The Physical Oceanography

of

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THE PHYSICAL OCEANOGRAPHY OF ST. MARGARET'S BAY

by

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1. INTRODUCTION

(A) Purpose

During 1966 the Marine Ecology Laboratory of the Fisheries Research Board began the development and expansion of its program of studies of biological and physical processes underlying marine production in order to shed further light on the food web (or food chain) in the sea. The concept of food chains has been widely used as a convenience in generalizing problems in biological production. The concept treats fisheries yield as the end of a chain of events which begins with the accumulation of small organic particles of energy derived in various ways from solar radiation. As the structuring of the system must ultimately be dependent on the nature of the physical characteristics of the environment, one must expend considerable effort towards measuring and understanding the physical environment under which marine production processes take place.

Although one is primarily interested in eventually applying food chain studies to the larger areas of the sea such as the continental shelf, and open Northwest Atlantic Ocean where heavy exploitation of fisheries stock occurs, the size and complexity of such areas pose formidable problems in adequate description, let alone understanding, of regulatory mechanisms. For this reason, the Marine Ecology Laboratory chose to lay the groundwork for the needed larger scale studies by initially looking in some detail at smaller systems. In 1965 St. Margaret's Bay, a small (5 x 10 miles) embayment about 25 miles west of Halifax, was selected as a model, and, during 1966 this area served as a focus for investigations by many of those at the Laboratory. These consisted of physical oceanographic observations, including current measurements at the entrance to the Bay, studies of the micro-structure of the surface layers in relation to wind stress and zooplankton distributions, the study of phytoplankton production, collection of zooplankton, sampling for abundance and studies of caloric contents of benthic invertebrates and observations on the abundance, foods, and physiology of the American plaice populations. In this report we describe the general physical oceanographic features of the Bay as they are derived from a food sampling program which took place over the period 1966=1969.

(B) Plan

Limited studies were initiated in St. Margaret's Bay in June and July 1966, in order to establish some of the very gross characteristics of the Bay. With this background the 1967, 1968 and 1969 program (Fig. 1.1) was designed to provide more detailed spatial and temporal information on tides and tidal currents, residual circulation, temperature and salinity structure, as well as the fluctuations in parameters ranging from a period of a few days to those occurring on a seasonal basis. From the extensive field measurement program, it was hoped that one would both obtain a reliable description of the physical oceanography of the Bay, and establish some of the fundamental features that determine the circulation, flushing and behaviour of such coastal embayments.

(C) Physiography

St. Margaret's Bay is a small embayment that extends between lat. 44°27'N and 44°42'N, and between long. 63°50'W and 64°04'W (6 x 10 miles). It is about 25 miles (40 km) west of Halifax and is a result of submergence since the Pleistocene times. The depths in the Bay range up to 80 metres near the mouth on the western side. The western part of the Bay is deep in comparison with that of the eastern. The general U-shaped bottom profile persists along the channel from the mouth of the Bay to Mill Cove. The bottom topography is relatively uniform with only minor irregularities, except off the headlands where the topography is irregular because of randomly scattered ledges and shoals composed of bedrock, boulders, coarse gravel and sand. Drumlins are characteristic of the northern St. Margaret's Bay area. The beaches of the Bay are composed of coarse sand and glacial erratics. The central unobstructed part of the Bay contains substrates of sand, silt, clay and various combinations of all three, with silty sand, or silty clay predominant.

Table 1.1 gives the areas and the volumes of the different layers in the Bay.

TABLE 1.1

Depth (m)	Area (10^4 m^2)	Volume (10^6 m^3)
0	13849)	
	)	1240
10	11320)	
		1020
20	9270)	
	)	835
30	7150)	
		640
40	5200)	
	)	470
50	3540)	
		310
60	2020)	
	)	
70	640)	120
	)	
75	200)	

It should be noted that while depths of up to 80 metres are found near the mouth of St. Margaret's Bay, a broad sill 5-10 miles in width with depths of about 45 metres, isolates the deep water in St. Margaret's Bay from that of the Scotian Shelf and offshore waters.

2. METHODS AND TECHNIQUES

(A) Vessels and Instruments

The survey work in St. Margaret's Bay has been carried out primarily from three vessels: the 50-ft M/V SIGMA-t which has been used most extensively for the temperature-salinity work as well as the current meter moorings; the M/V WHIP-THE-WIND, a slightly smaller vessel, which has been used for much of the drogue and dye work; and the M/V NAVICULA, a 65-ft vessel which has been used more extensively during the latter part of the survey and has been employed in all aspects of it.

Temperature and salinity measurements have been made primarily with Knudsen reversing water bottles and Richter & Wiese thermometers. Salinity determinations have been made in the laboratory using either an Auto-Lab or Hytech salinometer. On a few occasions, in situ measurements have been taken using an electrodeless induction salinometer, Industrial Instruments Model RS5-3, or a more sophisticated salinity-temperature-depth recorder (STD) designed by the National Research Council of Canada and developed by Guildline Instruments.

Currents were measured by moored self-recording meters employing a taut-wire subsurface float. These were left in position for periods varying from two weeks to two months. Three different types of current meters were employed. The primary type used was the buoyant, shallow-water Hydrowerkstatten (HW) current meter. This is a large torpedo-shaped meter which orients itself to the current. An impellor on the nose measures current speed and the magnetic compass in the case detects current direction. The information is recorded photographically every five minutes. The picture is recorded from the two dials corresponding to the impellor revolutions and case direction. Hence, an integrated current speed and an instantaneous current direction are obtained at five-minute intervals.

The second type meter used was the Braincon 316 Histogram meter. This instrument measures current speed with a Savonius rotor on the bottom of a three-foot-long cylindrical case. The case is fitted with a large vane to orient the meter with the curren t direction which is detected by magnetic compass. A time exposure records the data on film in a circular analog format. The film advances every 20 minutes and the advance is effected in one minute. Hence, the record obtained is an integrated current speed and direction value for a 19-minute period. Tilt magnitude and direction are also recorded to make corrections to readings.

The third recording current meter is the Plessey Model MO21. This is a small cylinder which is suspended horizontally and is aligned with the direction of the current by means of a vane on the rear section. An impellor on the front is driven by the current. The instrument was also fitted with an external thermistor to sense temperature in the range -2° to +40°C. Every 10 minutes the values of potentiometers coupled to each of the three sensors are measured and recorded in a binary code on magnetic tape. Hence, values for integrated current speed and instantaneous current direction and water temperature are recorded at 10-minute intervals.

The parachute drogues consisted of three parts (Fig. 2.1) similar to that described by Volkmann et al (1966) with slight modifications. The drogue portion consisted of a parachute with a canopy approximately 24 ft in diameter.

In order to track the drogue and maintain it at a fixed depth, it was connected to a surface marker with a length of steel or polypropylene rope.

The dye concentration from the dye release was measured continuously using a standard Turner Model III fluorometer fixed on a research vessel. In using the fluorometer, choice of associated equipment, i.e., submersible pump, size of hoses, were such that samples pumped from a pre-selected depth pass through the instrument in the shortest period of time. For surface and near-surface sampling, the speed of the support vessel was in the 3-4-knot range. This has been done to reduce the disturbances on the patch orientation from the ship movement.

Temperature recorders were also employed at selected depths. These were Braincon type 146 meters which recorded temperature on photographic film with periods varying from a few days to two months.

Measurements of tide were made from time to time at a total of five locations, using Ott float-type or Ottboro pressure-type water level recorders.

Unfortunately, many malfunctions occurred in the HW current meters in 1967, so that the information on the spatial variation of tidal currents was more limited than intended. The Plessey meters, which were also undergoing field trials at the time, gave rather more trouble than had been anticipated.

(B) Observations and Analyses

In June 1966 seven Braincon current meters were installed across the mouth of the Bay at five sites for approximately 29 days (Fig. 2.2). A total of 161 meter-days of current records were obtained. Seabed drifters were released at 48 stations and an RS-5 portable salinometer was used several times to measure temperature and salinity at 13 stations. Tide gauges were also installed. In April 1967 surveys of temperature and salinity, at approximately semi-monthly intervals, were initiated in order to gain information on the spatial distribution and seasonal variations of properties. Drift bottles and seabed drifters were added to the survey in May. The network consisted of 30 stations (Fig. 2.3) which were occupied until June 1968. The network was then reduced to seven stations (Fig. 1.1) which were occupied at approximately weekly intervals during summer and autumn. In 1969 the monitor network of stations was further reduced to three and this was continued until November 1969 (Stations 10, 25, 27, Fig. 2.3). From May to September 1967 current meters and temperature recorders were installed at a number of sites in the Bay and across the mouth. The aim of this survey was to determine the basic features of the tidal currents as well as the non-tidal features of the circulation. Owing to difficulties experienced in finding a suitable location to measure meteorological parameters that might be representative of a good portion of the Bay, the former hydrographic launch, MERGANSER, was fitted with instruments to measure wind speed and direction, air temperature, water temperature and solar insolation, and moored in the central part of the Bay. However, the measurements were discontinued abruptly in the autumn during a storm when the launch broke its mooring and was driven ashore and destroyed. Subsequently, a shore-based anemometer site was established. In 1968 a current measurement program commenced in April and continued until November. Emphasis was placed on maintaining moorings at two stations near the mouth. In June two moorings were placed off the mouth of the Bay in order to provide some information on the variabilities and general features of the offshore waters.

A considerable number of parachute drogues were tracked during 1967. Rhodamine dye was also released on numerous occasions to ascertain both bulk motions and a rough measure of diffusion. Drogue motions were measured mainly at 10-m and 30-m depth.

Temperature and salinity measurements were summarized in standard CODC format with density, specific volume anomaly and dynamic height anomaly computed for each station. Data have been plotted both spatially and as a time series. In addition, quantitative T-S calculations were undertaken.

Current meter records were read and frequency diagram prepared. Power spectrum analyses were computed. Where records were of sufficient length, harmonic analysis was carried out to yield the tidal constituents and permit extraction of residual currents.

Co-spectrum analyses were carried out to reveal possible relationships between variation in mean sea level and meteorological parameters.

3. OCEANOGRAPHIC FEATURES OF ST. MARGARET'S BAY

(A) Seasonal Climatic and Fresh Water Discharge

The climate of the Maritime Provinces is in many respects more continental than maritime owing to their being situated on the east coast of an immense continental land mass. Since the general movement of air masses is from west to east in these latitudes, air reaching the region has usually had a previous history over the continent. Only in the immediate coastal area does the climate become predominantly maritime.

Surface wind speed and direction are greatly affected by the presence of obstacles, such as hills, buildings, and trees. St. Margaret's Bay is surrounded by hills with elevations up to 300 ft. Owing to these local topographic effects it is difficult to make representative anemometer measurements that are applicable to the Bay as a whole.

In winter the weather over the Atlantic region of Nova Scotia is controlled by cyclonic storms which usually produce violent gales and snow changing to rain. In summer this area is under the predominating influence of winds from the south, southwest or west.

Anemometers were installed for short periods at several sites in the St. Margaret's Bay area. The hourly measurements from one of these was correlated with data from the permanent installation at Shearwater, near Halifax, which revealed a very similar pattern. Consequently, Shearwater data have been used for correlating with the oceanographic data.

Fig. 3.1 shows the wind roses at Shearwater, calculated from 10 year's observation, 1944-1954. The wind speed is in miles per hour. Fig. 3.2 shows the percentage frequency of the wind velocity during the mentioned ten years. The mean precipitation and temperature at Halifax were computed over a thirty-year period (1931-1960). The mean daily air temperature varies from 24.4°F in January to 64.3°F in August. The mean monthly precipitation (rainfall + equivalent snowfall) varies from 3.52 inches in June to 6.62 inches in January.

The two sources of fresh water in St. Margaret's Bay are:

1) Discharge from the drainage areas;

2) Direct precipitation.

For convenience, the drainage basin of St. Margaret's Bay has been divided into five areas, mainly on the basis of the significant rivers (Table 3.1 and Fig. 3.3). There are four basins discharging into the Bay, mainly through rivers.

TABLE 3.1

Drainage Area No.	Drainage Basin	Area of Drainage Basin ($miles^2$)
1	No major rivers	15.4
2	Hubbards River	35
3	Ingram River	53
4	Northeast and Indian Rivers	106
5	Hosier River	56

Only one of these drainage basins is gauged (Northeast and Indian Rivers, Fig. 3.3), and the discharge from the others was calculated assuming similarity in conditions. The precipitation on the Bay is measured by a rain gauge located at French Village.

From Figs. 3.4 to 3.6 it is noticed that the total discharge (precipitation + fresh water discharge from drainage areas) varies significantly from one year to the next. During 1967 peak values occurred in May, October and the end of November. In 1968 maximum discharges occurred in March and December, while in 1969 peak values occurred in January and December.

The annual amount of water reaching the Bay (discharge + precipitation) fluctuates greatly from one year to another (Table 3.2).

TABLE 3.2. PRECIPITATION AND FRESH WATER DISCHARGE INTO ST. MARGARET'S BAY.

Year	River Discharge (c.f.s.)	Precipitation (inch)	Precipitation (c.f.s.)	Total Fresh Water Input (c.f.s.)	Standard Deviation in Total (c.f.s.)
1967	977	69	274	1251	798
1968	615	46	182	797	532
1969	654	49	189	843	631

As can be seen from Table 3.2, direct precipitation accounts for about 25% of the fresh water that reaches the Bay.

(B) Flushing Time

From the salinity and fresh water discharges averaged over a year, the flushing time of St. Margaret's Bay was calculated. Assuming steady-state conditions throughout the Bay, the average residence time t of fresh water in the Bay is given by:

$$t = \frac{F}{R}$$

where R is the average rate of influx of fresh water over the year (taking evaporation into account and assuming that it has a magnitude of 30 cm/yr), and F is the accumulated volume of fresh water in the Bay. F is assumed to be given by:

$$F = \frac{S_0 - S}{S_0} \times \text{volume of the bay}$$

where S_0 is the salinity of "source water" outside the Bay and S is the mean salinity inside the Bay. If the fresh water is assumed to be completely mixed with the water of oceanic origin, this time is also the average residence time of oceanic water, i.e., the flushing time of the Bay. To calculate the flushing time numerically from the salinity and fresh water discharge observations, the following steps were carried out.

1) The salinity at the Stations 1-24 taken during the cruise in the period 7 April 1967 to 29 March 1968, approximately every two weeks, were added together at each depth.
2) The mean salinities over this period at depths 0, 10, 20, 30, 40, 50, 60 and 75 m were obtained and this denoted by s. The mean was computed first for each month and then the mean over the year (which is denoted by s).
3) The mean salinity at each layer was obtained by averaging the salinities at the top and bottom of the layer.
4) The area of the Bay at depths 0, 10, 20, 30, 40, 50, 60 and 75 m were calculated.

5) The volume of each layer was obtained from the formula

$$\text{volume of a layer} = \frac{\text{area at top of layer + area at bottom of layer}}{2}$$

$$\times \text{ thickness of layer.}$$

6) The mean salinity over the same period as in (1) at Station 28 at the same depths as in (2) was obtained (which is denoted by s_o).

7) The values for s_o and s obtained at each depth were substituted in the formula

$$f = \frac{s_o - s}{s_o}$$

and then multiplied by the volume of the appropriate layer.

8) Adding the values of (f x volume of layer) at each depth, F was obtained.

9) The rate of influx of fresh water was obtained as the mean over the period from 7 April 1967 to 29 March 1968.

10) The average flushing time was obtained by substituting in

$$t = \frac{F}{R} .$$

From the salinity and fresh water observations averaged over a year (April 1967 to the end of March 1968), the flushing time according to the above-mentioned assumptions is 7.1 days, i.e., the water of St. Margaret's Bay flushed about 51 times during that year.

By applying a two-layer model to the Bay and using Pritchard's formula (Lauff, 1967) to calculate the flushing time, the equation, for the mouth of the Bay, is modified to the form:

$$t = \frac{V(S_2 - S_1)}{S_2 R}$$

where S_2 is the mean salinity of the inflowing bottom layer, S_1 is the mean salinity in the outflowing surface layer, V is the volume of the water in the Bay, and R is the rate of influx of fresh water. This equation was applied to data taken at six stations (19-24, Fig. 2) across the mouth of the Bay. Calculations made by assuming the surface layers were 5-m and 10-m thick gave a flushing time for the Bay of 41 and 38 days respectively. This equation was also used to calculate the flushing time for the surface and bottom layers separately by taking the same section at the mouth of the Bay.

For the surface layer only, the average flushing time

$$t_{surface} = \frac{V_{surface}\,(S_2 - S_1)}{RS_1}$$

where S_2 and S_1 are the mean salinity over the depth of the bottom and surface layers separately.

For the bottom layer only, the average flushing time

$$t_{bottom} = \frac{V_{bottom}\,(S_2 - S_1)}{RS_2}$$

where S_2 and S_1 are the same as before.

It should be noted that $t_{total} \simeq t_{surface} + t_{bottom}$,

i.e., again, t_{total} = average residence time of oceanic water in the Bay,

while, $t_{surface}$ and t_{bottom} = residence time in the surface and bottom layers respectively.

Assuming the surface layer to be 5-m depth and bottom layer 70 m, then

$t_{surface} = 6.1$ days

$t_{bottom} = 35.0$ days.

For the surface layer of 10-m depth and a bottom layer of 65 m, then

$t_{surface} = 10.0$ days

$t_{bottom} = 28.0$ days.

The flushing time for the Bay u sing the steady-state assumption agrees with the flushing time of the surface layer in the two-layer model. The effect of evaporation as considered did not change the value of the figures of flushing time by more than 5%.

(C) Salinity and Temperature

(i) Horizontal

The network of 30 sampling stations taken in St. Margaret's Bay between the period April 1967 and May 1968 (Fig. 2.3) was usually occupied within two days. Twenty-five cruises were made during this period. Because of the small area of the Bay and its shallowness, the patterns of temperature structure that were constructed from these observations cannot represent a synoptic picture. This can be seen clearly by comparing temperature values at stations that were occupied twice in the same cruise. Salinity was also affected by the lapse of time, but not as much as temperature. Because of this, the values of surface temperatures were not drawn. The isohaline and isotherms were drawn for each cruise at horizontal surfaces of 0, 10, 20, and 30 m below surface (Figs. 3.7.1 to 3.7.4, and Figs. 3.8.1 to 3.8.24). In general, surface salinity near the shore is low, particularly in the northern parts of the Bay. Salinity on the western side of the Bay was generally lower than on the eastern side. Similarities of pattern at different levels depended upon the thickness of the mixed layer. This again depended upon the wind, fresh water content of the surface water, and the temperature structure. Due to higher precipitation during the winter, the surface salinity inside the Bay reached its lowest value of the year.

The shape of the isohaline depends on different factors, mainly the fresh water discharge, the wind, the effect of Coriolis force, and the tidal flow.

The southerly winds bring more saline water to the Bay in the surface layer than the winds from other directions. As this would tend to appear on the western side more than on the eastern side (Coriolis effect), the salinity difference between the sides is expected to be greater under the effect of northerly winds, than under any other condition. To test these, the salinities at the three easternmost stations and the three westernmost stations of the section at the entrance of the Bay (19-24) were averaged, as shown in the following table.

SALINITY CHARACTERISTICS AT THE MOUTH OF THE BAY WITH NORTHERLY WINDS

Date	Mean Surface Sal. of Stns. 22, 23, 24 (°/₀₀)	Mean Surface Sal. of Stns. 19, 20, 21 (°/₀₀)	Difference (°/₀₀)	Mean Difference (°/₀₀)
8/4/67	31.25	30.74	0.51	
5/10/67	30.41	30.12	0.29	
31/10/67	31.13	30.80	0.33	
16/11/67	31.02	30.83	0.19	0.30
11/12/67	30.76	30.33	0.43	
18/4/68	31.49	31.31	0.18	
1/6/68	30.92	30.77	0.15	

SALINITY CHARACTERISTICS AT THE MOUTH OF THE BAY WITH SOUTHERLY WINDS

Date	Mean Surface Sal. of Stns. 22, 23, 24 (°/₀₀)	Mean Surface Sal. of Stns. 19, 20, 21 (°/₀₀)	Difference (°/₀₀)	Mean Difference (°/₀₀)
17/5/67	30.17	29.91	0.26	
30/5/67	30.98	30.54	0.44	
17/7/67	29.88	29.75	0.13	
31/7/67	29.65	29.53	0.12	
31/8/67	30.07	30.04	0.03	0.09
18/6/67	30.72	30.76	-0.04	
20/1/68	31.28	31.30	-0.02	
2/2/68	30.98	31.04	-0.06	
15/3/68	31.43	31.49	-0.06	

The difference between the averages during southerly winds was found significantly greater than the difference during northerly winds.

At the Weather Station (Merganser) occupied in St. Margaret's Bay during the period May to September 1967, a temperature recorder was fixed at 4 feet below the sea surface. From the graph showing the variation of temperature with time (Fig. 3.9), it can be seen that the surface water temperature followed the same pattern as air temperature. The highest daily surface temperature occurred at the end of July 1967, with a value of 18.5°C. Most of the time the daily air temperature is higher than the surface water temperature.

From oceanographic stations taken over a tidal period during February 1968 the surface salinity varied from 30.25°/₀₀ to 31.00°/₀₀ inside the Bay and from 30.85°/₀₀ to 31.10°/₀₀ outside the Bay (Fig. 3.10). The bottom salinity inside the Bay varied from 31.05°/₀₀ to 31.20°/₀₀ during the tidal cycle. Outside the Bay it varied from 31.20°/₀₀ to 31.40°/₀₀. At the same two stations the temperature ranged from -1.0°C to 0°C at the surface and 0.4°C to 0.8°C at the bottom. Outside the Bay the temperature varied from -0.6°C to -0.2°C at the surface, and from 0.2°C to 0.9°C at the bottom.

About 30 Braincon thermographs were fixed at different stations in the Bay during the summer of 1967 (April-August). At each station one thermograph was fixed in the surface layer, and a second one in the bottom layer. These thermographs recorded the temperature every five minutes. The observations show that the temperature in the surface layer varied widely while the bottom layer remained relatively constant.

(ii) Vertical

To study the vertical variation of salinity and temperature from the network of 30 sampling stations, two sections were taken in the longitudinal and transverse directions of St. Margaret's Bay. The longitudinal section (Figs. 3.11.1 to 3.11.25) includes the stations 2, 4A, 8, 12, 15, 18, 21, 25, 26, 27, and 28. The transverse section (Fig. 3.12.1 to 3.12.12) covered stations 19, 20, 21, 22, 23, and 24. In most cases, the sampling stations at each section were taken over 2-3 hours for the transverse, and 3-4 hours for the longitudinal.

The highest temperature and lowest salinity in the transverse section occurred at the surface on the westernmost station. From the longitudinal section the low salinity and high temperature are seen to originate at the head of the Bay.

Station 21, which appears in both sections, was useful in that it exemplifies the differences that occur when one and the same station is occupied at different times in the same cruise. At the beginning of summer the surface water started to warm through solar radiation. The bottom salinity increased slightly. During the summer the surface temperature gradually increased until it reached its maximum in August. Temperature decreased with depth from May to November. During July and August the thermocline was well developed in the 5-20-m layer below surface. The steepness of the temperature gradient was greater inside the Bay than outside. Also, inside the Bay the stratification due to the fresh water discharge resulted in the salinity dominating the temperature determining the vertical structure. During the summer, under strong southerly winds, the thermocline zone goes deeper. Also, during the summer, the surface temperature at Owl's Head was slightly higher than at Paddy Point. At that time the surface salinity varied from one month to another depending on the fresh water input, while the bottom salinity did not change much.

During the fall and winter seasons the bottom salinity increased gradually. In winter the bottom water reached a maximum temperature of approximately 3.5°C, due to the inflow of oceanic water. In winter time, a temperature minimum occurs below the surface, while the bottom temperature is higher than the surface temperature.

The temperature structure at the transverse section shows that during the fall season the temperature has a subsurface maximum. This can be explained by the hypothesis that subsurface water is still warm from the accumulated heat of the summer.

By examining the vertical structure of the salinity from the 25 longitudinal sections taken over about a year, and relating these to the stage of tide and wind, several points can be made. When the tide was flooding and the wind was in the same direction, the thickness of the surface oceanic water layer increased. An easterly or westerly wind affected only the surface layer inside the Bay. Inside the Bay the surface salinity was affected mainly by the fresh water discharge, with the result that stratification of salinity varied between inside and outside.

In winter the mean wind was stronger than in the summer, thus supplying more energy for mixing the surface layer. From the salinity structure, it is seen that the surface layer to a depth of about 30 m was more uniform in the winter than at any time during the year. The thickness of the mixing layer diminished in the landward direction. Salinity of the deep water was largely determined by advection of the oceanic water which varied seasonally, revealing a maximum in the autumn and winter months. In general, the stability of water was higher in summer than in winter due to solar heating of the surface layer.

