TIDES, TIDAL STREAMS AND CURRENTS IN THE GULF OF ST. LAWRENCE

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MARINE SCIENCES BRANCH
DEPARTMENT OF MINES AND TECHNICAL SURVEYS
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CONTENTS

PREFACE

This is a review of the surveys carried out by Dr. Bell Dawson, Engineer in charge of the Tidal Survey, between 1894 and 1912, by H.W. Jones, Superintendent of the Tidal and Currents Division of the Canadian Hydrographic Service in 1932 and 1933; and by the Tides, Water Levels and Currents Section of that Service in 1958, 1959 and 1961.

The review serves to emphasize how little could be achieved over a season of many months' duration in the days when every observation had to be obtained manually from a ship at anchor. The recent development of current metres, which can be moored to the seabed and left for periods of two to four weeks to record automatically the water flow, has revolutionised this type of survey to a degree comparable with the effects of the introduction of electronic devices on other aspects of hydrographic work.

While the really conclusive deductions from the earlier work may be meagre, this summary is designed to separate the factual information from that which is partially or wholly supposition and thereby aid in planning the resurvey of the water movements in the Gulf.

The data have been presented in this account in a form considered appropriate for the over-all scientific investigation into the properties of the seawater in the Gulf. The information from the earlier surveys has already been incorporated in the Gulf of St. Lawrence Pilot for the use by mariners. Appendices to this account will be published when the resurvey of the various parts of the Gulf are completed and at the same time the information in the Pilot will be revised.

N.G. Gray,
Dominion Hydrographer.

Ottawa, February 16, 1962.

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W.I. Farquharson

INTRODUCTION

Systematic observations of the water movements were commenced by officers of the Tidal Survey under Dr. Bell Dawson in 1894, and have been continued in later years by the Canadian Hydrographic Service. Until very recently the movements were studied solely from the aspect of surface navigation; the present need for data for oceanographical and engineering purposes has widened the scope of the investigations and has led to the introduction of new types of recording apparatus capable of meeting these requirements.

So far as the vertical movements of the water are concerned there is a very extensive accumulation of data but it is nevertheless inadequate for the more detailed investigations now undertaken. In order to meet purely navigational requirements, tidal observations were almost invariably taken at wharves which are, for obvious reasons, built in the more sheltered inlets along any stretch of coastline. At wharves, which are approached through restricted channels or over relatively shallow bars, the tides are not representative of those in more open waters. It is now necessary to obtain observations off the more exposed parts of the coast and at off-lying islets.

When the tides were observed at wharves it was feasible to employ float operated tide gauges. In order to obtain observations where such facilities are not available, a number of gauges have been acquired which automatically transmit the changes in pressure over a transducer on the seabed, for a distance of from a few hundred feet to more than a mile, to a recorder on shore.

Until a few years ago there was no equivalent to the automatic tide gauge for obtaining long-period observations of the horizontal movements. Such measurements had of necessity to be obtained with instruments suspended from a ship at anchor and, in consequence, the acquisition of long-period observations at a number of sites was a lengthy and uneconomical process which was nowhere ever undertaken on an adequate scale. The detailed study of the horizontal movements has, however, become a feasible proposition with the introduction of self-recording metres which can be moored to the seabed, in order to operate over quite long periods at a pre-selected depth below the sea surface. Such automatic metres, capable of operating in the near-surface layers for continuous periods of 30 days, were first employed by the Canadian Hydrographic Service in 1958. Other types have since been acquired, and subsequently modified, to record at depths down to 500 metres for continuous periods of more than 15 days. The most recent acquisitions will operate at still deeper depths and for much longer periods.

A comprehensive survey of the water circulation in the Gulf of St. Lawrence will commence in 1962 in which these new metres will be employed. This then is an appropriate time to summarize the information hitherto acquired in the Gulf, for it may serve as some guide in the planning of this major survey.

1. THE PROPAGATION OF A TIDAL OSCILLATION

An oscillation comprises vertical and horizontal movements, the tides and tidal streams. These are the two components of the whole response of the water to the astronomical forces, and in this context the terms "tide" or "tidal" refer to the associated vertical and horizontal movements.

The tides are generated in the oceans and larger seas, for they alone are vast enough for the lunar and solar attractions exerted on any one part to be so different from those on another that a measureable transport of water from one part towards the other is created. The bays, gulfs, and straits of coastal waters are too small for the generation of an individual tide of any significance. The tidal oscillations within those inlets are maintained by the oceanic tides at their entrances, either by the rise and fall of those oceanic tides, or by the transport of water in and out of the basin by tidal streams, or by some combination of these vertical and horizontal movements.

In every ocean there are two tidal oscillations, one with a period of half, and the other with a period of the whole, of a lunar day. Each of these oscillations is maintained within every inlet by the ocean tides. Their relative magnitudes depend, to a very large extent, upon the dimensions of the particular inlet.

The tide is generated as a progressive wave and the rate of travel of that wave is governed by the depth of water and is equal to:-

$$\sqrt{gh}$$

where g is the coefficient of gravitational force
h is the mean depth of the gulf

From this formula, the following table gives the mean rate of travel for a progressive wave in a variety of depths:-

Mean depth	Mean rate
50 fathoms	58.2 knots
100 "	82.3 "
200 "	116.3 "
500 "	184.0 "
1000 "	260.2 "
2000 "	367.9 "

Thus, in an ocean the rate of travel is of the order of 400 knots, while in most inlets it will be less than 100 knots. The length of a wave depends upon its period, or time interval between successive crests, and upon its rate of travel. The period of the semidiurnal oscillation is 12 lunar hours, so, where the rate of travel is 70 knots, the length of the wave is 840 nautical miles. In a gulf of the appropriate dimensions, the crest of one wave will be at the head of the gulf when that of its successor reaches the entrance. The period of the diurnal wave is twice as long and, in consequence, the length of the diurnal wave is twice that of the semidiurnal wave. There are very few gulfs that are several hundreds of miles in length so that generally a gulf corresponds to only a portion of a wave-length. In the example quoted, if the gulf were 420 miles long it would correspond to half a semidiurnal wave-length, or if 210 miles long to a quarter of a semidiurnal wave-length.

At the boundary of an ocean or inlet the progressive wave is reflected and travels back along its original path. The interaction between this wave and the incoming wave creates a standing oscillation. That is to say there is no apparent travel of the crest of the wave, the water in one quarter of a standing oscillation rises everywhere simultaneously, while in the adjacent quarter it falls everywhere simultaneously. The rise and fall attains a maximum at the reflecting boundary and at every interval of half a wave-length from that boundary, while at the distance of a quarter and of three-quarters of a wave-length from the boundary, there are nodal lines with no rise or fall. See Figure 1a.

The phase relationship between the vertical and horizontal movements depends on whether the oscillation takes the form of a progressive wave, a standing wave or of some combination of the two. The tide is propagated as a progressive wave only in a strait, with no obstructing islands or shoals, which joins the ocean to an inland sea. With a progressive wave the tidal streams in the upper half set in the direction towards which the wave is travelling and have their greatest rates at the crest of the wave, that is, at the occurrence of high water. The streams set in the opposite direction in the lower half of the wave and have their greatest rates at the occurrence of low water. See Figure 1b.

With a standing oscillation the streams set towards that part of the oscillation where the level is rising and away from that part where the level is falling. The streams are slack at the instances when the levels are stationary, that is at the occurrences of high and low water, and have their greatest rates when the rate of change of level is greatest. At the boundary and at intervals of half a wave-length, where the rise and fall is greatest, the tidal streams have zero rates. They have their greatest rates across the nodal lines where the rise and fall is zero. See Figure 1a.

If the dimensions of a gulf correspond to half a wave-length, then when the oceanic tide at the entrance is high, the level at the head of the gulf will be low and vica versa. In this case there will be no transport of water in and out of the gulf by tidal streams across its entrance; the oscillation within the gulf will be solely maintained by the rise and fall of the ocean tide. There will be a nodal line at a quarter of a wave-length from the boundary and the range of the tide at that boundary will be the same as that of the ocean tide.

If the dimensions of a gulf correspond to a quarter of a wave-length, then high water will occur all over the gulf simultaneously with high water of the ocean tide at its entrance. In this case the oscillation will be maintained principally by strong tidal streams across the entrance, transporting water in and out of the gulf. The range of the tide will increase progressively up the gulf and will be very large at the boundary.

The gulf may correspond to any proportion of a wave-length, but if it exceeds a quarter of a wave-length there will be a nodal line in the gulf, and in consequence high water at the entrance will occur simultaneously with low water at the boundary and vice versa. If the gulf is less than a quarter of a wave-length then high or low water will occur simultaneously all over the gulf.

The period of the diurnal oscillation is twice as long as that of the semidiurnal oscillation, so that if a gulf corresponds to half a semidiurnal wave-length, it will correspond to a quarter of a diurnal wave-length. Thus the dimensions of a gulf may have very contrasting effects upon the semidiurnal and diurnal oscillations.

CORIOLIS FORCE

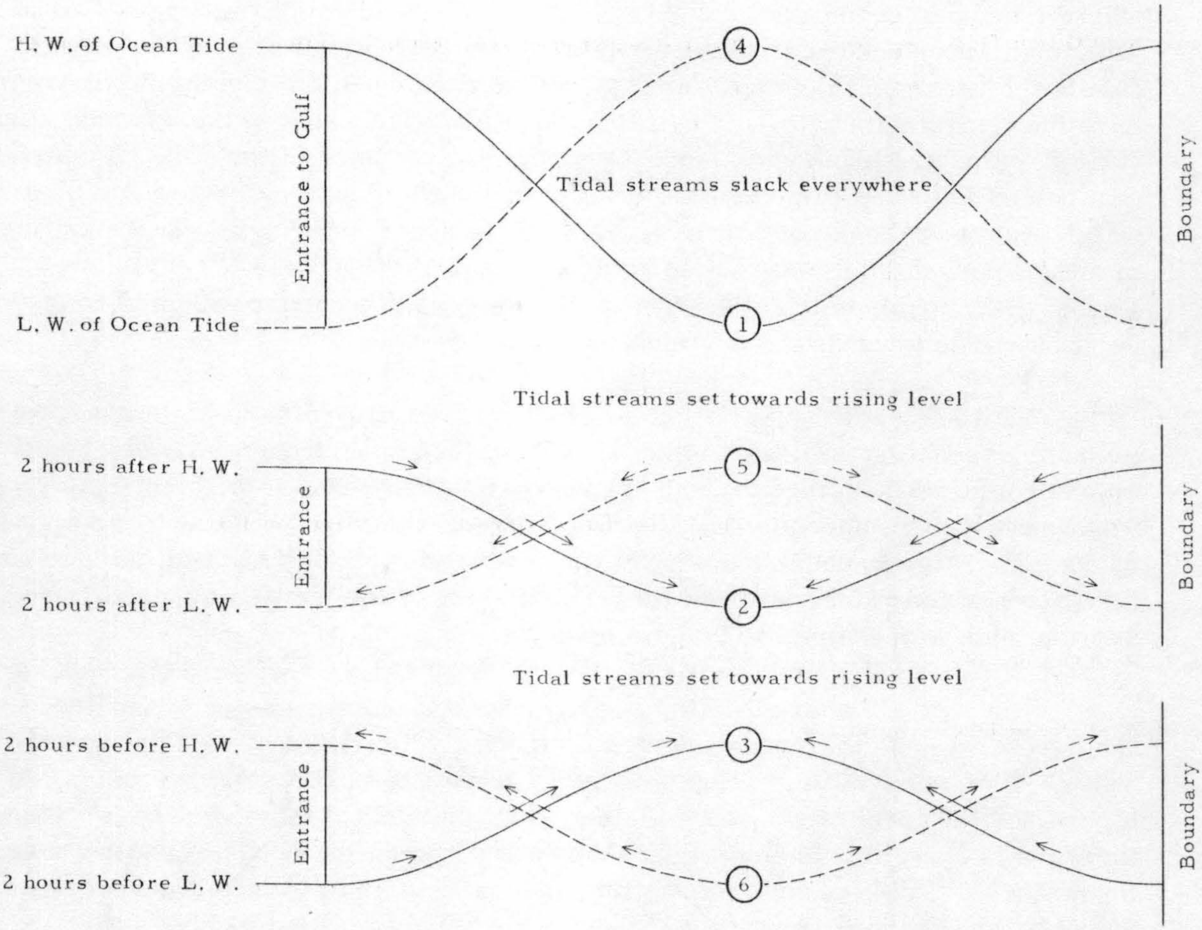
The gyroscopic force, which arises from the earth's rotation about its axis, has marked effects upon the tides in any body of water. In the northern hemisphere this force causes the path of particles of water moving over the earth's surface to be deflected to the right; in the southern hemisphere this effect is reversed. So that in the northern hemisphere when the tidal streams in a gulf or strait are setting westwards, Coriolis force creates a transverse gradient raising the level on the northern shore and depressing it on the opposite shore. When the direction of the streams is reversed, the gradient is likewise reversed. Thus, in any body of water the tides are the resultant of the primary oscillation along the longitudinal axis and of a transverse oscillation. The effects of the transverse oscillation upon the occurrences of high water and upon the ranges of the tide depends largely on whether the primary oscillation takes the form of a standing oscillation, of greater or lesser extent than a quarter of a wave-length, or whether it is propagated as a progressive wave.

With a standing oscillation exceeding a quarter of a wave-length, that primary oscillation has a transverse nodal line across the gulf, but the transverse oscillation reduces this line to a nodal, or amphidromic, point where the range of the tide is zero. At the right-hand end of the original nodal line, high water occurs at a quarter of a period after high water of the oceanic tide in the entrance to the gulf, that is, at the time when the ingoing tidal streams have their maximum rate. At half a period after high water in the entrance, the tidal streams are slack and high water occurs at the head of the gulf. A quarter of a period later the outgoing tidal streams have their maximum rate and high water occurs at the opposite end of the original nodal line. Thus, in the course of a tidal period, high water occurs later in an anti-clockwise progression around the amphidromic point. The range of the tide increases from zero at that point outwards towards the perimeter of the gulf.

If the standing oscillation is less than a quarter of a wave-length, the primary oscillation will have no nodal line and in consequence there will be no amphidromic point in the gulf. In the absence of Coriolis force, high water would occur simultaneously all over the gulf, but the effects of that force are to cause high water to occur rather earlier on the shore to the right of the ingoing tidal stream and rather later on the opposite shore, as compared with the average high water time for the gulf as a whole.

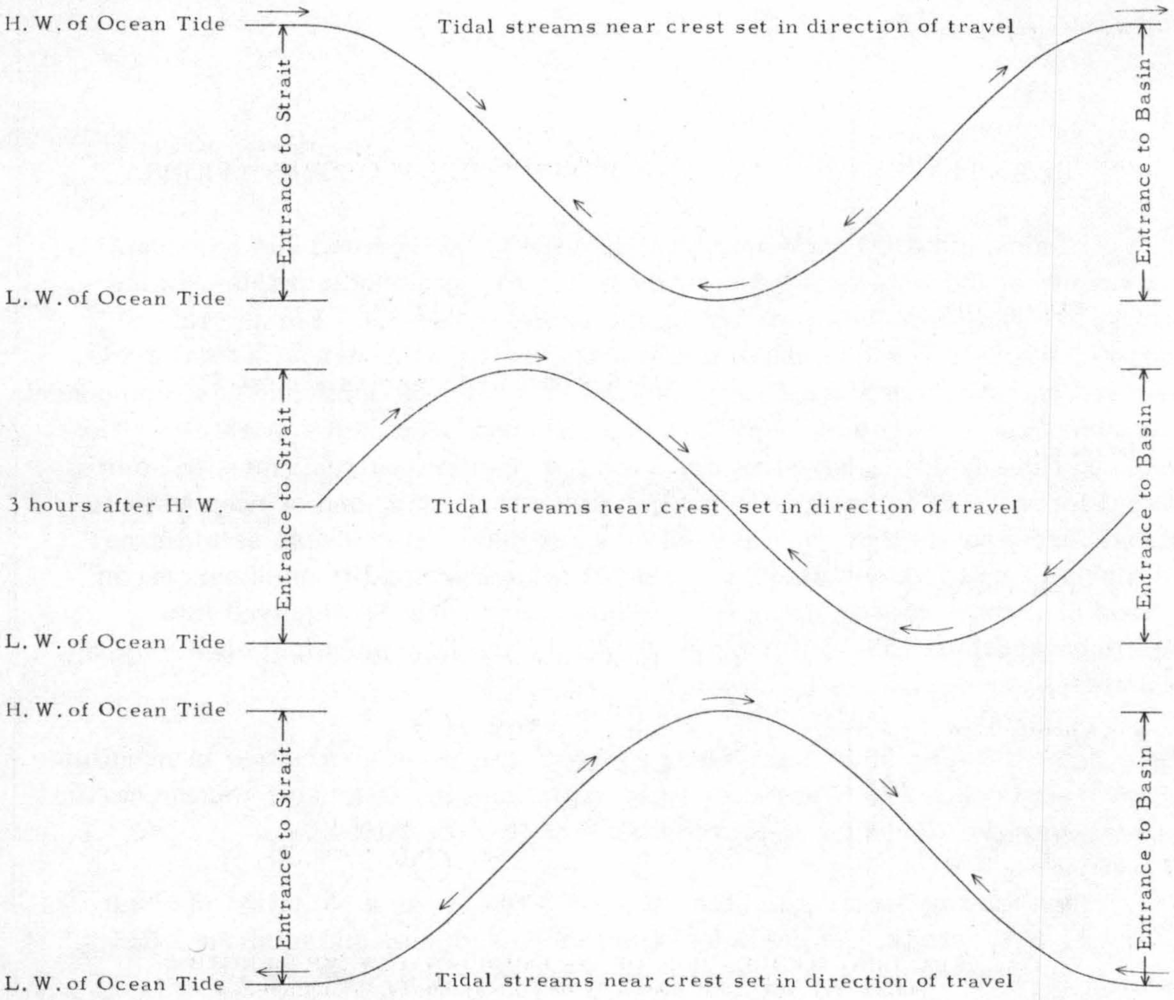
In a strait where the tide is propagated as a progressive wave, the tidal streams have their maximum rates at the occurrences of high and low water. The transverse gradients are thus maximum at these occurrences. At high water the level is raised on the shore to the right of the direction in which the wave is travelling and correspondingly lowered on the opposite shore. At low water the tidal streams are setting at their maximum rate in the reverse direction and the gradient is consequently the reverse of that at high water. Thus, on the shore to the right of the direction in which the wave travels, the level is raised at high water and depressed at low water, with a resulting increase in the tidal range along that shore. Exactly the opposite occurs along the other shore, the level is lowered by Coriolis force at high water and raised at low water. With a progressive wave this force has no effect upon the times at which high or low water occur.

In the most usual circumstances where the tidal oscillation is the resultant of both standing and progressive waves, the range of the tide will be greater and high water will occur earlier on the shore to the right of the direction of the ingoing tidal stream, as compared with conditions on the opposite shore.



STANDING OSCILLATION OF A SEMIDIURNAL WAVE LENGTH
Successive stages at intervals of 2 lunar hours, as numbered.

Fig. 1a



PROGRESSIVE WAVE WITH A SEMIDIURNAL PERIOD

Successive stages at intervals of 3 lunar hours

Fig. 1b

2. ANALYSES OF TIDAL AND TIDAL STREAM OBSERVATIONS

Tides and tidal streams, as respectively the vertical and horizontal components of the whole response of the water to the periodical tide-raising forces, are analyzed and predicted by the same processes. For the tidal streams, whose directions may change progressively throughout a tidal cycle, observed directions and rates are resolved into rates in north and east component directions, and these components are analyzed and predicted separately. The observed tides and tidal streams are each the resultant of responses to semidiurnal forces with an average period of half a lunar day, and of responses to diurnal forces with an average period of a full lunar day. These semidiurnal and diurnal forces vary with changes in astronomical conditions occurring in periods of from 2 weeks to 19 years. These forces can be resolved into constituents, which have differing periods, and the four principal ones, M_2, S_2, K_1 and O_1, are defined as follows:-

M_2	the average lunar semidiurnal force, which has a variation in magnitude of about ± 20% with the changes in the moon's distance from the earth, and one of about ± 4% in the nineteen-year variation.
S_2	the average solar semidiurnal force, which has a variation of about ± 27% with the declinations of the moon and sun, and of about ± 6% with the changes in the sun's distance from the earth.
K_1	the average lunisolar diurnal force, which has a variation of about ± 33% with the sun's declination, of about ± 15% with the moon's distance from the earth, and of about ± 12% in the nineteen-year variation.
O_1	the average lunar diurnal force, which has a variation of about ± 20% with the moon's distance from the earth, and one of about ± 18% in the nineteen-year variation.

The semidiurnal forces, M_2 and S_2, are in phase at new and full moon and in opposition at quadrature. The diurnal forces, K_1 and O_1 are in phase when the moon has maximum declination north and south of the equator, and are in opposition as the moon crosses the equator.

In the process of analysis the responses, in any locality, to the constituent forces are determined in the form of the phaselag, g, and the amplitude, H. The phaselag, for any response, corresponds to a time interval between the constituent force having its maximum tide-raising potential on the meridian of Greenwich, and the response to that constituent force attaining its maximum elevation as recorded in the local standard time. The amplitude for any response is a measure of the rise, relative to mean sea-level, of the water when it attains its maximum elevation, in response to the constituent force with its average maximum tide-raising potential.

The relative phaselags and relative amplitudes of the responses to these four principal constituent forces are everywhere conditioned by the depth, shape and size of the particular basin. It is extremely rare to find that the phaselags of the responses to M_2 and S_2 are the same and in consequence the resultant maximum response to these semidiurnal forces does not occur on the days of full or new moon, but at some interval from these occurrences which depends upon local conditions. These same conditions determine the relative magnitudes of the responses to M_2 and S_2, for, whereas the average magnitude of the solar force is 46% of that of the average lunar force, the average magnitude of the responses may be anywhere from 100% to 16% in different parts of the world. This is equally true of the relative phaselags and relative magnitudes of the responses to K_1 and O_1.

It is evident that the analysis of any continuous series of observations which does not cover nineteen years must depend upon assumptions. For analyses of the tide it is usual to rely upon observations covering the period of one year and to assume that the responses are varied in direct proportion to the forces by the nineteen yearly variations. The shorter the length of the continuous observations, the greater are the number of assumptions which must be made and the greater are the effects upon the analysis of any non-periodic fluctuations caused by changes in meteorological conditions. It the observations cover only a period of from 15 to 90 days, in addition to the assumptions made in the analysis of a year's observations, it is also necessary to assume that the responses of the water to astronomical changes occurring in the period of a year, or in one of six months, are directly proportional to the changes in the forces themselves. The minimum period over which the semidiurnal and diurnal tidal streams and the residual current can be separated is a lunar day. In order to be able to isolate the responses to the constituents M_2, S_2, K_1 and O_1 from any period of observations of less than 15 days, it is necessary to make assumptions with regard to the phaselag and amplitude relationships between M_2 and S_2 and with regard to those relationships between K_1 and O_1. These assumptions are based on the relationships known to exist at some other site in the locality.

The shorter the period of observation, the greater is the effect of non-periodic fluctuations upon the analysis, and the tidal streams appear to be much more susceptible to such fluctuations than the tides. Experience has shown that the results obtained by the analysis of short-period tidal stream observations, particularly those in open waters, are crude. For any scientific study of the tidal streams, a period of 15 days continuous observation is the minimum upon which any reliance can be placed. In forthcoming surveys that will be the standard accepted, but most of the data in the present report are based on much shorter periods of observation and any conclusions must be regarded as tentative.

