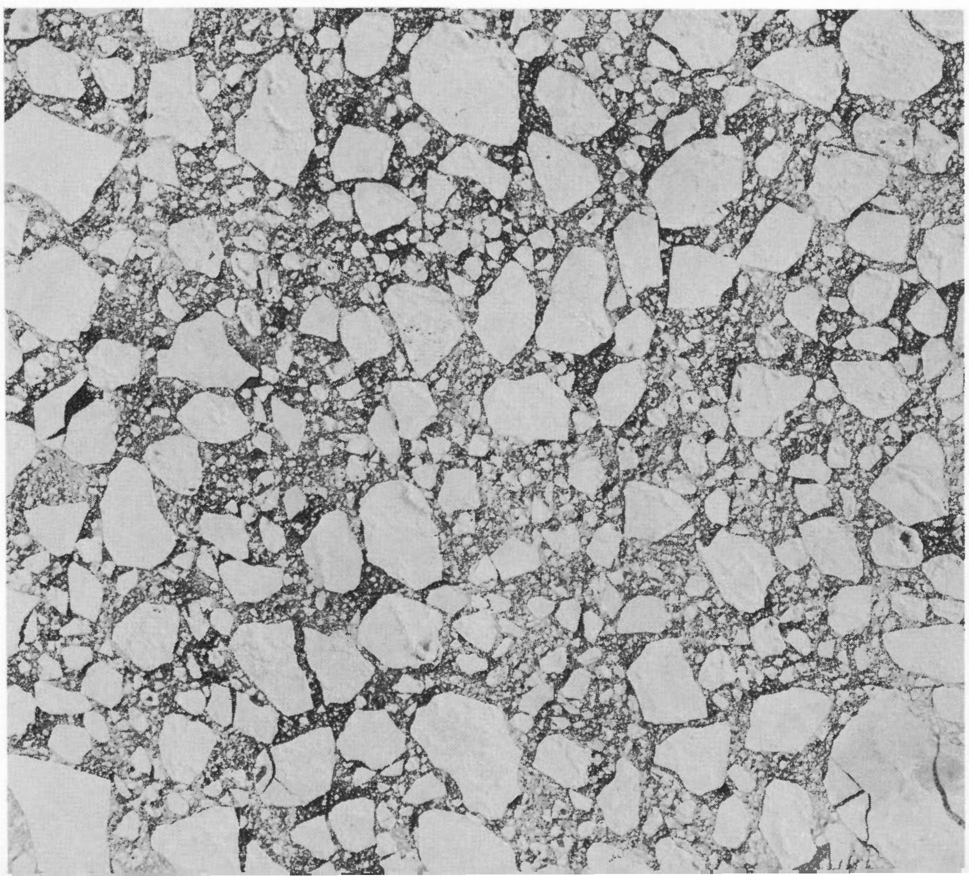


Figure 53
(April 15, 1959). This ice concentration consists of 9/450, winter 10/10, and pressure ridging 2/10. This is an area of 'working' ice where a consolidated field is being reduced to brash and block, and small to medium floes. This feature was particularly characteristic of the icefields at the western entrance of the Strait of Belle Isle. (Altitude 2,100 feet).

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