In order to learn more about relatively small-scale variations, an 8-mile segment consisting of 80 oceanographic stations was occupied twice, on June 24-25, 1969. A Guildline STD was used to make the measurements. The cross-sectional plots are shown in Figs. 3.13.1 and 3.13.2. Basically, a two-layer system was present at the time the measurements were taken consisting of a surface layer with temperature varying from 10-15°C and a deep layer (likely 20 m) with temperature 4-7°C.

Rather striking changes in the surface layer occurred between the two sets of observations. An idea of the extent of this variation is best revealed by noting the area covered between the 10° and 11°C isotherms on the two days.

On June 24 this layer was approximately one metre thick and was situated at about 10-m depth. The following day its average thickness had increased to approximately 10 m and for the region near the mouth of the Bay it extended from the surface to about 15-m depth. The apparent increase in volume of the 10-11°C water was accompanied by a marked increase in the 11-12°C water lying immediately above it. Another abrupt change occurred near the mouth of the Bay (seaward of Station 10). Here the thermocline has been largely destroyed.

The change which took place over a 24-hour period was of sufficient magnitude that most of it must have been brought about by advective processes. Some of these differences may have been produced by lateral motion within the Bay. Alternatively, a major change may have occurred in the circulation pattern in the approach area to the Bay, which in turn generated a significant exchange in the surface layer throughout a large part of the Bay.

It was feared that some of the recorded changes in temperature and salinity between the two occupations may have been apparent rather than real owing to instrumental calibration shifts. Unfortunately, insufficient independent sampling was carried out to ascertain whether this in fact did happen. However, careful checks upon return of the STD to the laboratory did not reveal any significant instrumental shifts. From the previous performance and stability characteristics of the instrument, there are no valid grounds for doubting the temperature measurements. However, there may have been insufficient cleaning of the salinity cell during the two-day experiment. If so, it could conceivably have produced a shift of as much as 0.1°/₀₀. With this possibility present it cannot be determined with certainty whether or not the salinity differences recorded in the deep layer were real or apparent.

However, despite these uncertainties the bulk of the change which occurred in the upper layer and near the mouth cannot be attributed to instrument malfunction. Thus, the experiment provided valuable preliminary information on the time and space variability present in St. Margaret's Bay. More comprehensive measurements are needed to define the underlying mechanisms.

From the three sampling stations 10, 19, and 27 (Fig. 2.3) taken for about 20 months, it can be seen that the mean salinity in the upper 20 m was lower than the corresponding one outside the Bay (Fig. 3.14 to 3.16). The salinity stratification varies inside and outside the Bay.

To study the formation of different water masses inside and outside the Bay, a number of sampling stations were taken along a 38-mile section. This section was taken in a longitudinal direction to the Bay on a line from 44°33.9'N lat, 63°59.5'W long to 43°57.5'N lat, 63°40.8'W long. At these stations an STD was used as well as water bottles. This section was taken four times as follows.

19-20 November 1968	(Fig. 3.17.1)
2 July 1969	(Fig. 3.18.1)
10 July 1969	(Fig. 3.18.1)
14 August 1969	(Fig. 3.19.1)

The vertical structure of salinity along the section taken in November 1968 (Fig. 3.17.2) shows that a mixed layer existed with a thickness of 30-40 m inside and outside the Bay. Seaward of the 100-m depth contour, the stratification varied from about 31.3 to 32.2 over the length of the section. For the sections taken in July (Figs. 3.18.2 and 3.18.3) and August (Fig. 3.19.2), the surface layer varied in depth from 10-15 m. The salinity in the surface layer was higher in July and August than in November. This may be due to the higher precipitation in November and higher temperature in July and August. The bottom water below 100 m seemed not to change from one season to another. The most striking contrast was the presence of a strong lateral gradient in temperature and salinity in LaHave Basin in November as compared to the July and August structure.

At the end of October 1968 oceanographic stations were occupied along Halifax Section (Fig. 3.20.1). The stratification of the water masses along that section (Fig. 3.20.2) is similar to that taken from St. Margaret's Bay to LaHave Basin in November of the same year. The vertical temperature and salinity structure on the Scotian Shelf appears similar to that described by Hachey (1961), revealing the presence thermally of 3 layers: a warmer surface layer, a cold (< 5°C) intermediate layer, and a deep warm layer (> 8°C) in LaHave Basin where depths reach approximately 250 m.

In St. Margaret's Bay the surface waters and bottom waters were respectively co-linear with the surface and a portion of the intermediate layer outside the Bay, but the thickness of the surface layer inside and outside the Bay is different. The deep warm saline water in LaHave Basin which has its source seaward of the Continental Shelf was absent from St. Margaret's Bay.

(iii) Seasonal

Inside the Bay the surface salinity varied from about 23.30°/.. to 31.30°/.. during the year. Values of low salinity were observed near the mouth of the rivers. Outside the Bay the range of surface salinity was $30.30^{\circ}/_{\circ\circ}$ to $31.60^{\circ}/_{\circ\circ}$. During the year the bottom salinity inside and outside the Bay varied from about $31.60^{\circ}/_{\circ\circ}$ to $33.00^{\circ}/_{\circ\circ}$. From the section taken across the Bay from Owl's Head to Paddy Point, the salinity varied from one side to the other. At most times the salinity was higher at Paddy Point than that at Owl's Head. This was due to the effect of Coriolis force. The average difference in salinity from the eastern to western side of the Bay was about $0.50^{\circ}/_{\circ\circ}$. The difference in salinity between surface and bottom varied from one season to another, the difference inside the Bay usually being larger than that outside the Bay. From the three sampling stations 10, 19, and 27, taken for about 20 months, the seasonal variation of salinity with depth showed the intrusion of the water masses of high salinity during the winter season at both stations 10 and 27.

Except during winter the temperature usually decreased with depth. During the year the surface temperature ranged from about -0.10°C in February-March to 17.7°C in July-August.

At 0, 10, 20, and 30 m the range of temperatures was as follows.

Depth	Minimum	Maximum	Range
0 m	-0.10	17.70	17.80
10 m	-0.63	12.24	12.87
20 m	-0.43	5.80	6.23
30 m	-0.34	3.70	4.04

These ranges vary slightly inside and outside the Bay.

The difference in temperature between the surface and bottom layers varied between 15.9°C during the summer to about -2.5°C during winter months. From the 30 Braincon thermograph observations (April-August 1967), it was seen that the temperature in the surface layer varied widely, while at the bottom layer it seemed more uniform.

(D) Qualitative and Quantitative Study of the Water Characteristics (Temperature, Salinity)

To follow the changes of temperature and salinity over the year, T-S diagrams were plotted, and are shown here for selected stations along the axial section of the Bay. Each figure represents the T-S structure at one station for different cruises. The stations represent conditions inside the Bay (Station 12, Figs. 3.21.1 to 3.21.3), at the entrance (Station 21, Figs. 3.21.4 to 3.21.6), and outside the Bay (Station 28, Figs. 3.21.7 to 3.21.9). At Station 12 the spring conditions, encountered on the first two trips of 7 and 25 April 1967, changed over the entire water column towards the summer conditions by 29 May. The temperature of the bottom water rose by 1° and the temperature range increased from less than 2° on 7 April to more than 3° on 15 May cruise. On subsequent cruises, a strong thermocline was exhibited with a characteristic difference across it of more than 5°C. The temperature and salinity of the bottom layer remained almost constant (< .50°/$_{\circ\circ}$ salinity and < .5°C) from 18 June to 31 August 1967. Fresh water inflow appeared as a decrease in the surface salinity, which reached a minimum on the 14 August survey. On the 14 September survey the whole of the water column showed an increase in salinity and a decrease in the temperature difference between top and bottom, indicating probably an invasion of oceanic water. The increase of salinity was manifested even more for the 27 September survey. From that date until the end of the year, the loss of heat and subsequent increase of mixing reduced the temperature difference between top and bottom of the water column as seen in the following table.

TEMPERATURE DIFFERENCE BETWEEN SURFACE AND BOTTOM AT STATION 12

Date	27 Sept.	11 Oct.	1 Nov.	16 Nov.	12 Dec.
Temperature Difference	11.4°C	8.4°C	6.2°C	2.4°C	0.6°C

On the 12 December survey the winter conditions were fully developed, the temperature difference between top and bottom was small with the lower temperature at the surface and the stratification maintained by salinity differences. This continued until the end of March when observations showed an increase of temperature at the surface, and thus, a temperature minimum in the middle layers. Salinity, however, increased from top to bottom. This temperature minimum was last observed on 17 April and conditions returned to those observed at the beginning of the observations.

Stations 21 and 28 show the same characteristics as Station 12, thus indicating that it is possible to reduce the number of stations without corresponding loss of information. At Station 28, however, the salinity does not fall below 30°/₀₀, while it falls to 29°/₀₀ at Stations 21 and 12, and the surface temperature never rises above 14°, as compared to 18° at Stations 12 and 21.

To look quantitatively at the temperature-salinity distribution in the Bay as a whole, Stations 1-24 were taken and weighted according to location in the Bay. The volume of water present within each temperature and salinity interval was then plotted as appears in Figs. 3.21.10 to 3.21.31. The first two cruises represent typical spring conditions. The greatest volume of the Bay lay within narrow limits of temperature and salinity (> 90% within 2°C and $1°/_{oo}$). Spring runoff showed as small quantities of less salty water, not particularly warm. The effect of solar heating appeared in the third cruise, extending the temperature range to 5°C, from 3.6°. For the next few cruises fresh water runoff appeared as small volumes of fresher water. The volume of this water was so small that it did not show continuity from one cruise to the next, thus pointing to the desirability of increasing the frequency of sampling. The cruise of 18-20 June showed a clear summer pattern, with a well developed thermocline, with about 1/6 of the volume of the Bay above the thermocline. This increased in the following months with minor fluctuations. Below the thermocline, however, water of almost constant temperature and salinity existed at all times. Thus, in cruises of July and August, a local maximum of volume occurred at temperature range 2.0°-2.2°, and salinity range $31.4°/_{oo}$-$31.8°/_{oo}$. Surveys undertaken after storms further exhibited an increase of less salty water due to increased runoff. Fall conditions started by lowering the surface (less salty) water temperature while the bottom temperature continued for some time to rise only slightly. Thus, surface temperature which reached a maximum exceeding 19° in August started to decrease, while the temperature of bottom water continued to rise slightly. By the 11-13 December cruise the temperature of the low salinity water became less than that of the bulk of the salty water, thus establishing the winter conditions when fresher colder water is at the surface, and salty less cold water at the bottom. This again continued until the end of March when the surface water temperature began to rise, giving rise to a temperature minimum in the intermediate layers. In April the seasonal cycle again started.

(E) Currents

(i) Surveys

A number of current surveys were carried out in the Bay between 1966 and 1969.

In 1966 five moorings were made at the entrance to the Bay, five current meters at 20 feet below surface, and two at a few feet above the bottom. The position of the stations for 1966 were as follows (Fig. 2.1):

Station No.	Depth (ft)	Latitude (W)	Longitude (N)	Starting Date	Days of Data
1	15	44°30.46'	64°00.12'	29/6/66	27
2	20	44°30.44'	63°59.30'	28/6/66	28
2	130	44°30.44'	63°59.30'	28/6/66	28
3	20	44°30.46'	63°59.00'	29/6/66	2
3	168	44°30.46'	63°59.00'	29/6/66	13
4	20	44°30.45'	63°58.05'	29/6/66	22
5	20	44°30.45'	63°56.90'	28/6/66	2
5	20	44°30.45'	63°56.90'	9/7/66	7

The current meters used in this mooring were Braincon type 316.

In 1967 the current survey was extended to include most of the Bay area. Fifty-nine moorings were installed. Nine meters were Braincon type 316, and 83 were Hydrowerkstatten buoyant and non-buoyant type. From these moorings good records were obtained from 8 Braincon and 36 HW current meters. The meters were positioned at about 6 m below the surface and a few metres above the bottom at selected stations in the Bay. Some of these current meters recorded the current continuously for 30 days. The positions of the stations for the 1967 current survey were as follows.

Station No.	Depth (feet)	Latitude (W)	Longitude (N)	Starting Date	Days of Data
2	25	44°38'	64°00'	10/5/67	28
				7/7/67	5
				22/8/67	13
4	110	44°37'	64°02'	7/7/67	20
				8/8/67	16
6	108	44°38'	63°58'	10/5/67	24
11	25	44°35'	64°01'	6/5/67	48
				30/6/67	18
	133			4/8/67	18
	135			6/5/67	10
12	25	44°35'	64°00'	6/5/67	15
	160			6/5/67	12
14	25	44°36'	63°57'	9/5/67	41
				17/6/67	19
16	25	44°33'	64°02'	9/5/67	28
	196			4/8/67	30
				13/6/67	30
				9/5/67	30
17	25	44°33'	63°59'	13/6/67	17
	26			14/5/67	28
	153			14/5/67	30

Station No.	Depth (feet)	Latitude (W)	Longitude (N)	Starting Date	Days of Data
18	25	44°33'	63°59'	19/5/67	29
	180			19/5/67	20
19	15	44°31'	64°00'	2/5/67	26
				29/6/67	28
	18			2/8/67	27
	25			1/6/67	27
	205			1/6/67	5
20	18	44°31'	64°00'	4/5/67	27
	25			2/6/67	25
				1/7/67	22
	216			2/6/67	29
	250			4/5/67	27
21	18	44°31'	63°59'	6/5/67	21
				2/8/67	27
	207			6/5/67	28
				2/8/67	24
22	110	44°31'	63°58'	3/5/67	29
				2/6/67	23
23	23	44°32'	63°58'	2/6/67	28
	25			2/5/67	30
				30/6/67	27
24	22	44°32'	63°57'	2/5/67	29
				1/6/67	29
				30/6/67	10
26	165	44°29'	63°58'	14/5/67	26

In 1968 after incorporating improvements in the recording mechanism, better results were obtained from the moorings of HW current meters. During April and May currents were measured at six stations in the Bay. Subsequently, measurements were taken at only one station (19) on a continuing basis throughout the year, and intermittently at Station 24. The positions of the stations during the 1968 current survey at St. Margaret's Bay were as follows.

Station No.	Depth (feet)	Latitude (W)	Longitude (N)	Starting Date	Days of Data
6	17	44°38'	63°58'	25/4/68	21
10	20	44°35'	64°02'	24/5/68	21
	26			25/4/68	11
	187			25/4/68	24
13	20	44°36'	63°59'	25/4/68	24
	20			24/5/68	20
	141			25/4/68	24
	141			24/5/68	20
15	20	44°34'	64°00'	27/4/68	23
	20			24/5/68	22
19	10	44°31'	64°00'	27/4/68	22
	10			24/5/68	22
				19/6/68	26
				16/7/68	10
				30/7/68	26
				25/8/68	26
				1/10/68	22
				24/10/68	24
	20			27/4/68	22

Station No.	Depth (feet)	Latitude (W)	Longitude (N)	Starting Date	Days of Data
19	20	44°31'	64°00'	19/6/68	25
				30/7/68	26
				25/8/68	26
	26			24/5/68	22
	33			27/4/68	22
				19/6/68	25
				30/7/68	26
				25/8/68	25
	40			24/5/68	22
	98			28/4/68	-
				19/6/68	25
				30/7/68	26
				25/8/68	19
	174			19/6/68	25
				30/7/68	26
	184			25/8/68	28
				1/10/68	22
				24/10/68	24
	194			27/4/68	22
24	20	44°32'	63°57'	25/5/68	22
				19/6/68	26
				25/8/68	17
	26			30/4/68	20
	89			1/10/68	22

In 1969 moorings were placed at Stations 19 and 24 several times. The current record is not yet read, so the data are not analyzed.

(ii) General Circulation

The water movement in St. Margaret's Bay is complex, as can be seen from current meter records, drogue and dye studies. Three factors are responsible for initiating the motion.

(1) tidal forces,

(2) meteorological conditions in the area of the Bay, and oceanic circulation outside,

(3) fresh water discharge and subsequent mixing.

The pattern depends further on the Coriolis effect, the bottom topography, and the stratification of the water. To model the circulation in a simplified manner, currents were broken into three parts (Table 3.3).

(a) regularly periodic part which is dominated by the M_2 component of the current and appears in Table 3.3 for a series of stations taken across the entrance of the Bay,

(b) anticlockwise current which is deduced from the difference between residual currents (total current minus the tidal components) on the two sides of the entrance,

(c) stratified current (mainly thermohaline circulation) uniform for any particular layer and deduced from the residual of the measured current by subtracting the anticlockwise current.

In the calculation of the anticlockwise and the stratified circulation, two stations were taken on the sides of the Bay where the currents were recorded at the surface and at the bottom for a period more than 15 days during 1966 to 1968.

From the current measurement at these stations the harmonic constituents were calculated, sometimes from 29 days if enough length of record was available, other times for 15 days. From the harmonic constituents Z_0 at each station on each side of the Bay was taken as the estimate for the residual current produced by the anticlockwise and the stratified circulation. If the anticlockwise and stratified circulations were denoted by A and T respectively, then

At the surface

West Side	East Side
$Z_0 = -A-T$	$Z_0 = A-T$
$\downarrow$	$\uparrow$
towards the sea	towards the Bay

At the bottom

towards the sea	towards the Bay
$\downarrow$	$\uparrow$
$-A+T$	$A+T$

The depth of the upper current meters was chosen at 6 m so that the current would represent the surface motion above the thermocline layer. Table 3.3 gives M_2, A and T for these two stations at different times during 1966, 1967 and 1968.

Results of current meter data analysis indicate that at the entrance of the Bay, the magnitude of the first type of currents reaches a peak of about

21 cm/sec. This is a periodic current which decreases in magnitude from the entrance to the head of the Bay. The magnitude of the second type at the surface is seen to be 2-3 cm/sec, while the third varies between 1 and 1.5 cm/sec. At a depth of 30 m the magnitudes of the second and third types are about 0.5 and 0.1 cm/sec. The surface values reported here may be an underestimate as the current meters were located at a depth of 6 m.

(iii) Surface and Bottom Currents

From the current observations taken in the Bay during 1966 to 1968, some of the better quality records were chosen to give an indication of the variation of the currents at the surface and at the bottom.

To study the currents at the mouth of the Bay, five stations were taken during 1966 from which four records were reliable. Harmonic analyses were carried out to determine the tidal constituents. From these analyses, it is shown that the current floods for about five and a half hours and ebbs for seven hours. The current at the central part of the mouth of the Bay follows the tidal cycle but the other stations are distorted by eddies. This effect is readily apparent from the tidal ellipse diagram drawn for each station across the mouth of the Bay (Fig. 3.22). The tidal velocity decreases as the depth increases. This is shown at Station 2, Fig. 3.22, taken at 130-ft depth. To study the surface currents in the Bay, four stations were selected for about a 2-week period from 15 to 31 May 1967. These were Stations 2, 14, 16 and 12. At these stations, the variation of the current during the tidal period does not follow the tidal cycle. This is not totally unexpected, as tidal currents must decrease rapidly towards the head of the Bay, while the effects of winds and fresh water discharges will become relatively more important (Fig. 3.23). Another unexpected feature observed in the Bay during this period was that water flowed into the Bay from the west side and left from the east side; this is the opposite of the normal pattern of water movement in the Bay. In the central part of the Bay, away from the immediate influence of islands and shoals, surface water flows seaward for approximately 7 hours and inward for 5 hours and also gives a net outflow over a tidal cycle.

The residual current is obtained by adding the two components of motion along the arbitrarily chosen major and minor axes. The major axis was chosen at 350° and the minor at 080°.

From the variation of the daily residual of the surface current in the Bay, it seems that the Bay is affected by both the wind blowing over the Bay as well as the atmospheric pressure system moving across the Atlantic coast of Nova Scotia. This pressure adds currents from outside to inside the Bay if the pressure over the Bay is high, and outside is low, and vice-versa.

As mentioned previously, the effect of the tide on the water flow varies in two dimensions. Tidal currents decrease towards the inner part of the Bay and also with depth. This tidal effect can be seen from the values of the M_2 constituent (as the predominant tide in the Bay is semi-diurnal) for the different stations at various depths (Table 3.4).

From the limited number of good records of the stations, it was not possible to establish the residual current patterns over the entire Bay. However, from frequency distribution histograms of the direction and speed of water flow, it was possible to gain some understanding of the general circulation of the Bay. From the stations taken at the mouth of the Bay during 1966 (Fig. 3.24.1), 1967 (Fig. 3.24.1), and 1968 (Fig. 3.24.1), it is evident that the surface current enters the Bay from the east side and leaves from the west side. Velocities were greater in the most frequent directions. Thus, the transport has almost the same pattern (Fig. 3.24.2). Additional measurements of currents on each side at the mouth were taken at different times. In all cases, it gave qualitatively the same result (Fig. 3.25).

From these current observations at the surface and at the bottom, some insight can be gained about the general circulation in the Bay. The lateral surface circulation pattern is typically counterclockwise with inflow on the eastern side of the mouth and outflow along the western side. The vertical-longitudinal circulation consists of a net outflow in the surface layer and a net inflow at the bottom layer (Fig. 3.26). This mean circulation pattern is markedly altered under strong wind conditions or fluctuating pressure patterns.

In order to study the variation of the daily residual current with depth, a number of current meters were moored at Station 19 on the western side of the mouth of the Bay (Fig. 2.3). Fig. 3.27 shows the percentage distribution of current direction at Station 19 at each depth for different periods. Only once were the records suitable for harmonic analysis, viz. from 19 June to 14 July 1968, when five meters were moored at 3-, 6-, 10-, 30- and 53-m depths below surface. Fig. 3.28 shows the variation of residual currents at each depth for each day.

Fig. 3.29 shows the progressive vector diagram of the daily residual currents for each depth separately at Station 19. It shows that at the western side of the mouth of the Bay the direction of the net movement of the water at all depths is in the seaward direction. This is consistent with the interpretation that the anticlockwise circulation pattern observed at the surface in the Bay does, in fact, continue to exist at all depths.

(F) Variation of Sea Level at St. Margaret's Bay and Halifax Harbour

(i) Sea level observations

A study of the variation of sea level at St. Margaret's Bay has not been carried out previously. At Halifax Harbour the seasonal variation was examined for approximately a 6-year period from 1960-1966. In addition to the data from the permanent gauge in Halifax Harbour, five tide gauges were installed at different places in the Bay (Fig. 3.30). The positions of the tide gauges were as follows.

Place	Station No.	Latitude	Longitude
Boutilier's Point	482	44°39'20" N	63°57'21" W
Indian Harbour	484	44°31'34" N	63°36'40" W
Mill Cove	475	44°34'48" N	64°03'28" W
Owl's Head	473	44°31'19" N	64°03'34" W
Hubbards	480	44°38'15" N	64°03'34" W
Halifax Harbour	490	44°40'00" N	63°35'00" W

The tide gauge at Halifax Harbour is a pressure sensing device connected to an

Ott analog recorder. The original tide gauge at Halifax was installed since September 1895. The gauges at St. Margaret's Bay are float-operated Ott recorders, installed temporarily in 1966, at some stations for only a few months and at others for about two years. The only permanent station still operating at St. Margaret's Bay is the one installed at Boutilier's Point. The record is changed once every month at all the gauges, but daily checks are taken. The sea level data used in these analyses are as follows.

Name of Station	Station No.	Dates
Owl's Head	473	4/67 - 12/67
		1/68 - 11/68
Mill Cove	475	7/66 - 10/66
		4/67 - 12/67
		1/66 - 11/68
Hubbards	480	4/67 - 12/67
		1/68 - 11/68
Boutilier's Point	482	6/66 - 10/66
		4/67 - 12/67
		1/68 - 12/68
		1/69 - 6/69
Indian Harbour	484	7/66 - 9/66
Halifax Harbour	490	1/66 - 12/66
		1/67 - 12/67
		1/68 - 12/68
		1/69 - 11/69

The observed hourly height data were analyzed by the harmonic method (LEAST SQUARES).

The residual heights were obtained as the observed minus the predicted. The predicted height of sea level is obtained from the accumulation of the various harmonic constituents at each hour.

Hourly heights, daily and monthly mean sea levels were extracted and computed by the Tides and Water Levels, Marine Sciences Branch, Ottawa.

In addition to these sea level data, two meteorological stations were taken to give the variation of mean sea level pressure for the period 1966 to 1968. These two stations are:

Shearwater, Dartmouth, N. S.	44°38' W lat	63°30' N long
Western Head, N. S.	43°59' W lat	64°40' N long

The distance between these two stations is about 67 miles. The pressure at each station was taken every three hours and then averaged to give the daily mean pressure. The difference between the daily means at the two stations gives the daily pressure difference.