When the phase relationship between the vertical and horizontal movements is considered, it must be borne in mind that the tidal observations are recorded as heights, that is as displacements from mean sea-level, while the tidal stream observations are recorded as rates of change of displacement. Thus in analysis, the phaselags of the tidal constituents relate to high water - that is, maximum positive displacement - while the phaselags of the tidal stream constituents relate to maximum ingoing tidal stream - that is, maximum rate of change of displacement in the ingoing direction.

With a progressive wave, maximum ingoing tidal stream occurs at high water, thus, if the phaselags, g, of the tidal stream constituents are similar to the phaselags, g, of the corresponding tidal constituents in the same locality, this is a clear indication that the oscillation takes the form of a progressive wave.

With a standing wave, maximum ingoing stream occurs with the maximum rate of rise in the inner part of a gulf, that is one-quarter of a cycle before the occurrence of high water in that part of a gulf. Thus, if the phaselags, g, of the tidal stream constituents are similar to $(g-90°)$ of the corresponding tidal constituents, this relationship shows that the oscillation has the form of a standing wave.

3. THE TIDES IN THE GULF OF ST. LAWRENCE

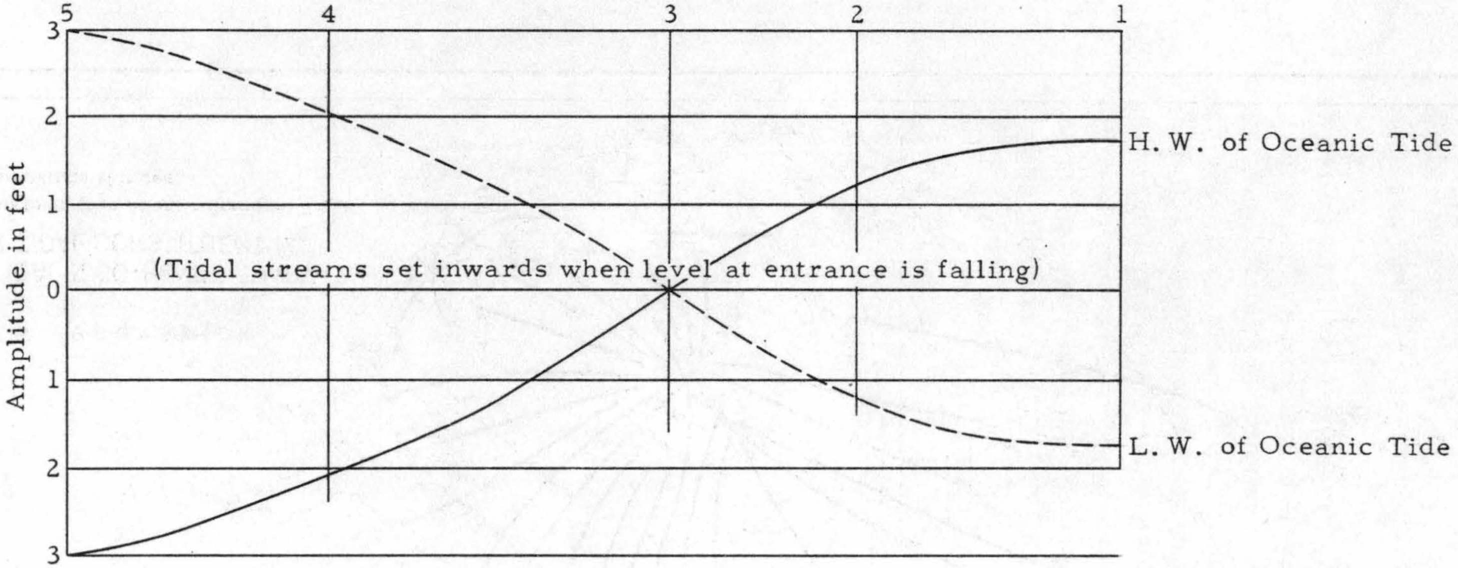
The propagation of the tides, or of any of its constituents, can be most clearly illustrated by a cotidal chart. The data for such charts are based on the analyses of long-period observations of the vertical tidal movements on the coast and at the offlying islands and on the analyses of long-period observations of the horizontal tidal movements. At the present time there is little detailed information available on the horizontal movements, and of necessity the cotidal charts for the Gulf of St. Lawrence are derived from the tidal observations alone.

On these charts the relative occurrences of high water in various parts of the Gulf are depicted by cotidal lines; a cotidal line being defined as a line along which high water of the tidal constituent occurs simultaneously at all points. The relative amplitudes of that constituent in various parts of the Gulf are depicted by co-range lines; a co-range line being defined as a line along which the amplitude is everywhere the same.

The boundary between an oscillation inside a gulf and the oceanic oscillation is rarely clearly defined topographically. If, however, the dimensions of the gulf exceed a quarter of a wave-length, as indicated by the presence of an amphidromic point, then there will be a decrease in the range of the tide from the oceanic boundary towards that amphidromic point. In this case the boundary can be fixed as conforming approximately to the co-range line with the highest value. In the case of the Gulf of St. Lawrence, this line appears to run near a line joining Louisburg, N. S. to Burin Peninsula, Nfld., and not across the narrowest part of Cabot Strait. If the area within this boundary corresponded to half a semidiurnal wave-length, it would also correspond to a quarter of a diurnal wave-length. This, however, is evidently not the case, for the indications are that the diurnal amphidromic point lies well to seaward of this boundary. It therefore follows that the dimensions of the gulf within this boundary are less than half a semidiurnal wave-length.

Figure 3a. shows diagramatically the semidiurnal oscillation along its longitudinal axis, from the assumed boundary with the ocean, across the gulf to the estuary of St. Lawrence River. Figure 3b. shows the cotidal chart for the semidiurnal tidal constituent M_2, based on coastal observations. It shows the influence of Coriolis force in the reduction of the nodal line to an amphidromic point and in the anticlockwise progression of the cotidal lines around that point. The cotidal lines are given for each change of 15° in phaselag, which is equivalent to a time interval of 31 minutes. The co-range lines are given at intervals of .25 feet in amplitude, which is the same as .50 feet in range.

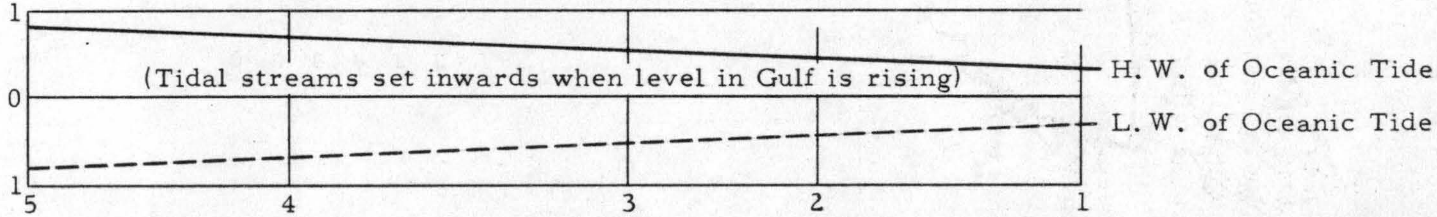
Figure 3c. shows diagramatically the diurnal oscillation along the longitudinal axis of the gulf, between the same boundaries as that of the semidiurnal axis. Figure 3d. is the cotidal chart for the diurnal constituent K_1, and, with this standing oscillation of less than a quarter of a wave-length, the influence of Coriolis force is apparent in the fact that, relative to the average high water phaselag in the Gulf, high water occurs earlier in the northeastern part and later in the southwestern portion. On this chart the cotidal lines are also given for each change of 15° in phaselag, but for the diurnal constituent K_1 this is equivalent to a time interval of 60 minutes.



Semidiurnal oscillation along longitudinal axis of Gulf of St. Lawrence.

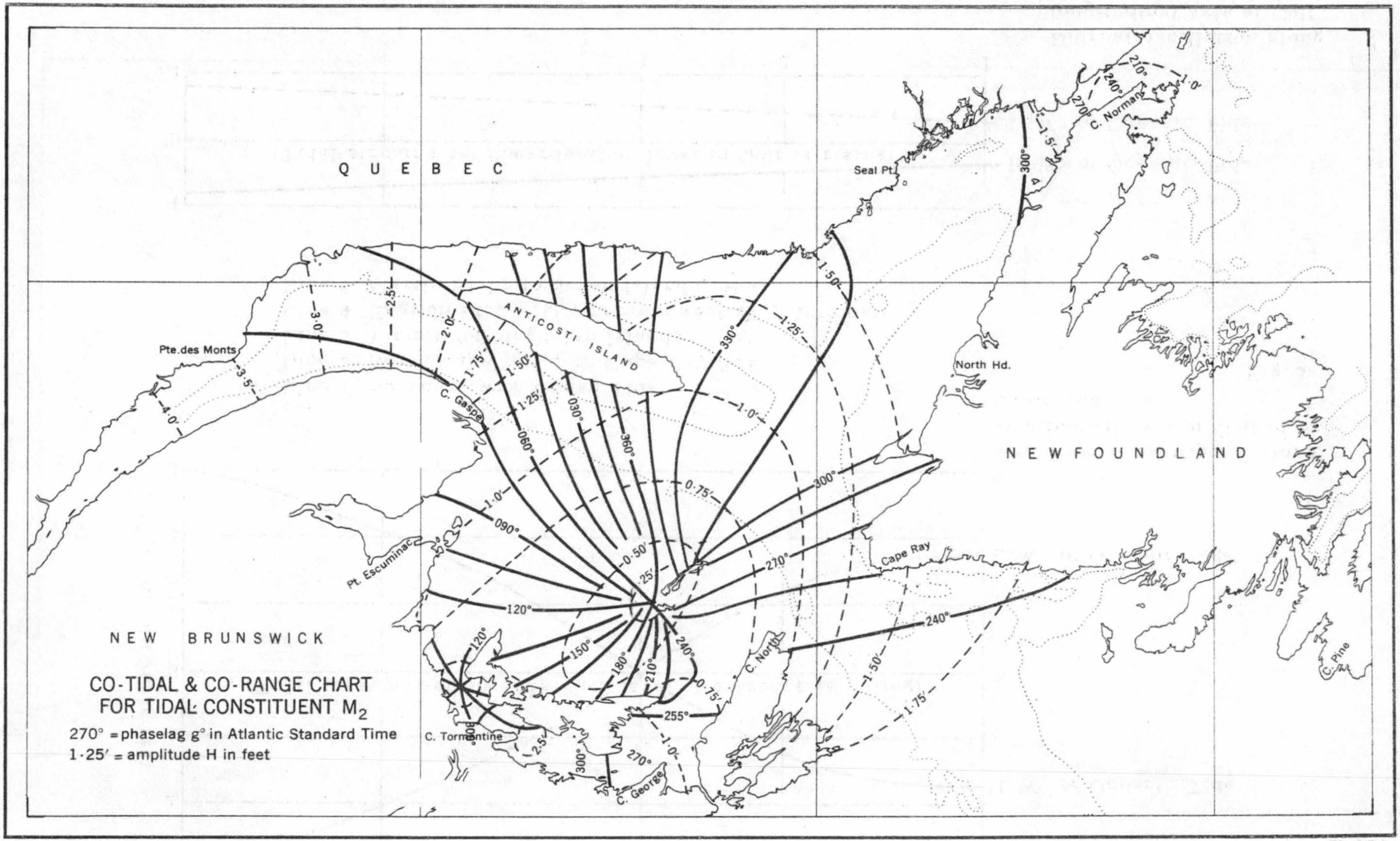
Fig. 3a

Line 1 Boundary with Ocean Tide
Line 2 North Cape N. S., to Cape Ray N. F.
Line 3 Vicinity of Magdalen Islands
Line 4 English Pt., P. Q., to Southwest Pt., Anticosti
Line 5 Martin River to Seven Islands, P. Q.



Diurnal oscillation along longitudinal axis of Gulf of St. Lawrence

Fig. 3c



CO-TIDAL & CO-RANGE CHART FOR TIDAL CONSTITUENT M_2

270° = phaselag g° in Atlantic Standard Time

1·25′ = amplitude H in feet

Fig:3b

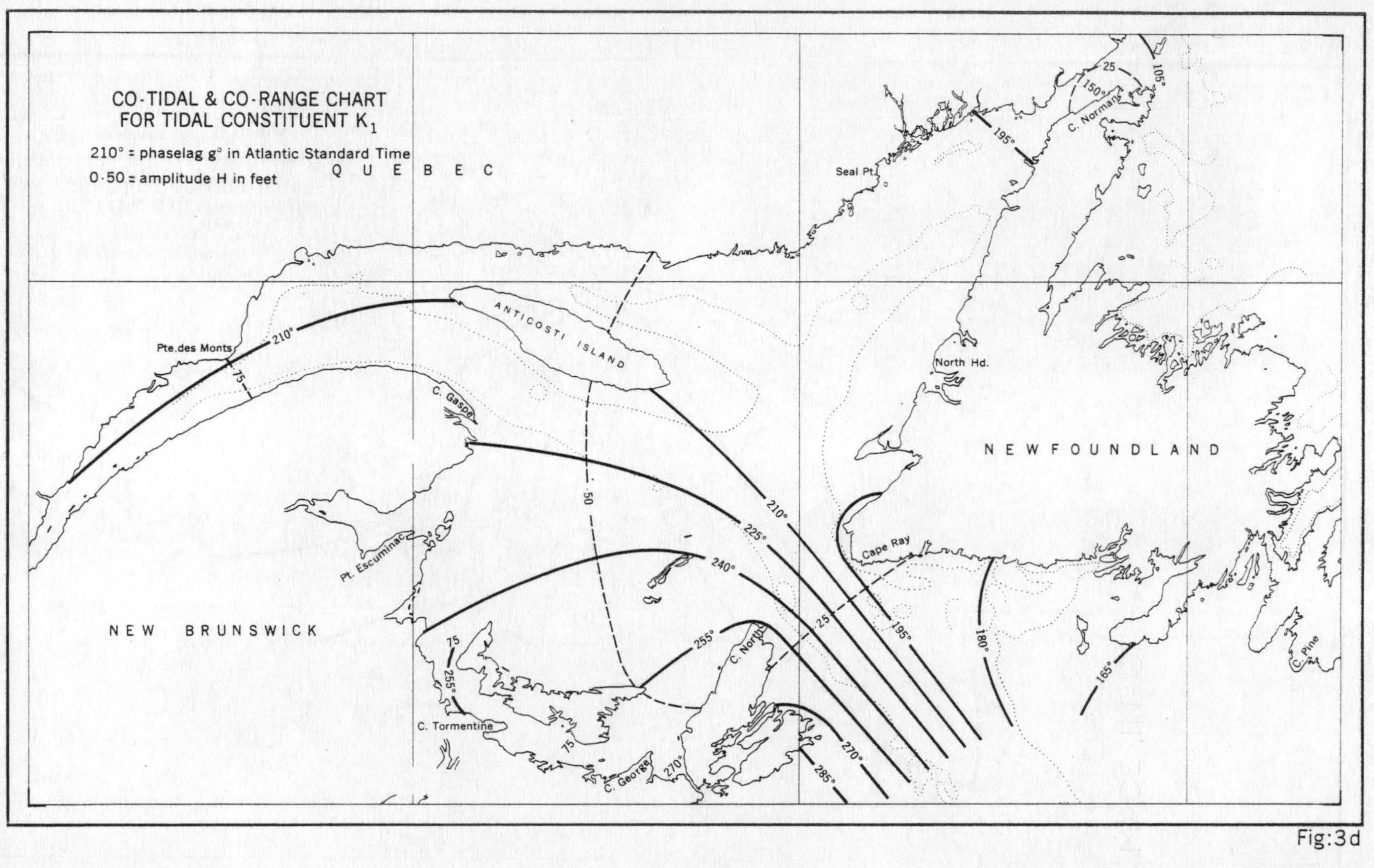

CO-TIDAL & CO-RANGE CHART
FOR TIDAL CONSTITUENT K_1
210° = phaselag g° in Atlantic Standard Time
0·50 = amplitude H in feet
QUEBEC
NEWFOUNDLAND
NEW BRUNSWICK
ANTICOSTI ISLAND
Pte.des Monts
C. Gaspe
Pt. Escuminac
C. Tormentine
C. George
C. North
Cape Ray
North Hd.
Seal Pt.
C. Norman
C. Pine
25
150°
105°
195°
210°
75
50
225°
240°
255°
25
210°
195°
180°
165°
75
255°
75
270°
270°
285°

Fig:3d

OBSERVATIONAL DATA AND INTERPRETATIONS

A. CABOT STRAIT

DATA

During June and July, 1959 the Canadian Hydrographic Service obtained a number of long-period observations in the near-surface layers and some simultaneous short-period observations in the deeper layers. There are in addition some short-period obervations obtained by the Tidal Survey in 1894, together with notes on the surface sets experienced by mariners sailing in these waters.

In 1959 observations were obtained at a series of depths at each of the numbered stations shown on Figure A1. except station 4, at which the metre failed to operate. At each, a self-recording metre was moored for a period of 15 days or more, recording direction and rate every five minutes at an average depth of 13 metres. Observations were taken at five additional depths at each of the six stations for periods of 48 lunar hours, except at station 3, where they had to be abandoned owing to bad weather after 24 lunar hours.

The observations obtained with the self-recording metres were analyzed for two component directions, one being that in which the ingoing stream attains its maximum rate and the other in a transverse direction. The harmonic constants for the constituents in these two component directions are given in Table A1, together with the average direction and rate of the resultant residual current. The direction of the ingoing stream is northwest and that of the transverse direction is northeast in all cases. The fact that g of M_2 for the northwesterly direction is earlier than that for the northeasterly direction indicates that at stations 1, 2, 5 and 6 the streams rotate in a clockwise direction. The amplitudes H for the minor direction at stations 3, 5 and 6 are relatively small, so that the flow is nearly rectilinear at these stations.

The harmonic constants for the short-period observations taken at these stations are given in Table A 2. These were computed from comparisons between simultaneous observations with the self-recording metre at the same station. The exceptions were those at stations 3 and 4, where the self-recording metres were not in operation at the times when the other observations were made. In these cases the harmonic constants were computed from comparisons with the self-recording metre at station 2. The constants are in all cases given only for the direction in which the ingoing stream attains its maximum rate, for it is not considered that the relatively small transverse rates can be determined with adequate accuracy with instruments suspended from a ship anchored in very deep water.

The average direction and rate of the residual currents at a depth of 13 metres, for the periods during which the self-recording metres were in continuous operation, are included in Table A1. The day-to-day fluctuations in those residual currents are indicated by the daily averages, as computed over a solar day, given in Table A3. The mean residual currents at all depths over the period of simultaneous observations at each station are included in Table A2.

Figure A1 also shows the lettered stations at which observations were taken during the survey of 1894. Those observations, together with the information supplied by mariners, do provide some additional data with regard to the currents in the near-surface layers.

INTERPRETATION OF TIDAL STREAM DATA

The responses to the semidiurnal constituent M_2 for the whole profile of the section line surveyed are shown on Figure A2. In constructing this diagram the greatest weight has been given to the data obtained with the self-recording metres at a depth of 13 metres. In the case of the simultaneous observations at station 1, Table A3. shows that because these were obtained during a period of very marked changes likely to have disturbing effects on the analyses of the tidal streams, the responses at depths other than 13 metres have been given very little weight.

Figure A2. shows that the response to the constituent M_2 is fairly uniform all along the section line, with a phaselag g of about 300°, and an amplitude H of about 0.4 knots in the upper layers. The cotidal chart, Figure 3b. shows that near the oceanic boundary of the semidiurnal oscillation, the M_2 tidal constituent has a phaselag of about 240°, while in Gaspe Passage the corresponding phaselag is about 060°. The ingoing tide stream with a phaselag of 300°, thus reaches its maximum rate about 4 hours before high water in Gaspe Passage. This indicates that in this area the phase relationship between the tides and tidal streams of the semidiurnal oscillation conforms fairly closely to that expected with a standing wave.

The responses to the diurnal constituents are not strong and the analysed values, even in Table A1 where they are based on at least 15 days' observations, are erratic. The responses to the diurnal constituent K_1 are shown on Figure A3. and have been weighted with the same considerations as were employed in depicting those of the semidiurnal constituent M_2. Along the section line as a whole, g of K_1 has a value of about 150°, which compares with a phaselag of about 225° for the tidal response to this constituent in the middle of Cabot Strait. Along the longitudinal axis of the diurnal oscillation high water occurs everywhere simultaneously, and if this oscillation corresponded exactly to a standing wave, then the ingoing diurnal tidal stream would have its maximum rate a quarter of a period before diurnal high water and would therefore have a phaselag g of (225° - 90°) or 135°. The actual phaselag g = 150°, indicates that this diurnal oscillation also conforms closely to a standing wave.

INTERPRETATION OF CURRENT DATA

If the data in Table A3 are considered, it will be noted that prior to June 22nd, there were very considerable fluctuations in the residual currents at a depth of 13 metres, particularly at stations 1 and 3. There were a succession of storms during this period, and during the night of June 19 a particularly intense one. The effect of this storm was to reverse the normal southeasterly set at station 1, and to cause temporarily a west-northwesterly set across the whole of Cabot Strait, In assessing the most usual set of the near-surface currents through Cabot Strait at this time of year, it is considered that the recorded sets of the currents during this early period should be disregarded. The following are therefore the values provisionally accepted:-

At station 1, the mean set over the last 20 days was 124°, .52 kn.
At station 2, the observed set was very consistent and had an average value of 128°, .63 kn.
At station 3, the observations were obtained mainly during the early disturbed period. It seems probable that this station lies on the fringe of the southeasterly current setting out of the Gulf at stations 1 and 2.
At station 4, the self-recording meter failed to function, but observations taken at depths of 7 and 27 metres between July 14-16, showed an average set of 240°, .14 kn.
At station 5, the average set during the settled period from June 21-27 was 248°, .64 kn.
At station 6, the recorded sets fell into two distinct groups, those in a direction of about 320° and those in one of about 200°. It would seem that this station lies near the boundary between two different sets. The means of the recorded currents in the two groups gives a set of 322°, .50 kn offshore of station 6 and one of 201°, .55 kn inshore of this station.

The near-surface currents have been depicted on Figure A4., this incorporates the data just referred to, the very short-period observations in 1894, reports on ice movements, and the sets experienced by mariners. It is reported that ice moving eastwards across the line joining Bird Rocks and Cape North takes divergent paths, part continuing eastwards to Cape George, Nfld., and part setting out of the Gulf with the current off Cape North. The east-going path again divides off Cape George, a smaller part of the ice setting northeastward along the Newfoundland coast, while the main part sets into St. Georges Bay and thence southwards down the coast and out of the Gulf past Cape Ray. This would seem to confirm the existence of the southgoing current sometimes observed at Station 6.

It seems to be fairly well established that there is a west-going current along the south shore of Newfoundland. The counterclockwise swing of the current across the entrance to the Gulf, as depicted on Figure A4. is a phenomenon which occurs elsewhere under similar topographical conditions. In the estuary of St. Lawrence, and in Hudson Strait, there are insets, confined to the right-hand shore by Coriolis force, which, when a marked constriction of the channel is reached, swing anticlockwise across the channel to join an outset off the opposite shore.