From the hourly observed values at each tidal station the residual heights and the harmonic constituents were obtained. The power spectrum for the residual heights was computed to show the hidden periodicity. The power spectrum for St. Margaret's Bay has been determined only for Boutilier's Point station for three months of residual heights from January 24 to April 24, 1968. This time was chosen because the water level was strongly distorted by meteorological conditions. Also, the power spectrum for Halifax Harbour was computed for the residual heights during that period. The co-spectrum, quad-spectrum, and the coherence between the residuals at Boutilier's Point and Halifax Harbour have been done. The coherence was also made between the daily residual heights at Halifax Harbour and Boutilier's Point on one hand, and the corresponding daily pressure difference on the other.

(ii) Daily variations in sea level

The mean sea level at Halifax and St. Margaret's Bay varies from day to day, and from season to season. The range of the tide varies between 6.40 ft and 3.30 ft during the year. The hourly sea level heights vary between 0.85 feet to 7.90 ft above chart datum. Day-to-day fluctuations in sea level were analyzed with the view to determining the presence of any statistically significant periodicities, the response of sea level to atmospheric pressure, and the relationship to meteorological differences in summer and winter. The mean daily sea level (Fig. 3.31) varies with approximately the same phase in St. Margaret's Bay as in Halifax Harbour, although the amplitude is sometimes different. This difference in amplitude may be attributed to the effect of bottom topography. The range of variation at Boutilier's Point (St. Margaret's Bay) is greater than the corresponding one at Halifax Harbour. Sometimes a phase shift in the daily observed sea level occurs, however, the time lag is usually quite small. The lowest and highest value of the daily mean sea level was observed at Boutilier's Point (St. Margaret's Bay) during January 1968.

From the seasonal variation of daily sea level, it was seen that a rapid change in sea level occurs during the fall and winter of every year. Also, the daily mean and monthly mean sea level shows higher values during the fall and winter than during the spring and summer seasons.

From the tidal harmonic constituents, Table 3.5, the predicted height of the sea level at each station was calculated. Subtracting this perdicted height from the corresponding observed height, the hourly residual height is obtained, from which the mean daily residual can be calculated. The variation of the residual heights of the sea level have the same trend at most of the stations (Fig. 3.32) at any one time.

(iii) Spectral analysis of sea level and atmospheric pressure at St. Margaret's Bay and Halifax Harbour

The computation of the power spectra and cross spectra of the daily mean and residues of water heights at Halifax Harbour and Boutilier's Point at St. Margaret's Bay, and daily mean sea level pressure data at Shearwater and Western Head was carried out, using the Fast Fourier Transformation (FFT), (V. A. Benignus, 1969 and others). The analysis of the power spectrum was carried out by the Tides and Water Levels, Marine Sciences Branch at Ottawa (L. F. Ku, MSB Report 1970). A co-sine taper over 1/10 of each of the series was applied to enhance the characteristics of the spectral estimates. The series were multiplied by a factor to make its variance equal to 100, so that the energy in the spectra can be interpreted in terms of the percentage of the variance. The power and cross spectrum and the coherence between the water level residues at Boutilier's Point and Halifax Harbour was calculated from three months' continuous observations taken between January 24 and April 24, 1968.

Fig. 3.33 gives the spectrum of the residues at Boutilier's Point and Halifax Harbour where cusp-like features are found in the tidal frequency bands.

The spectra of the residues at Halifax for a period of three and twelve months was computed. It can be seen that the two spectra are nearly similar (Figs. 3.33 and 3.34), which indicates that the tidal constituents have been very largely removed from the residues even over a 3-month period. The peaks of energy at the high frequency end of the spectra is due to the aliasing effect of still higher frequencies.

As expected, coherence between Boutilier's Point and Halifax Harbour is high at low frequencies (> 0.69 for semi-diurnal and lower frequencies) and falls off to an average of 0.5 with great scatter at frequencies of up to 0.21 CPH, and falls still further to an average of 0.15 at higher frequencies. The phaselag fluctuates around -10° but is scattered widely at frequencies higher than 0.23 CPH. Seventy-five percent of the variance is coherent between Halifax Harbour and Boutilier's Point. The coherence is even greater between the daily mean atmospheric pressure between Shearwater and Western Head, the coherence not falling below 0.87, the phaselag being almost constant at -10°. More than 99% of the variance energy is coherent. The difference in time scale, however, should be noted and the coherence between Halifax Harbour and Boutilier's Point is expected to be also high in the long time scale.

Spectra of daily mean sea level at Halifax Harbour and atmospheric pressure at Shearwater and the pressure gradient between Shearwater and Western Head are shown in Fig. 3.35. The ordinate in the figure represents $\log_{10}$ of the spectral energy, and the abscissa denotes the frequency in cycle/hour (CPH).

Fig. 3.35 shows that at low frequency there is a good response between the daily mean sea level and the direct atmospheric pressure. At high frequency there is a reasonable correlation between the daily mean sea level and the pressure gradient between Shearwater and Western Head.

The coherence between the daily mean sea level at Halifax Harbour on one hand and the daily mean sea level pressure at Shearwater and Western Head on the other hand, is moderate (Fig. 3.36), the coherent energy being 48% between Halifax Harbour and Shearwater and 51% between Halifax Harbour and Western Head. In both cases a local maximum occurs around a frequency in the range of 0.35 and 0.40 cycles/day. The phaselag is scattered moderately around 160° in both cases.

Coherence between the daily mean sea level at Halifax Harbour and the daily mean atmospheric pressure gradient between Shearwater and Western Head shows less coherent energy, the coherent energy being 33% of the variance. This indicates that a good part of the coherent energy is tidal energy that is not filtered out by meaning the sea level heights over 24-hour periods, that part of the tidal energy gives a good coherence with the part of the atmospheric tide that remains after the atmospheric pressure is meaned over 24 hours. This conclusion is strengthened by noticing that the coherence drops significantly when the cross spectrum between the daily mean residuals at Halifax on one hand and the daily mean atmospheric pressure at Shearwater and Western Head on the other hand is made (Fig. 3.37). Although the tidal components are not completely absent from the residuals, they are significantly reduced.

(G) Tracer Experiments at St. Margaret's Bay Using Dye Techniques

During the summer of 1967 a number of experiments were conducted using Rhodamine dye to study the flow and diffusion patterns in the Bay. In each experiment four to six litres of 40% solution of Rhodamine-B in acetic acid was discharged at the surface. After the initial dye drop release, the visual observations and position of extremities of the dye patch were usually made. This normally continued for the first three to four hours after the release of the dye, depending on weather conditions. The visual surface drift of the dye patches were measured by a Decca navigator system fixed on the survey ship. A few hours after a release, depending on weather conditions, the dye became indetectable visually and was then measured continuously using a standard Turner Model III fluorometer fixed on the research vessel. The boundaries were defined by the concentration lines of 2.5×10^{-10}.

In calm waters the dye dispersed slowly and tended to diffuse vertically. Following a dye release, aerial photographs of the patch were sometimes taken from an aircraft using a Bolex H.16 movie camera, also stills with ZIES IKON.

A number of dye experiments in the Bay were conducted on the following dates.

Dye Experiment No.	Date
1	26 June 1967
2	27 June 1967
3	28 June 1967
4	7 August 1967
5	10 August 1967
6	23 August 1967
7	5 September 1967

The table below shows the wind speed and direction during the days of the experiments.

WIND MEASUREMENTS

Dye Experiment No.	Date	Time	Wind Speed (m.p.h.)	Direction
1	26/6/67	0637	9	SW
		0720	10	SW
		0820	8	SW
		0912	11	SW
		0937	15	W
		1220	18	W
		1339	14	W
2	27/6/67	0659	Calm	-
		0745	Calm	-
		1045	12	SE
		1200	12	SE
		1307	15	SE
		1414	16	S
		1504	16	S
		1612	12	S
3	28/6/67	0638	Calm	-
		0740	6	E
		0830	7	E
		1045	14	E
		1237	17	E
		1310	18	E
		1340	15	SE
		1520	13	E
		1555	12	E
		1730	10	E
4	7/8/67	0515	6	NW
		0715	4	NW
		0815	6	NW
		0915	7	SW
		1000	Calm	-
		1200	9	S
		1400	12	SE
		1530	10	SE
5	10/8/67	0515	8	SW
		0600	7	SW
		0700	8	S
		0800	8	S
		1045	18.5	S
		1300	17.5	S
		1326	17	S
		1414	16.5	S
		1615	18.5	S
		1711	19.5	S
		1808	15	S

WIND MEASUREMENTS cont'd

Dye Experiment No.	Date	Time	Wind Speed (m.p.h.)	Direction
6	23/8/67	0537	Calm	-
		0700	4.5	W
		0900	4	NW
		1030	5	NW
		1200	4	NW
		1300	5	W
		1400	5	NW
7	5/9/67	0616	13	W
		0745	16	W
		1045	16	NW
		1200	15	W
		1315	16	W
		1400	18	W

For dye experiment No. 1 (Fig. 3.38) the wind was southwest and later changed to west. One interesting feature about this experiment was that during the first three hours the dye patch moved a distance of about one mile. Under the effect of tidal flow and the wind, the dye patch travelled about 2.5 miles in the next three hours.

During experiment No. 2 (Fig. 3.39) the wind and tidal flow were in the same direction which made the dye patch disperse towards the head of the Bay.

In dye experiment No. 3 (Fig. 3.40) the patch showed curvature in the first six hours.

In experiment No. 4 (Fig. 3.41) the tide was flooding and the wind was northwest, which gave a very elongated shape to the patch. Later on, at 0900, the tide and the wind direction were opposite to each other, thus enlarging the dispersion of the patch in all directions. This was shown clearly in the patch extremities at 1200 and 1400 hours.

For dye experiment No. 5 (Fig. 3.42) the wind on that day was first light southwest and later on increased to strong southerly, which affected the dispersion of the patch. In the figure it can be seen that the patch moved about half a mile during the first three hours under the effect of a light wind, as well as from the tidal flow. During the next six hours it moved about three miles under the effect of the strong southerly wind.

With respect to dye experiment No. 6 (Fig. 3.43) the wind was light west to northwest. The dispersion of the patch was controlled by the tidal flow in the first four hours. After that, the tide changed its cycle and the wind started afresh. It is interesting to see the effect of the tidal flow when it changes its cycle. Three surface drogues were released in the same area as the dye patch. Fig. 3.44 shows a good agreement with the movement of the dye patch and the surface drogues. This is clearly seen for drogue No. 1 at 1239 AST, drogue No. 2 at 1144 AST, and drogue No. 3 at 1135 AST.

In the dye experiment No. 7 (Fig. 3.45) the patch moved to the north under the effect of the tidal flow. When the tide changed its cycle, the patch with an elongated shape moved to the south. This may be due to the northwest wind at that time.

The aerial photographs were not clear enough to give indication of the variation in the patch dispersion. The dispersion of the dye patch in vertical direction to the depth was not studied, due to the difficulty in sampling using only one boat.

(H) Surface and Subsurface Currents as Measured by Parachute Drogues

In addition to current meter measurements a number of lagrangian type observations were made, using parachute drogues during the period May to September 1967.

The aim of the program was to determine residual motion in the surface layer and in the deep water. Accordingly, drogues were set at 10 m and 30 m. During the period May-September, 13 experiments were undertaken and a total of 55 drogues were released and tracked. The data for each drogue consisted of a set of successive positions fixed by Decca navigator from a survey ship. Duration of drogue sets varied from a minimum of about four hours to a maximum of 240 hours. In general, the shorter the set period, the more frequently position determinations were made.

The trajectory of each drogue is shown in Figs. 3.46.1 to 3.46.11. The mean speed and direction for each drogue was calculated. The components of speed in the north and east directions were calculated and denoted by u and v respectively (Table 3.6). The speed, denoted by c, is equal to $\sqrt{u^2 + v^2}$. The values of mean speed, which approximate residual current, varied from about 7 cm/sec to 0.2 cm/sec at the 10-m and 30-m depths respectively. At 30 m the mean flow was directed inward in most cases, whereas at 10 m the flow varied from time to time depending on the weather conditions. The overall results of the drogue experiments confirmed the general anticlockwise circulation pattern in the surface layer and inflow of deep water as measured by the current meters.

4. DISCUSSION AND CONCLUSION

The work done in St. Margaret's Bay represents a series of experiments of different oceanographic methods and techniques. Although some of them were done in parallel, most were done in series, due to the limitations of manpower and facilities.

Most of the results were described and discussed in the appropriate chapters. The discussion here will cover the points that were not discussed and will be dealt with under two headings: meteorology and oceanography.

a) Meteorology: A problem exists when considering weather observations appropriate for combining with oceanographic data. In large expanses of water, long, regular and dependable series of weather observations do not normally exist, while in small expanses like St. Margaret's Bay, local weather conditions, which vary around the Bay, have a relatively great effect. If one confines one's attention to gross features, local conditions can recede in importance, and average conditions for the area can be used. This is the justification for using Shearwater station for meteorological observations.

Precipitation, however, was gauged locally, as this is more subject to local variations than most of the other meteorological elements. The method of calculating the fresh water discharge contains the weak assumption that conditions of precipitation and subsequent events for the water substance are the same in all drainage areas around the Bay. This is because only two rivers were gauged. These two have a common drainage basin. The results were extended according to the assumption of uniformity. This is why the fresh water discharge fluctuates so greatly. Even then, it fluctuates less violently than the rainfall over the

Bay itself, which is to be expected. If we assume that precipitation on the Bay and the surrounding area occurs in the same amounts, it can be seen that the efficiency of the catchment area is about 70%, i.e., the catchment area delivers 70% of the precipitation into the Bay. The percentage is highest for (wet) years, and lowest for (dry) years, the difference being 4%, between 1967 and 1968. Although this is in the right direction, the accuracy of the calculation does not allow great weight to be attached to it.

b) Oceanography: Although sharp variations in temperature and salinity occur in short intervals of time in the Bay, as was evidenced by the two detailed transects of 24 and 25 June, 1969 the gross features of temperature and salinity repeat annually with great regularity (though not necessarily at the same dates). This (short period variation and long period regularity) indicates that the conditions in the Bay result from an interplay between local conditions and the oceanic waters. These effects of local conditions appear mainly in the surface layer, and are manifested in the temperature (e.g. T.S. of Station 12 between cruises of 7 April and 25 April, 1967, or 18 June-31 August, 1967). The effects of oceanic conditions appear mainly in the lower layer and are manifested in salinity changes (e.g. T.S. of Station 12 between cruises of 25 April, 15 May, 1967 or 31 August, 14 September, 1967).

The movement of the water indicates a residence time of oceanic water in the order of a month. This has been calculated according to the normal assumptions of a salty lower layer topped by a less salty outgoing surface layer. In St. Margaret's Bay other possibilities exist, e.g. the horizontal anti-clockwise circulation might be more important in the exchange than the classical two layered circulation. The calculation can be carried out in the same manner as in the two layered circulation, with the oceanic water extending along the eastern side, entraining the fresh water and exiting along the west side. There is some evidence of this in the salinities on the two sides, and it can be further established, or rejected by precise levelling of sea level on both sides of the Bay. This has a vital importance for biology, as, depending on the character of the exchange, the residence time of oceanic water in the deeper layer will vary. If the exchange is a two layered exchange, the deep layer becomes continuously renewed with an average period of a month. If the exchange occurs in the surface anticlockwise circulation, the deep layer would be renewed only occasionally, the complete renewal taking a short time, but occurring only occasionally and the possibility of upwelling is significantly decreased.

A third possibility is the renewal during the tidal cycle, the incoming tide being more saline than the ebbing tide. The tidal excursion varies between 500 and 1,000 metres. Other processes of mixing and diffusion would have to be invoked to allow exchange with water at the head of the Bay. No set of observations were taken to test this possibility.

In conclusion the water in St. Margaret's Bay is mostly of oceanic origin. During summer, a strong thermocline develops and the fresh water discharge into the Bay is confined to the top layer. During winter time, the thermocline breaks and the stratification is maintained by salinity differences. Temperature increases slightly from top to bottom.

Tides are the principal movers of water in the Bay. Although the magnitude of tidal currents decrease away from the entrance of the Bay towards the head, they dominate in 90% of the area. The exchange of water of the Bay is affected by tides, fresh water discharge, and wind. The residence time in the surface layer in a two layered system is in the order of a week, but the residence time in the deep layer depends on the hypothesis postulated for the circulation. It is possible by careful experiments to establish how much of the circulation is two layered and how much occurs within the surface layer.

The stations taken regularly indicated that the same amount of information could have been obtained from a few number of stations. When changes occurred, however, they occurred rather rapidly, and a shorter time interval between observations is, therefore, indicated.

Sea level variation at Halifax and at Boutilier's Point is primarily tidal. Although analysis of hourly values over three months give a reasonable estimate of the tidal constants, a longer period is necessary if the constants are to be used to remove the tidal component from sea level variations. The residuals obtained for Halifax Harbour averaged over a day do not give good coherence with the daily mean of atmospheric pressure at Shearwater or at Western Head. This is not surprising as the long period non-tidal fluctuations of the sea level at Halifax cannot be attributed to local fluctuations of pressure, but are most probably connected with large scale systems. When the daily mean sea level was used instead of the daily mean residual, coherence was higher due to the incomplete filtering of the tidal component from the sea level, and the presence of atmospheric tidal components in the pressure. The coherence was again low between the daily mean sea levels, and the daily mean residuals on one hand and the daily mean pressure gradient between Shearwater and Western Head on the other, probably because the time scale is sufficiently long to allow other adjustments than sea level variation.

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TABLE 3.3. CURRENT COMPONENTS IN ST. MARGARET'S BAY.

Station No.	Starting date	Length of current meter records (days)	Depth of current meter records (metres)	Amplitude of M_2 (cm/sec)			Velocity of anticlockwise circulation cm/sec (A)			Velocity of thermohaline circulation cm/sec (T)		
				From 29 days data	From first 15 days data	From second 15 days data	From 29 days data	From first 15 days data	From second 15 days data	From 29 days data	From first 15 days data	From second 15 days data
2	28/6/66	28	6	-	20.4	18.2	-	2.5	3.7	-	0.5	1.5
5	9/7/66	17	6	-	16.1	13.9						
17	14/5/67	30	47	4.4	-	-	0.5	-	-	0.1	-	-
16	10/5/67	30	60	5.8	-	-						
19	19/6/68	26	6	-	5.8	5.2	-	2.9	2.2	-	0.1	0.4
24	19/6/68	26	6	-	9.5	7.9						

TABLE 3.4.1

NORTHERLY COMPONENT OF TIDAL CONSTITUENTS AT THE SURFACE, ST. MARGARET'S BAY, MAY 1967

A = amplitude (knots)
θ = phaselag

Tidal Constituent	Station #19 A	Station #19 θ	Station #24 A	Station #24 θ	Station #16 A	Station #16 θ	Station #17 A	Station #17 θ
Z_0	.115	180	.002	180	.014	0	.040	180
O_1	.037	359	.012	188	.029	295	.006	101
K_1	.021	242	.027	16	.018	357	.008	63
M_2	.111	170	.143	171	.051	176	.077	189
S_2	.045	192	.059	217	.021	187	.031	270
M_4	.003	222	.005	307	.014	23	.020	343
MS_4	.009	196	.004	181	.013	64	.014	82
MF	-	-	-	-	-	-	-	-
N_2	.023	147	.029	148	.010	153	.016	166
P_1	.007	242	.009	16	.006	357	.003	63
K_2	.012	192	.016	217	.006	187	.008	270

Tidal Constituent	Station #18 A	Station #18 θ	Station #11 A	Station #11 θ	Station #14 A	Station #14 θ	Station #2 A	Station #2 θ
Z_0	.032	0	.027	180	.010	180	.032	0
O_1	.011	326	.004	8	.005	246	.012	59
K_1	.023	333	.011	205	.005	164	.017	24
M_2	.103	169	.041	57	.015	140	.022	111
S_2	.030	199	.014	149	.007	351	.011	177
M_4	.014	296	.009	311	.002	7	.003	74
MS_4	.016	234	.012	310	.003	99	.002	316
MF	-	-	.008	76	.004	64	.033	202
N_2	.021	146	.008	104	.004	43	.012	357
P_1	.007	333	.004	205	.002	164	.005	24
K_2	.008	199	.004	149	.002	351	.003	176

TABLE 3.4.2

EASTERLY COMPONENT OF TIDAL CONSTITUENTS AT THE SURFACE, ST. MARGARET'S BAY, MAY 1967

A = amplitude (knots)
θ = phaselag

Tidal Constituent	Station #19 A	Station #19 θ	Station #24 A	Station #24 θ	Station #16 A	Station #16 θ	Station #17 A	Station #17 θ
Z_0	.022	0	.002	0	.057	180	.075	180
O_1	.017	183	.008	358	.031	28	.016	272
K_1	.005	72	.004	29	.012	83	.019	141
M_2	.003	80	.024	261	.002	266	.002	99
S_2	.006	127	.020	311	.029	80	.026	328
M_4	.008	344	.010	321	.020	168	.002	301
MS_4	.003	210	.005	32	.025	98	.007	99
MF	-	-	-	-	-	-	-	-
N_2	.001	58	.005	238	.000	243	.000	76
P_1	.002	72	.001	29	.004	83	.006	141
K_2	.002	127	.006	311	.008	80	.007	328
	Station #18 A	Station #18 θ	Station #11 A	Station #11 θ	Station #14 A	Station #14 θ	Station #2 A	Station #2 θ
Z_0	.138	180	.011	180	.018	0	.002	180
O_1	.035	233	.006	131	.008	31	.001	358
K_1	.027	114	.007	219	.004	44	.003	66
M_2	.010	259	.025	327	.006	230	.005	201
S_2	.023	320	.014	282	.002	116	.003	150
M_4	.028	352	.002	7	.000	267	.004	75
MS_4	.022	152	.005	194	.003	187	.004	185
MF	-	-	.008	232	.010	165	.003	252
N_2	.002	236	.018	304	.001	261	.003	22
P_1	.009	114	.002	219	.001	44	.001	66
K_2	.006	320	.004	282	.001	116	.001	150

TABLE 3.4.3

NORTHERLY COMPONENT OF TIDAL CONSTITUENTS AT THE BOTTOM,
ST. MARGARET'S BAY, MAY 1967

A = amplitude (knots)
θ = phaselag

Tidal Constituent	Station #26 A	Station #26 θ	Station #20 A	Station #20 θ	Station #22 A	Station #22 θ	Station #16 A	Station #16 θ
Z_0	.044	0	.139	0	.057	0	.001	0
O_1	.011	251	.021	273	.002	110	.014	264
K_1	.027	286	.033	41	.014	54	.014	284
M_2	.113	132	.070	104	.048	154	.112	154
S_2	.015	107	.020	2	.009	218	.031	203
M_4	.025	271	.024	276	.012	15	.004	133
MS_4	.002	111	.018	118	.005	27	.004	122
MF	-	-	-	-	-	-	.002	310
N_2	.023	109	.014	81	.010	131	.005	290
P_1	.009	286	.011	41	.005	54	.005	284
K_2	.004	107	.005	2	.002	218	.008	203
	Station #17 A	Station #17 θ	Station #18 A	Station #18 θ	Station #6 A	Station #6 θ		
Z_0	.008	180	.028	0	.079	0		
O_1	.004	202	.013	186	.027	298		
K_1	.007	252	.012	1	.021	253		
M_2	.010	109	.083	108	.045	140		
S_2	.028	162	.028	163	.017	242		
M_4	.004	282	.012	287	.015	290		
MS_4	.006	86	.007	91	.017	109		
MF	.005	310	-	-	-	-		
N_2	.021	340	.017	85	.009	117		
P_1	.002	252	.004	1	.007	253		
K_2	.008	162	.008	163	.005	242		

TABLE 3.4.4

EASTERLY COMPONENT OF TIDAL CONSTITUENTS AT THE BOTTOM, ST. MARGARET'S BAY, MAY 1967

A = amplitude (knots)
θ = phaselag

Tidal Constituent	Station #26 A	Station #26 θ	Station #20 A	Station #20 θ	Station #22 A	Station #22 θ	Station #16 A	Station #16 θ
Z_0	.014	0	.009	0	.013	0	.025	0
O_1	.003	133	.001	37	.005	283	.006	193
K_1	.007	268	.009	305	.005	263	.005	62
M_2	.009	42	.020	14	.003	64	.010	244
S_2	.017	351	.018	8	.004	63	.010	307
M_4	.006	221	.006	225	.000	222	.003	32
MS_4	.002	278	.005	322	.002	337	.004	21
MF	-	-	-	-	-	-	-	-
N_2	.002	19	.004	351	.000	41	.004	303
P_1	.002	268	.003	305	.001	263	.006	177
K_2	.005	351	.005	8	.001	63	.002	62

Tidal Constituent	Station #17 A	Station #17 θ	Station #18 A	Station #18 θ	Station #6 A	Station #6 θ
Z_0	.005	0	.009	180	.001	0
O_1	.004	192	.008	254	.006	134
K_1	.003	137	.006	188	.006	15
M_2	.011	19	.003	198	.001	50
S_2	.013	28	.006	316	.016	220
M_4	.002	216	.005	150	.007	162
MS_4	.004	139	.004	218	.016	336
MF	.004	120	-	-	-	-
N_2	.007	277	.001	175	.000	27
P_1	.001	137	.002	188	.002	15
K_2	.004	28	.002	316	.004	221

TABLE 3.5. THE HARMONIC CONSTITUENTS FOR ST. MARGARET'S BAY AND HALIFAX HARBOUR

Name of Station	Station Number		Z_0	O_1	K_1	M_2	S_2	M_4	MS_4	MF	N_2	P_1	K_2	Duration of Analysis	Year
Mill Cove	475	A	3.85	0.19	0.39	2.12	0.46	0.10	0.07	0.02	0.53	0.12	0.12	3 months	1966
		θ	0	46	67	237	269	43	183	205	223	67	269		
Boutilier's Pt.	482	A	3.42	0.16	0.41	2.08	0.44	0.09	0.12	0.08	0.56	0.13	0.12	3 months	1966
		θ	0	42	65	234	263	344	233	171	212	65	263		
Indian Harbour	484	A	1.48	0.17	0.37	2.04	0.42	0.10	0.05	0.06	0.48	0.12	0.11	2 months	1966
		θ	0	41	65	237	269	39	189	230	225	65	269		
Owl's Head	473	A	4.49	0.18	0.37	2.07	0.44	0.10	0.06	0.02	0.48	0.12	0.12	6 months	1968
		θ	0	51	71	237	265	50	171	235	221	70	262		
Mill Cove	475	A	4.63	0.17	0.37	2.13	0.47	0.10	0.05	0.03	0.43	0.11	0.13	5 months	1968
		θ	0	44	68	233	261	39	184	263	210	67	258		
Hubbards	480	A	4.56	0.18	0.38	2.14	0.43	0.11	0.06	0.02	0.45	0.12	0.12	5 months	1968
		θ	0	43	70	235	261	39	175	227	218	68	258		
Boutilier's Pt.	482	A	4.29	0.18	0.36	2.07	0.43	0.12	0.06	0.04	0.41	0.11	0.12	3 months	1968
		θ	0	42	69	235	263	53	178	211	221	68	260		
Halifax Harbour	490	A	4.07	0.16	0.34	2.07	0.47	0.13	0.06	0.03	0.47	0.09	0.13	12 months	1967
		θ	0	37	61	233	261	38	158	297	215	68	256		
Halifax Harbour	490	A	4.15	0.15	0.34	2.09	0.46	0.12	0.06	0.06	0.45	0.11	0.13	12 months	1968
		θ	0	37	62	234	263	39	166	216	212	60	257		

A = amplitude in feet
θ = phase in degrees

TABLE 3.6. TIME, POSITIONS, VELOCITIES, AND DIRECTIONS COMPUTED FROM DROGUE OBSERVATIONS

Date	Drogue No.	Depth (m)	Time of Release	Time of Recovery	Duration (hrs-min)	No. of Observations	Mean Speed (cm/sec) u^1	v^2	σ	Direction
11/5/67	2	10	0920	16/5 1230	123-10	5	-0.2	+0.8	0.8	104°
30/5/67	0	10	0910	7/6 1002	192-52	8	-1.0	+0.4	1.1	161
30/5/67	9	30	0927	1/6 1207	50-40	5	+1.9	-1.4	2.4	325
2/6/67	6	10	1830	7/6 1125	112-55	5	+1.9	-0.1	1.9	357
5/7/67	1	10	0831	5/7 1622	7-51	4	+0.1	-1.8	1.8	272
5/7/67	2	10	0657	5/7 1425	7-28	4	+2.4	+0.1	2.4	003
5/7/67	3	10	0731	5/7 1550	8-19	4	+1.2	-0.7	1.4	328
5/7/67	4	30	0745	5/7 1525	7-40	4	-2.1	-0.5	2.2	194
5/7/67	5	30	0819	5/7 1635	8-16	4	+4.6	-1.0	4.7	348
5/7/67	6	30	0755	5/7 1515	7-20	4	-4.4	+0.3	4.4	176
5/7/67	7	30	0842	5/7 1610	7-28	4	-4.2	+0.9	4.3	168
5/7/67	8	10	0705	5/7 1438	7-33	4	-6.7	+2.3	7.1	161
5/7/67	9	10	0713	5/7 1453	7-40	4	-4.4	+2.6	5.1	149
11/7/67	1	10	1155	11/7 1646	4-51	4	-5.8	-0.9	5.8	189
11/7/67	2	10	1209	11/7 1700	4-51	4	-0.7	+2.0	2.1	109
11/7/67	3	30	1242	11/7 1709	4-27	4	+2.2	-0.3	2.2	353
11/7/67	4	30	1250	11/7 1555	3-05	3	+4.0	+2.1	4.5	028
26/7/67	1	10	1715	29/7 1303	67-48	3	+3.6	-1.3	3.8	339
26/7/67	3	10	1725	29/7 1251	67-26	3	+2.7	-0.9	2.9	341
26/7/67	6	10	1730	28/7 1547	46-17	2	+1.3	+0.3	1.3	011
26/7/67	8	10	1737	29/7 1242	67-05	3	+2.8	-0.3	2.8	353
26/7/67	9	10	1740	29/7 1228	66-48	4	+1.5	+0.5	1.6	018
31/7/67	1	10	1533	4/8 1540	96-07	9	-1.4	+0.8	1.6	151
31/7/67	3	10	1538	4/8 1507	95-29	9	+0.0	+0.6	0.6	090
31/7/67	9	10	1543	4/8 1530	95-47	9	-1.2	+0.6	1.3	154
8/8/67	1	10	0920	11/8 1510	77-50	6	+2.3	-1.1	2.6	334
8/8/67	3	10	0925	11/8 1457	77-32	6	+2.2	-0.8	2.4	339
8/8/67	9	10	0930	11/8 1433	77-03	6	+2.9	-1.5	3.2	333
15/8/67	1	30	0835	18/8 0844	72-09	5	+2.5	-0.0	2.5	359
15/8/67	6	30	0845	18/8 0923	72-38	5	+2.4	-1.0	2.6	338
15/8/67	3	30	0852	18/8 1209	75-17	6	+2.1	-0.5	2.2	346
15/8/67	4	10	0900	18/8 1247	75-47	6	+0.2	+0.1	0.2	023
15/8/67	5	10	0907	18/8 1235	75-28	6	+0.4	+0.8	0.9	066
22/8/67	1	10	0900	25/8 1040	73-40	4	-0.8	+1.1	1.4	126
22/8/67	6	10	0909	25/8 1125	74-16	6	+1.5	-0.5	1.6	340
22/8/67	5	10	0919	25/8 1145	74-26	6	+1.1	-0.6	1.3	330
22/8/67	3	10	0934	25/8 1120	73-46	6	-0.1	+0.4	0.4	108
22/8/67	2	10	0949	23/8 0905	23-16	3	-3.5	-0.4	3.5	186
29/8/67	6	10	0816	1/9 1034	74-18	3	+0.4	+0.7	0.8	061
29/8/67	2	10	0820	1/9 1013	73-53	4	-0.9	+0.6	1.1	146
29/8/67	1	30	0829	1/9 1046	74-17	3	+2.1	+0.6	2.2	015
29/8/67	3	30	0834	1/9 1100	74-26	3	+2.1	+0.4	2.2	010
12/9/67	1	30	0857	15/9 1050	73-53	4	+2.7	-1.1	2.9	337
12/9/67	3	30	0907	15/9 1025	73-18	4	+1.1	-0.1	1.1	354
12/9/67	5	30	0915	15/9 0950	72-35	4	-1.4	-1.5	2.0	226
19/9/67	1	30	0902	20/9 0826	23-24	2	-1.4	-0.8	1.7	210
19/9/67	3	30	0920	21/9 0950	48-30	3	-0.6	-0.2	0.7	196
19/9/67	1	30	1007	21/9 0955	47-47	3	-1.2	-1.3	1.8	229
19/9/67	4	30	1015	21/9 1010	47-54	3	-2.8	-1.7	3.3	211

1 Positive in North direction
2 Positive in East direction

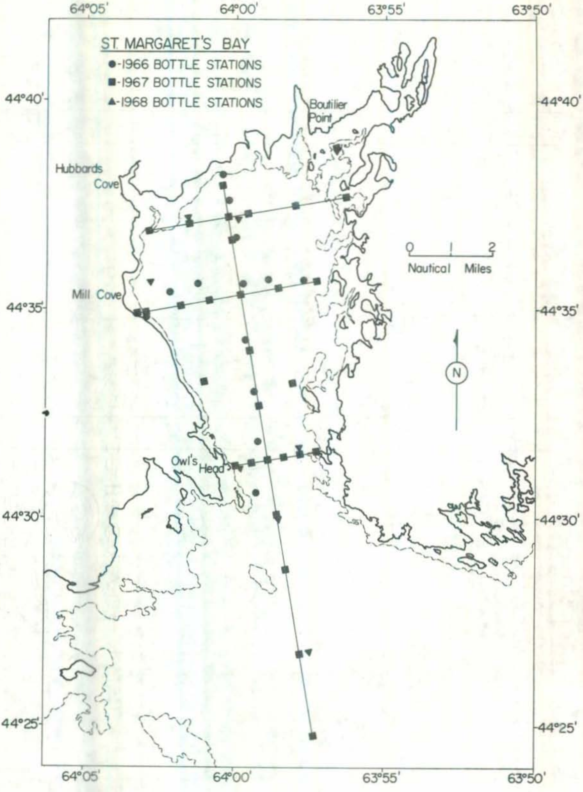


Fig. 1.1. Chart of St. Margaret's Bay showing the location of the sampling stations taken during 1966-1968.

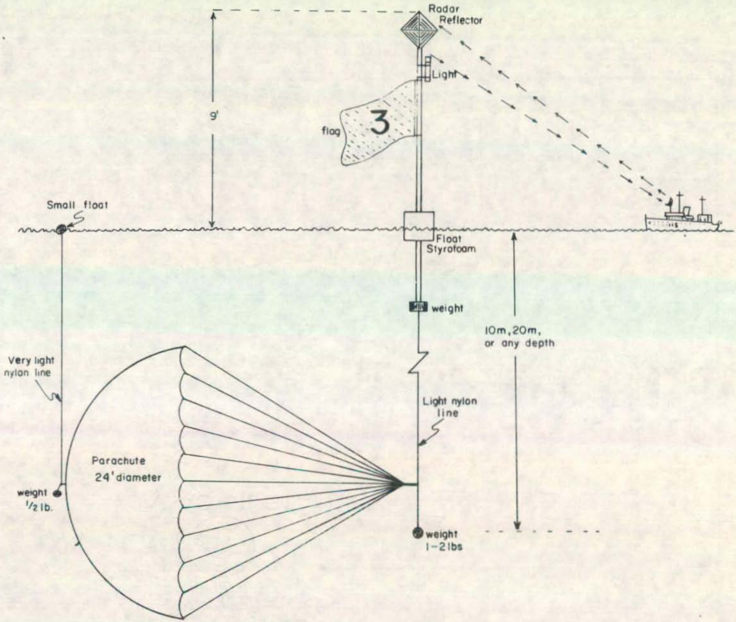


Fig. 2.1. Sketch of drogue assembly.

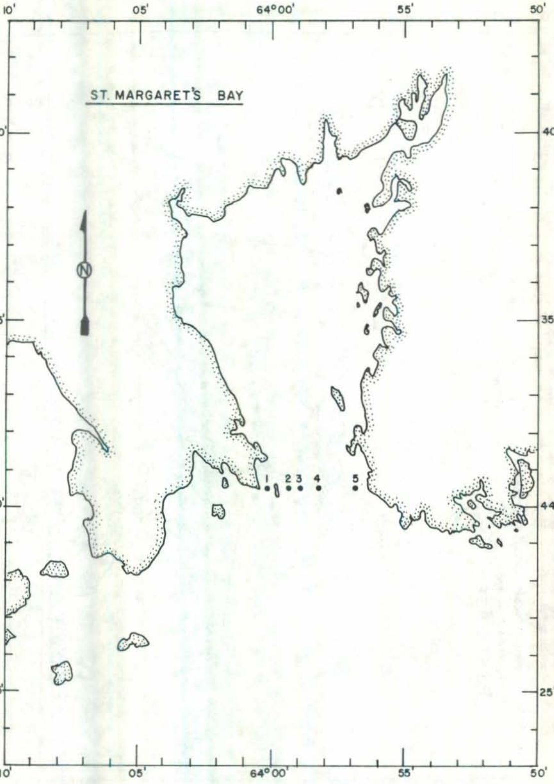


Fig. 2.2. Location of current stations taken at the mouth of the Bay during 1966.

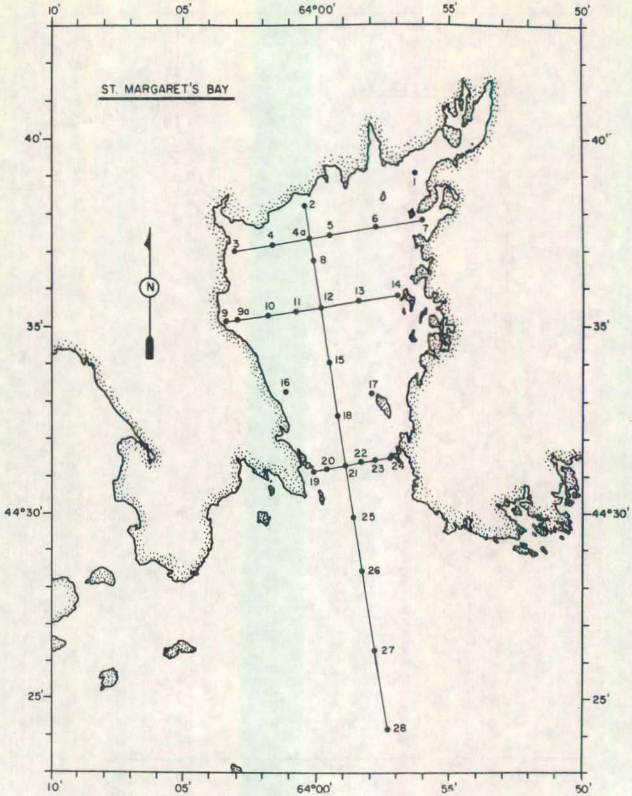


Fig. 2.3. Sampling stations taken in St. Margaret's Bay during the period April 1967 to June 1968.

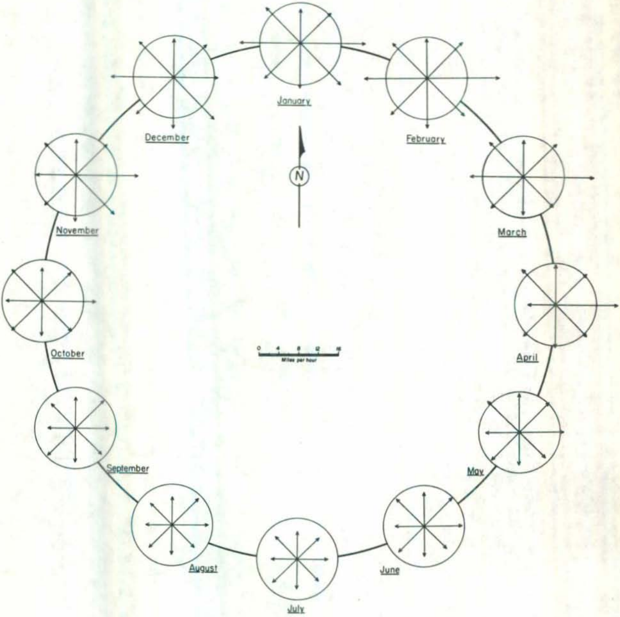


Fig. 3.1. Wind roses for Halifax, N.S. for 10 years (1944-1954).

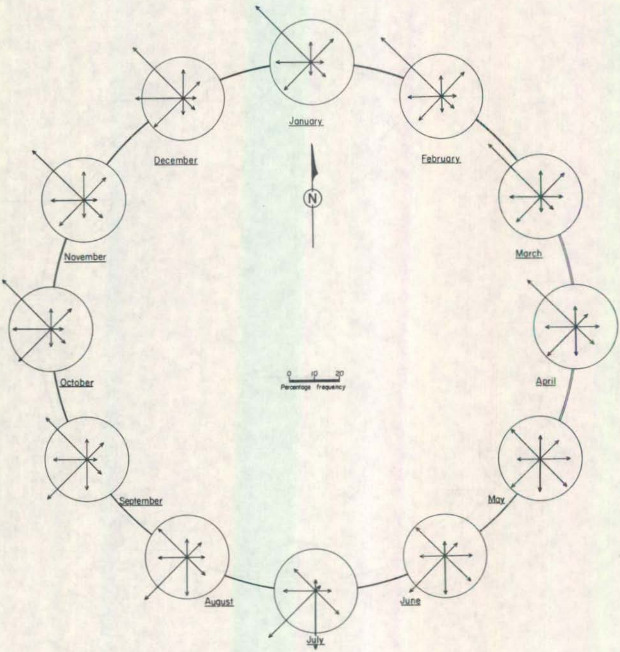


Fig. 3.2. Percentage frequency of wind velocity at Halifax, N.S. for 10-year period (1944-1954).

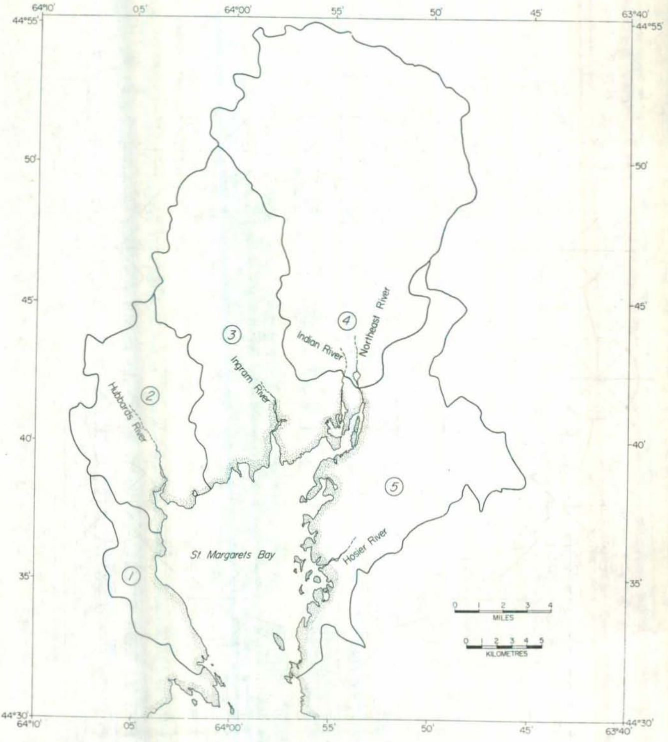


Fig. 3.3. Chart showing the drainage areas surrounding the Bay.

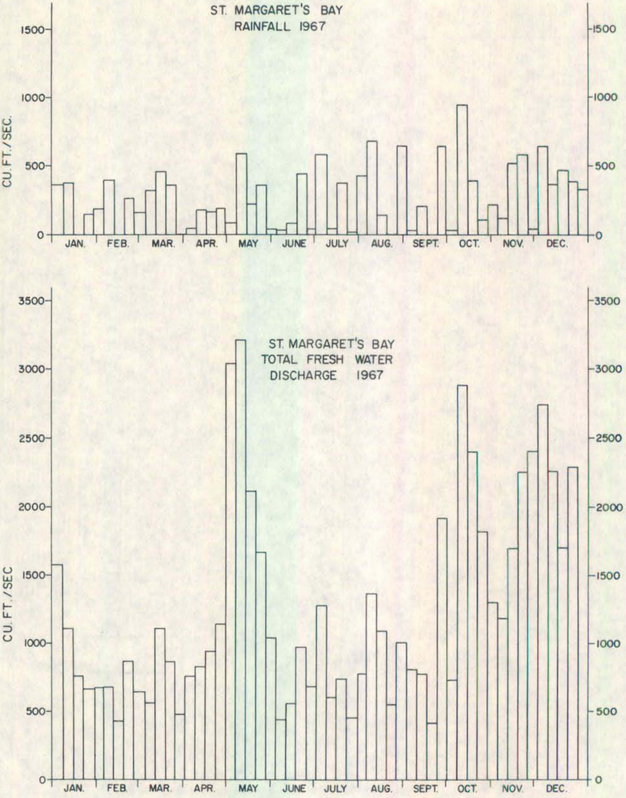


Fig. 3.4. Rainfall and total fresh water discharge (precipitation + discharge from drainage areas) during 1967.

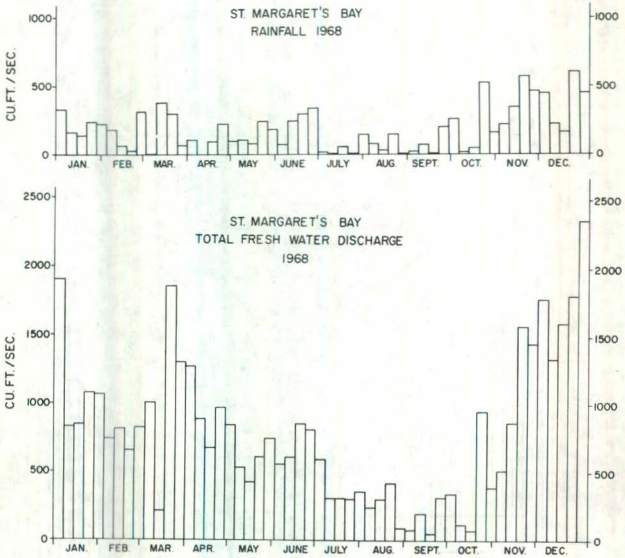


Fig. 3.5. Rainfall and total fresh water discharge (precipitation + discharge from drainage areas) during 1968.

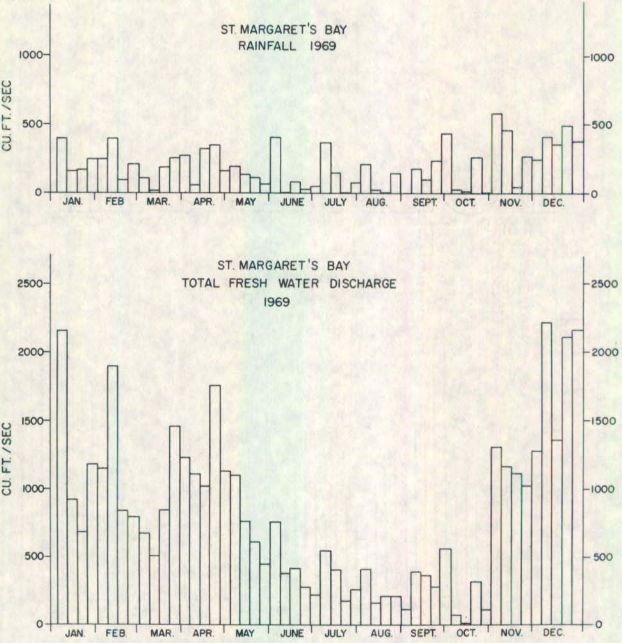


Fig. 3.6. Rainfall and total fresh water discharge (precipitation + discharge from drainage areas) during 1969.

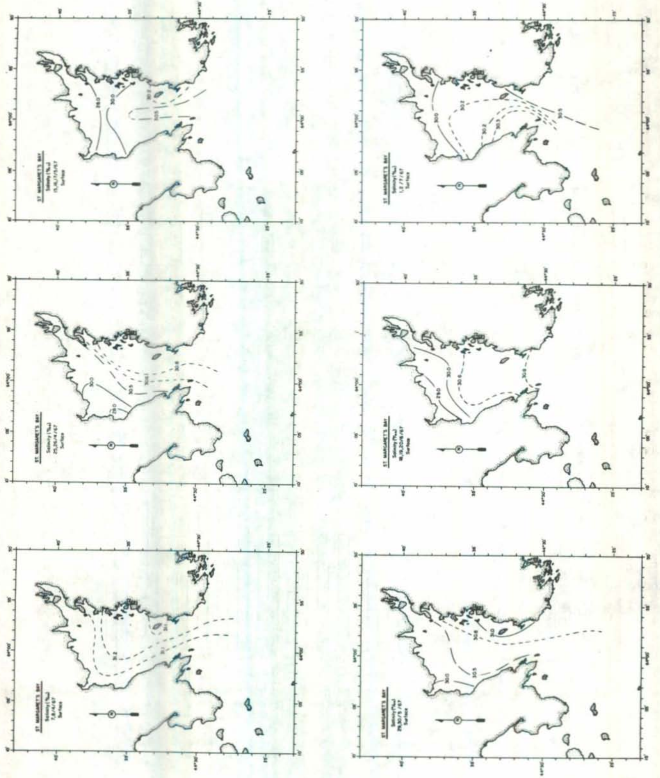


Fig. 3.7.1. Surface salinity for cruises taken in the Bay between April 1967 and July 1967.