At depths other than 13 metres, the currents were measured only for periods not exceeding 2 days and the values obtained over such a short time may bear little or no resemblance to the seasonal averages. However, those at depths of less than 100 metres are fairly uniform in direction and tend to decrease in rate from the surface downwards; the observations at station 1 did not conform in these respects but were obtained during a period when conditions were markedly disturbed. Figure A5. is based on the apparent relationship between the currents in the upper 100 metres, and on the deduced average directions and rates of the currents at 13 metres.

No assumptions can be made as to the average directions and rates of the currents in the deeper layers for they may normally differ appreciably from those in the upper layers and may react to changes in meteorological and oceanographical conditions quite differently. In any future investigation the deep currents will be observed over long periods with metres not available at the time of the survey in 1959.

Table A1.

Tidal Streams and Currents at 13-Metre Depth

(Analyses from observations over a period of 15 to 29 days)

Longitudinal Directions

Stn.	Direction	M2 g°	M2 H	M2 kn	S2 g°	S2 H	S2 kn	K1 g°	K1 H	K1 kn	O1 g°	O1 H	O1 kn	Residual Current Dir.	Residual Current Rate	
1	324°	322°	.42	"	022°	.09	"	171°	.23	"	180°	.17	"	116°	.37	kn
2	334°	303°	.61	"	004°	.09	"	140°	.16	"	137°	.14	"	128°	.63	"
3	353°	268°	.42	"	047°	.05	"	144°	.10	"	182°	.31	"	293°	.16	"
4		Meter failed														
5	334°	302°	.41	"	260°	.04	"	151°	.18	"	137°	.28	"	254°	.50	"
6	348°	301°	.51	"	243°	.02	"	165°	.19	"	138°	.20	"	242°	.20	"

Transverse Directions

Stn.	Direction	M2 g°	M2 H	M2 kn	S2 g°	S2 H	S2 kn	K1 g°	K1 H	K1 kn	O1 g°	O1 H	O1 kn	Residual Current Dir.	Residual Current Rate
1	054°	052°	.20	"	175°	.09	"	312°	.08	"	270°	.06	"		
2	064°	033°	.34	"	094°	.05	"	000°	.09	"	341°	.18	"		
3	083°	178°	.05	"	220°	.03	"	315°	.12	"	386°	.20	"	See above	
4		Meter failed													
5	064°	032°	.02	"	-	-		283°	.11	"	276°	.11	"		
6	068°	031°	.09	"	153°	.10	"	255°	.08	"	048°	.14	"		

Table A2.

Tidal Streams and Currents at Various Depths

Station 1

Depth	Meter	Direction	M_2		S_2		K_1		O_1		Residual	
7m	G	323°	339°	.49	039°	.10	115°	.34	124°	.25	057°	.23
13m	PW	324°	322°	.42	022°	.09	171°	.23	180°	.17	055°	.12
18m	E	319°	325°	.46	025°	.10	140°	.38	149°	.28	295°	.12
45m	E	302°	345°	.29	045°	.06	180°	.59	189°	.44	314°	.27
73m	E	297°	007°	.35	067°	.08	158°	.55	167°	.41	293°	.16
150m	E	322°	315°	.31	015°	.07	124°	.48	133°	.25	093°	.22

June 16 - 18 (48 hours)

Station 2

Depth	Meter	Direction	M_2		S_2		K_1		O_1		Residual	
7m	G	328°	317°	.57	016°	.09	179°	.16	176°	.14	096°	.60
13m	PW	334°	303°	.61	004°	.09	140°	.16	137°	.14	123°	.62
18m	E	321°	309°	.53	008°	.08	148°	.25	145°	.22	114°	.49
45m	E	323°	228°	.51	347°	.08	092°	.23	089°	.20	105°	.28
95m	E	317°	298°	.38	357°	.06	100°	.42	097°	.37	048°	.24
180m	E	280°	324°	.45	023°	.07	100°	.47	097°	.41	143°	.20

July 6— 8 (48 hours)

Station 3

Depth	Meter	Direction	M_2		S_2		K_1		O_1		Residual	
7m	G	011°	292°	.22	071°	.03	143°	.12	181°	.36	125°	.58
13m	PW	353°	268°	.42	047°	.05	144°	.10	182°	.31		
27m	E	340°	288°	.21	067°	.03	139°	.12	177°	.37	123°	.48
79m	E	340°	306°	.19	085°	.02	144°	.05	182°	.16	124°	.34
183m	E	313°	298°	.28	077°	.03	110°	.06	148°	.17	132°	.21
420m	E	313°	296°	.20	075°	.02	145°	.09	183°	.27	152°	.10

July 9 - 10 (24 hours)

Station 4

Depth	Meter	Direction	M_2		S_2		K_1		O_1		Residual	
7m	E	346°	296°	.41	344°	.05	155°	.11	154°	.21	314°	.14
13m			–		–		–		–		–	
27m	N	338°	285°	.21	333°	.03	160°	.11	159°	.21	243°	.13
73m	N	343°	322°	.33	010°	.04	160°	.11	159°	.19	236°	.14
183m	E	310°	320°	.45	008°	.05	126°	.21	125°	.38	224°	.12
420m	E	340°	289°	.37	337°	.04	152°	.15	151°	.27	120°	.10

July 14 - 16 (48 hours)

Station 5

Depth	Meter	Direction	M_2		S_2		K_1		O_1		Residual	
7m	G	331°	309°	.27	267°	.03	183°	.15	061°	.24	214°	.35
13m	PW	334°	302°	.41	260°	.04	151°	.18	137°	.28	224°	.58
27m	E	330°	311°	.25	269°	.03	143°	.13	123°	.20	221°	.50
73m	E	310°	331°	.28	289°	.03	176°	.10	056°	.16	224°	.46
183m	E	278°	344°	.21	302°	.02	153°	.15	043°	.24	211°	.07
420m	E	315°	317°	.33	275°	.03	168°	.23	048°	.36	303°	.10

June 26 - 28 (48 hours)

Table A2. (con't) Tidal Streams and Currents at Various Depths

Station 6

Depth	Meter	Direction	M_2		S_2		K_1		O_1		Residual	
7m	G	342°	295°	.50	304°	.05	158°	.14	124°	.16	306°	.37
13m	PW	342°	301°	.51	310°	.05	179°	.19	142°	.22	323°	.45
27m	E	342°	285°	.49	294°	.05	233°	.10	196°	.12	305°	.28
55m	E	349°	287°	.32	296°	.03	151°	.17	112°	.19	335°	.14
137m	E	357°	271°	.56	280°	.05	181°	.12	144°	.14	260°	.07
240m	E	349°	264°	.52	273°	.05	133°	.05	096°	.06	346°	.06

July 11-13 (48 hours)

G. = Gurley current recording rate, direction by bearing of drogue.
PW. = Paddlewheel current meter, continuous observations for 15 to 29 days.
E. = Ekman current meter.
N. = Neyrpic B. B. T. current meter.

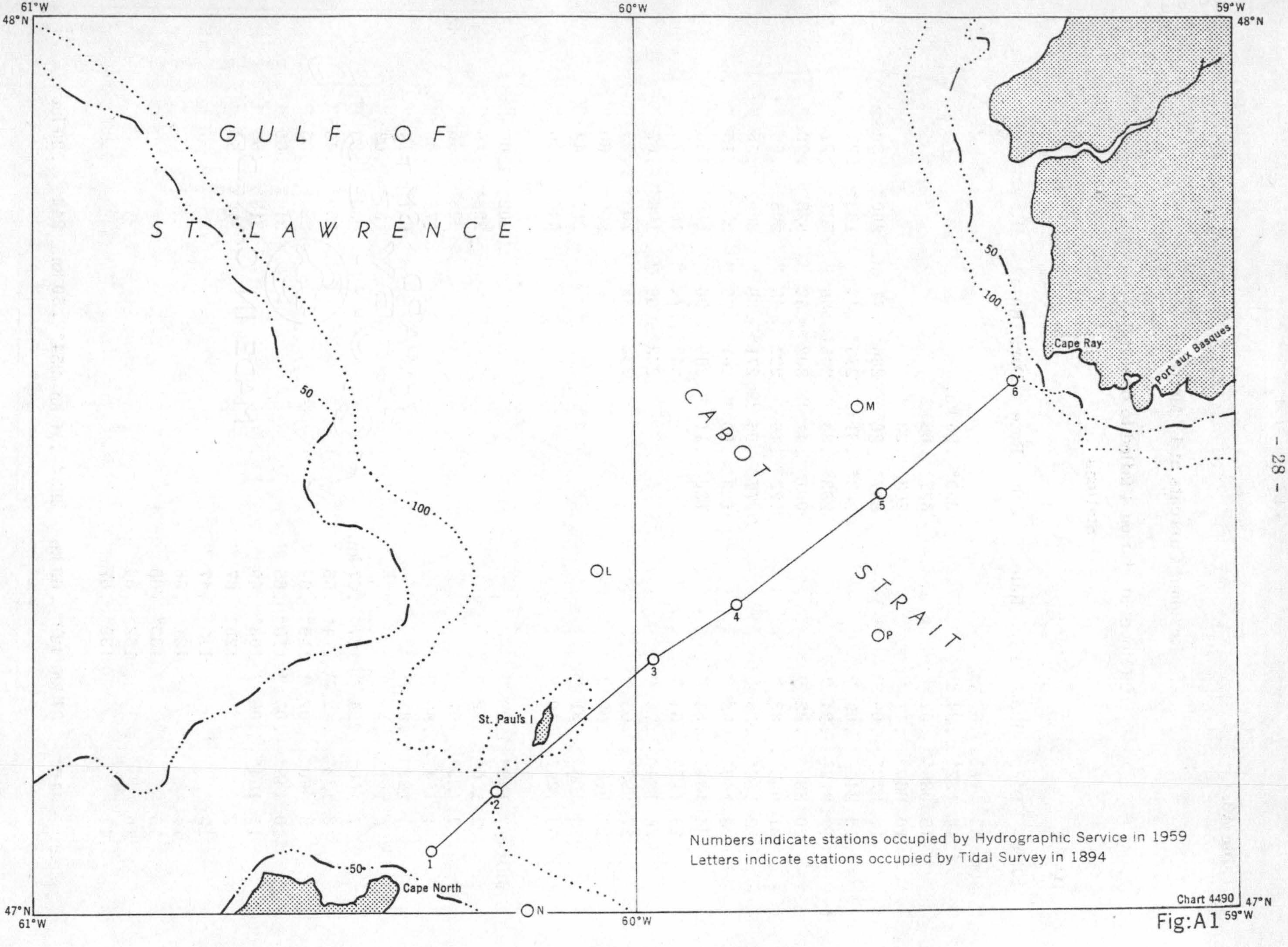
Table A3.

Residual Currents at 13 Metres

(Meter at station 4 failed to operate)

Stations

DATE	1		2		3		5		6	
1959	Dir.	Rate	Dir.	Rate	Dir.	Rate	Dir.	Rate	Dir.	Rate
June 13	117°	.37 kn.								
14	122°	.34 "			299°	.26 kn.				
15	336°	.32 "			337°	.62 "				
16	066°	.17 "			263°	.23 "				
17	073°	.09 "			297°	.28 "	286°	.41 kn.	200°	.30 kn
18	246°	.06 "			283°	.31 "	275°	.44 "	183°	.21 "
19	313°	.24 "			283°	.38 "	291°	.60 "	337°	.21 "
20	339°	.92 "			001°	.41 "	302°	.52 "	323°	.90 "
21	045°	.38 "			123°	.16 "	227°	.45 "	205°	.55 "
22	142°	.38 "			277°	.05 "	271°	.39 "	200°	.56 "
23	140°	.52 "			123°	.09 "	261°	.73 "	254°	.15 "
24	134°	.65 "			126°	.11 "	250°	.96 "	189°	.53 "
25	117°	.54 "					243°	.74 "	189°	.75 "
26	124°	.76 "					233°	.66 "	196°	.67 "
27	093°	.65 "					232°	.45 "	205°	.59 "
28	096°	.62 "							200°	.60 "
29	106°	.31 "							217°	.42 "
30	124°	.40 "							044°	.26 "
July 1	149°	1.09 "							202°	1.06 "
2	126°	.72 "							223°	.46 "
3	129°	.91 "							328°	.56 "
4	124°	.86 "							275°	.09 "
5	123°	.88 "							017°	.14 "
6	121°	.92 "							137°	.09 "
7	106°	.24 "	127°	.67 kn.					034°	.33 "
8	122°	.42 "	114°	.55 "					299°	.45 "
9	060°	.07 "	119°	.64 "					324°	.33 "
10	148°	.05 "	110°	.85 "					340°	.60 "
11	164°	.06 "	108°	.69 "					313°	.55 "
12			128°	.67 "					312°	.50 "
13			145°	.47 "						
14			121°	.66 "						
15			135°	.65						
16			132°	.64						
17			139°	.67						
Mean	116°	.37 kn	128°	.63 kn	293°	.16 kn	254°	.50 kn	242°	.20 kn



Numbers indicate stations occupied by Hydrographic Service in 1959
Letters indicate stations occupied by Tidal Survey in 1894

Fig:A1

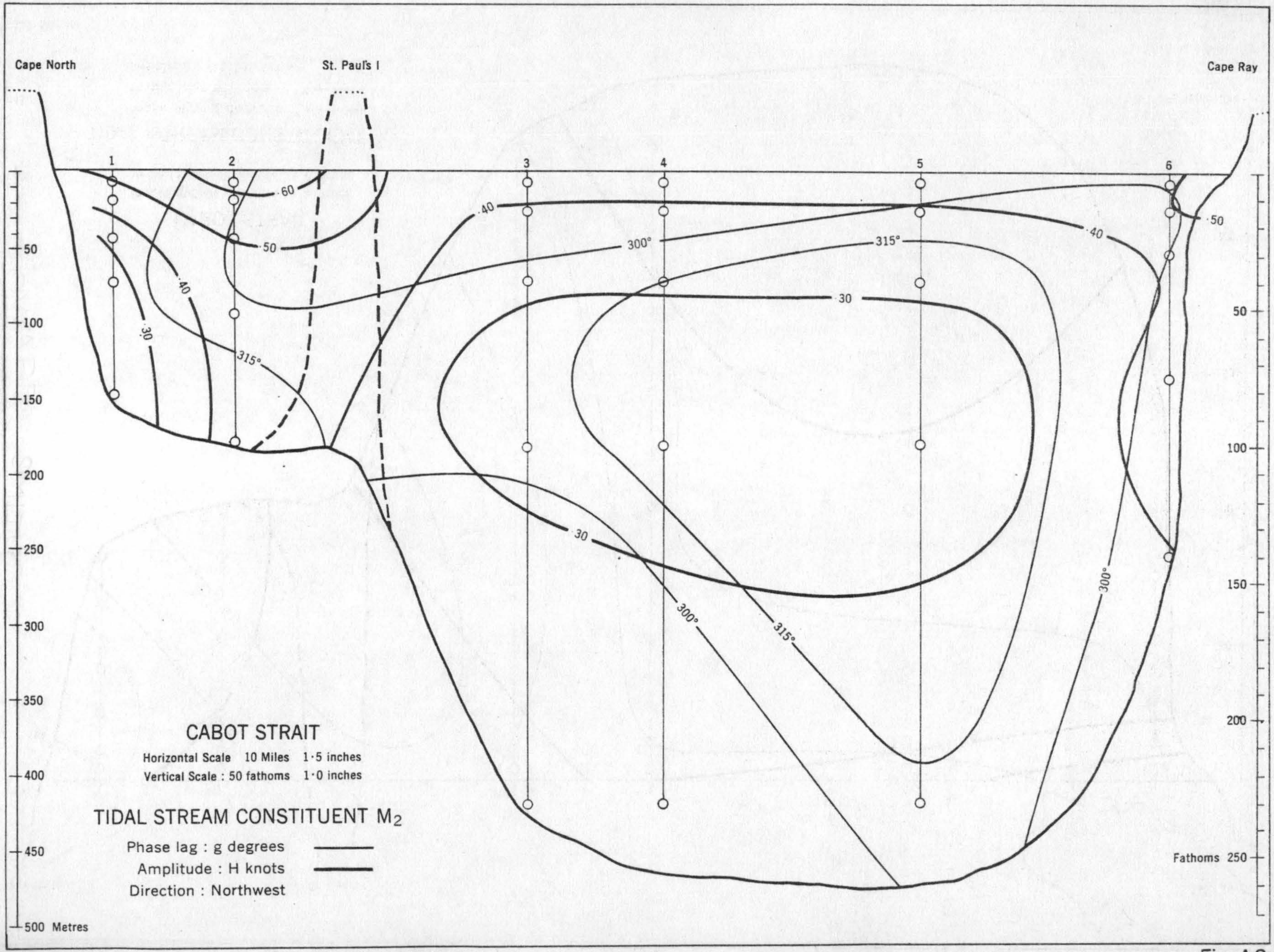

Cape North
St. Paul's I
Cape Ray
1
2
3
4
5
6
·60
·50
·40
·30
315°
300°
·40
·30
·30
300°
315°
300°
315°
·40
·50
300°
50
100
150
200
250
300
350
400
450
500 Metres
50
100
150
200
Fathoms 250
CABOT STRAIT
Horizontal Scale 10 Miles 1·5 inches
Vertical Scale : 50 fathoms 1·0 inches
TIDAL STREAM CONSTITUENT M_2
Phase lag : g degrees
Amplitude : H knots
Direction : Northwest

Fig:A2

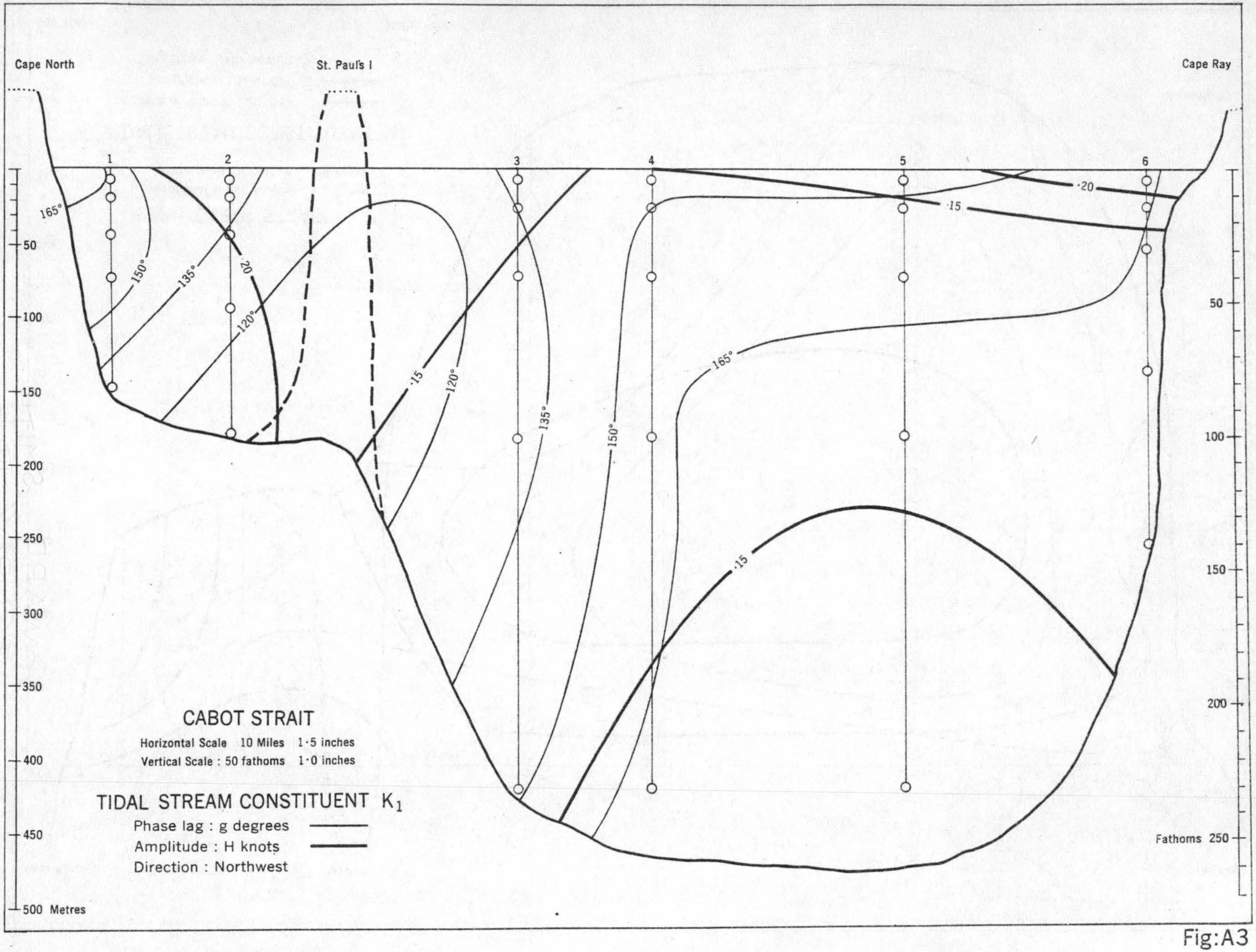

Cape North
St. Paul's I
Cape Ray
1
2
3
4
5
6
165°
150°
135°
120°
·20
·15
120°
135°
150°
165°
·15
·15
·20
50
100
150
200
250
300
350
400
450
500 Metres
50
100
150
200
Fathoms 250
CABOT STRAIT
Horizontal Scale 10 Miles 1·5 inches
Vertical Scale : 50 fathoms 1·0 inches
TIDAL STREAM CONSTITUENT K_1
Phase lag : g degrees
Amplitude : H knots
Direction : Northwest