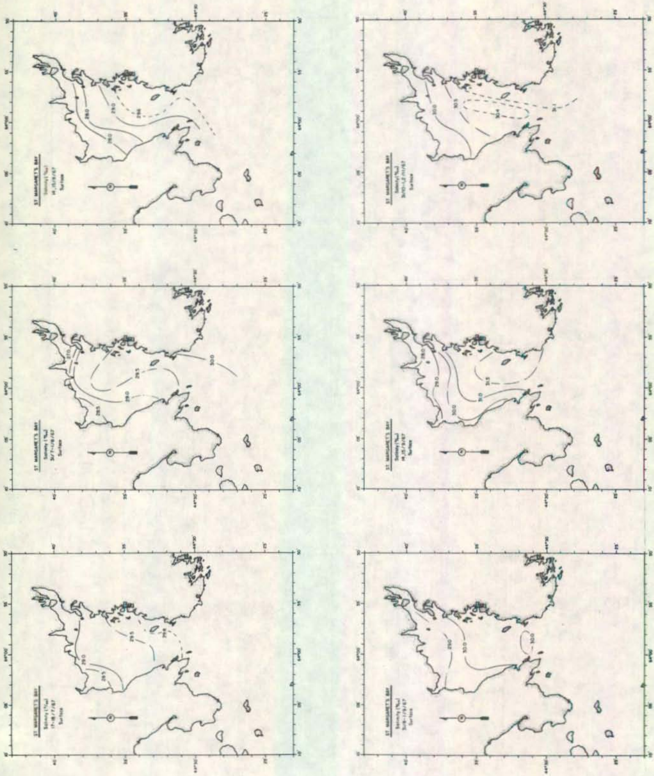


Fig. 3.7.2. Surface salinity for cruises taken in the Bay between July 1967 and November 1967.

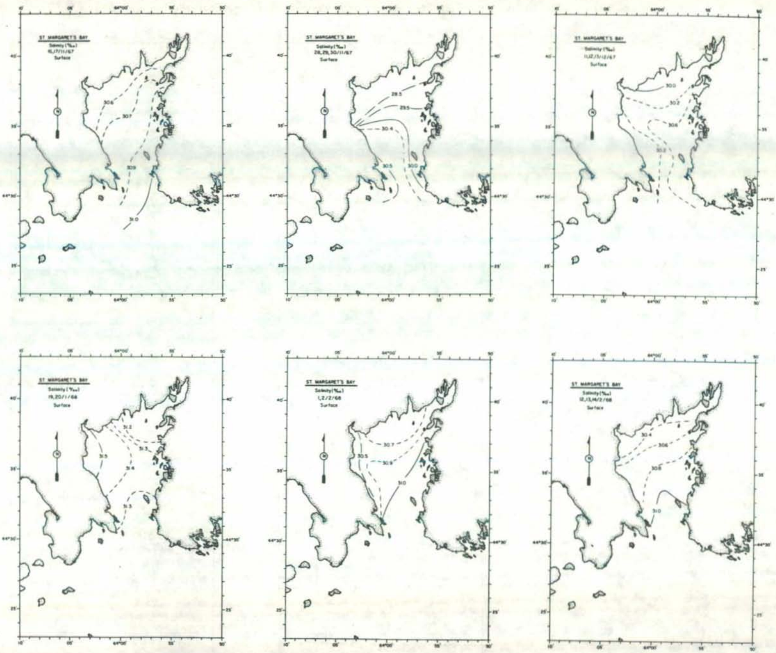


Fig. 3.7.3. Surface salinity for cruises taken in the Bay between November 1967 and February 1968.

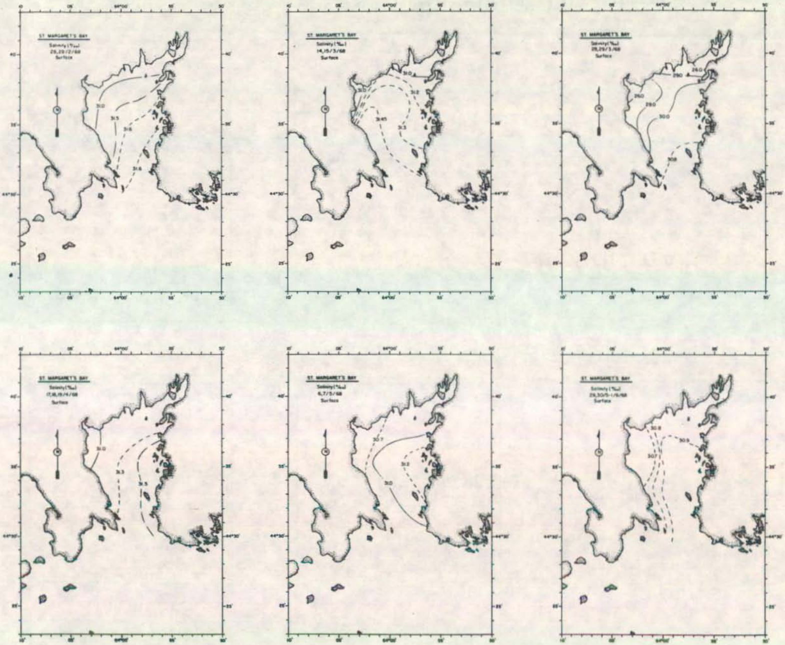


Fig. 3.7.4. Surface salinity for cruises taken in the Bay between February 1968 and June 1968.

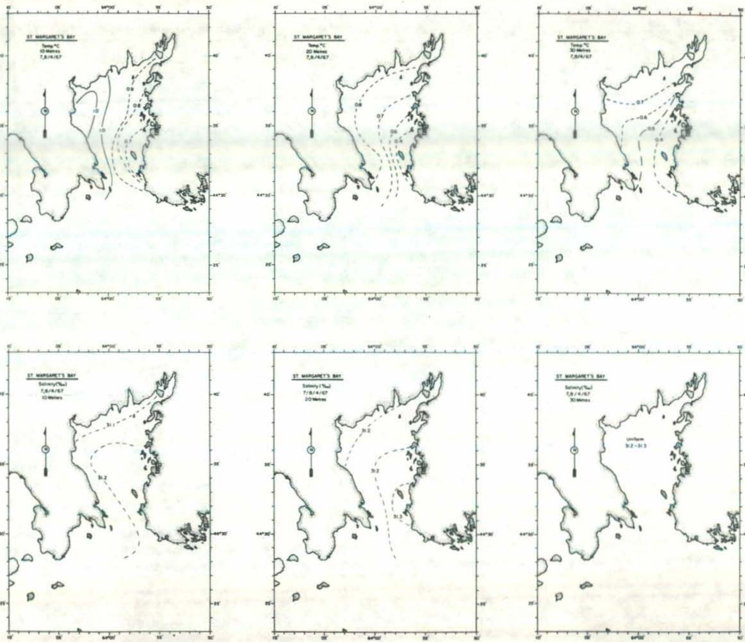


Fig. 3.8.1. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 7-8 April 1967.

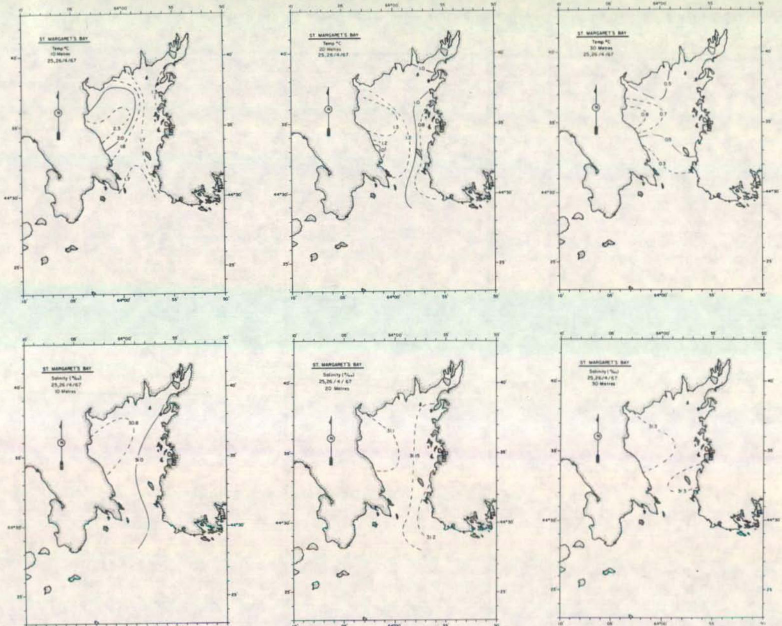


Fig. 3.8.2. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 25-26 April 1967.

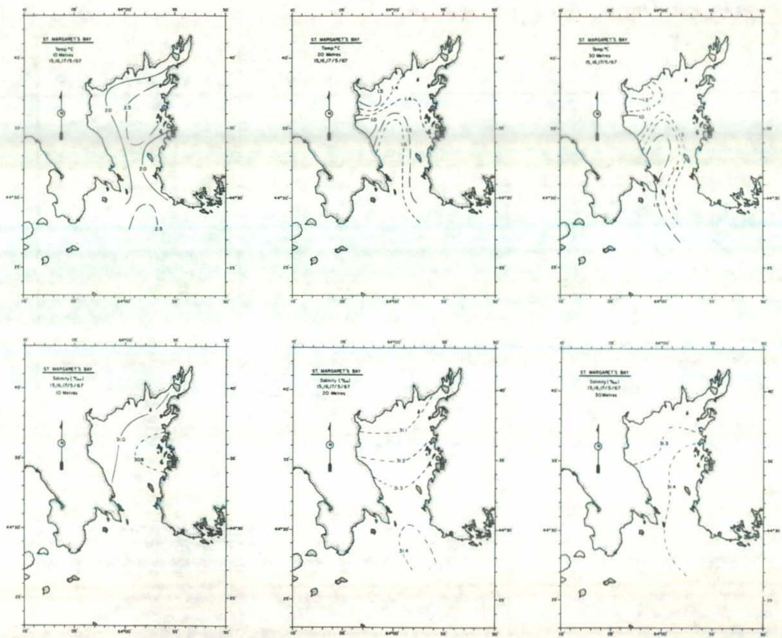


Fig. 3.8.3. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 15-17 May 1967.

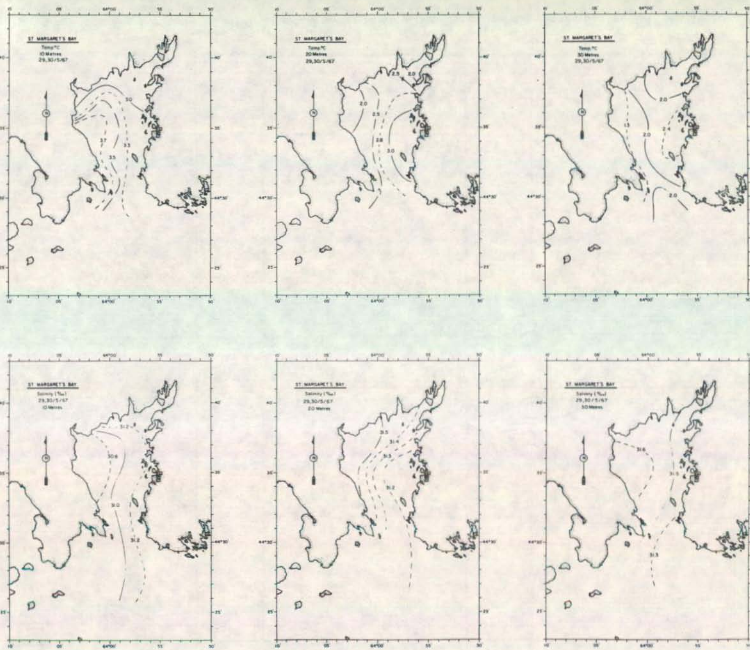


Fig. 3.8.4. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 29-30 May 1967.

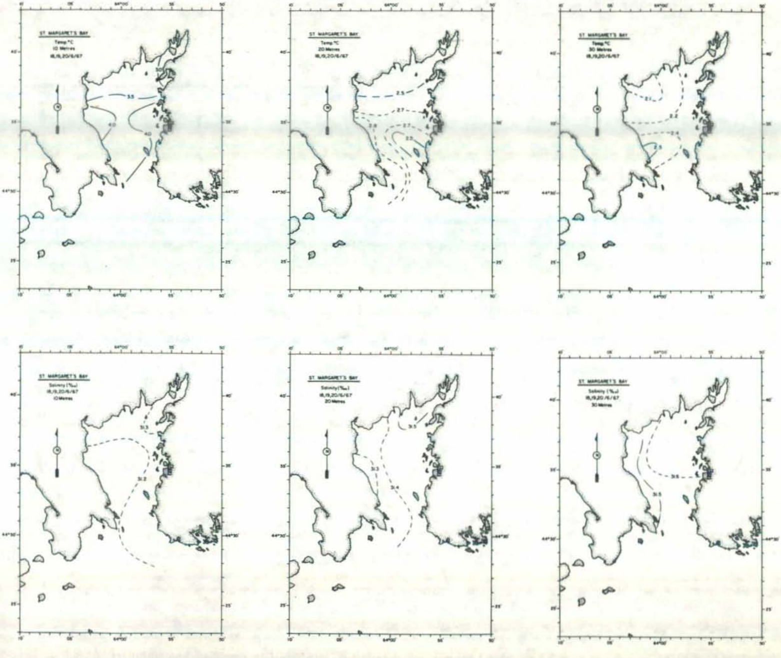


Fig. 3.8.5. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay 18-20 June 1967.

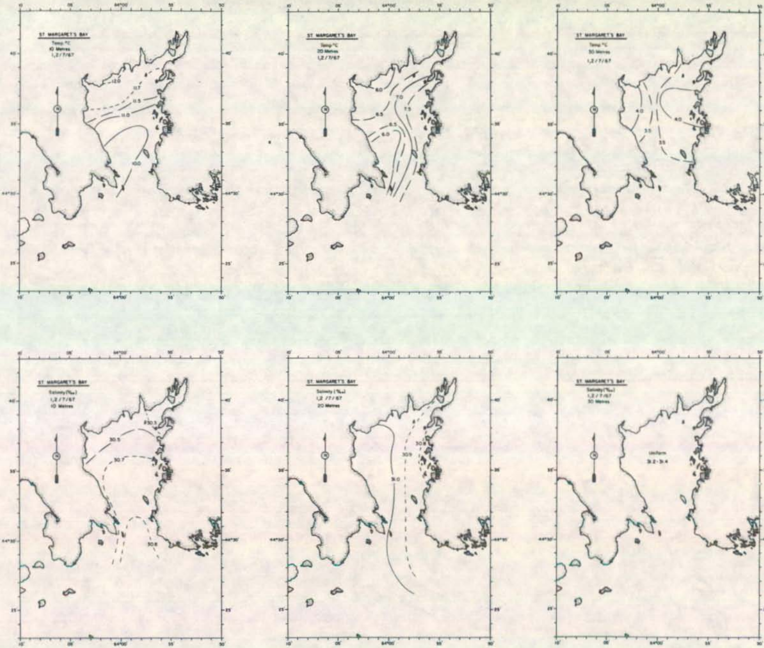


Fig. 3.8.6. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay 1-2 July 1967.

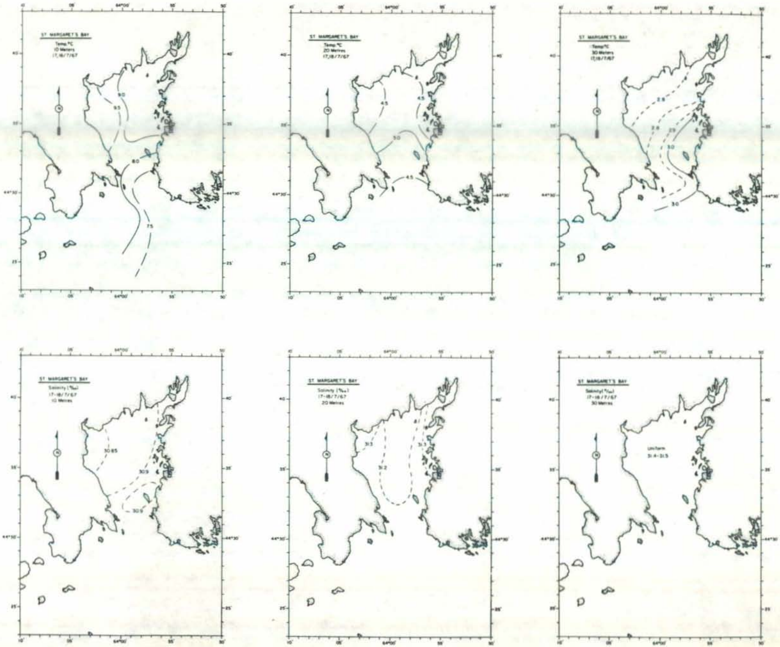


Fig. 3.8.7. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay 17-18 July 1967.

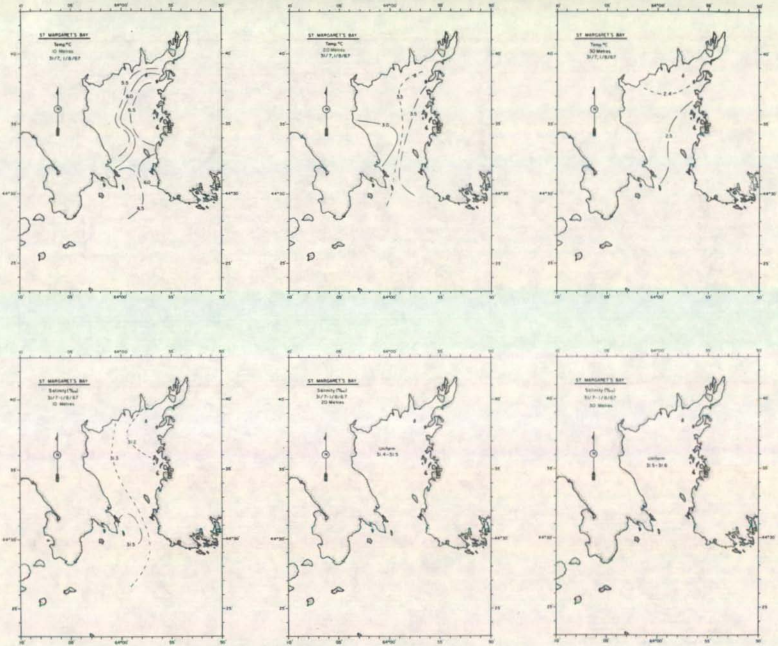


Fig. 3.8.8. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 31 July-1 August 1967.

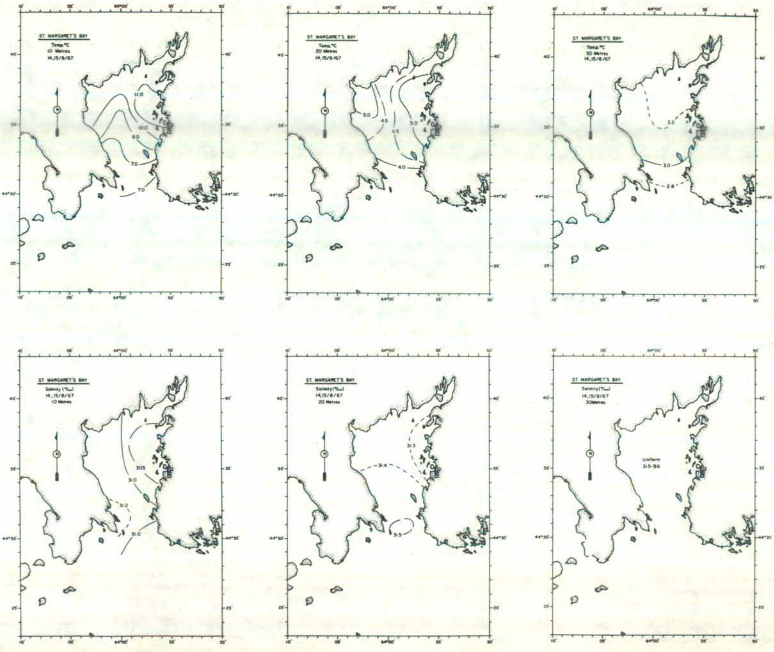


Fig. 3.8.9. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 14-15 August 1967.

Fig. 3.8.10. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay 31 August-1 September 1967.

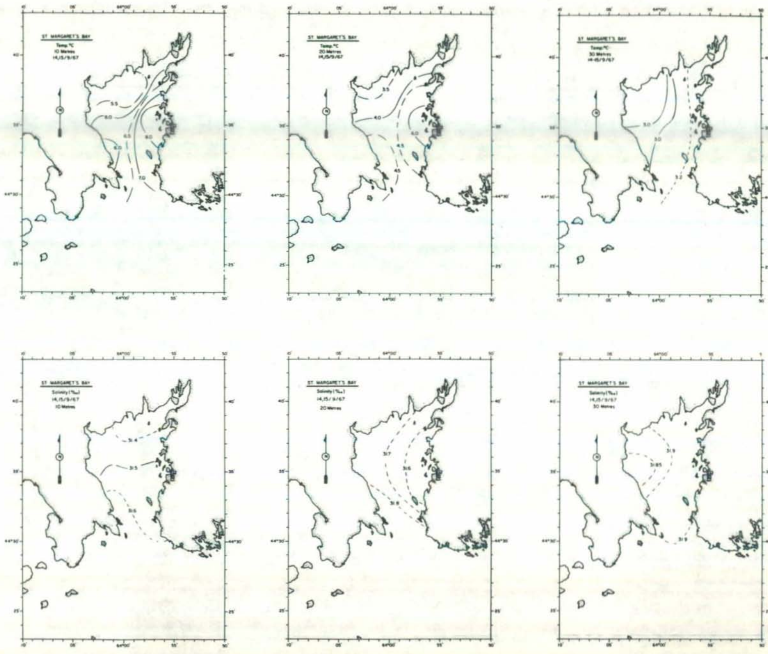


Fig. 3.8.11. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay 14-15 September 1967.

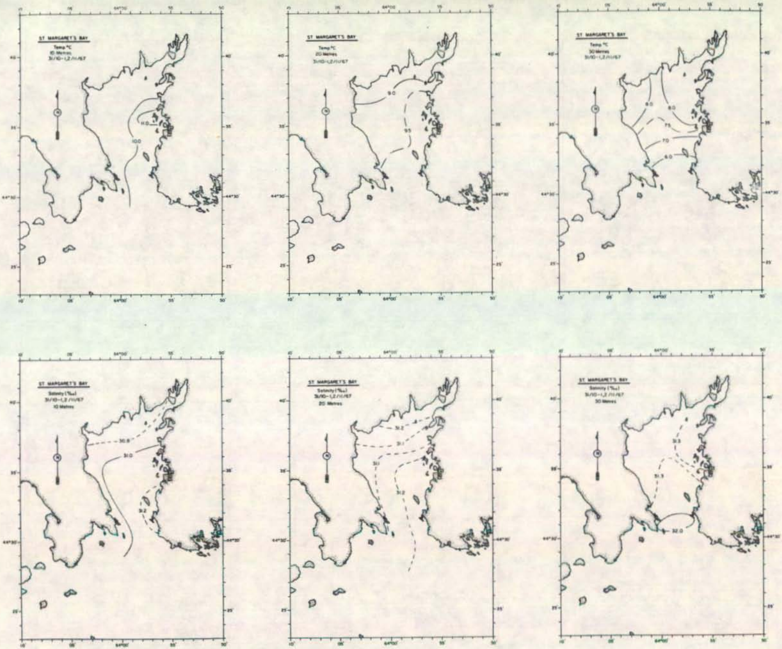


Fig. 3.8.12. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay 31 October-2 November 1967.

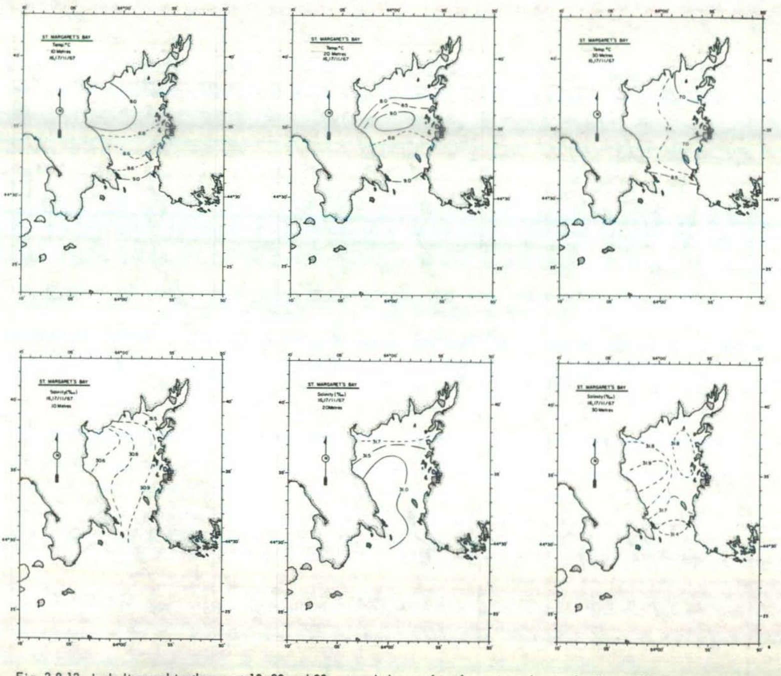


Fig. 3.8.13. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 16-17 November 1967.

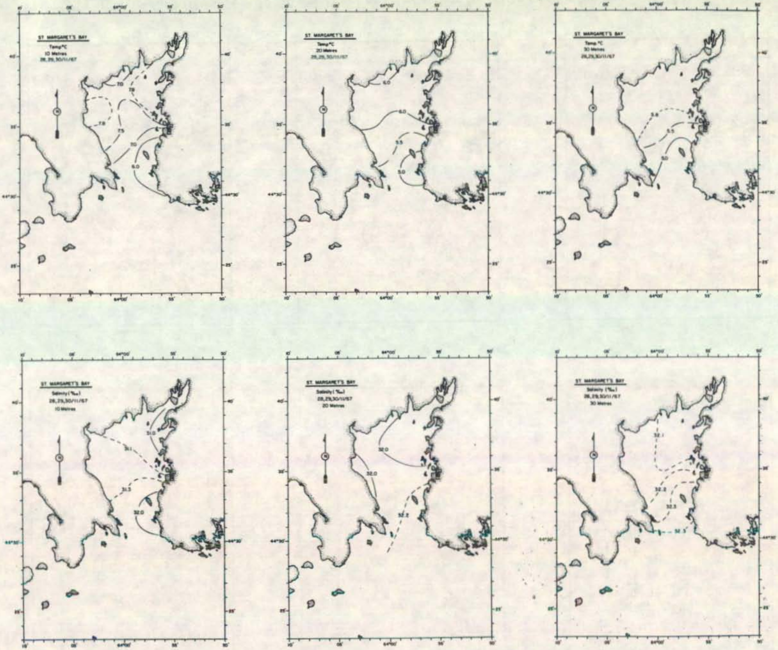


Fig. 3.8.14. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 28-30 November 1967.

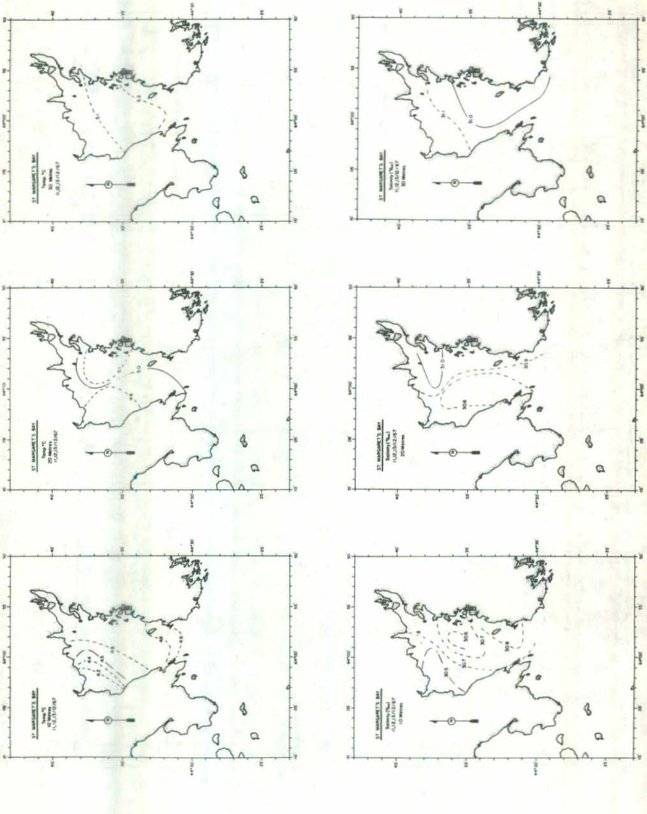


Fig. 3.8.15. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 11-13 December 1967

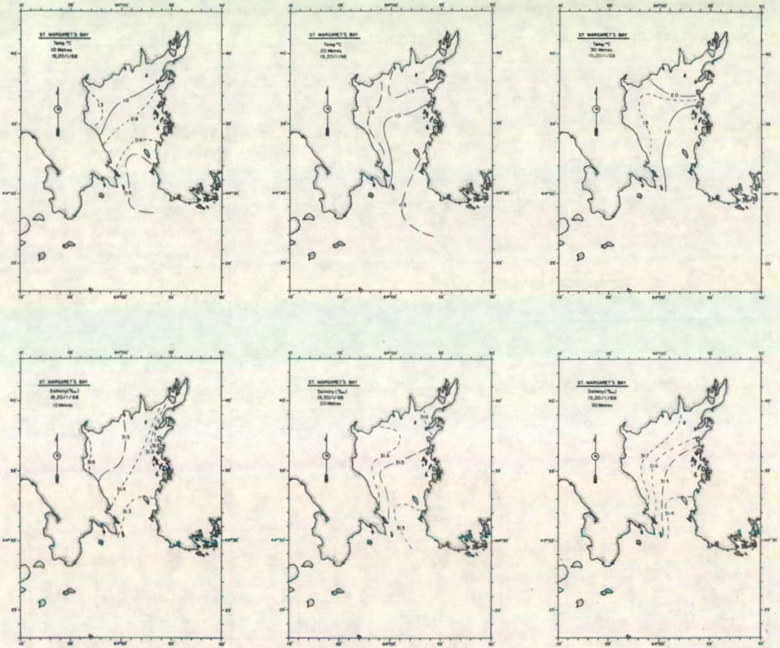


Fig. 3.8.16. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 19-20 January 1968.

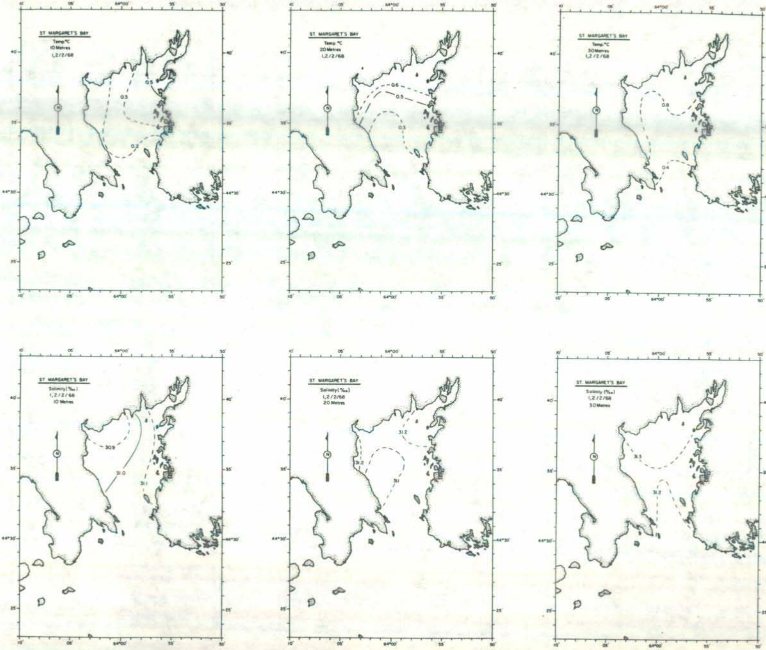


Fig. 3.8.17. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 1-2 February 1968.

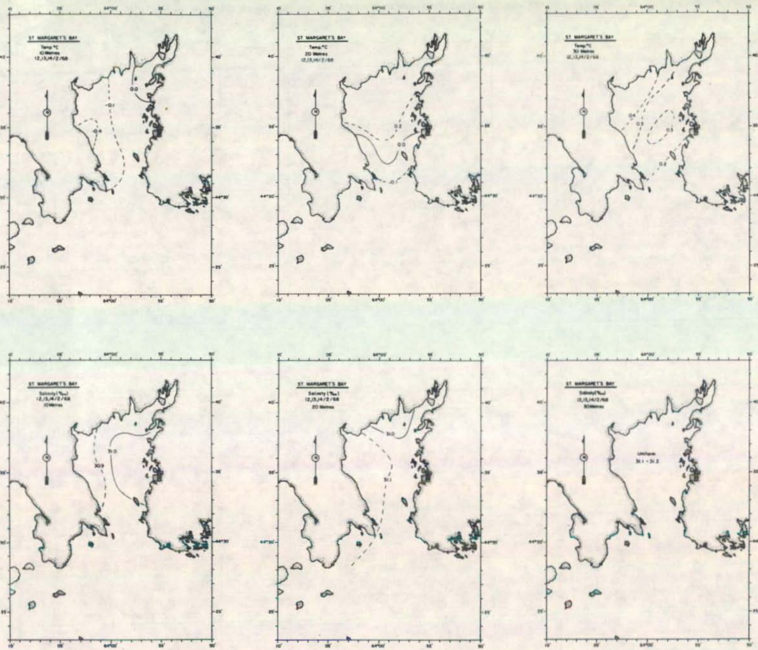


Fig. 3.8.18. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 12-14 February 1968.

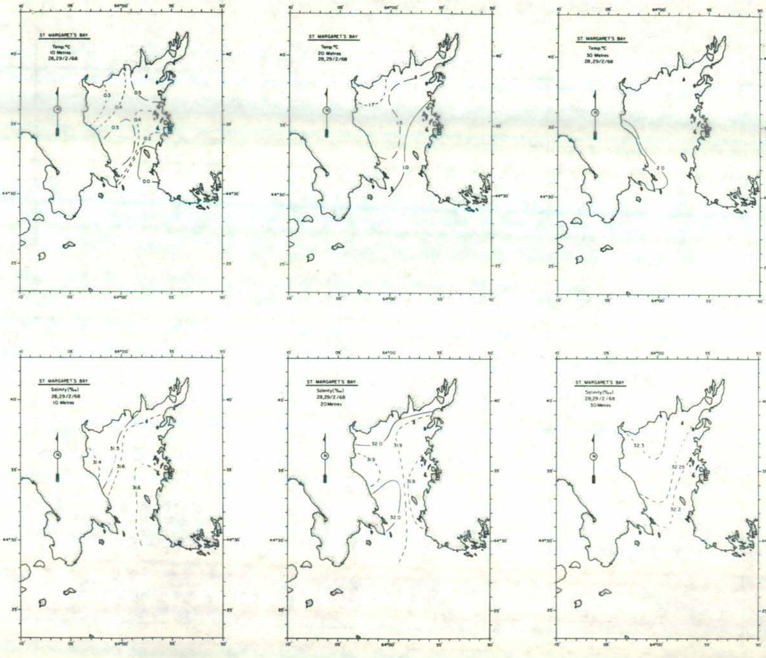


Fig. 3.8.19. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 28-29 February 1968.

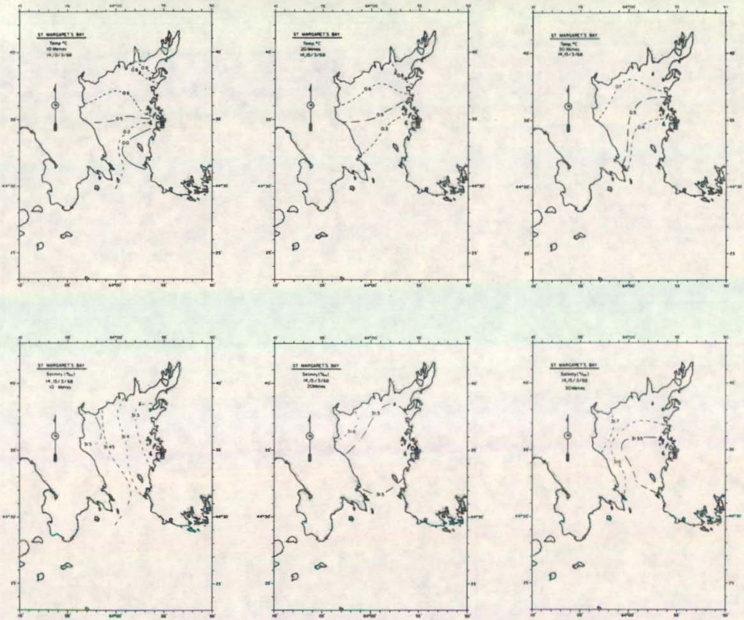


Fig. 3.8.20. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 14-15 March 1968.

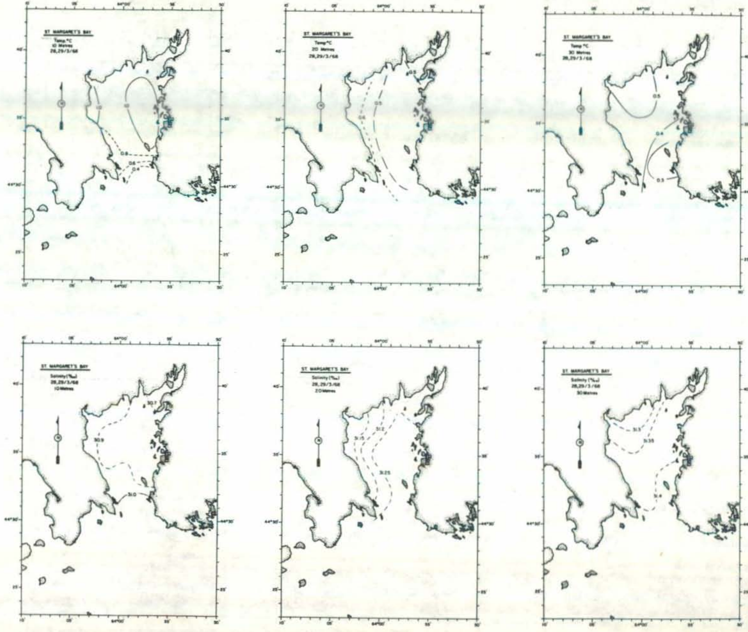


Fig. 3.8.21. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 28-29 March 1968.

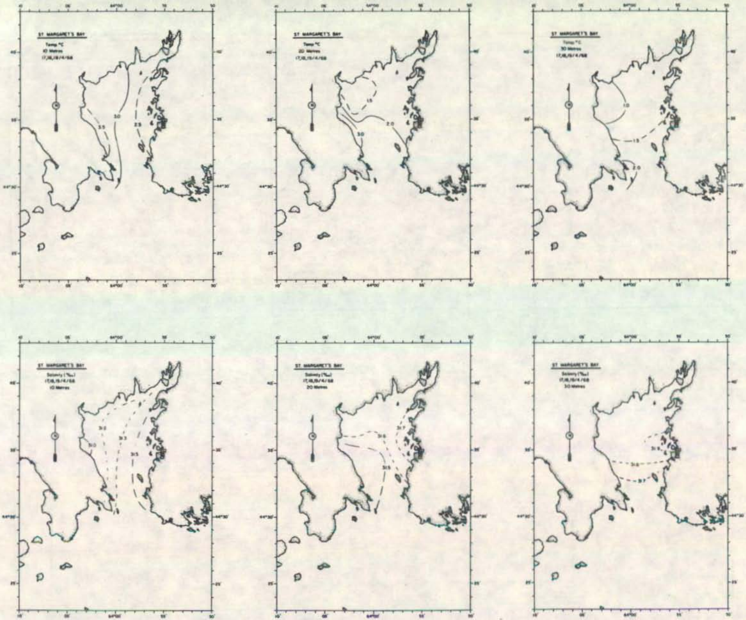


Fig. 3.8.22. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 17-19 April 1968.

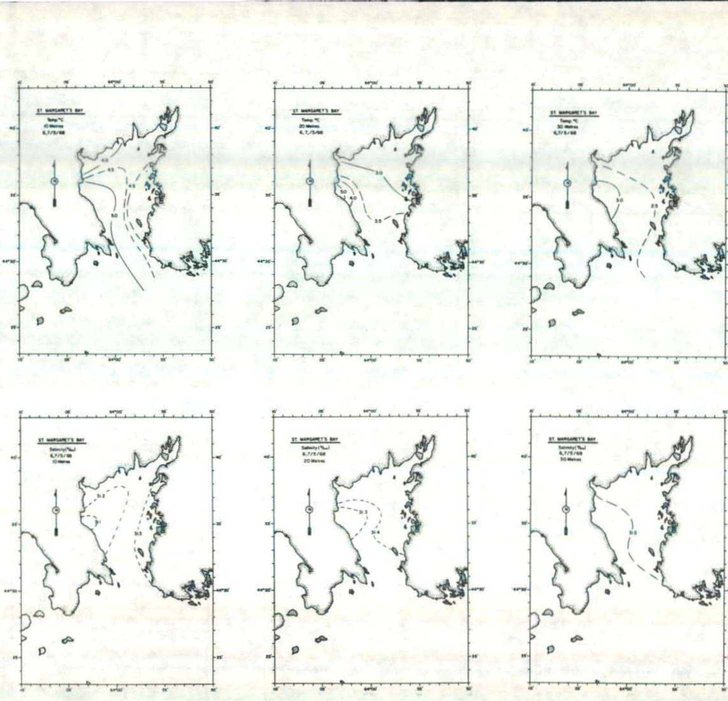


Fig. 3.8.23. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 6-7 May 1968.

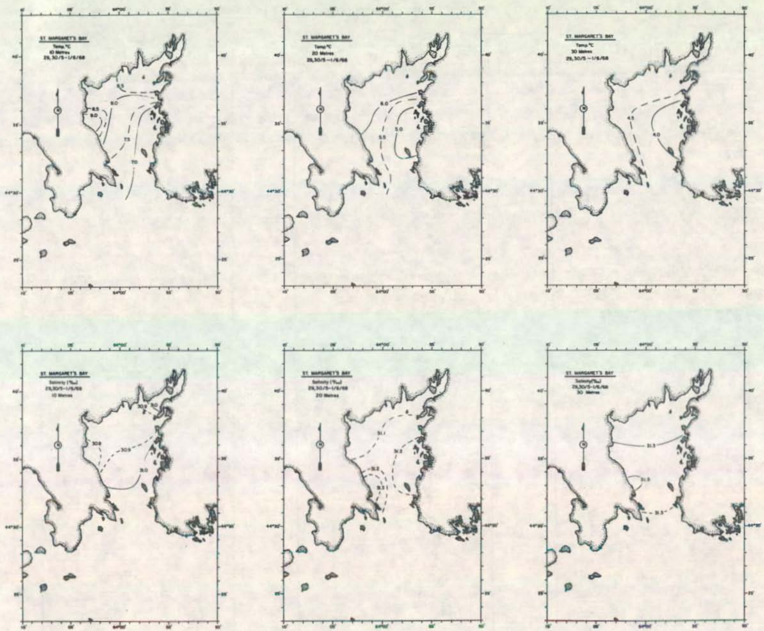


Fig. 3.8.24. Isohaline and isotherms at 10, 20 and 30 metres below surface for cruise taken in the Bay on 29, 30 May-1 June 1968.

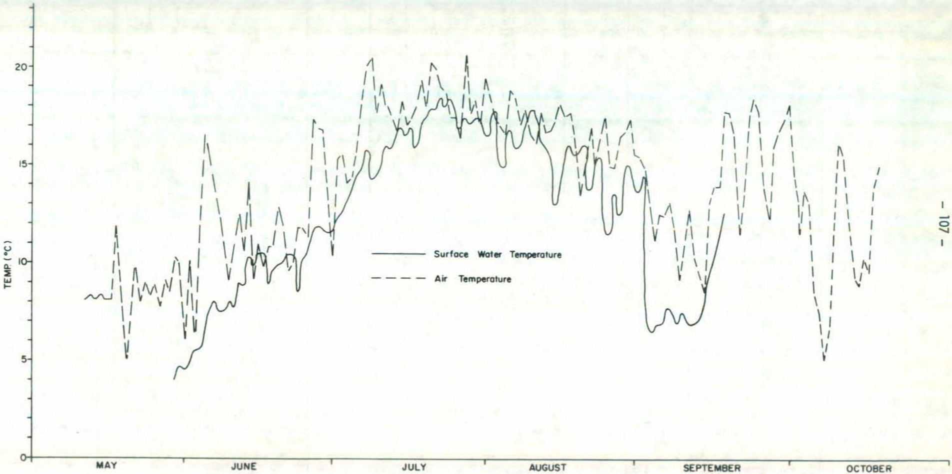


Fig. 3.9. Variation of daily mean of air and surface water temperature during May-October 1967 (Merganser Weather Station).

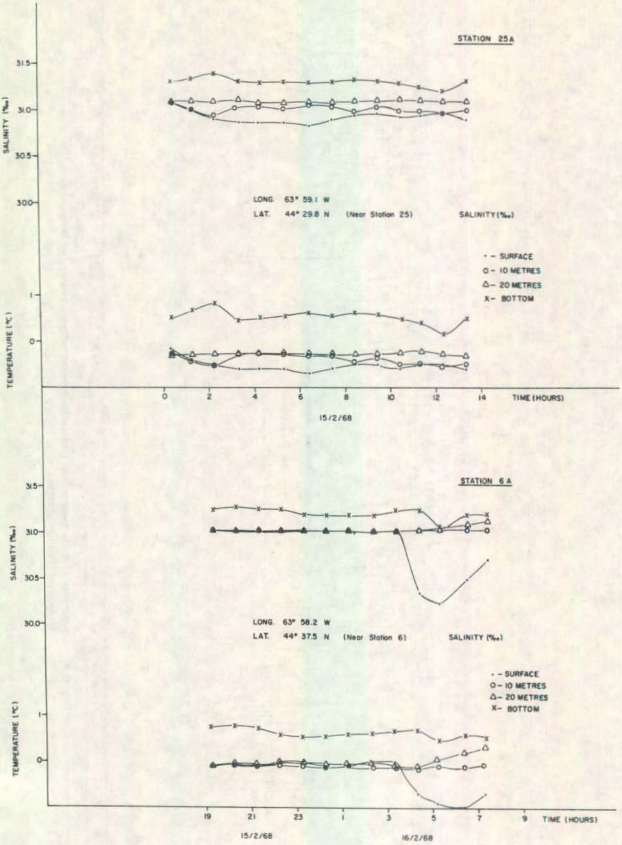
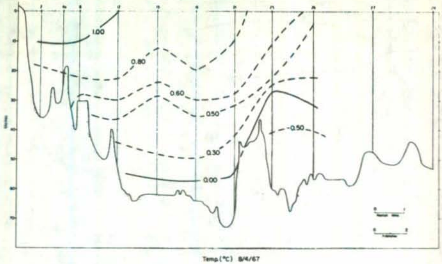
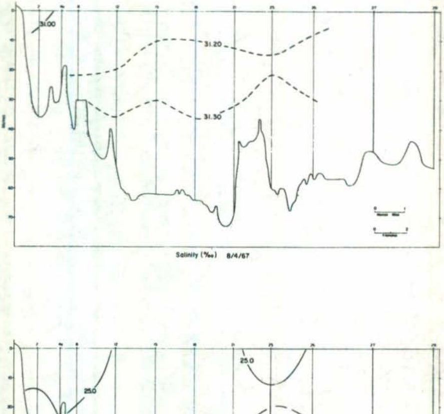


Fig. 3.10. Variation of temperature and salinity during tidal cycle at Station 6A (inside the Bay) and Station 25A (outside the Bay).





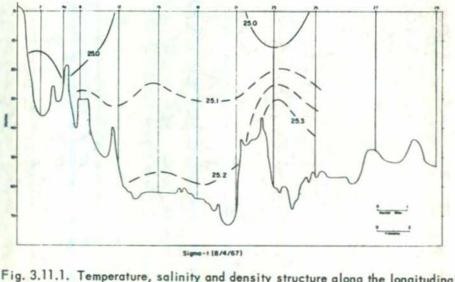
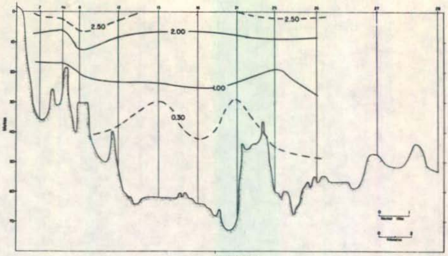
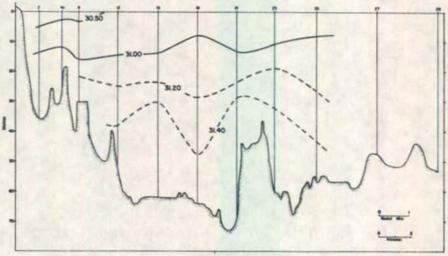


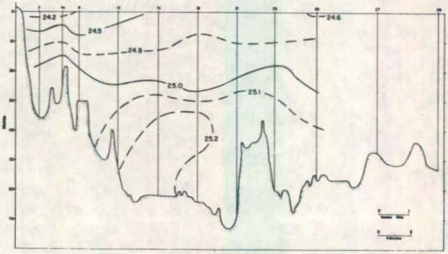
Fig. 3.11.1. Temperature, salinity and density structure along the longitudinal axis of the Bay for April 4, 1967.