Fig:A3

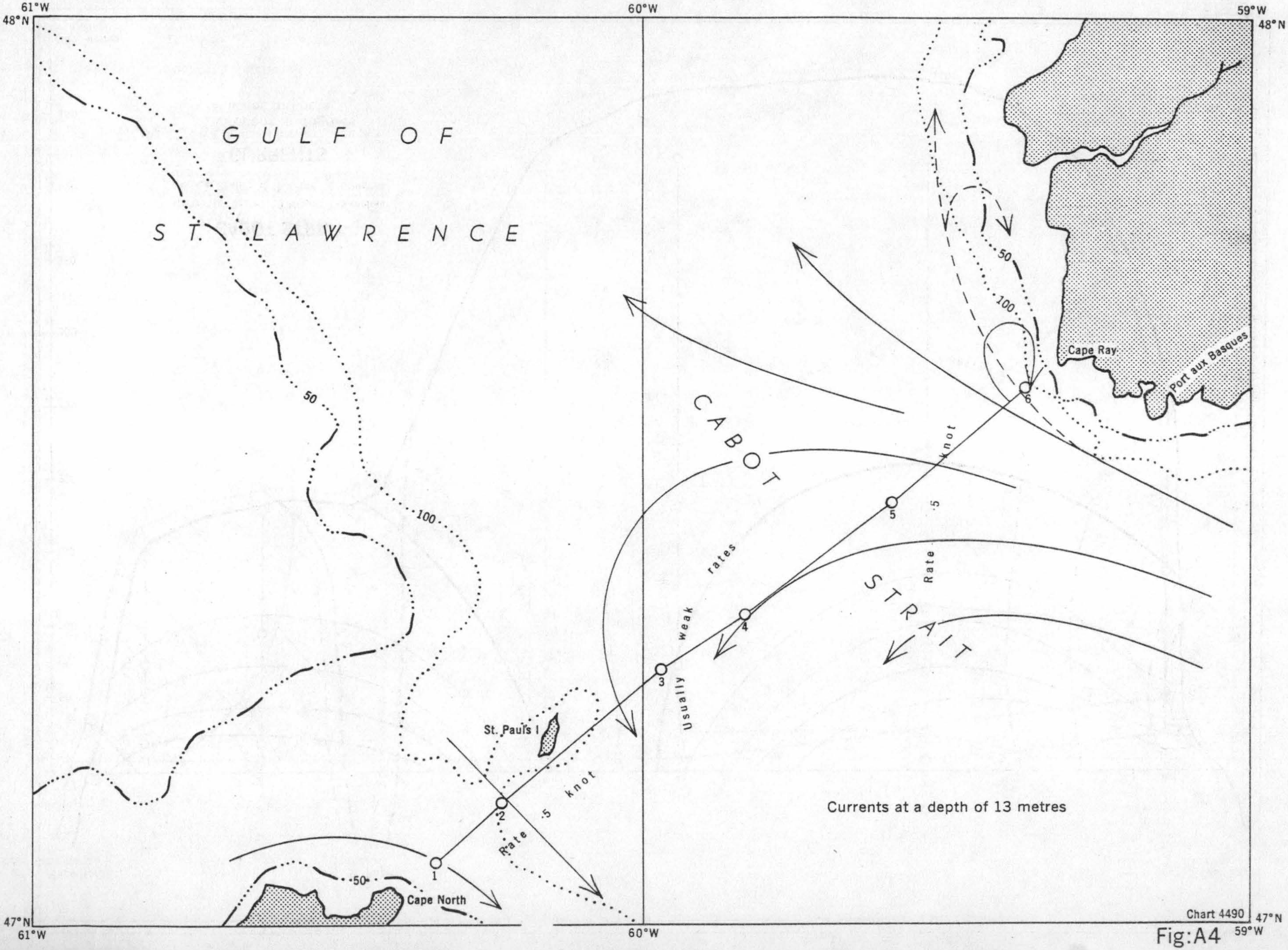

61°W
48°N
60°W
59°W
48°N
GULF OF
ST. LAWRENCE
50
100
CABOT
STRAIT
Usually weak rates
Rate .5 knot
Rate .5 knot
50
100
Cape Ray
Port aux Basques
1
2
3
4
5
6
St. Pauls I
Cape North
50
Currents at a depth of 13 metres
Chart 4490
47°N
61°W
60°W
47°N
59°W

Fig:A4

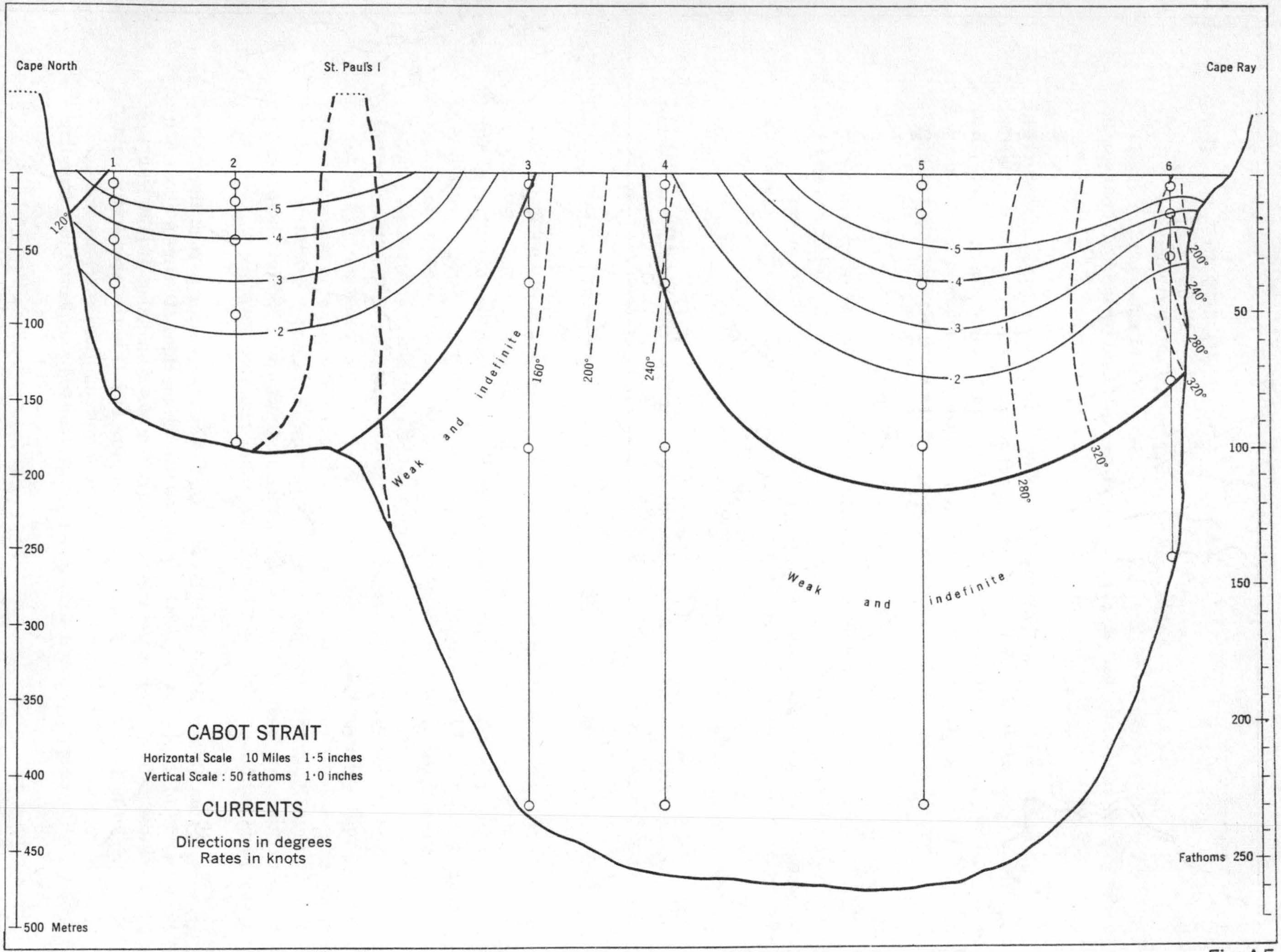

Cape North
St. Paul's I
Cape Ray
1
2
3
4
5
6
120°
·5
·4
·3
·2
160°
200°
240°
280°
320°
200°
240°
280°
320°
Weak and indefinite
Weak and indefinite
50
100
150
200
250
300
350
400
450
500 Metres
50
100
150
200
Fathoms 250
CABOT STRAIT
Horizontal Scale 10 Miles 1·5 inches
Vertical Scale : 50 fathoms 1·0 inches
CURRENTS
Directions in degrees
Rates in knots

Fig:A5

B. NORTHUMBERLAND STRAIT

DATA

A detailed survey of this area was carried out between June and September 1958 by the Canadian Hydrographic Service and many earlier tidal observations and some tidal stream observations obtained by the Tidal Survey in 1908 were incorporated in it.

In the 1958 survey additional tidal observations were made at a number of sites throughout the Strait. Tidal stream observations were made at a depth of 7 metres, over periods of from 6 to 24 days, with self-recording metres, and a large number of intermediate sites were occupied for periods of a lunar day, at which observations were taken with meters suspended from the ship while at anchor.

The tidal observations have been analyzed and cotidal and co-range charts, Figures B1. and B3. have been constructed for the semidiurnal tidal constituent M_2 and for the diurnal tidal constituent K_1. The tidal stream observations were similarly analyzed and the corresponding charts, Figures B2 and B4. were constructed for the semidiurnal tidal stream constituent M_2 and for the diurnal tidal stream constituent K_1.

The daily values of the residual currents at the primary stations, shown on Figure B5., are given in Table B1.

INTERPRETATION OF SEMIDIURNAL TIDAL AND TIDAL STREAM DATA.

Figure B1. illustrates the anticlockwise progression of high water in that part of the Gulf lying to the northward of Prince Edward Island. It will, however, be seen that part of this oscillation swings round the east coast of the island and moves in the reverse direction up Northumberland Strait. In the eastern part of the Strait this oscillation is travelling back toward the main oscillation which enters the western end of the Strait. The interaction of these two oscillations creates a standing wave in the western part of the Strait, with an amphidromic point off West Point, P. E. I. It will be noted that the high-water phase of the oscillation travelling westwards through the Strait is about 310° all over an area lying in and to the east of the narrows off Cape Tormentine, while in the western entrance the high-water phase is about 130°. So that high water in one area coincides with low water in the other and vice versa.

From Figure B2. it will be seen that over the greater part of the western end of the strait the phaselag of the westgoing tidal stream is about 030°. The greatest rate of rise in the western entrance has a phaselag of (130°-90°) or 040°, which is similar to that of the greatest rate of fall in the area to the east of the narrows. The relationship between the tides and tidal streams in this area therefore corresponds nearly exactly with that to be expected in a standing wave. The location of the node in this area is determined by the relative amplitudes of the semidiurnal tides on the boundaries of the standing wave. These are respectively 2.5 feet near the narrows and 0.75 feet in the western entrance and in consequence the node lies only a relatively short distance within that entrance.

The phaselag is 030° for the outward, or westgoing, stream in the western part of the Strait, and it follows that the phaselag for the inward, or eastgoing, stream in that part of the Strait is 210°. This is similar to the phaselag of the inward, or westgoing, stream near the eastern entrance. As the high-water phaselag over a large area in the central part of the strait is 310°, it follows that the streams in both halves of the Strait are setting towards this area over a great part of the period while the tide is rising there, and conversely are setting outwards from this area for a large portion of the period while the tide is falling in that central area. The line of separation between the two incoming or between the two outgoing streams is not a fixed one. If it were, there would be an abrupt change of 180° in the phaselag of the streams at this line of separation, and no streams would flow across that line. Figure B2. shows that there is a rapid change in phaselag of the tidal streams in the area extending from a line joining Rice Point and Cape Cliff to the narrows off Cape Tormentine. Over a large part of the tidal period the line of separation between the two streams lies in this boundary zone, gradually moving from its eastern end into the narrows.

The following is a brief account of the set of the semidiurnal tidal streams throughout a cycle. At high water in the central area, the streams are westerly throughout the whole Strait, except in its eastern entrance where they are turning to the eastward. During the succeeding two hours the eastgoing stream gradually extends its influence until it reaches the eastern edge of the boundary zone, so that the line joining Rice Point and Cape Cliff separates the two outgoing streams. Thereafter the line of separation gradually moves towards the narrows, which are reached about an hour before low water. The eastgoing stream becomes established over the whole of the Strait by the time of low water in the central area, except in the eastern entrance where the stream is starting to turn to the westward. During the first two hours of the rising tide, the incoming stream becomes established all over the eastern part of the Strait up to line joining Rice Point and Cape Cliff. During the following three hours this meeting of the two streams gradually moves towards the narrows, and after a further hour the westgoing stream is again flowing throughout practically the whole of the Strait.

Figure B1. shows that there is a large change, amounting to about 125°, in the phaselag of the semidiurnal oscillation between its arrival at the two entrances of the Strait, and this results in the creation of a standing wave in the western half of the Strait. With the diurnal oscillation - as can be seen from Figure B3. - the change in phaselag between the two entrances amounts only to about 15°. In consequence of this similarity, the two oscillations approach the central part of the Strait practically simultaneously and increase the range of the diurnal tide in that area.

Figure B4. shows that the phaselags of the westgoing diurnal stream differ in the two halves of the Strait by about 150°. This indicates that for the greater part of the diurnal cycle the streams are either flowing inwards towards each other, or outwards in opposite directions. There is a quite abrupt line of separation in the narrows and in consequence the rates of the diurnal streams are practically zero in this locality.

RESIDUAL CURRENTS

Table B1. gives the daily values of the residual currents recorded at ten of the primary stations during the two months July 20 to September 21, 1958; the positions of these stations are shown on Figure B5.

It is apparent that, with the exception of those recorded at stations F1. and AB1, the currents are weak and for that reason their rates are given in nautical miles per day, rather than in knots.

At F1. the average set over a twelve-day period was 136°, 9.6 nautical miles and to some extent this set is probably due to a runoff of land water from the rivers flowing into Hillsborough Bay. During the period August 9 to 11 there was an exceptionally strong southeasterly set at this station and at the same time quite strong southeasterly sets at stations K5. and H1. This was the only occasion when there was evidence of a constant easterly set throughout the greater part of the Strait. It is thought that on this occasion the usual offset experienced at F1. was reinforced by the set through the Strait. Except for this occasion, the sets in the Strait were weak and erratic and it must be concluded that there is no persistent set through it.

At AB1. the average set over a twenty-four-day period was 185°, 6.0 nautical miles, and any strong sets invariably set approximately in this direction. This strong southerly set appears to be confined to the vicinity of East Point, P.E.I., and is possibly an offshoot from an easterly current setting along the north coast of that island.

Table B1.

Residual Currents - Rates in Nautical Miles per Day

Date	Western Entrance		Central Parts						Eastern Entrance	
	Dir:	Rate	Dir:	Rate	Dir:	Rate	Dir:	Rate	Dir:	Rate
							H_1			
July 20							277°	2		
21							246°	3		
					H_6					
22					187°	3	330°	4		
23					181°	2	289°	4		
24					193°	1	316°	1		
25					033°	1	316°	1		
26					311°	3	349°	2		
27					298°	3	292°	4		
28					309°	2	290°	5		
29							311°	6		
30							240°	4		
31							229°	4		
Aug. 1							251°	2		
2							216°	3		
3							240°	2		
4							242°	1		
5							253°	3		
6							168°	1		
			K_5		F_1					
7			198°	4			269°	1		
8			224°	2			006°	1		
9			168°	9	141°	14	131°	6		
10			172°	8	121°	23	128°	9		
11			179°	7	140°	17	125°	6		
12			152°	6	129°	16	184°	2		
13			155°	3	121°	15				
14			155°	5	146°	11				
15			155°	4	142°	9				
	L_1									
16	050°	0	335°	0	176°	7				
17	170°	1	335°	2	271°	4				
18	345°	1	335°	1	297°	2				
19	078°	5	335°	0	104°	5				
20	092°	6			103°	6				
21	081°	7								
					J_2					
22	070°	4			...	0				
23	212°	0			125°	0				
24	160°	1			125°	1				
25	070°	3			125°	1				
26	020°	2			305°	0				
27					305°	1				
									AB_1	
28					...	0			202°	5
29					305°	1			212°	3
30					305°	0			353°	8
							G_1			
31					305°	0	037°	2	343°	6

Table B1.(cont) Residual Currents - Rates in Nautical Miles per Day

Date	Western Entrance		Central Parts						Eastern Entrance	
	Dir:	Rate	Dir:	Rate	Dir:	Rate	Dir:	Rate	Dir:	Rate
					J_2		G_1		AB_1	
Sept. 1					305°	1	170°	3	148°	7
2					125°	3	198°	2	211°	21
3					125°	0	002°	2	199°	24
4					305°	0	022°	1	160°	12
5					305°	0	270°	0	167°	11
6					I_2		354°	3	231°	6
7					290°	0	013°	1	068°	3
8					...	0	132°	5	125°	3
9					110°	5	321°	1	189°	11
10					290°	4	058°	2	205°	10
11					290°	1	133°	6	117°	11
12					110°	5	079	3	198°	21
13			K_{10}		110°	1			175°	12
14			140°	4	110°	2			202°	12
15			140°	1	290°	1			151°	3
16			320°	2	290°	2			202°	11
17			140°	1	290°	3			240°	6
18			320°	1	290°	4			027°	2
19			140°	0	290°	3			033°	10
20			140°	2	290°	3			076°	13
21					290°	3				

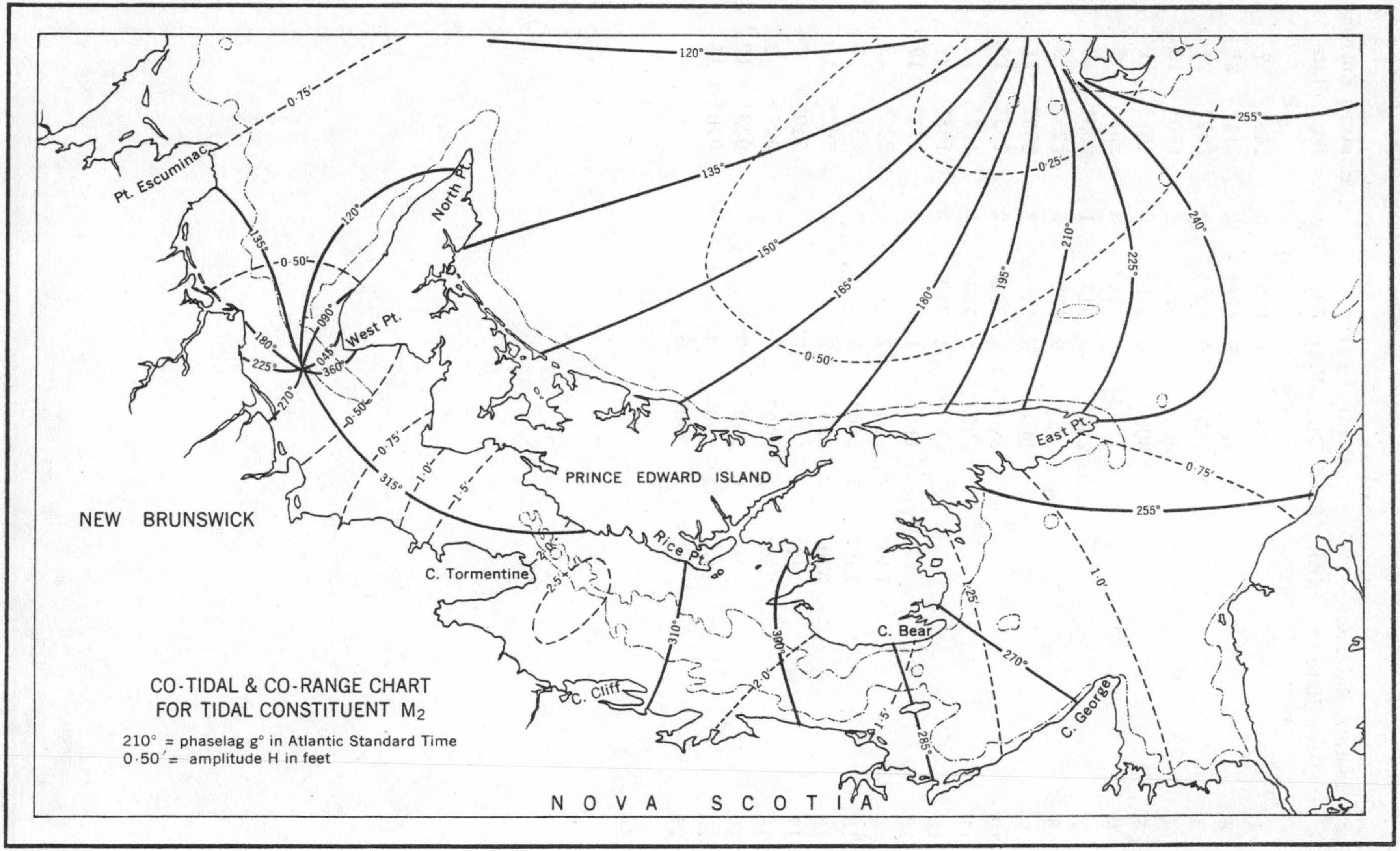
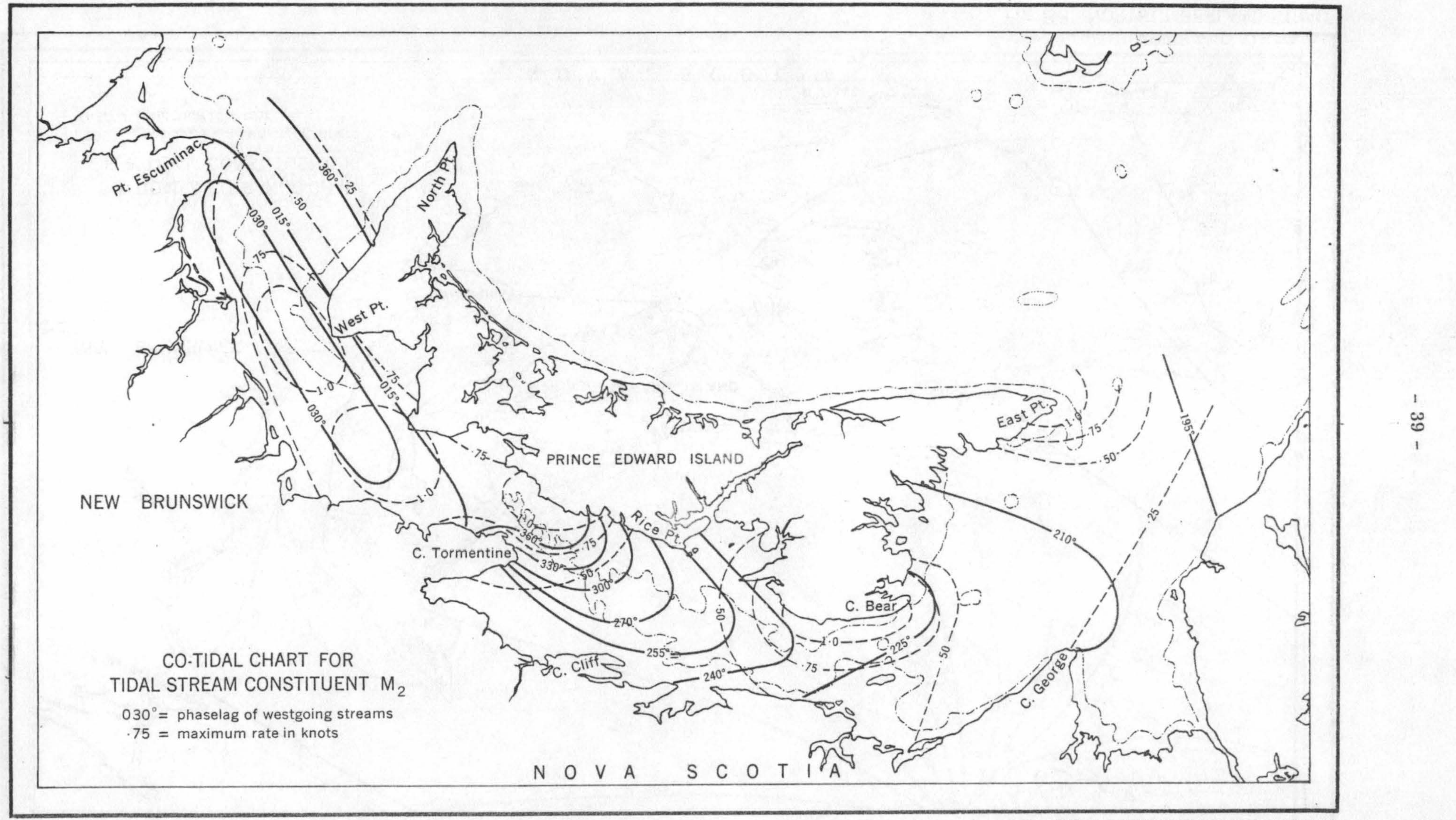