Temp.(°C) 26/4/67

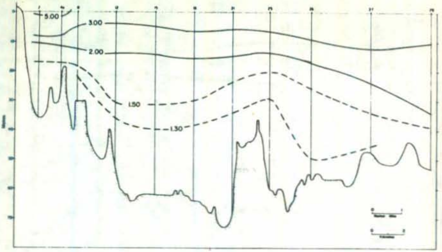


Salinity (‰) 26/4/67

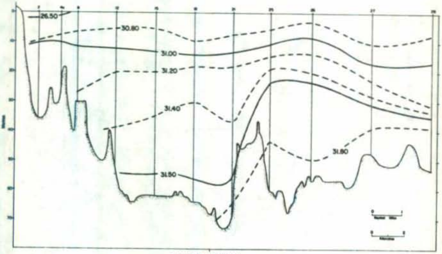


Sigma-t (26/4/67)

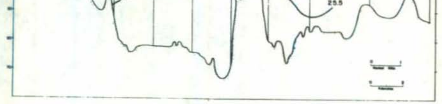
Fig. 3.11.2. Temperature, salinity and density structure along the longitudinal axis of the Bay for 26 April 1967.



Temp.(°C) 15/5/67



Salinity (‰) 15/5/67



Sigma-t (15/5/67)

Fig. 3.11.3. Temperature, salinity and density structure along the longitudinal axis of the Bay for 15 May 1967.

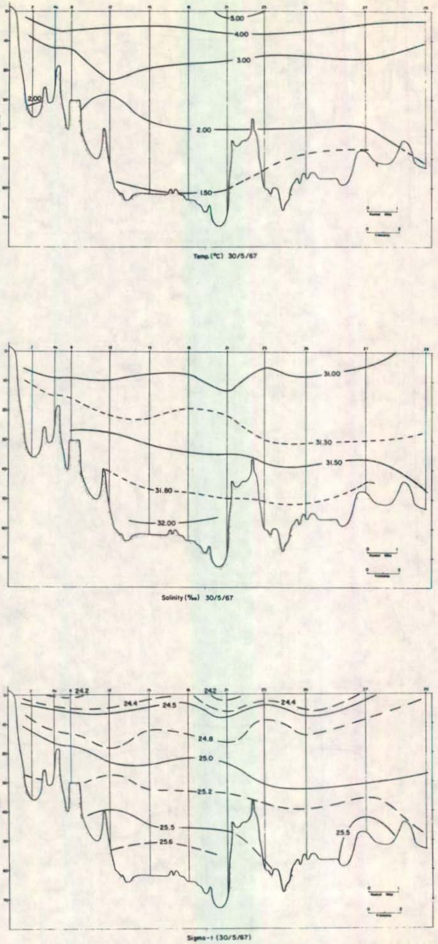
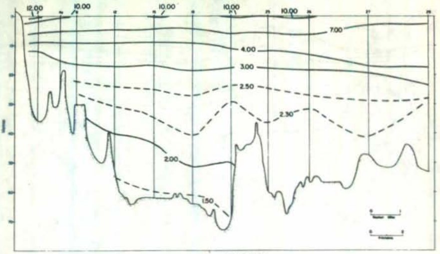
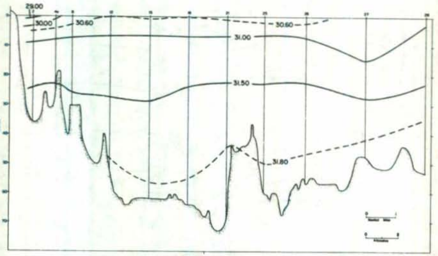


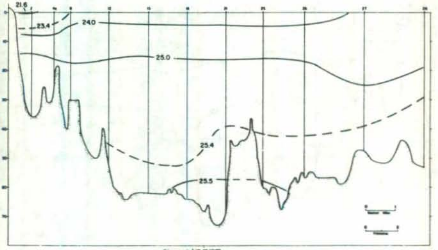
Fig. 3.11.4. Temperature, salinity and density structure along the longitudinal axis of the Bay for 30 May 1967



Temp. (°C) 19/6/67

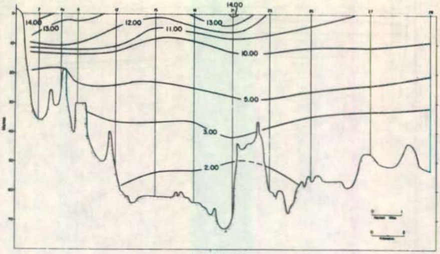


Salinity (‰) 19/6/67

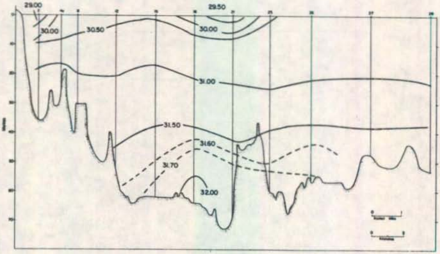


Sigma - t (19/6/67)

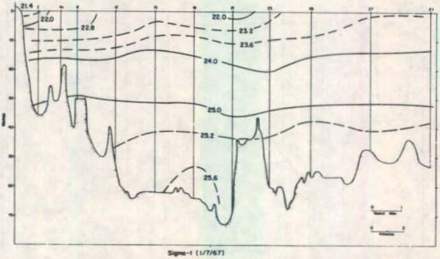
Fig. 3.11.5. Temperature, salinity and density structure along the longitudinal axis of the Bay for 19 June 1967.



Temp.(°C) 1/7/67

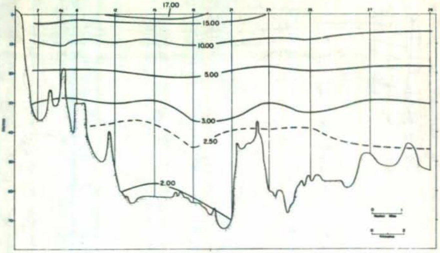


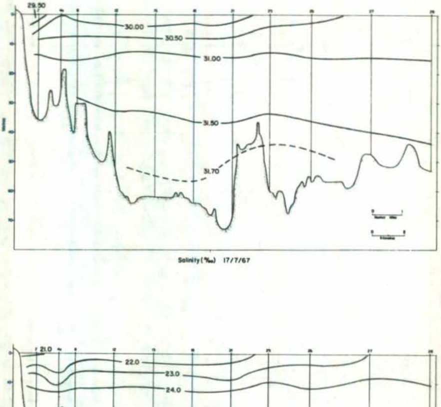
Salinity (‰) 1/7/67



Sigma-t (1/7/67)

Fig. 3.11.6. Temperature, salinity and density structure along the longitudinal axis of the Bay for 1 July 1967.





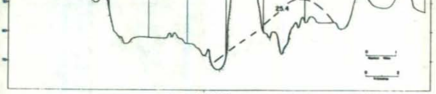


Fig. 3.11.7. Temperature, salinity and density structure along the longitudinal axis of the Bay for 17 July 1967.

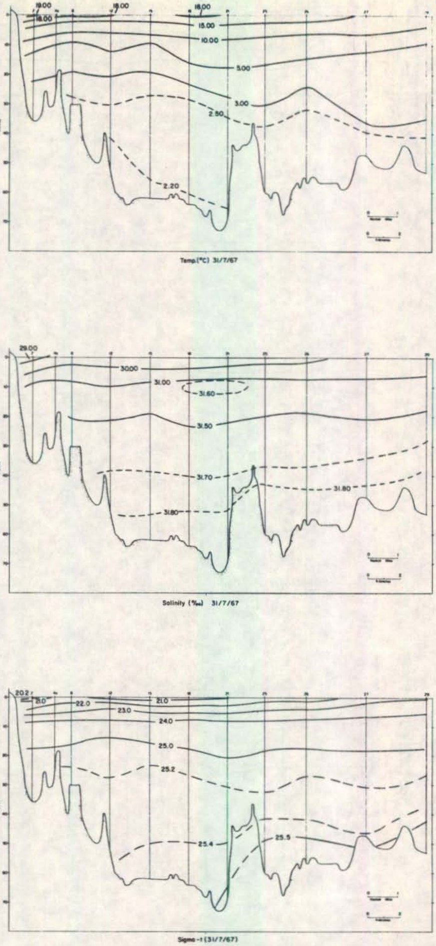
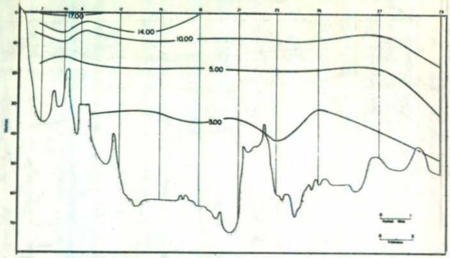
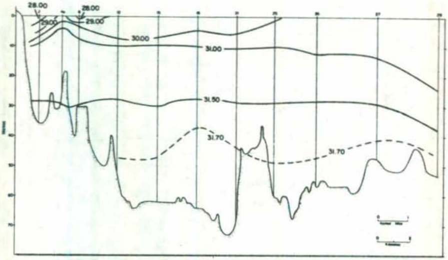


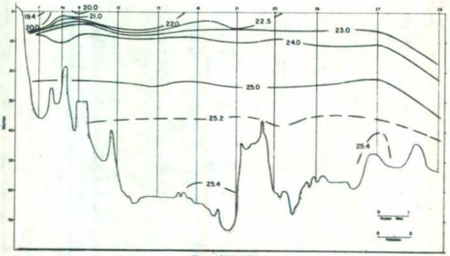
Fig. 3.11.8. Temperature, salinity and density structure along the longitudinal axis of the Bay on 31 July 1967



Temp. (°C) 14/8/67



Salinity (‰) 14/8/67



Sigma-t (14/8/67)

Fig. 3.11.9. Temperature, salinity and density structure along the longitudinal axis of the Bay on 14 August 1967.

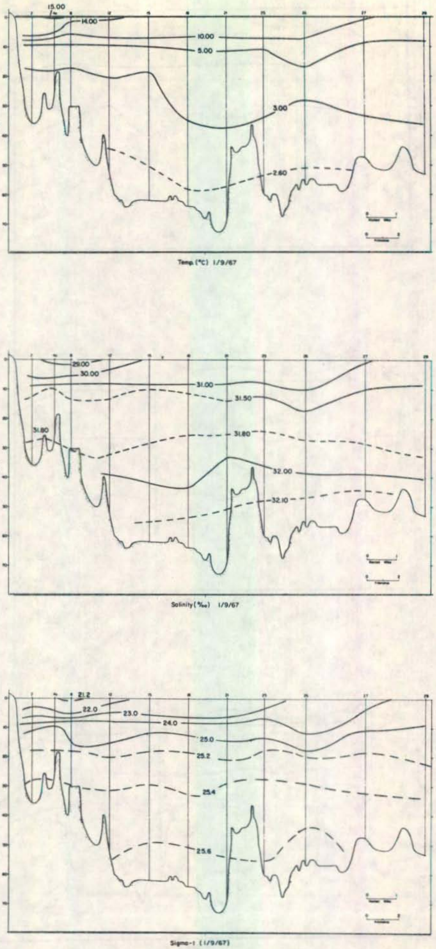
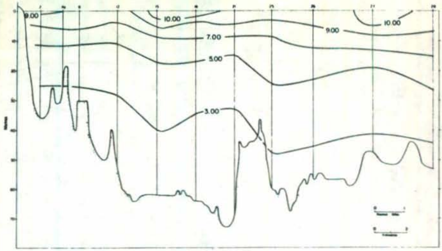
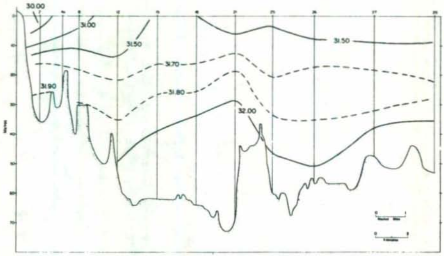


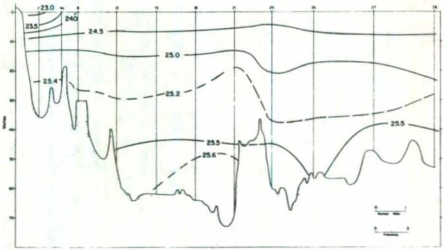
Fig. 3.11.10. Temperature, salinity and density structure along the longitudinal axis of the Bay on 1 September 1967.



Temp. (°C) 14/9/67



Salinity (‰) 14/9/67



Sigma-t (14/9/67)

Fig. 3.11.11. Temperature, salinity and density structure along the longitudinal axis of the Bay on 14 September 1967.

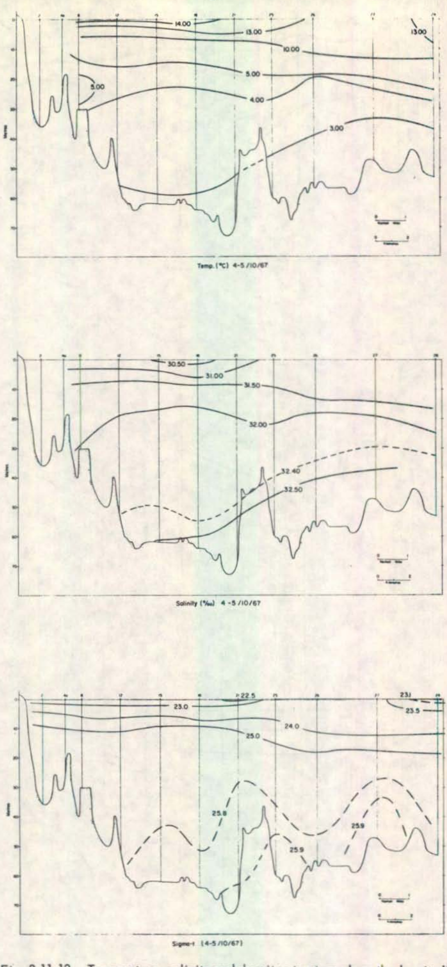


Fig. 3.11.12. Temperature, salinity and density structure along the longitudinal axis of the Bay on 4-5 October 1967.

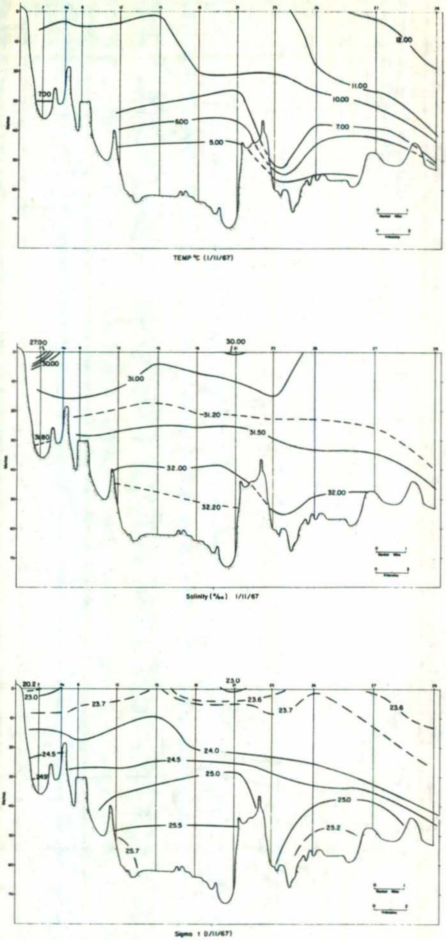


Fig. 3.11.13. Temperature, salinity and density structure along the longitudinal axis of the Bay on 1 November 1967.

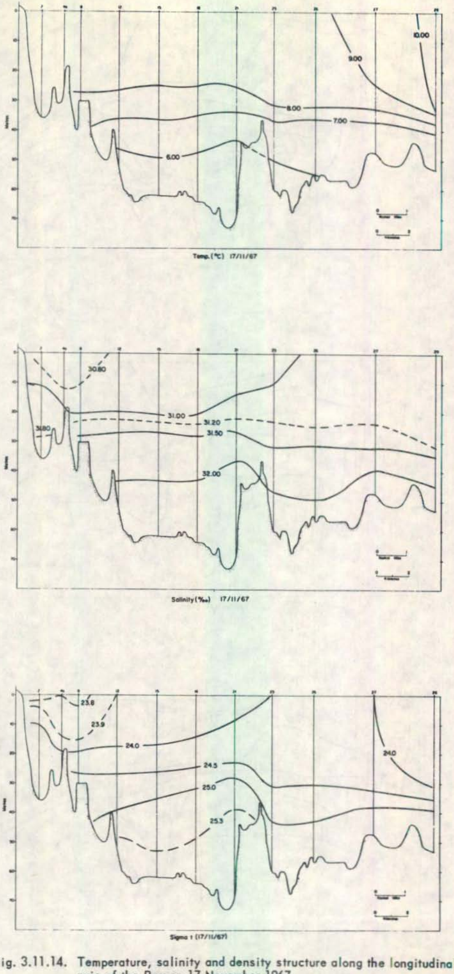


Fig. 3.11.14. Temperature, salinity and density structure along the longitudinal axis of the Bay on 17 November 1967.

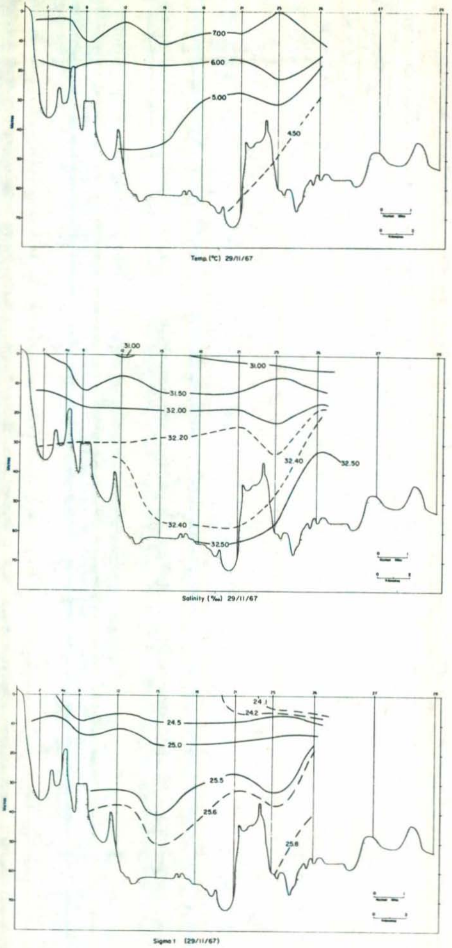
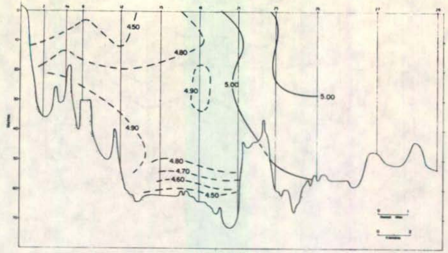
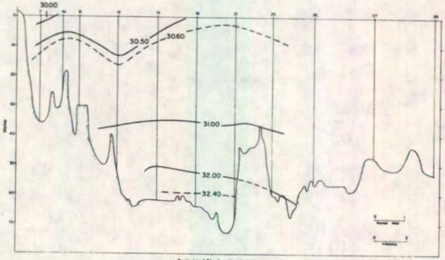


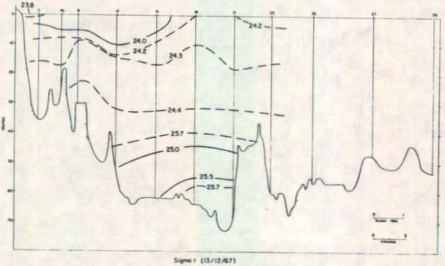
Fig. 3.11.15. Temperature, salinity and density structure along the longitudinal axis of the Bay on 29 November 1967.



Temp. (°C) 13/12/67



Salinity (‰) 13/12/67



Sigma t (13/12/67)

Fig. 3.11.16. Temperature, salinity and density structure along the longitudinal axis of the Bay on 13 December 1967.

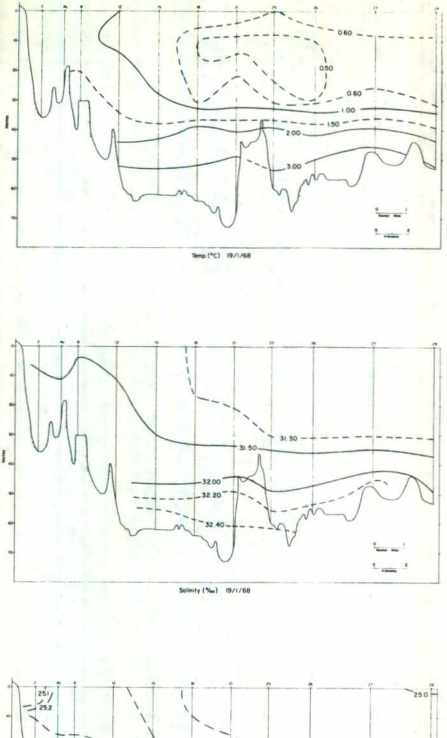


Fig. 3.11.17. Temperature, salinity and density structure along the longitudinal axis of the Bay on 19 January 1968.

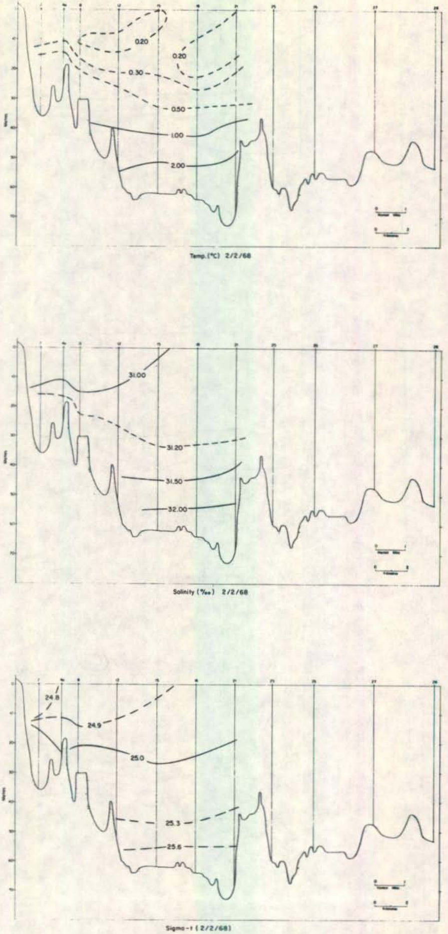
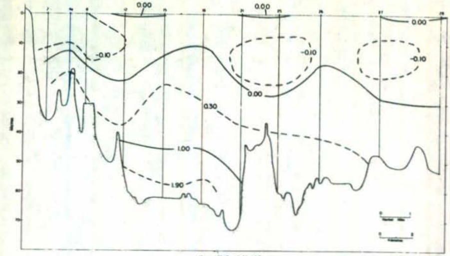
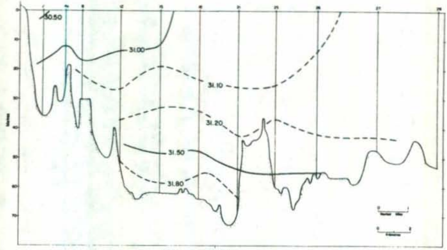


Fig. 3.11.18. Temperature, salinity and density structure along the longitudinal axis of the Bay on 2 February 1968.