Fig: B1 NORTHUMBERLAND STRAIT



CO-TIDAL CHART FOR TIDAL STREAM CONSTITUENT M_2

030° = phaselag of westgoing streams
·75 = maximum rate in knots

Fig: B2 NORTHUMBERLAND STRAIT

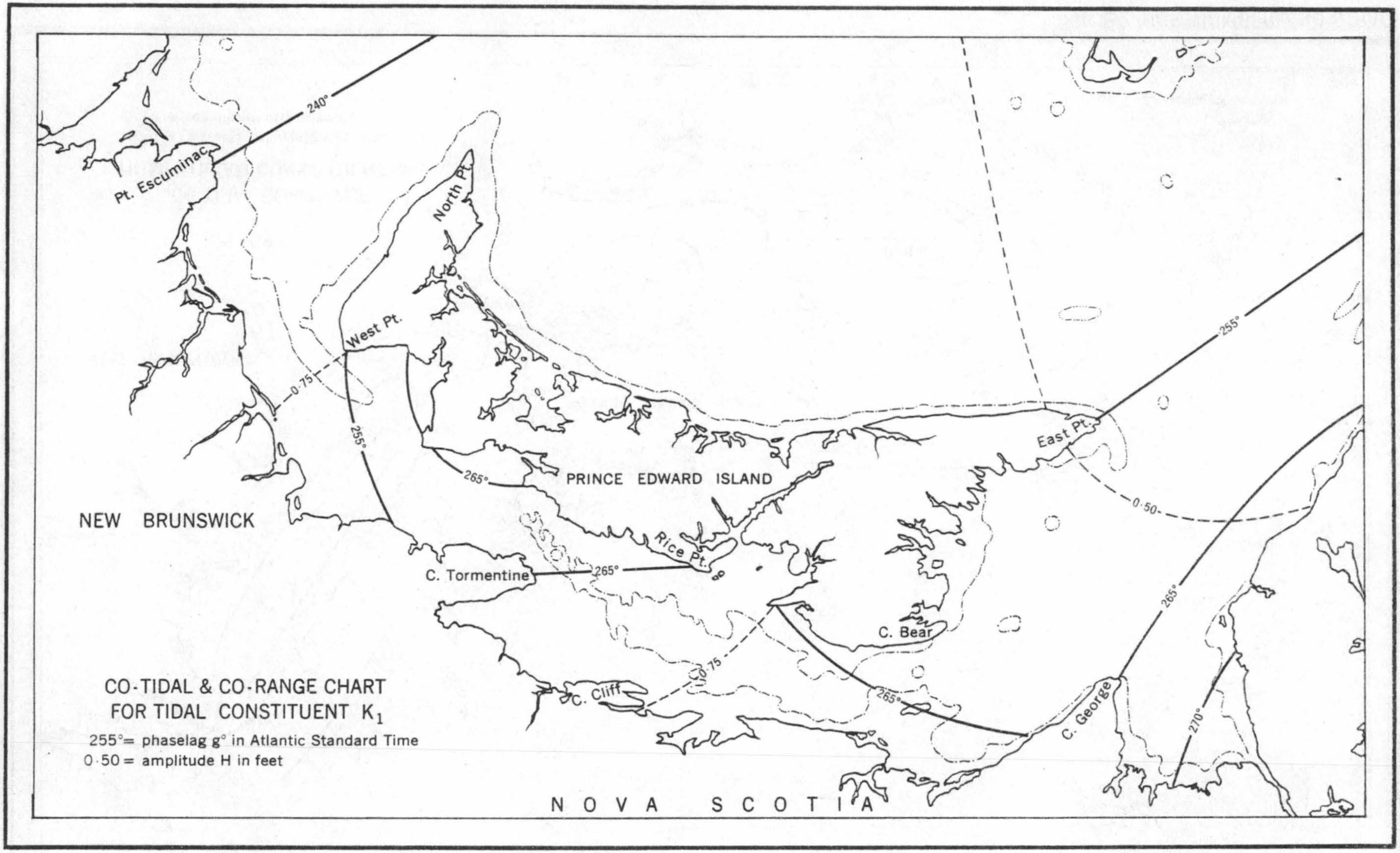
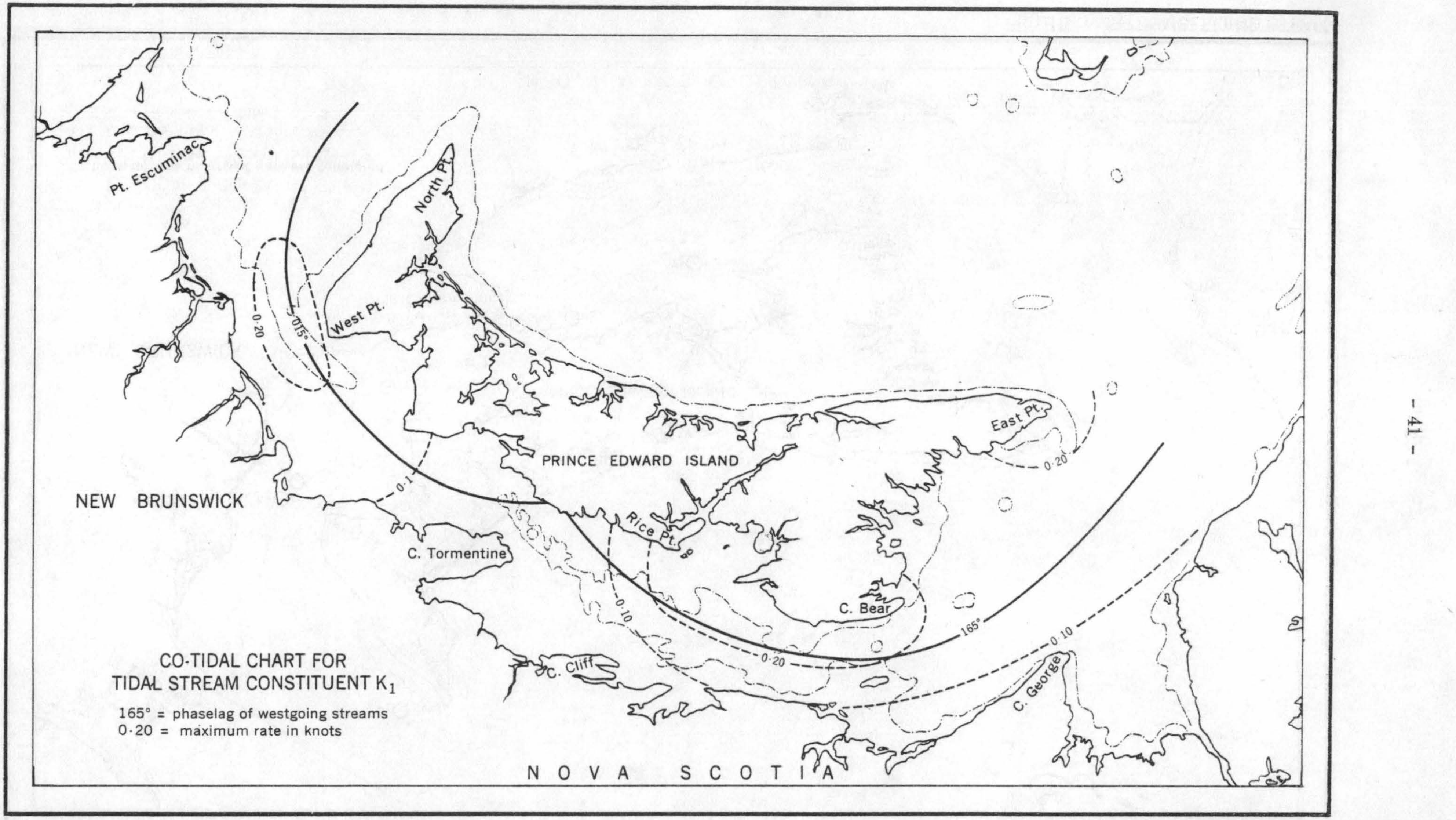


Fig:B3. NORTHUMBERLAND STRAIT



CO-TIDAL CHART FOR
TIDAL STREAM CONSTITUENT K_1

165° = phaselag of westgoing streams
0·20 = maximum rate in knots

Fig: B4 NORTHUMBERLAND STRAIT

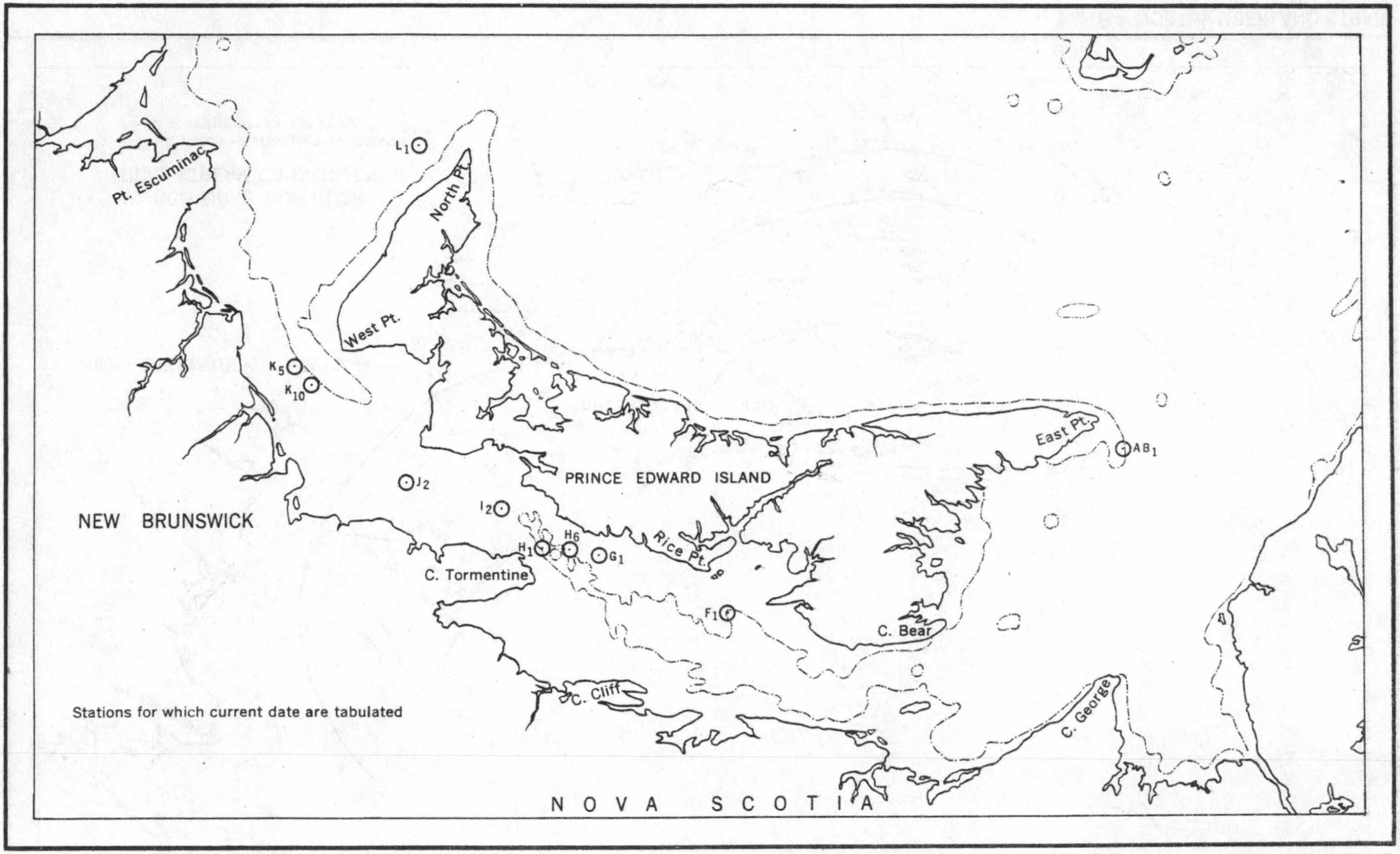


Fig: B5 NORTHUMBERLAND STRAIT

C. BELLE ISLE STRAIT

DATA

The only systematic observations in this area were made by the Tidal Survey during the summers of 1894 and 1906. In this report only the data obtained during the second of these summers has been used. The survey of 1894 was the first carried out by the Tidal Survey following its formation the previous year. It is therefore not surprising that the observations were not of a very high standard. Analyses of the observations of 1894 show wide divergencies at nearby sites, and in comparison with the rates observed in the same vicinity in 1906, they are improbably high.

The observations were made for only short continuous periods at each site, but these short-period observations were in some cases repeated more than once at several of the sites. Continuous periods of tidal stream observations covering one or more lunar days were analyzed in conjunction with simultaneous periods of tidal observations at Forteau Bay and the harmonic constants for the tidal streams deduced from these comparisons. These analyses were carried out for observations at all the lettered sites shown on Figure C1. At the site marked "mooring", a schooner was anchored throughout the greater part of the survey. Observations of the turn of the stream were obtained continuously from the schooner. These observations have been used for computing the phaselag of the maximum westgoing tidal stream at that site. The observations at sites U and V in 1906 were taken only for three periods of one lunar day each and the analyses showed considerable divergencies. These observations have been disregarded in the analyses of the tidal streams, and the phaselag, as found from the long series of slack-water observations at the schooner mooring, has been accepted as representative of this western part of the Strait.

The phaselags and amplitudes of the principal constituents M_2, S_2, K_1, and O_1 for the tidal streams are tabulated below:-

Phaselags and Amplitudes for Westgoing Tidal Streams

	M_2		S_2		K_1		O_1	
PLACE	g	H	g	H	g	H	g	H
Mooring	238°	–	–	–	–	–	–	–
R	242°	.50 kn	262°	.17 kn	077°	.19 kn	059°	.15 kn
T	230°	.84 "	253°	.29 "	105°	.48 "	087°	.38 "
Q	238°	.55 "	261°	.19 "	121°	.18 "	103°	.14 "
P	240°	.51 "	263°	.18 "	096°	.28 "	078°	.22 "
K	244°	.25 "	267°	.09 "	192°	.13 "	174°	.10 "

It is apparent that the phaselags, g, for the semidiurnal constituents M_2 are very similar, and, allowing for the errors to be expected from such short-period observations, it is reasonable to assume a value of 238° as representative of the phaselag for this constituent throughout the whole of the Strait. The amplitudes H are more erratic, and while it is quite probable that the rate, .25 knot, is correct for the open waters where site K lies, the rate for site T, in the middle of the Strait, is very high in comparison with those in the same vicinity. The rates at sites U, and V, which are not tabulated, were respectively .59 and .51 knot, and it is probable that all over the Strait from the western entrance to Cape Norman, the average value for H of M_2 is about 0.55 knot.

The phaselags, g, for the diurnal constituent K_1 are much more erratic, but this is to be expected with short-period observations. There is no real indication of a progressive change from one end of the Strait to the other and in consequence an average value of 125° has been selected as a uniform value for g of K_1 throughout the Strait.

The phaselags and amplitudes of the principal constituents of the tide in the Strait and at nearby ports in the Gulf of St. Lawrence and on the Atlantic seaboard are given in the following table:-

Phaselags and Amplitudes of the Tidal Constituents
in and Near Belle Isle Strait

PLACE	M_2		S_2		K_1		O_1	
	g	H	g	H	g	H	g	H
Harrington	314°	1.76	337°	.60	202°	.47	184°	.45
Port Saunders	301°	1.77	323°	.59	203°	.47	185°	.42
Blanc Sablon	298°	1.58	328°	.58	190°	.43	180°	.31
Forteau Bay	285°	1.34	308°	.46	180°	.34	162°	.27
Red Bay	244°	1.01	255°	.33	151°	.25	113°	.15
Battle Harbour	182°	1.21	217°	.53	103°	.26	071°	.18
St. Anthony	178°	1.03	210°	.51	108°	.27	097°	.19

The tidal data are obviously sparse and in particular there are no analyses of the tides along the southern shore of the Strait.

INTERPRETATION OF SEMIDIURNAL TIDAL AND TIDAL STREAM DATA

From the preceding tabulation of the phaselags and amplitudes of the tidal constituents, it can be deduced that at the boundary between Belle Isle Strait and the Gulf of St. Lawrence, the phaselag and amplitude for the response to M_2 are respectively about 300° and 1.6 feet. While at the boundary between the Strait and the Atlantic Ocean, the corresponding phaselag and amplitude are respectively 185° and 1.1 feet.

The semidiurnal tides and tidal streams within the Strait are governed by these two oscillations on its boundaries. The phaselag for the maximum rate of the M_2 tidal stream is 238°, that is approximately half way between the occurrences of high water at the western and eastern boundaries. In Table C1., the heights of the M_2 tidal constituent, at the two entrances, have been computed for each change of phaselag of 20° throughout a tidal cycle. The differences in elevation between the two ends have been calculated from those heights. It will be seen with a phaselag of about 235° the levels at the two ends are the same, each being about 0.7 foot above mean sea-level, and that with this state the westgoing stream has its maximum rate. The head is highest at the western end with a phaselag of about 325°, and highest at the eastern end with one of about 145°; near these occurrences the tidal streams are slack.

These conditions are akin to those which occur with a standing oscillation. With such an oscillation the streams have their maximum rates when the rate of change of level is greatest; in this case, they have their maximum rates when the rate of change of difference in level, or in head, is greatest.

The heights of the tidal constituent M_2 at the two ends of the Strait were also calculated in greater detail at 10° intervals of phaselag, for the period from high water at the eastern end to high water at the western end. The intervening high-water phaselags and amplitudes of the tidal constituent M_2 are governed by those at the entrances.

These heights are given in Table C2. and were used to construct Figure C2. for drawing the gradients from one end of the Strait to the other. The gradients control the high water-levels which can be attained along the centre line of the Strait and the phaselags when they are attained.

Figure C2. is a schematic diagram illustrating the form in which this tidal constituent is propagated from one end to the other; changes in depth and cross-section have not been taken into account, so that the diagram does not conform exactly to nature. However, when taken in conjunction with the known amplitudes and phaselags at a few points, it facilitates the construction of the cotidal chart Figure C3.

This cotidal chart shows the existence of what is known as a "degenerate amphidromic point", which is an imaginary point, lying inland to the left of the direction in which the wave travels, from which the cotidal lines tend to radiate, and which the co-range lines tend to encircle. Near the middle of the Strait the high-water phaselag is 240°, while throughout the Strait the phaselag for maximum westgoing stream is 238°. Thus in this part the relationship between the tide and tidal stream is that occurring in a progressive wave, while towards the entrances the relationship tends to become more similar to that in a standing oscillation. With a progressive wave the transverse gradients created by Coriolis force are maximum at high and low water, with the consequence that the range of the tide is increased on the shore to the right of the direction in which the wave travels and correspondingly decreased on the opposite shore. The range of the tide is not affected by Coriolis force when the tide is propagated as a standing wave, for then the streams are slack at high and low water. Thus there is a progressive change, throughout the Strait, in the degree to which Coriolis force causes a difference in the range of the tide on its two sides. This effect is maximum near the middle of the Strait, where the co-range lines, instead of running transversely across it, tend to encircle the imaginary amphidromic point situated in Newfoundland.

INTERPRETATION OF DIURNAL TIDE AND TIDAL STREAM DATA

The phaselags and amplitudes of the response to the diurnal tidal constituent K_1, previously tabulated, indicate a phaselag of about 195° and an amplitude of about 0.42 foot for the western boundary of the Strait, and about 105° and 0.26 foot respectively for the Atlantic boundary. The diurnal tide thus undergoes changes similar to those of the semidiurnal tide throughout the Strait.

Tables C4. and C5. give the differences in height, and the heights, of the tidal constituent K_1 at the boundaries of the Strait. The phaselag of the diurnal tidal stream has not been established with any degree of certainty, and the accepted phaselag for the maximum westgoing tidal stream, 125°, differs somewhat from the phaselag, 140°, for the maximum rate of increase in head at the western end, as found in Table C4. It is, however, evident that the diurnal tide is propogated through the Strait in a manner similar to that of the semidiurnal tide, and Figure C4. has been constructed from the calculated gradients along the Strait during the period between high water of the tidal constituent K_1 at each of its entrances. This again is only a schematic diagram but, taken in conjunction with the phaselags and amplitudes of K_1 at the few points where they are known, it has facilitated the construction of the cotidal chart Figure C5.

THE RESIDUAL CURRENTS THROUGHOUT THE STRAIT

No long-period observations were taken at any one site during these early surveys, so that it is not feasible to arrive at any mean seasonal value of the residual current.

Some comparisons between the currents on opposite sides of the Strait were obtained when the ship occupied stations on alternate sides, and also when the ship was at anchor on one side, by plotting the movements of icebergs off the other coast.

The currents through the Strait, as deduced from the analyses of near-surface observations covering periods of one or more lunar days, are given in Table C5. These observations, together with remarks by Tidal Survey on the effect of meteorological conditions on the set of the residual current, or dominant flow, fairly well establish the following three points:-

1. A distinct tendency for the current to set in the same direction over quite long periods of time. In 1906 the set, during the latter half of June was continuously westward, with a change to the eastward at the beginning of July which persisted until the early part of August. In late August there was, possibly only briefly, a temporary set to the westward. The easterly set was definitely over by the end of August, and in the observations taken in September 1894 and 1906, the set was always westerly. In his report on these surveys, Dr. Dawson quotes the statement by a lightkeeper who had been stationed at Armour Point light, at the western entrance to the Strait, for 15 years, that " a westerly current is generally predominant from the end of April until early July, the actual period varying somewhat from year to year. During the summer months the current is weak and erratic but towards autumn the westerly current again becomes predominant".

2. The direction and force of the wind have little effect upon the direction and rate of the current. In his report Dr. Dawson refers to several gales occurring during the two seasons and shows how small was their effect upon the dominant flow. His conclusions may be summarized by the following extracts from that report:- "During both seasons, a careful watch was kept, to detect any influence of the wind upon the movement of the water; and the continuous meteorological observations, taken on board, afforded complete weather data for comparison. But it may be stated in general that the effect of the local winds in producing a drift in their own direction is remarkable slight, considering the situation of this Strait".

3. This point, less clearly established, is that the near-surface current in either direction extends across the Strait from shore to shore. During the periods of predominantly westerly set it was observed at V and Q on the north side and at P and T in the centre of the Strait. During the period of negligible set at the end of August 1906, observations were taken at V on the north side and at U on the south side, and during the periods of easterly set it was observed at Q on the north side, at R on the south side and at K in the eastern entrance. There is no evidence from the near-surface observations that the westerly set is appreciably stronger or more prevalent off the north shore, or that the easterly set is more apparent off the south shore.

It has been shown that the semidiurnal and diurnal tidal streams in the Strait are governed by the oscillations at its two entrances. These are oscillations relative to mean sea-level at each entrance, and should mean sea-level at either end be higher than that at the other end, then a current flowing from the higher to the lower level would be introduced. There are definite seasonal changes in mean sea-level in both the Atlantic Ocean and the Gulf of St. Lawrence and as these seasonal changes are not in phase there is a seasonal variation in the relative mean sea-levels in the two areas. At Harrington in the northeastern part of the Gulf there are 19 years of continuous tidal records, but at St. John's, Nfld., which is the nearest point on the Atlantic Ocean where a permanent tide gauge is installed, the records are available for much shorter periods. However, these records are adequate to show that the seasonal changes there are in phase with those at Halifax, N.S., where a period of 19 years records, which are simultaneous with those at Harrington, are available. The following table shows the average monthly variations from the 19 years' mean, given to thousandths of a foot at Harrington and Halifax:-

Mean Monthly Variations in Sea-Level

Place	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Halifax	+110	+113	+ 30	- 64	-124	- 80	-152	-117	-102	+ 34	+162	+112
Harrington	+ 39	- 28	-124	-181	-137	+ 26	- 11	+ 13	+ 5	+130	+158	+105
Difference	+ 71	+141	+154	+117	+ 13	-106	-141	-130	-107	- 96	- 4	+ 7

If the changes in sea-level in the Atlantic entrance to Belle Isle Strait are similar to those at Halifax, then a westerly current could be expected to prevail from January until May and an easterly one from June until November. The tabulated variations are very long-term means, there are considerable differences from year to year and of course very much larger short-period fluctuations.

There are thus some grounds for believing that there may be an association between variations in the relative levels of the sea at the two entrances to the Strait and the near-surface currents which flow through it.

SUMMARY

The available data with regard to the tides, tidal streams and currents in Belle Isle Strait are scanty and of rather poor quality. It would, however, appear that the vertical movements of the tides and the horizontal movements of the tidal streams and currents within the Strait are largely controlled by tidal oscillations at the two entrances, and by the relative mean levels of the sea in those entrances.

A certain number of comparative observations were taken during these surveys of the flow in the near-surface layer and at a depth of between 20 and 25 fathoms, which is about two-thirds of the total depth. These indicated that the dominant flow was the same at both depths but that it was rather less conspicuous at the deeper. It would seem therefore that the residual currents are fairly homogeneous both across the Strait and in the depth profile.

Owing to the paucity of the data, the inferences drawn cannot be regarded as conclusive. In any future survey it would be desirable to obtain not only simultaneous observations at a variety of depths on sections across the Strait, but also to establish a tide gauge near the Atlantic entrance so that a correlation, if any, between the relative changes in sea-level at this gauge and that at Harrington, and the set of the residual current through the Strait, could be established.

Table C1.

Height Differences of Semidiurnal Constituent M_2 at Western and Eastern Entrances and Set of Tidal Stream through Belle Isle Strait

	Heights in feet		Differences	
Phaselags	1. Gulf	2. Atlantic	1. - 2.	Tidal Streams
015°	+0.41	-1.08	+1.49 feet	eastgoing
035°	-0.14	-0.95	+0.81 "	"
055°	-0.68	-0.71	+0.03 "	058° maximum E
075°	-1.13	-0.38	-0.75 "	eastgoing
095°	-1.45	0	-1.45 "	"
115°	-1.59	+0.38	-1.97 "	"
135°	-1.55	+0.71	-2.26 "	148° slack
155°	-1.31	+0.95	-2.26 "	westgoing
175°	-0.92	+1.08	-2.00 "	"
195°	-0.41	+1.08	-1.49 "	"
215°	+0.14	+0.95	-0.81 "	"
235°	+0.68	+0.71	-0.03 "	238° maximum W
255°	+1.13	+0.38	+0.75 "	westgoing
275°	+1.45	0	+1.45 "	"
295°	+1.59	-0.38	+1.97 "	"
315°	+1.55	-0.71	+2.26 "	"
335°	+1.31	-0.95	+2.26 "	328° slack
355°	+0.92	-1.08	+2.00 "	eastgoing

Table C2.

Heights of Semidiurnal Constituent M_2 Between High Water at Western and Eastern Entrances to Belle Isle Strait

	Heights in Feet			Heights in Feet	
Phaselags	1. Gulf	2. Atlantic	Phaselags	1. Gulf	2. Atlantic
300°	+1.600	-0.465	235°	+0.676	+0.707
295°	+1.594	-0.376	225°	+0.414	+0.843
285°	+1.545	-0.191	215°	+0.139	+0.953
275°	+1.450	0	205°	-0.139	+1.034
265°	+1.311	+0.191	195°	-0.414	+1.083
255°	+1.131	+0.376	185°	-0.676	+1.100
245°	+0.918	+0.550			

Table C3.

Height Differences of Diurnal Constituent K_1 at Western and Eastern Entrances and Set of Tidal Stream Through Belle Isle Strait

	Heights in Feet		Differences	
Phaselags	1. Gulf	2. Atlantic	1. - 2.	Tidal Streams
200°	+0.42	-0.02	+0.44 feet	westgoing
220°	+0.38	-0.11	+0.49 "	215° slack
240°	+0.30	-0.19	+0.49 "	eastgoing
260°	+0.18	-0.25	+0.43 "	"
280°	+0.04	-0.27	+0.31 "	"
300°	-0.11	-0.26	+0.15 "	305° maximum E
320°	-0.24	-0.22	-0.02 "	eastgoing
340°	-0.34	-0.16	-0.18 "	"
360°	-0.41	-0.07	-0.34 "	"
020°	-0.42	+0.02	-0.44 "	"
040°	-0.38	+0.11	-0.49 "	035° slack
060°	-0.30	+0.19	-0.49 "	westgoing
080°	-0.18	+0.25	-0.43 "	"
100°	-0.04	+0.27	-0.31 "	"
120°	+0.11	+0.26	-0.15 "	125° maximum W
140°	+0.24	+0.22	+0.02 "	westgoing
160°	+0.34	+0.16	+0.18 "	"
180°	+0.41	+0.07	+0.34 "	"

Table C4.

Heights of Diurnal Constituent K_1 Between High Water at Western and Eastern Entrances to Belle Isle Strait

	Heights in Feet			Heights in Feet	
Phaselags	1. Gulf	2. Atlantic	Phaselags	1. Gulf	2. Atlantic
195°	+.420	0	145°	+.270	+.207
185°	+.414	+.047	135°	+.210	+.234
175°	+.395	+.092	125°	+.144	+.254
165°	+.365	+.135	115°	+.073	+.266
155°	+.322	+.174	105°	+ 0	+.270

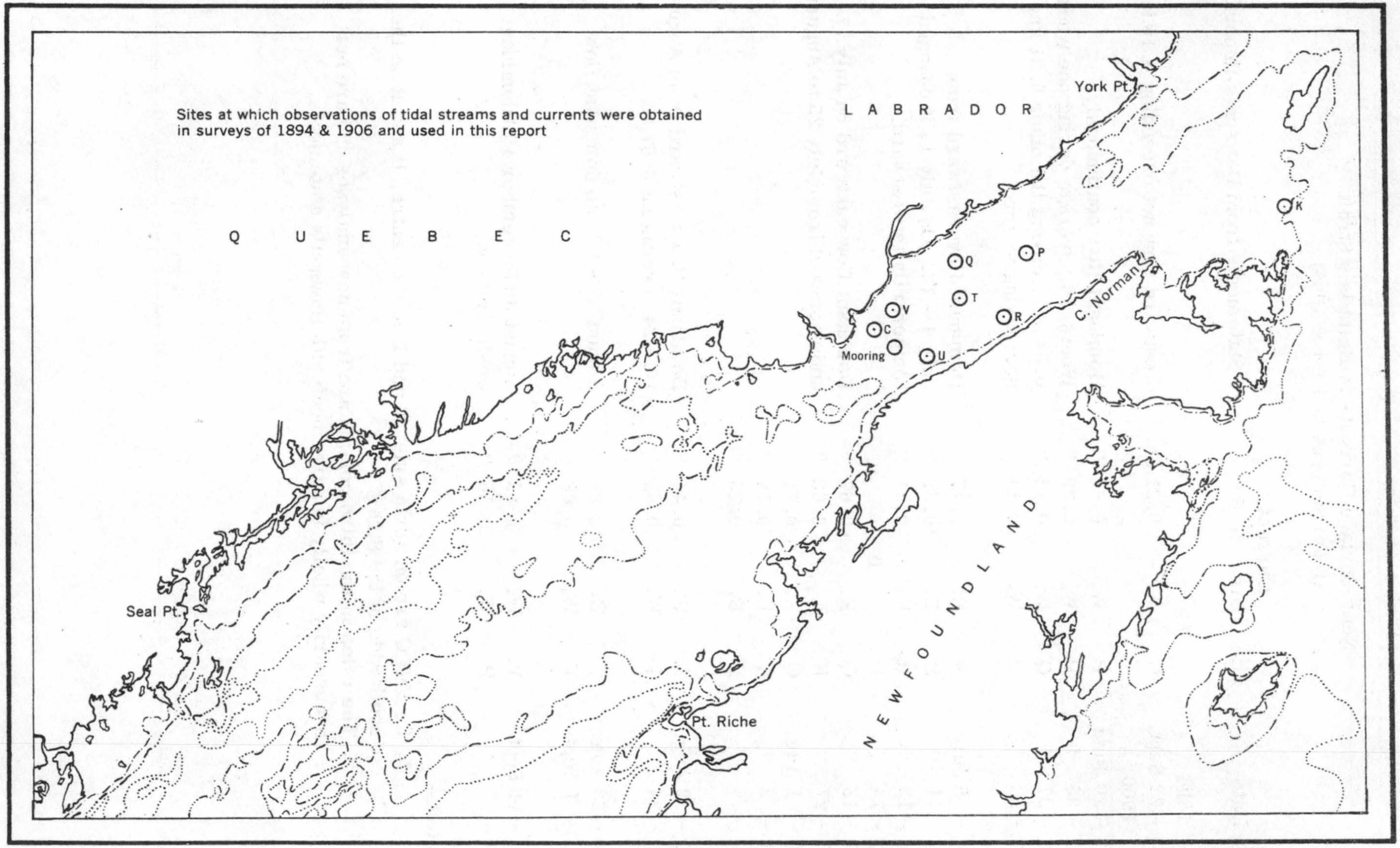
Table C5.

Near-Surface Currents in Belle Isle Strait
(from Surveys in 1894 & 1906)

Date	Site	Current Dir.	Rate	Statements from Dawson's Report
1894				
20 - 22 Sept.	C	W.	0.21 kn.	Westward flow not exceeding 0.18 kn.
1906				
18 - 20 June	P	W.	0.42 "	Dominant flow continuously Westward, average during one week 0.64 kn., during the other 0.21 kn., decreasing to zero.
21 - 23 "	P	W.	0.39 "	
25 - 27 "	Q	W.	0.14 "	
27 - 29 "	Q	W.	0.14 "	
4 - 5 July	R	E.	0.47 "	Dominant flow eastward from July 4 - 13. On July 14 it changed temporarily to westward.
9 - 11 "	R	E.	0.39 "	
11 - 13 "	R	E.	0.21 "	
13 - 14 "	R		0	
17 - 18 "	Q	E.	0.67 "	Dominant flow eastward on July 17-18, and eastward from July 25 to August 4.
25 - 27 "	K	E.	0.63 "	
30 - 1 Aug.	Q	E.	0.71 "	
31 - 2 "	Q	E.	0.79 "	
2 - 3 "	R	E.	0.25 "	
20 - 22 Aug.	T	W.	0.44 "	Dominant flow westward from August 20 - 24, averaging 0.57 kn.
22 - 24 "	T	W.	0.65 "	
27 - 29 Aug.	U	E.	0.01 "	August 27 - 29, no dominant flow
31 - 1 Sept.	V	W.	0.08	
10 - 11 Sept.	V.	W.	1.13 "	August 30, September 15, dominant westerly flow.
18 - 19 "	P	W.	0.58 "	

Notes:-

1. C, V & Q are on north side, T and P in the centre, U and R on the south side of the Strait.
2. The rates in the third column are from new analyses and are not necessarily wholly in agreement with Dawson's statements.



Sites at which observations of tidal streams and currents were obtained in surveys of 1894 & 1906 and used in this report

Fig:C1 STRAIT OF BELLE ISLE

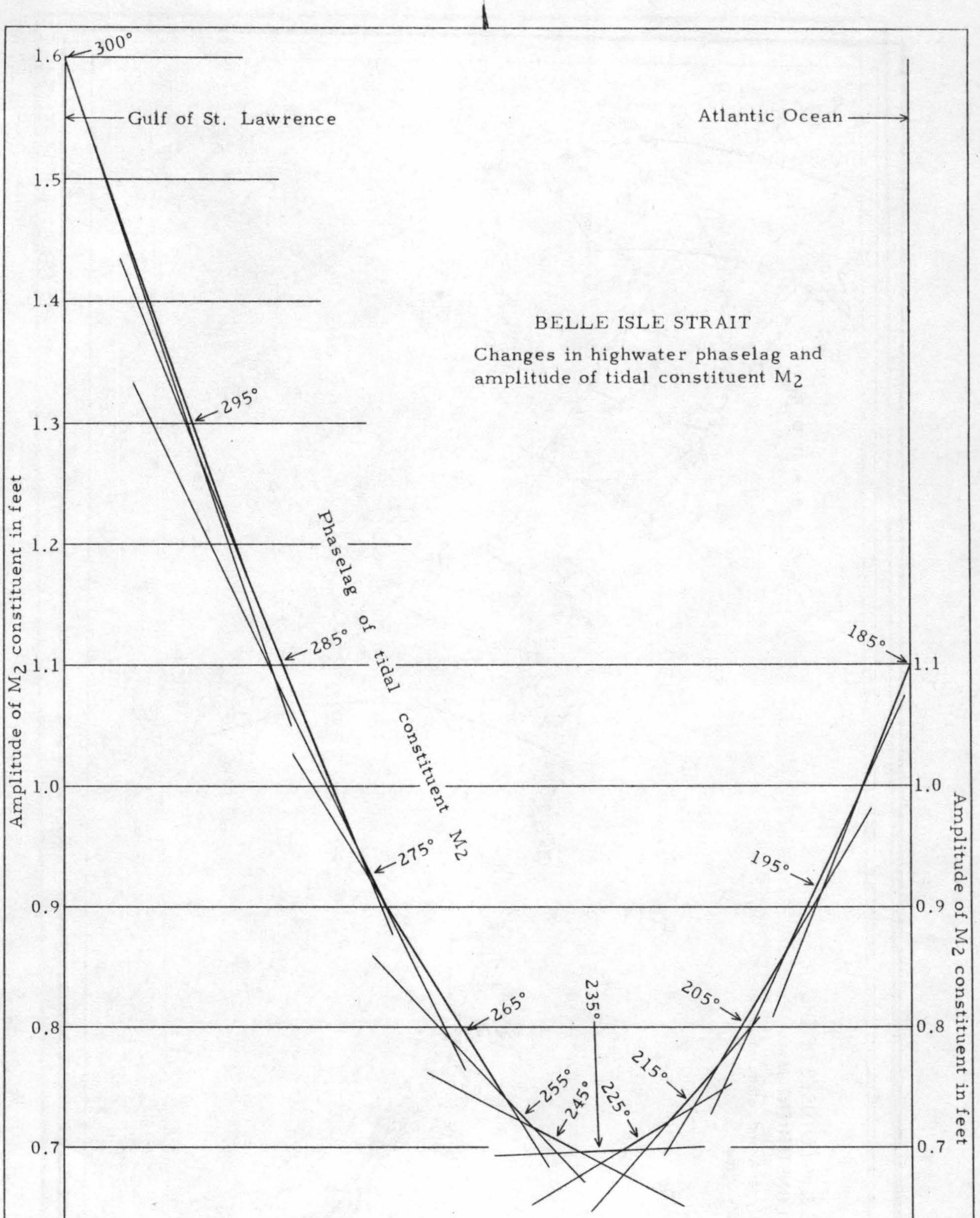

BELLE ISLE STRAIT
Changes in highwater phaselag and amplitude of tidal constituent M_2
Gulf of St. Lawrence
Atlantic Ocean
Amplitude of M_2 constituent in feet
Amplitude of M_2 constituent in feet
Phaselag of tidal constituent M_2
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
300°
295°
285°
275°
265°
255°
245°
235°
225°
215°
205°
195°
185°

Fig. C2

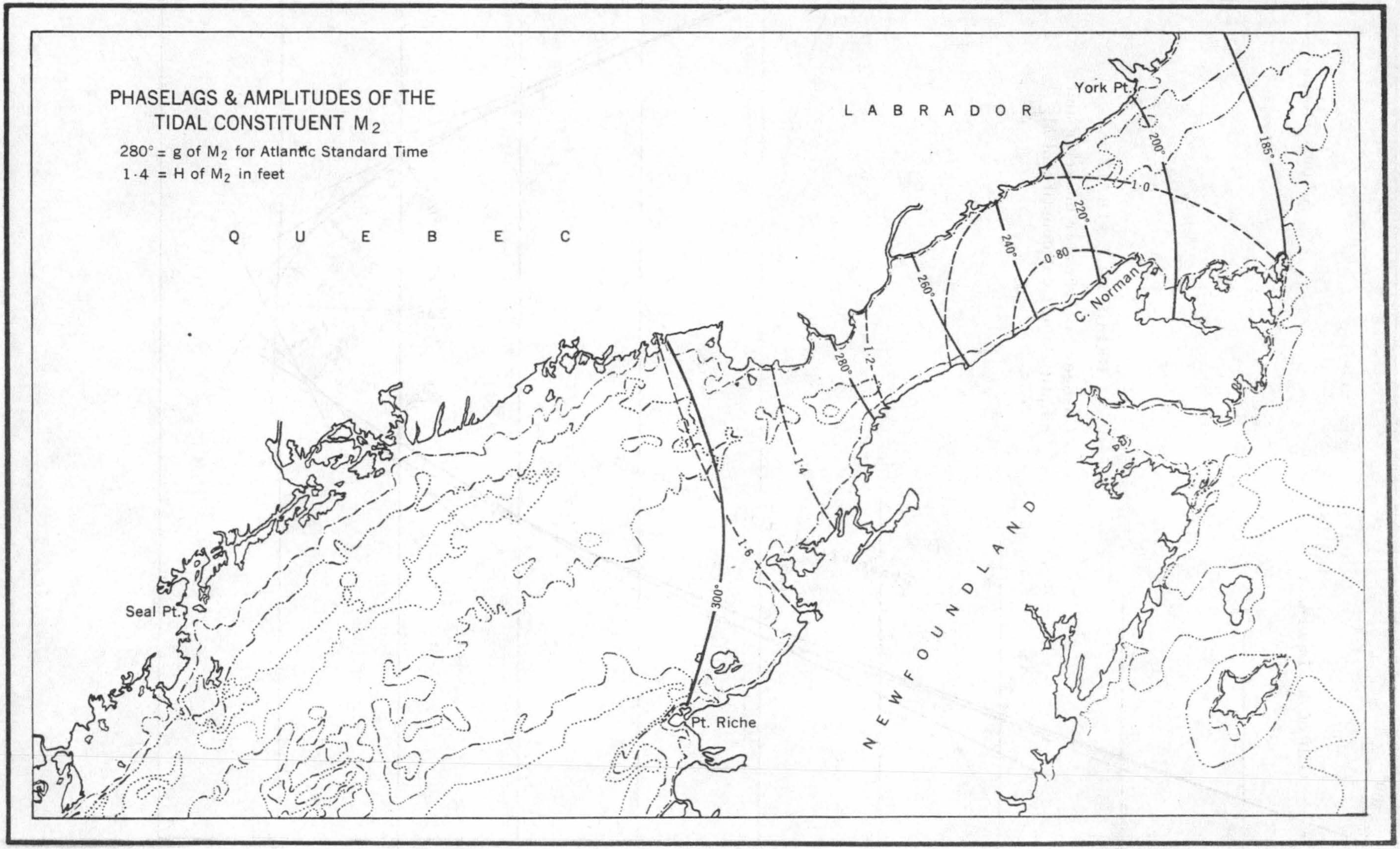


Fig:C3 STRAIT OF BELLE ISLE

BELLE ISLE STRAIT

Changes in highwater phaselag and amplitude of tidal constituent K_1

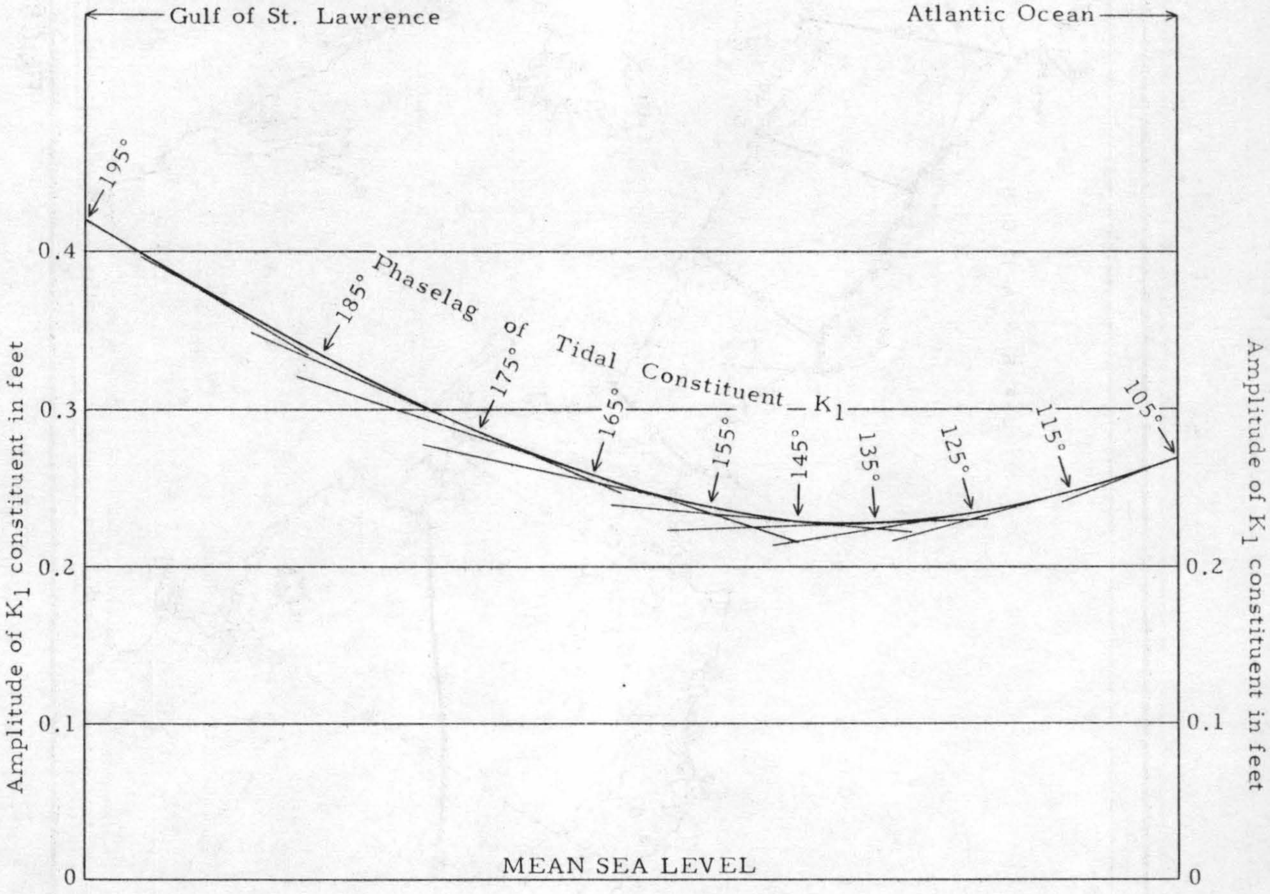


Fig. C4

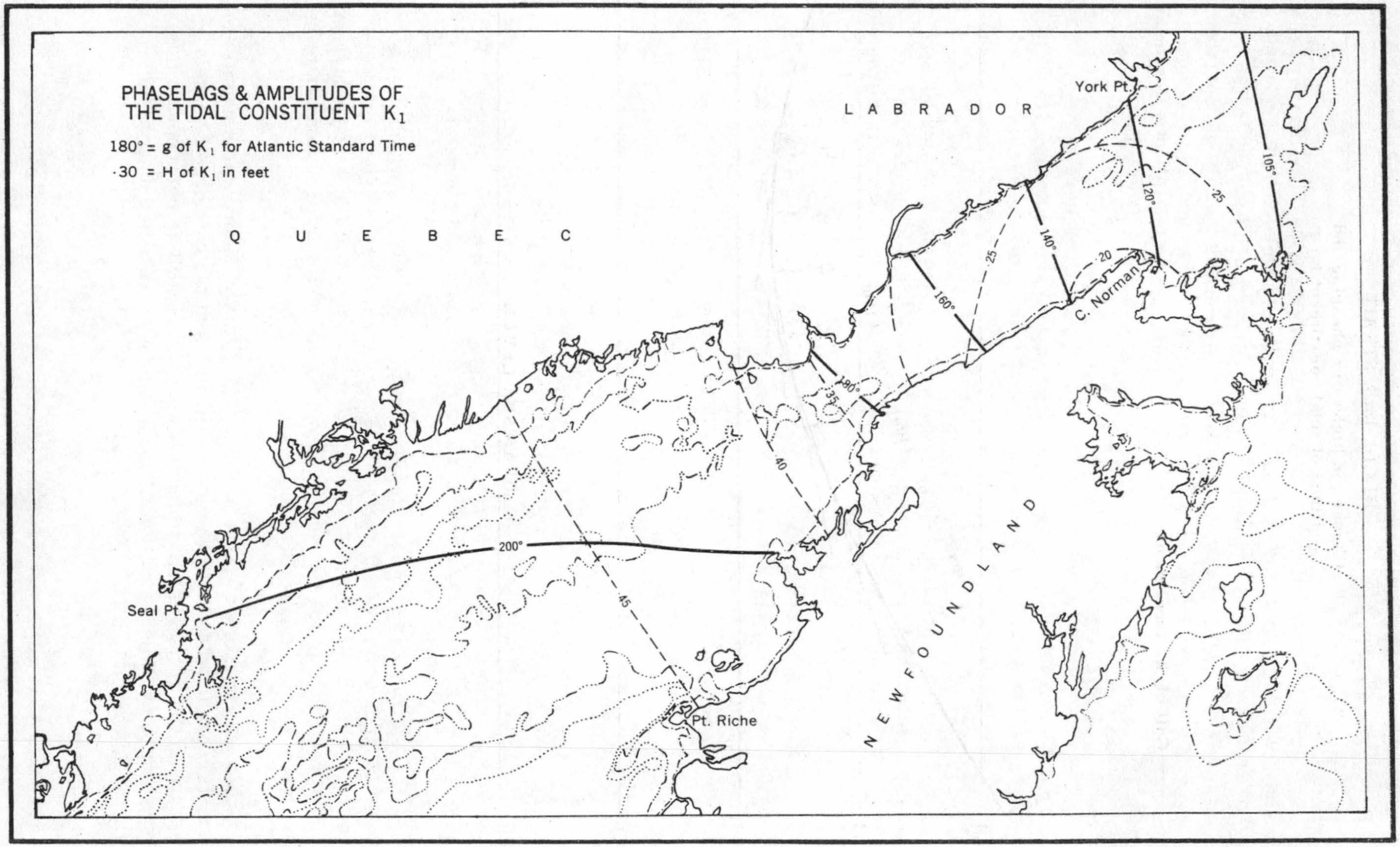


Fig:C5 STRAIT OF BELLE ISLE

D. GASPÉ AND JACQUES CARTIER PASSAGES

DATA

These data consist of observations obstained by the Tidal Survey in 1911 and 1912, with some information from earlier surveys in 1895 and 1896, and observations by the Hydrographic Service during a brief survey in 1961. In the earlier surveys systematic observations were made only in the surface layers, at a depth of 6 metres. A few observations were taken in the deeper layers but they were not adequate for any accurate determination of the currents in those layers.

During the surveys of 1911 and 1912, observations were made at several stations over one or more quite long consective periods and practically all the near-surface data for the Gaspé current come from these surveys. During the recent survey, observations over a 17-day period at a near-surface depth of 13 metres, were made in the centre of Gaspé Passage, and also at a depth of 164 metres for a few days at this position. At two sites, one about 6 miles off Southwest Point, Anticosti, and the other in midchannel near the western end of Jacques Cartier Passage, observations were made at depths of 64 metres over periods of 15 days.

All the early observations used in this report have been re-analyzed by the methods employed for the modern observations. The data are thus comparable, except in respect of directions which were only relatively crudely recorded in the early surveys, so that whereas the directions for the modern data are given in degrees, those for the earlier surveys are given only in general terms such as "eastgoing", "ingoing" etc. The rates obtained in the old and new surveys appear to be in reasonably good agreement, where it is possible to make direct comparisons. The phaselags of the tidal streams, which indicate the times at which the maximum streams occur, are more erratic in the older surveys, but convey the impression given by the recent observations that in fact these phaselags are uniform over the whole area, and at all depths covered by the surveys. The discrepancies arise from poor observing conditions, or from non-periodical fluctuations in the flow.

In addition to the observations from the early surveys which it was possible to analyse by modern methods, a number of other observations were made from which it is possible to deduce the general set of the surface currents and the direction in which the tidal streams rotate. This information has been incorporated in the remarks that follow.

In his reports Dr. Dawson of the Tidal Survey incorporates useful information acquired from local fishermen and from the masters of vessels navigating in the area. In many cases it was not possible to corroborate this information by actual observation; it is, however, commented upon in the course of this investigation.

The sites at which observations were made are shown on Figure D1. ; at (A), (R), (B), (E), (C), (F) and (P) observations were made in 1911 and 1912 and these have been re-analyzed. This is also the case with the observations at (Q) which lies about 35 miles to the west of (A). At (D), (H), (K) and (J) observations were made which were not adequate for detailed analyses. At stations a, A, AB, B, BC, C, DS, D and DN observations were made during the survey of 1961, the great majority of these observations were obtained only over the period of one lunar day. The data thus falls largely into two groups, the near-surface observations of the current along the south shore of Gaspe Passage from the earlier surveys, and observations at a variety of depths obtained mainly in the northern part of the Passage and at the western end of Jacques Cartier Passage during the recent reconnaissance.

The phaselags and amplitudes of the tidal responses to the principal semidiurnal and diurnal constituents, M_2 and K_1, at places in Gaspe Passage and Jacques Cartier Passage are given in Table D_1 and are shown diagramatically on Figures 3b. and 3d. The responses of the tidal streams to these constituents are given in Table D2.

The near-surface rates of the Gaspe Current, in its central part and near its northern fringe are given in Table D3, a and b. The residual currents observed during the 1961 survey are given in Table D4a. and D4b.

INTERPRETATION OF THE SEMIDIURNAL TIDAL AND TIDAL STREAM DATA

In Tables D3a. and 3b. the phaselags g for the semidiurnal constituent M_2 of the tidal streams show considerable variations. There is, however, no indication of a progressive change either in and out of Gaspe Passage nor transversely across the passage, at any depth. It is likely that the differences are largely due either to the quality of the observations or, with the very short periods of observation, to the influence of non-periodical effects. The semidiurnal oscillation is developed as a standing oscillation and in consequence no great changes in the phaselags of the tidal streams are to be expected. A phaselag of 360° for the ingoing stream can be considered acceptable for Gaspe Passage as a whole, at all depths. The phaselag g for the tides in the Passage is about 060°, so the ingoing stream has its maximum rate about 2 hours before high water.

The rates in Gaspe Passage are weak and nearly uniform down to a depth of 164 metres, and the rate of M_2 is about 0. 45 knot, very similar to that in Cabot Strait. This semidiurnal rate will vary with changes in astronomical conditions from about 0. 2 to 0. 7 knot. At the western end of Jacques Cartier Passage where the channel is constricted and relatively shallow, the rates are very much stronger, that of M_2 being rather greater than a knot.

In his reports Dr. Dawson emphasizes the clockwise rotation of the near-surface tidal streams on the northern side of the Passage. In Table D2., the rotation is indicated by the letters C, R and A, standing respectively for "clockwise" "rectilinear" and "anticlockwise". The direction of rotation, as observed with metres suspended from the ship while at anchor for periods of only a day, is often not very satisfactory, as movements of the ship relative to the seabed may adversely affect the observations when the flow is weak. Nevertheless, the direction of rotation in the near-surface layers was almost invariably clockwise.

Although he obtained no systematic observations at depths below 6 metres, Dawson took some pains to determine whether the onshore set, which occurs in the near-surface layers soon after high water with the clockwise rotation of those streams, persisted in the deeper layers. He came to the conclusion that this clockwise rotation was confined to the near-surface layers. The recent observations, as shown in Table D2., indicate that at a depth of 164 metres there is a distinct tendency for an anticlockwise rotation. It follows, therefore, that there must be an intermediate stage where the streams are rectilinear. However, the long-period observations at 13 metres at station B and those of 64 metres at station C showed that at neither of them was the direction of rotation constant, but at the former a clockwise rotation predominated and at the latter an anticlockwise rotation was predominant.

If the rates of rotary streams are layed off from a common point in the directions towards which they set, an ellipse can be drawn through the plotted points. The observations were in all cases analyzed in two component directions, one in the direction of the long axis of the ellipse and the other in a direction at right angles. The analyses of the observations over periods of 15 days at stations B and C gave the following values for the tidal stream constituent M_2:-

		Long Axis			Short Axis		
Stn.	Depth	Dir:	Phaselag	Amp.	Dir:	Phaselag	Amp.
B	13 m	296°	356°	.34 kn	026°	086°	.05 kn
C	64 m	315°	357°	.35 kn	225°	087°	.09 kn

At each station the directions of the long axes, the phaselags and rates for both axes are very similar, but the directions of the short axes differ by nearly 180°. So that whereas at B in the near-surface layers the ingoing stream is followed by a northeasterly set, more or less simultaneously in the deep layers the ingoing stream is followed by an offshore set. To date, however, no long-period observations have been taken simultaneously at a series of depths at a single station, to prove whether at the same site the streams do rotate in opposite directions in different layers of water.

INTERPRETATION OF THE DIURNAL TIDAL AND TIDAL STREAM DATA

The phaselags of K_1 of the tide in Gaspe Passage is about 220°, and with a true standing oscillation the phaselag of the associated tidal stream would be (220° - 90°) or 130° for the ingoing direction.

The phaselags of K_1 of the tidal streams, as given in Tables D3a. and 3b. show even greater divergencies than those of the tidal stream constituent M_2. This is, however, not very surprising, for few of the observations were taken for long consecutive periods and the rates of these streams are very small. It again seems reasonable to assume that with a standing oscillation the phaselags will be nearly uniform all over Gaspe Passage and a phaselag of 140° has been accepted as a representative value. This is in quite close agreement with the expected value of 130°, and is not very different from the accepted phaselag of 150° in Cabot Strait. As regards rates of the diurnal streams, if an average value for the amplitude of K_1 of .08 knot is accepted, then the variation in the maximum rates of the diurnal streams will be from 0 to 0.25 knot with changes in astronomical conditions.

The relative amplitudes, K_1/M_2 of the tides and tidal streams: In any gulf where there are one or more amphidromic points these relative amplitudes will vary greatly in the vicinity of these points. At a semidiurnal amphidromic point the amplitude of the M_2 tide will be zero, while the amplitude of the M_2 tidal stream will be large. At this point the amplitudes of the K_1 tide and tidal stream will have their average magnitudes. However, away from the vicinity of such points there is a more or less similar relationship between the semidiurnal and diurnal amplitudes of the tides and those of the tidal streams.

It can be deduced from the information in Table D1. that, with the tides in Gaspe Passage, the amplitude of K_1 is about one-third that of M_2. With the tidal streams in Gaspe Passage the average amplitudes of M_2 and K_1 are respectively 0.45 and 0.08 knot, giving a relative amplitude for K_1 of about one-sixth that of M_2. The fact that the relative amplitude of K_1 in the tides is twice as great as in the tidal streams is in accordance with expectation. With tides it is the vertical displacement which is recorded and analyzed, with the tidal streams it is the rate of horizontal displacement which is measured. In order to compare the relative displacements brought about by semidiurnal and diurnal streams, the periods of the streams must be taken into account. As the period of the diurnal stream is twice as long as that of the semidiurnal stream, a diurnal stream with a relative rate of one-sixth will cause a relative displacement of one-third. So that when vertical and horizontal displacements are considered, the relative magnitude of the K_1 displacement is the same in both cases.

INTERPRETATION OF RESIDUAL CURRENT DATA

Outgoing Current along Gaspe Shore: The rates measured in the surface layers of the Gaspe current were almost wholly obtained during the surveys of 1911 and 1912. The rates were recorded at stations (Q), (A), (B), (C) and (P), all of which were situated about 4 1/2 miles offshore. The strongest currents were found at stations (A), (B) and (C), where the average rate was about 1.7 knots. At the first two the daily rates varied between 1.0 and 2.4 knots, but at (C) the variations lay between 0.5 and 3.1 knots. In Gaspe Passage the most favourable combination of the semidiurnal and diurnal streams barely reaches a rate of a knot, so that at (A) and (B) the outgoing current always dominates the ingoing tidal stream.

At (Q) which lies about 35 miles west from (A) the average rate of the current was about 1.1 knots and still further west the average rate does not exceed a knot. At (P), off Cape Gaspe, the average rate is also about 1.1 knots. It would therefore appear that the Gaspe current has its narrowest width and consequently its greatest rate off the coast between Cape Magdalen and English Point.

In his reports Dawson quotes local information and shipping for a statement that the inshore boundary of the Gaspe current is one or two miles from the coast. Observations over a single day were obtained at station a in 1961 and on that occasion the current at 7 metres was very weak and setting onshore. The rate of the tidal streams at this inshore station was the same as the general average in Gaspe Passage, or about 0.45 knot. These observations confirm Dawson's reports that close to the coast the outgoing current is not dominant as it is farther offshore and that both ingoing and outgoing tidal streams are experienced.

Stations (R), (E) and (F) lie between 9, 11 1/2 and 11 miles offshore respectively. Only a few observations were obtained at these stations but the rates of the outgoing current were distinctly lower than those observed at the stations 4 1/2 miles offshore. The average rate of the current was about 0.8 knot and it is probable, therefore, that these stations lie fairly close to the offshore boundary of the Gaspe current. A single day's observations were obtained in 1961 at station AB, which lies about 12 miles offshore; on this day the outgoing current in the upper layers had a rate of about 0.2 knot.

Dawson stated that the Gaspe current extends to a great depth, being strong at 30 fathoms and still distinctly felt at 90 fathoms. It is doubtful, however, that accurate determinations of the deep currents could have been made with the appliances then in use. In the course of a single day's observations made in 1961 at station A, the outgoing current in the surface layers had a rate of 1.4 knots, but comparative observations over a few hours at depths of 64 and 164 metres indicated that the current at those depths was negligible.

Dawson reached the conclusion that the velocity of the Gaspe current varied with astronomical conditions.

The ingoing and outgoing tidal streams flowing past a prominent headland eddy on its downstream side. In the eddy areas there are parts where the ingoing and outgoing streams set in a similar direction, in consequence there is a preponderance of set in this direction, that is, a residual current. Over the area as a whole the predominant set in one part is counterbalanced by one in the reverse direction in some other part. As these predominant sets, or residual currents, are derived directly from the tidal streams, their magnitudes vary with those of the tidal streams and hence with astronomical conditions.

The tidal streams set through Gaspe Passage in very uniform directions and rates without any evidence of eddying, and there is in consequence no reason for assuming any direct relationship between the rate of the tidal streams and that of the Gaspe current. The observations obtained by Dawson have been reanalyzed and the rates of the outgoing residual current and the dates on which they were observed are given in Table D3a. In the adjoining column the amplitudes of the semidiurnal tide at Father Point are tabulated. These show that on occasions the current was very strong when the tidal amplitude was large, but conversely some of the strongest rates were observed when the tidal amplitude was small. There is actually no evidence of any correlation between the two.

Displacement of Gaspe current: The following is an extract from Dawson's report: - "During exceptional weather conditions it is possible for the main south-eastward current, which consists of water of the least density, to lie in the middle of the passage between Gaspe coast and Anticosti".

This statement was based on density and current observations taken during the survey of 1895. On September 9-10 the current at station (B) was not, as is usual, strong enough to overcome the ingoing tidal stream, for the resultant set was for some hours to the west. On September 11-12 at station (D) the current was found to set transversely across the Passage in a northerly direction, and on the following day a tendency for a transverse set was also recorded at station (E). Normally the water of least density is to be found in the path of the current along the Gaspe coast. However, during this particular period the water of least density occupied a width of eleven miles in the centre of the Passage.

Continuous observations at a depth of 13 metres over a 15-day period at station B during the 1961 survey, showed that, at this station in the centre of the Passage, the average current did set in a transverse direction of 065° at an average rate of 0.2 knot. Table D4a. shows that at this station sets between northeast and north are not very unusual, and in consequence the transverse sets observed at stations (D) and (E) in 1895 likewise may be not very unusual. The scanty data at present available suggests that the Gaspe current is most closely confined to the southern shore when setting with its stronger rates, because of the increased influence of Coriolis force. When the current is weak it is probably much more diffused and has a tendency to spread out across the Passage.

It is evident that a great deal remains to be learned about the Gaspe current and this can only be acquired by means of synohronous observations at a variety of depths along a series of section lines across its path.

Currents in the northern part of Gaspe Passage:

The following is an extract from Dr. Dawson's report: "From the observations of the season of 1911 at the stations off the south coast of Anticosti and those in the middle of the passage, all the evidence indicates a preponderance of inward flow to the northwest. The stronger and more persistent set on the surface is in that direction. Also, the undercurrent gives the same indication, although the observations being intended more directly for other purposes, were not taken specially with this object. It also appears from the investigations of 1895 that the deep water, below 100 fathoms is practically quiescent". He proceeds to the conclusion that "this inward flow to be sufficient in amount to compensate for the outflow of the Gaspe current, with possibly a small contribution also from Mingan Strait (Jacques Cartier Passage)".

The three series of observations over continuous periods of 15 days obtained in 1961, at station B in mid-passage at a depth of 13 metres, at station C off the coast of Anticosti at a depth 64 metres, and at station D at the west end of Jacques Cartier Passage at a depth of 64 metres, do not support this contention. At these stations the average residual currents were respectively 065°, .19 knot, 136°, .09 knot and zero. During this survey no long-term observations in the near-surface layers were obtained off the coast of Anticosti. One brief comparison gave the currents at 64 metres at C, at 7 metres at C and 13 metres at B, as 200°, .1 knot, 043° .4 knot, and 077° .25 knot, respectively. This suggests that the transverse set recorded in the upper layers at station B, may also be a common feature closer inshore, and that a similar set observed by Dawson at (D) may not be so unusual as he supposed.

As regards the set in the deeper layers, it has been said earlier that the deep observations obtained by Dawson cannot be regarded as reliable. It is evident from Table D. 4a, in which the long-period current observations obtained in 1961 are shown, that the directions and rates of the currents are everywhere subject to considerable fluctuations and that no firm conclusions as to the usual circulation in Gaspe Passage can be drawn until a great deal more data are obtained.

Jacques Cartier Passage: The data in this Passage are even more inadequate than those available for Gaspe Passage. The only long-period observations are those obtained in 1961 for a depth of 64 metres at station D in the western entrance to Jacques Cartier Passage. At this depth the current was always weak, with the exception of one day when the set was inwards at a rate of about a quarter of a knot. There was no residual current when the observations were averaged over a 15-day period. On that day when the current at 64 metres had its greatest inward rate at station D, at a site nearby the current at 7 metres set outwards at a similar rate, while at the immediate depth of 18 metres there was a weak ingoing set.

Dawson's conclusions as to the residual currents in Jacques Cartier Passage were as follows:-

1. At the western end: "The difference in the amount of set each way, as shown by the surface observations during calm weather, is in favour of the inward directions".
2. Off Natashquan Point: "On the whole, from a total of 627 observations, the set was southeastwards for two-thirds of the time".
3. Off the east end of Anticosti: "The water thus makes southward and westward on the whole, around the east end of Anticosti; which is very significant in showing the direction from which the water comes, that forms the return flow to make up for the Gaspe current. This is further confirmed by the continuous observations of the lightship off Heath Point, during the seasons of 1910 and 1911. Although they give the direction on the surface only, they were so continuous as to afford a good average indication; and they show that the set southwestward (S.S.W. True) is more frequent and stronger than in other directions.

   From the observations of the season of 1911 and the anchorages off the south coast of Anticosti and those in the middle of the passage between Anticosti and the Gaspe coast, all the evidence indicates a preponderance of inward flow to the northwest".

The data acquired during the 1961 survey was not adequate to confirm any of these statements, but such evidence as was obtained tends to disprove the existence of ingoing near-surface currents in the areas mentioned by Dawson. It seems more probable that any inward set is confined to the deeper waters of Gaspe Passage.

With the means at his disposal, Dr. Dawson's achievements were quite remarkable, but without self-recording meters and the facilities for operating them at any chosen depths, he was never able to obtain any synoptic view of conditions. In consequence, the flow and counter flow of the various water masses still remains a matter for speculation.

Table D1.

Tides

Phaselag, g, for occurrence of high water, amplitude, H, in feet.
Phaselags given for Atlantic Standard Time.

Position	M_2 g	M_2 H	K_1 g	K_1 H	Period of Observations
Havre St. Pierre	024°	1.81	217°	.64	29 days
Mingan	034°	2.14	207°	.55	30 "
Heath Point, Anticosti	338°	1.07	228°	.45	30 "
Southwest Point, Anticosti	053°	1.66	210°	.59	4 years
Point Menier, Anticosti	058°	2.18	214°	.75	30 days
Gaspe	070°	1.21	223°	.63	30 "
Fox River	072°	1.69	223°	.57	30 "

Table D2.

Semidiurnal and Diurnal Tidal Streams

Phaselag, g, for occurrence of maximum ingoing rate in Atlantic Standard Time. Amplitude, H, the maximum rate in knots. Direction given is that of ingoing tidal streams.

Stn.	Meter	Dir.	M_2 g	M_2 H	K_1 g	K_1 H	Rotation	Period of Observation
Data for depths of 6 or 7 metres								
(Q)	Gurley	ingoing	354°	.21	109°	.08	–	15 days
(A)	"	"	353°	.50	118°	.10	–	18 "
(B)	"	"	013°	.37	148°	.09	–	10 "
(C)	"	"	008°	.41	129°	.12	–	19 "
a	Ott.	320°	336°	.44	–		R	1 "
A	"	336°	348°	.51	–		C	1 "
(R)	Gurley	ingoing	360°	.58	171°	.08	–	1 "
(E)	"	"	337°	.45	–	–	–	5 "
(F)	"	"	031°	.46	054°	.12	–	7 "
AB	Ott.	296°	354°	.42	143°	.07	C	1 "
B	Ott.	303°	358°	.37	125°	.08	C	1 "
BC	"	304°	006°	.41	134°	.10	C	1 "
DS	"	291°	008°	1.27	–	–	–	1 "
DN	"	256°	007°	1.11	–	–	–	1 "
(H)	Gurley	ingoing	002°	–	–	–	C	4 "
(K)	"	"	359°	–	–	–	C	4 "
(J)	"	"	006°	–	–	–	C	4 "

Table D2. (con't) Semidiurnal and Diurnal Tidal Streams

			M_2		K_1			
Stn.	Meter	Dir.	g	H	g	H	Rotation	Period of Observation
Data for depths of 13 metres								
AB	BBT	303°	359°	.34	150°	.07	C	1 days
B	PW	296°	356°	.34	162°	.05	C	15 "
Data for depths of 18 & 24 metres								
DS 24m	BBT	288°	002°	1.29	-	-	-	1 "
DN 18m	BBT	273°	005°	.86	-	-	-	1 "
Data for depths of 64 metres								
a	BBT	300°	337°	.36	-	-	C	1 "
AB	BBT	302°	333°	.40	103°	.03	C	1 "
B	BBT	289°	009°	.37	121°	.03	R	1 "
C	BBT	315°	357°	.35	120°	.05	A	15 "
D	BBT	295°	006°	.92	139°	.11	-	15 "
Data for depths of 164 metres								
AB	BBT	287°	352°	.31	157°	.06	A	1 "
B	BBT	296°	356°	.38	-	-	A	6 "
C	BBT	285°	010°	.50	-	-	C	2 "

Notes: Gurley meter recording rate, directions not precise.
Ott meter recording rate, direction by gyro bearing of drogue.
BBT Neyrpic meter continuous record of rate and direction.
C tidal stream directions rotate clockwise.
R tidal stream directions rectilinear.
A tidal stream directions rotate anticlockwise.

Table D3a.

Gaspe Current (near centre)

Eastgoing rate in knots, tidal amplitude in feet

1911 Survey				1912 Survey			
Stn.	Date	Rate	Tidal amplitude	Stn.	Date	Rate	Tidal amplitude
(Q)				(Q)	July 24	1.27	2.8
					" 25	1.27	3.2
					" 26	1.37	3.7
					" 27	1.09	4.0
					" 28	1.25	4.1
					" 29	1.43	4.3
					" 30	1.53	4.5
					" 31	.97	4.7

Table D3a. (con't) Gaspe Current (near centre)
Eastgoing rate in knots, tidal amplitude in feet.

	1911 Survey				1912 Survey		
Stn.	Date	Rate	Tidal amplitude	Stn.	Date	Rate	Tidal amplitude
					Aug. 1	.93	4.7
					" 2	.71	4.5
					Sept. 3	.40	4.0
					" 4	.88	3.6
					" 5	1.38	2.9
					" 6	1.24	2.5
				Mean 1.12 kn.			
(A)	June 27	1.87	6.2	(A)	Aug. 6	1.99	2.4
	" 28	2.04	6.0		" 7	1.79	2.6
	" 29	2.37	5.8		" 8	1.73	2.7
	" 30	2.40	5.5		" 9	1.50	3.1
	Aug. 30	1.52	5.3		" 10	1.63	3.7
	" 31	1.12	4.9		" 11	1.29	4.5
					" 12	1.43	5.8
					" 13	1.89	6.2
					" 14	2.08	6.8
					" 15	2.24	6.8
					" 16	2.41	6.3
				Mean 1.84 kn.			
(B)	June 8	2.06	3.1				
	" 9	2.06	3.5				
	" 10	2.14	4.0				
	" 12	1.08	4.0				
	Aug. 8	.97	3.7				
	" 9	1.20	4.1				
	" 10	1.27	4.4				
	" 22	1.88	4.5				
	" 23	1.81	5.1				
				Mean 1.61 kn.			
(C)	July 25	1.55	5.4	(C)	Aug. 28	2.69	4.8
	" 26	1.35	5.7		" 29	3.11	5.2
	" 27	1.67	6.0		" 30	2.95	5.2
	" 28	2.25	6.2		Sept. 19	1.20	2.2
	Aug. 14	1.53	4.9		" 20	1.27	2.2
	" 15	.89	4.9		" 21	.73	2.1
	Sept. 14	1.78	4.1		" 24	.47	4.0
					" 25	.48	4.2
					" 26	.69	4.5
				Mean 1.54 kn.			

Table D3a. (con't) Gaspe Current (near centre)
Eastgoing rate in knots, tidal amplitude in feet

1911 Survey				1912 Survey			
Stn.	Date	Rate	Tide amplitude	Stn.	Date	Rate	Tide amplitude
(P)	Aug. 26	.70	5.1	(P)	Sept. 12	2.43	6.6
					" 13	1.85	6.6
					Oct. 1	.53	4.1
					" 2	.68	3.7
					" 3	.71	3.3
					" 4	.75	2.9
					" 9	1.55	6.5
					" 11	.64	6.7

Mean 1.09 kn

Table D3b.

Gaspe Current (near northern edge)

(R)	July 1	1.03	5.0				
(E)	June 19	.67	3.2				
	" 20	.54	3.2				
	Sept. 5	.86	2.9				
	" 6	1.00	2.9				
(F)	Sept. 26	.27	5.6	(F)	Aug. 21	1.20	2.2
	" 27	.23	5.0		" 22	1.29	2.2
	" 30	.76	2.3				

Table D4a.

Gaspe and Jacques Cartier Passages - Currents Observed in 1961
Rates in kn

Date 1961	Station B				Station C		Station D		
	7 m	13 m	64 m	164 m	64 m	164 m	7 m	18 m	64 m
June 5		072° .17							
" 6		356° .22			124° .29	130° .26			
" 7		156° .14			115° .31	104° .17	*153° .25	317° .13	295° .23
" 8		056° .29			106° .34		+006° .07	284° .08	015° .03
" 9		308° .32			100° .25				.00
" 10					155° .09				295° .02
" 11					244° .02				115° .01
" 12					218° .10				115° .11
" 13		358° .21			191° .08				115° .15
" 14		142° .13			356° .05				115° .09
" 15		138° .13			161° .12				115° .04
" 16		084° .07			161° .17				115° .07
" 17		088° .44			212° .06				115° .01
" 18		057° .52			288° .05				295° .02
" 19		039° .19			021° .01				295° .13
" 20		101° .23		327° .10	263° .04				295° .10
" 21		092° .22		342° .11					115° .01
" 22		080° .19		346° .11					
" 23		069° .17		001° .09					
" 24		049° .10		039° .06					
" 25		030° .24		049° .09					
" 26		051° .26							
" 27		073° .17							
" 28		073° .12							
" 29	100° .28	102° .15	115° .15						

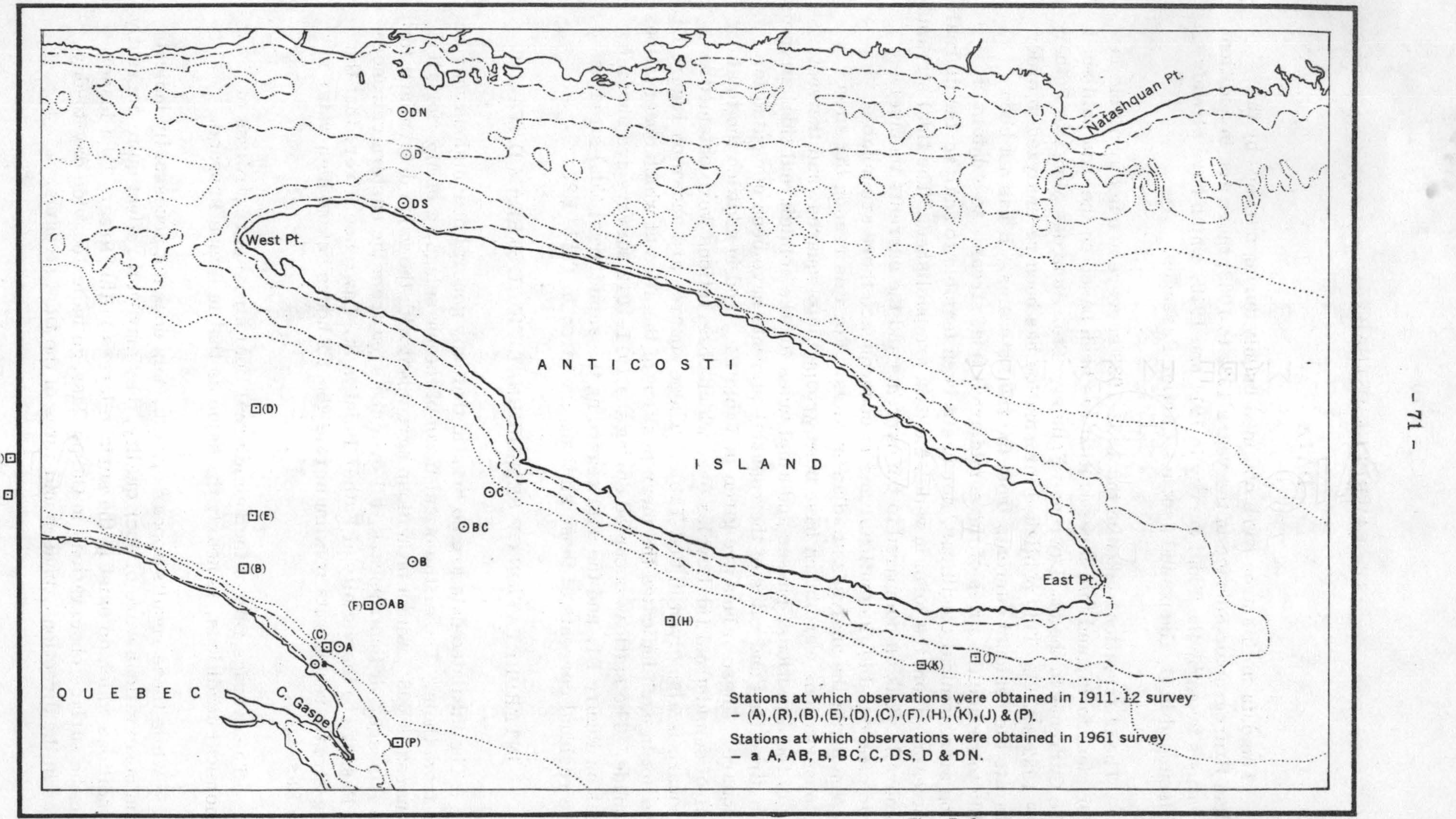
*at DN, observations at 7 m and 18 m. + at DS, observations at 7 m and 24 m.

Table D4b.

Gaspe and Jacques Cartier Passage - Current Observed in 1961
Rates in kn

Station and Depths

Date 1961	Stn.	7 m	13 m	64 m	164 m	Stn.	13 m	Stn.	64 m	Stn.	164 m
June 12	A	141° 1.4	142° 1.3					C	218° .10		
								D	115° .11		
June 16	AB	116° .19	143° .19	131° .03	226° .06	B	084° .07	C	161° .17		
								D	115° .07		
June 18	BC	139° .12	-	-	-	B	057° .52	C	288° .05		
								D	295° .02		
June 23	a	231° .08	-	311° .09	-	B	069° .17	-	-		001° .09
June 29	B	100° .28	102° .15	115° .15	-		-		-		-



Stations at which observations were obtained in 1911-12 survey
– (A),(R),(B),(E),(D),(C),(F),(H),(K),(J) & (P).

Stations at which observations were obtained in 1961 survey
– a A, AB, B, BC, C, DS, D & DN.

Fig. D.1 GASPE AND JACQUES CARTIER PASSAGE

E. ST. LAWRENCE ESTUARY

DATA

The data in this area were obtained mainly during surveys by the Canadian Hydrographic Service in the years 1932 to 1933; there are in addition observations taken by the Tidal Survey in 1911 and 1912, which have already been discussed in D, Gaspe and Jacques Cartier Passages.

The observations taken in the 1932-1933 surveys are not available in their original form, and this investigation has been based on the data published in "The Currents in the St. Lawrence Estuary - Ste. Anne des Monts to Father Point - 1932-1933". This published information has been re-analyzed in order to separate the residual currents from the tidal streams. It has not been possible to reduce the rates of the semidiurnal tidal streams to a datum of common astronomical conditions, nor has it been feasible to analyze the diurnal tidal streams, from the form in which the data are published. The tidal streams are generally weak as compared to the currents and the currents themselves undergo considerable fluctuations, and in consequence there are notable discrepancies in the analyses at adjacent sites. For this reason the sites where observations were taken have been grouped into squares, and the vector means of the directions, phases and amplitudes for the semidiurnal tidal streams and the directions and rates of the residual currents have been computed for each square. These values are given in Table E1., and in addition the total number of semidiurnal tidal cycles over which observations were obtained in each square is also given in that Table. These squares are shown on Figure E1. and the dot in each indicates the mean position of the sites at which observations were made. The stations occupied during the 1911-1912 surveys are shown by crosses on Figure E1. and the data regarding the semidiurnal tidal streams and the residual currents at those stations are given in Table E2.

INTERPRETATION OF SEMIDIURNAL TIDAL STREAM DATA

The tabulated data are so erratic that only general conclusions may be drawn from them. The arithmetical mean of the phaselags, g of M_2, for all the squares is 006°, which is in close agreement with the value determined for Gaspe Passage. It thus appears, all over the area from the eastern entrance to the Passage to the vicinity of Father Point in St. Lawrence River, that the ingoing stream reaches its maximum rate about 2 hours before high water in Gaspe Passage.

The average rate of the semidiurnal tidal streams,regardless of astronomical conditions, is nearly the same as that in Gaspe Passage.

While these results appear erratic, this does not necessarily indicate that the observations were of poor quality; they may well reflect quite correctly the conditions which do exist in the surface layers in this area. To a lesser degree the surface observations in Gaspe Passage indicated wide day-to-day changes in the directions, phases and rates of the tidal streams.

INTERPRETATION OF RESIDUAL CURRENT DATA

The residual currents given in Tables E1. & E2. are shown on Figure E2. The pecked lines on that figure show the general directions of the set of the currents, traversely across the estuary from off Pointe-des-Monts until they turn eastward off the south shore to become merged with the Gaspe current.

The rates along the south shore are somewhat erratic and in the vicinity of Point Metis they are relatively weak. These inshore currents show a definite increase in rate after they have been reinforced by the transverse set from the vicinity of Pointe-des-Monts.

There were no systematic observations of the subsurface currents in this area, and no full account of this cross-set and its influence upon the Gaspe current can be made until continuous observations are obtained at a series of stations across the estuary and at a variety of depths at each.

Table E1.

Tidal Streams and Currents - 1932-33 Survey

Square	Ingoing Stream Dir:	g of M_2	H	Residual Current Dir:	Rate	Cycles Observed
1	262°	329°	.32	183°	.48	6
2	223°	016°	.18	205°	.52	13
3	-	-	-	-	-	-
4	175°	068°	.33	175°	.15	7
5	200°	057°	.30	087°	.59	10
6	217°	028°	.20	150°	.70	4
7	268°	004°	.37	022°	.25	7
8	243°	343°	.54	131°	.24	4
9	208°	005°	.26	076°	1.05	10
10	245°	358°	.38	086°	.79	21
11	249°	005°	.35	077°	.63	10
12	261°	005°	.47	081°	1.13	15
13	282°	312°	.26	084°	.38	13
14	195°	351°	.55	070°	.64	7
15	231°	013°	.36	059°	.42	10
16	251°	012°	.39	081°	.36	7
17	203°	353°	.34	062°	.10	5
18	180°	025°	.45	056°	.72	2
Means		006°	.36			

Table E2.

Tidal Streams and Currents - 1911-12 Survey

Stn.	Ingoing Stream			Residual Current		Cycles
	Dir:	g of M_2	H	Dir:	Rate	Observed
(Q)	West	354°	.21	East	1.12	14
(A)	"	353°	.50	"	1.87	18
(R)	"	360°	.58	"	1.03	2
(B)	"	013°	.37	"	1.61	10
(E)	"	337°	.45	"	.77	2
Means		358°	.42			

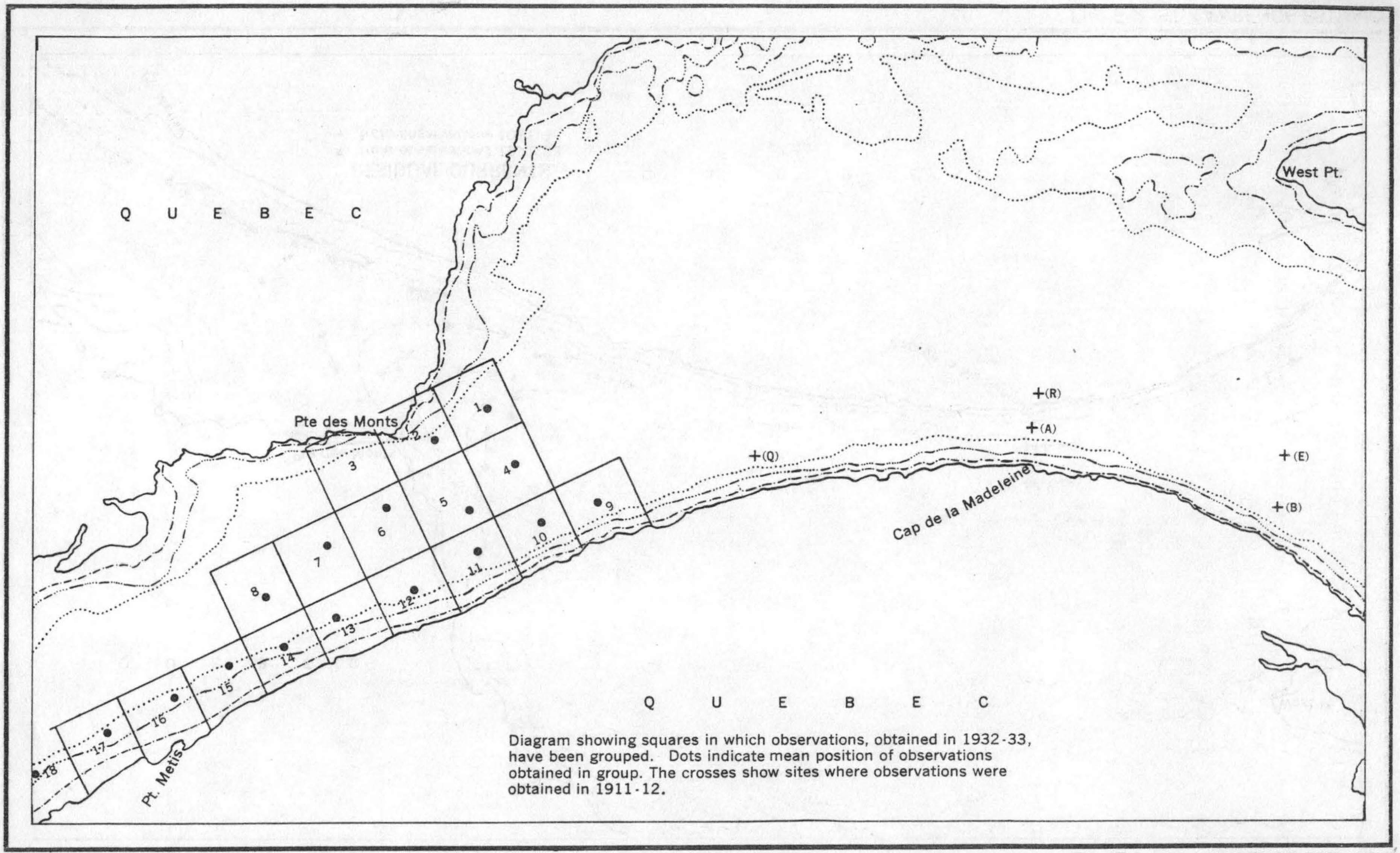


Diagram showing squares in which observations, obtained in 1932-33, have been grouped. Dots indicate mean position of observations obtained in group. The crosses show sites where observations were obtained in 1911-12.

Fig. E.1 ST. LAWRENCE ESTUARY

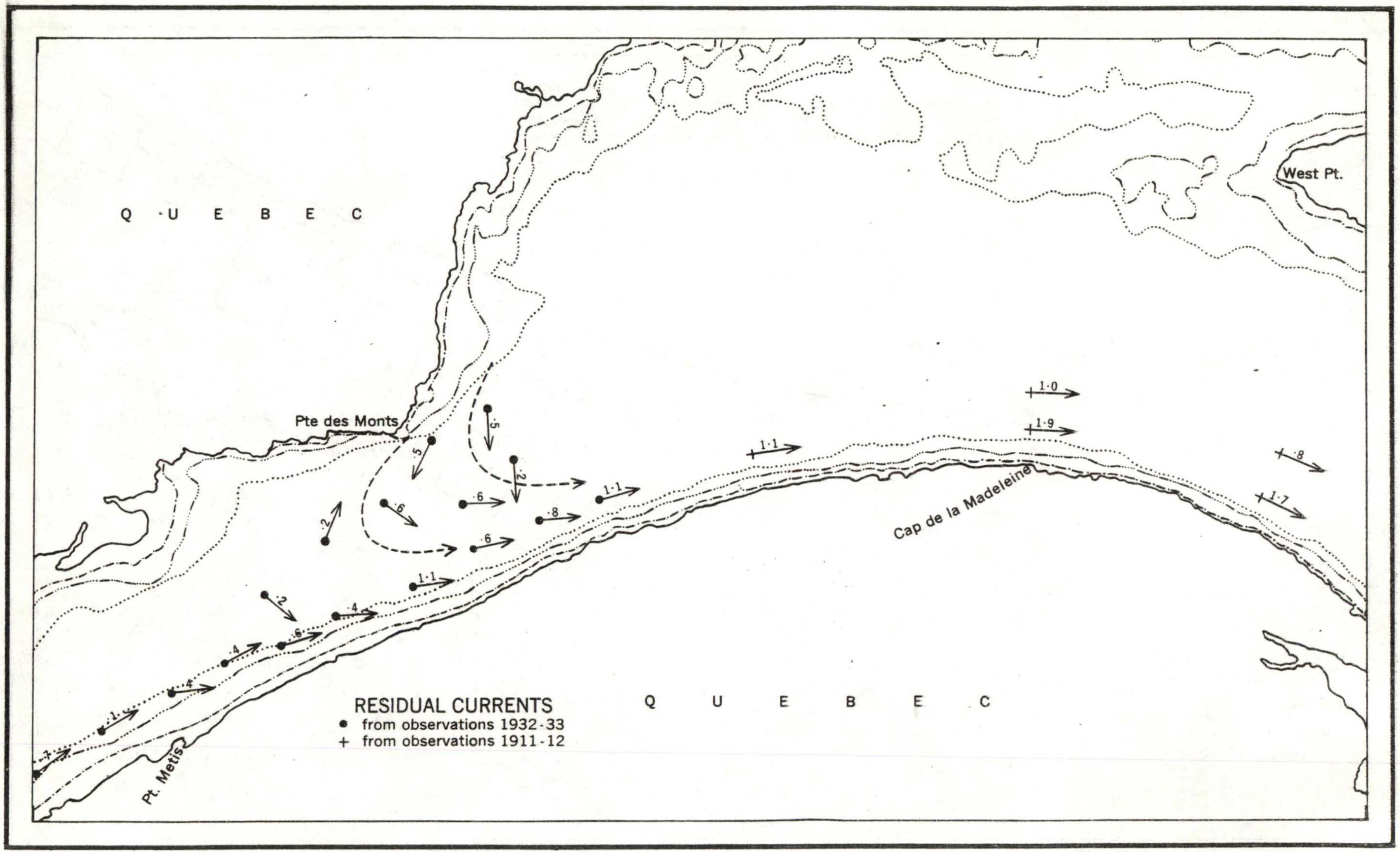


Fig. E.2 ST. LAWRENCE ESTUARY