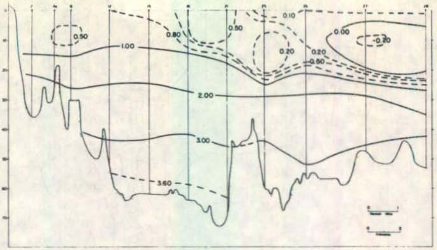
Temp. (°C) 12/2/68



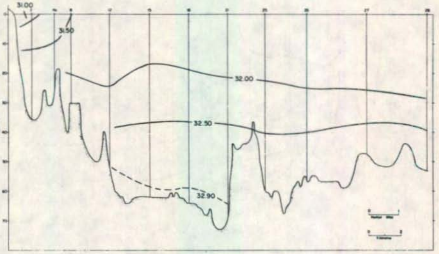
Salinity (°/oo) 12/2/68

Sigma-t (12/2/68)

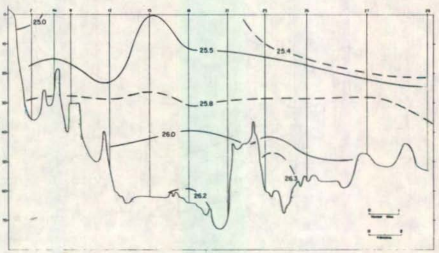
Fig. 3.11.19. Temperature, salinity and density structure along the longitudinal axis of the Bay on 12 February 1968.



TEMP. °C (28/2/68)



Salinity (‰) 28/2/68



Sigma-t (28/2/68)

Fig. 3.11.20. Temperature, salinity and density structure along the longitudinal axis of the Bay on 28 February 1968.

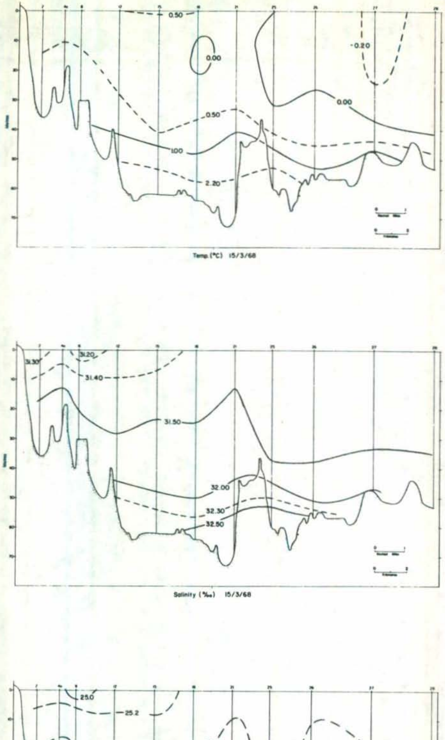


Fig. 3.11.21. - Temperature, salinity and density structure along the longitudinal axis of the Bay on 15 March 1968.

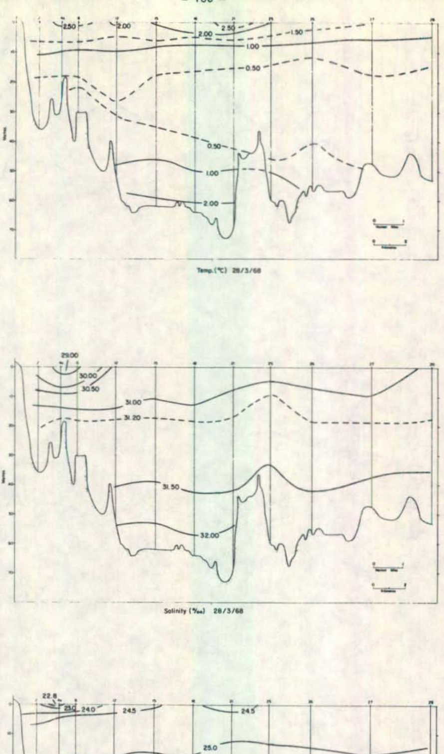


Fig. 3.11.22. Temperature, salinity and density structure along the longitudinal axis of the Bay on 28 March 1968.

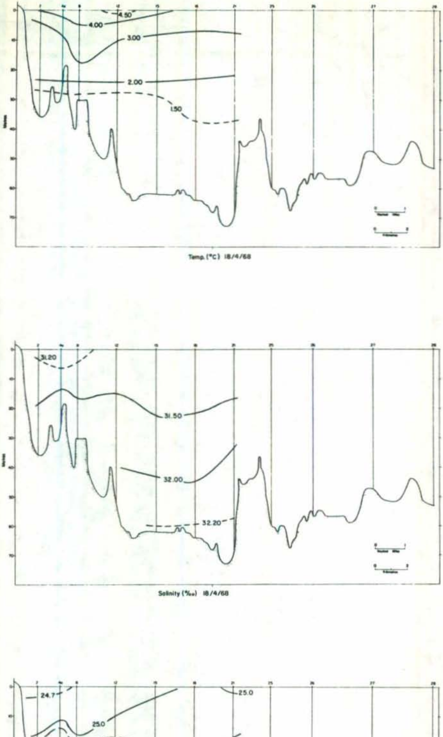


Fig. 3.11.23. Temperature, salinity and density structure along the longitudinal axis of the Bay on 18 April 1968.

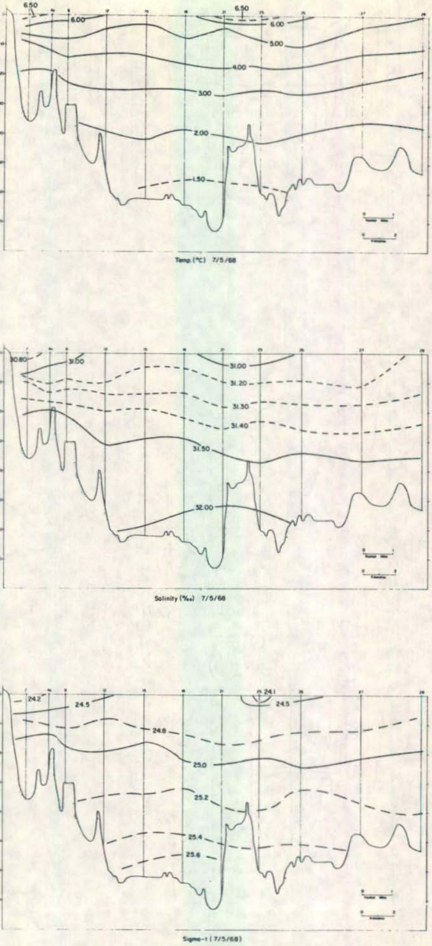
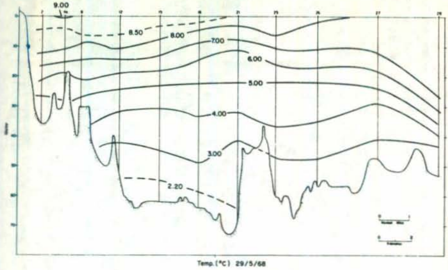
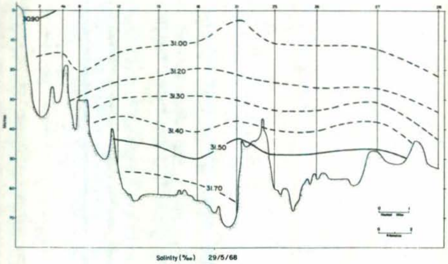


Fig. 3.11.24. Temperature, salinity and density structure along the longitudinal axis of the Bay on 7 May 1968.





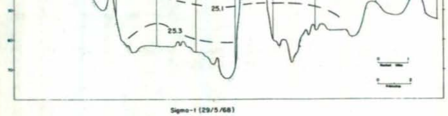


Fig. 3.11.25. Temperature, salinity and density structure along the longitudinal axis of the Bay on 29 May 1968.

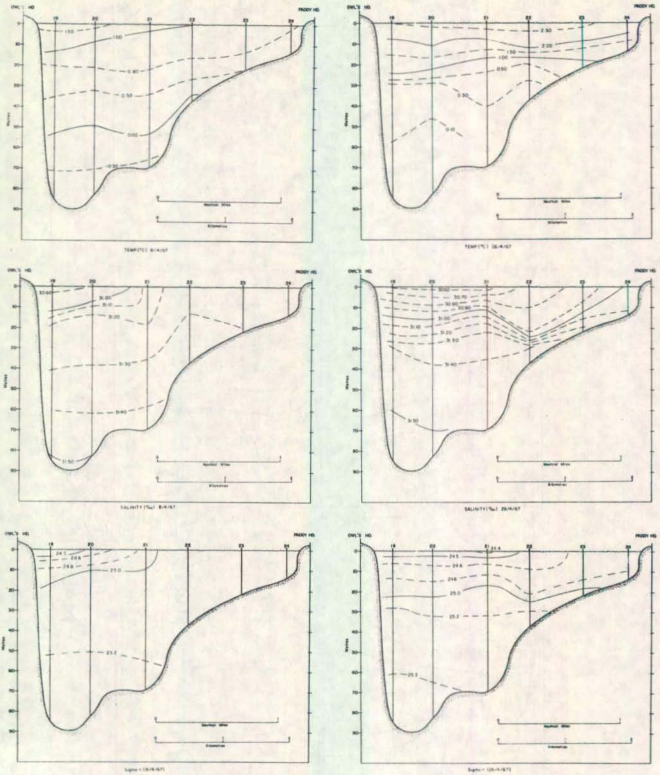


Fig. 3.12.1. Temperature, salinity and density structure with a cross-section near the mouth of the Bay for cruise on April 8 and April 26, 1967.

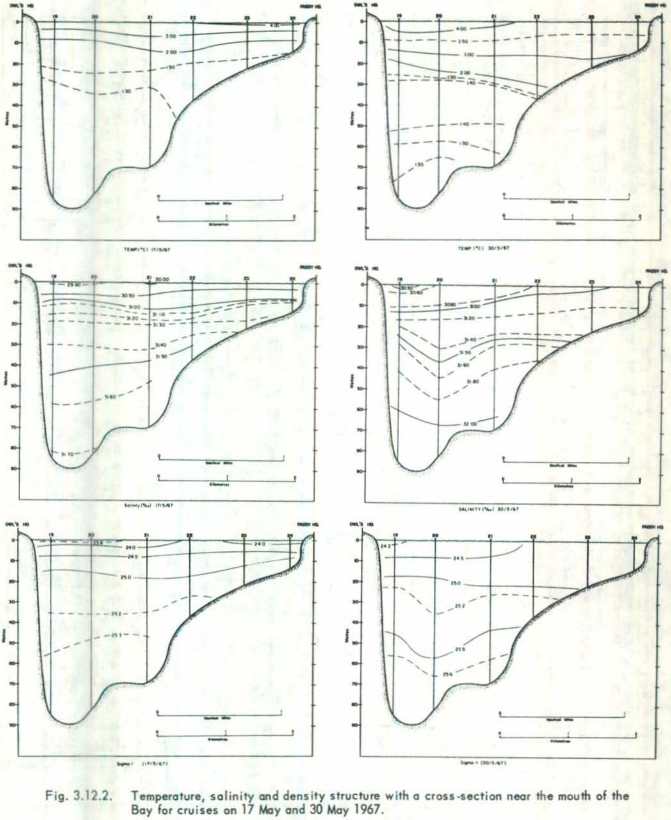


Fig. 3.12.2. Temperature, salinity and density structure with a cross-section near the mouth of the Bay for cruises on 17 May and 30 May 1967.

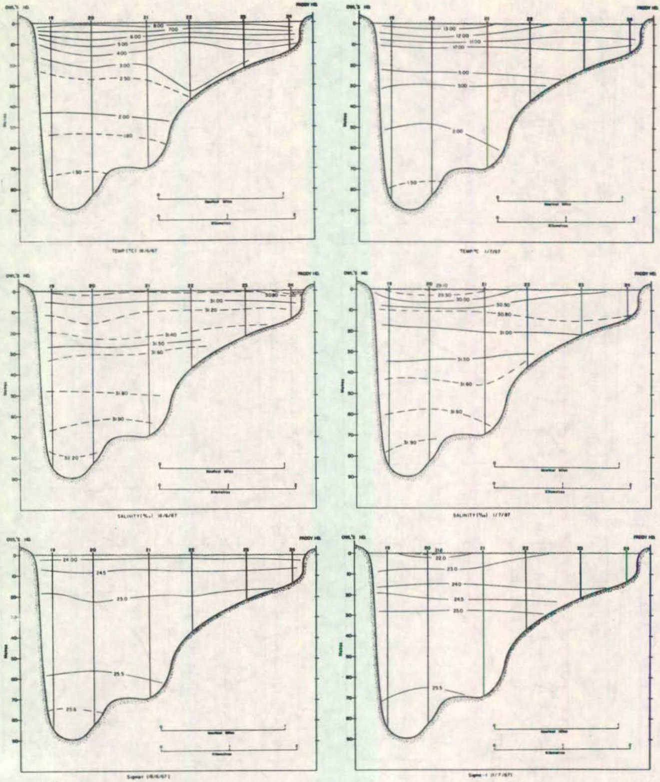


Fig. 3.12.3. Temperature, salinity and density structure with a cross-section near the mouth of the Bay for cruises on 18 June and 1 July 1967.

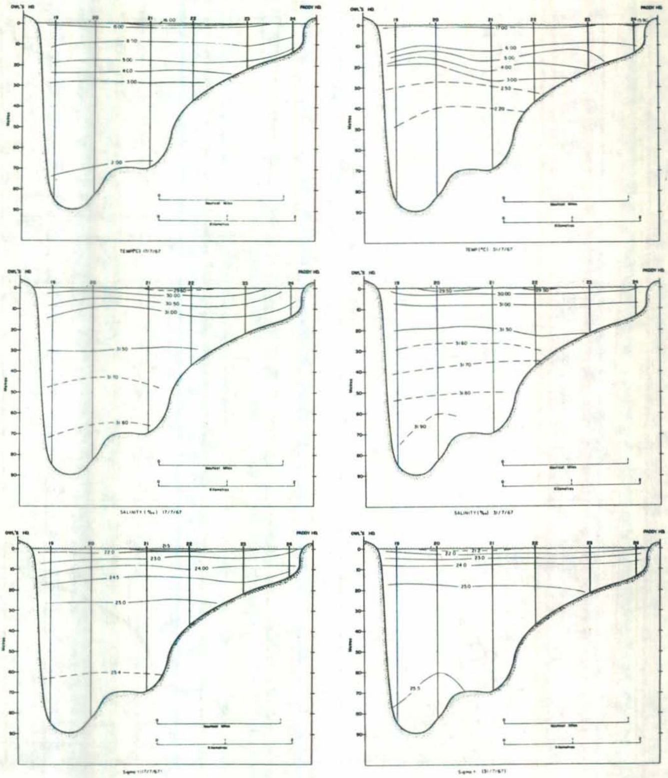


Fig. 3.12.4. Temperature, salinity and density structure with a cross-section near the mouth of the Bay for cruises on 17 July and 31 July 1967.

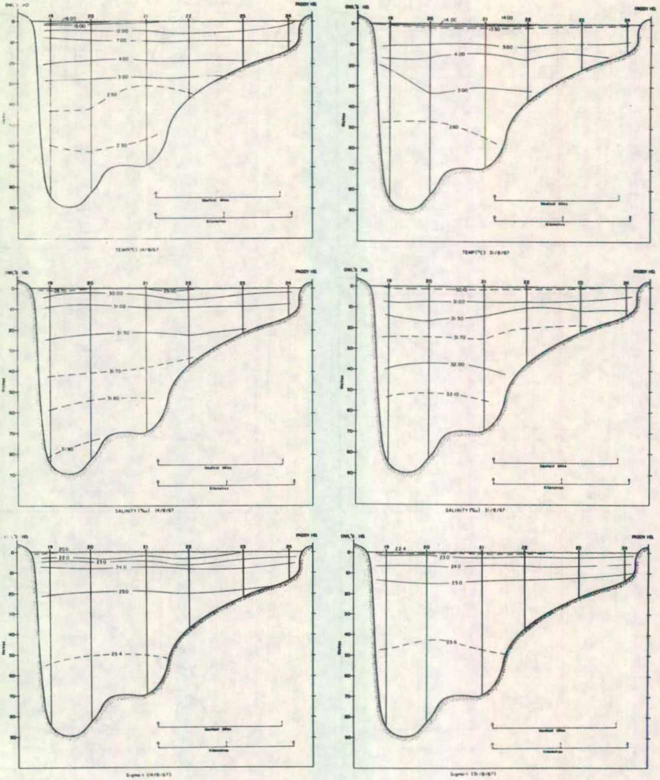


Fig. 3.12.5. Temperature, salinity and density structure with a cross-section near the mouth of the Bay for cruises on 14 August and 31 August 1967.

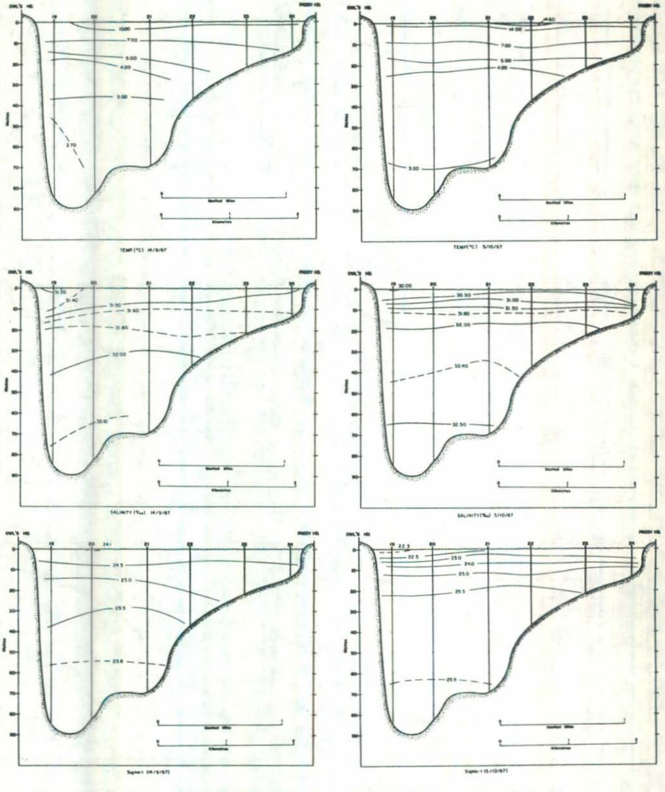


Fig. 3.12.6. Temperature, salinity and density structure with a cross-section near the mouth of the Bay for cruises on 14 September and 5 October 1967.

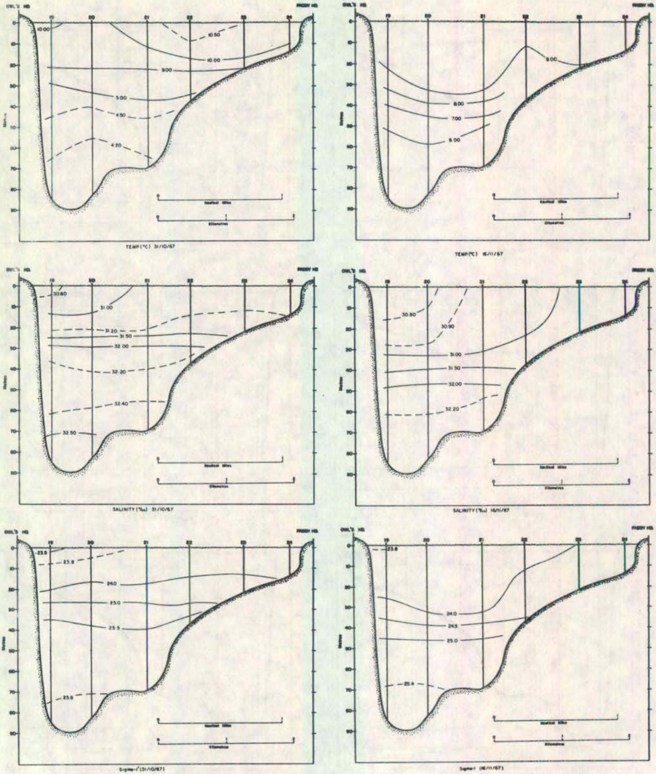


Fig. 3.12.7. Temperature, salinity and density structure with a cross-section near the mouth of the Bay for cruises on 31 October and 16 November 1967.

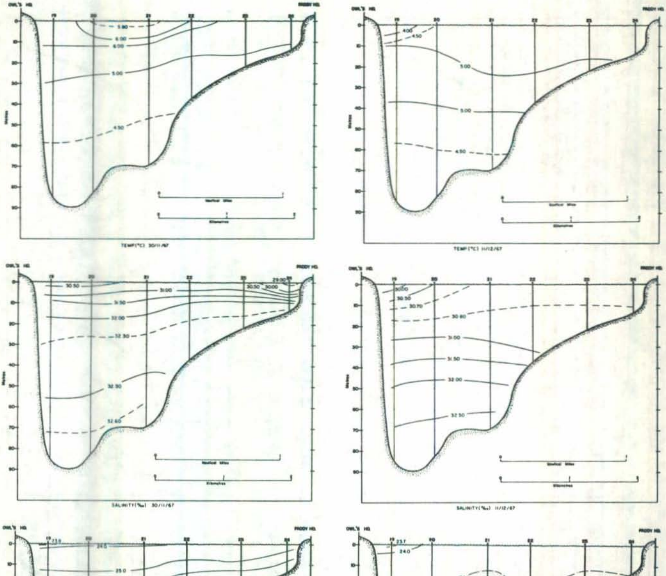


Fig. 3.12.8. Temperature, salinity and density structure with a cross-section near the mouth of the Bay for cruises on 30 November and 11 December 1967.

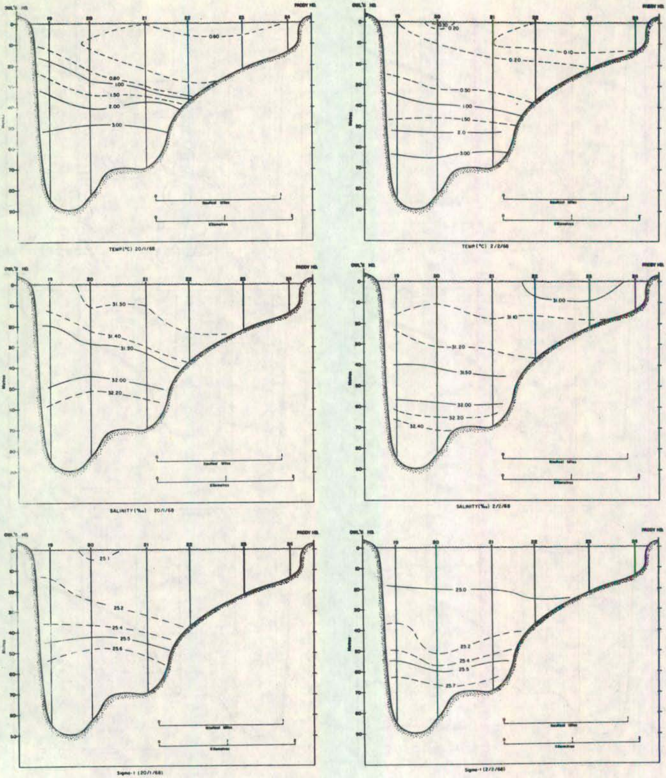


Fig. 3.12.9. Temperature, salinity and density structure with a cross-section near the mouth of the Bay for cruises on 20 January and 2 February 1968.

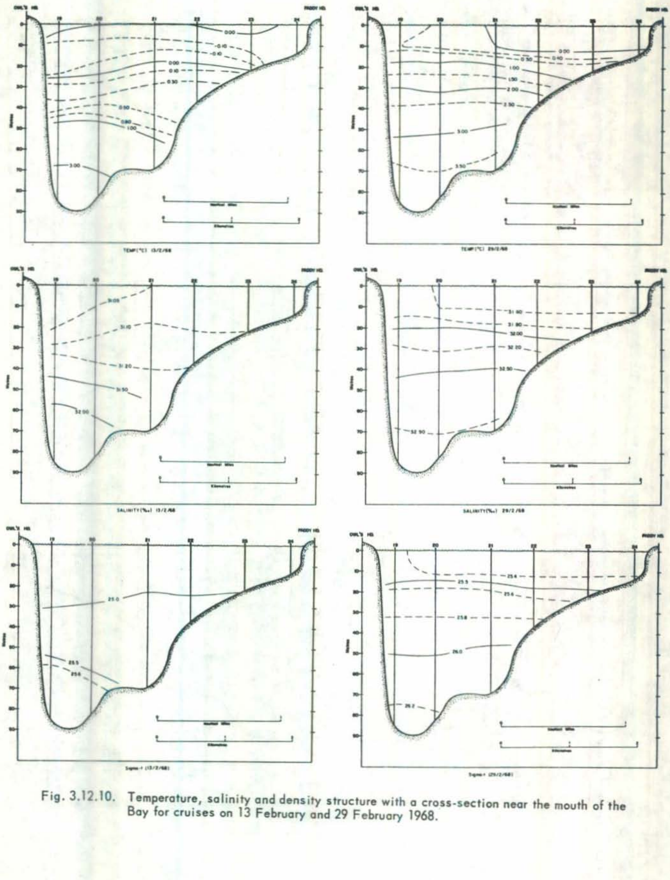


Fig. 3.12.10. Temperature, salinity and density structure with a cross-section near the mouth of the Bay for cruises on 13 February and 29 February 1968.

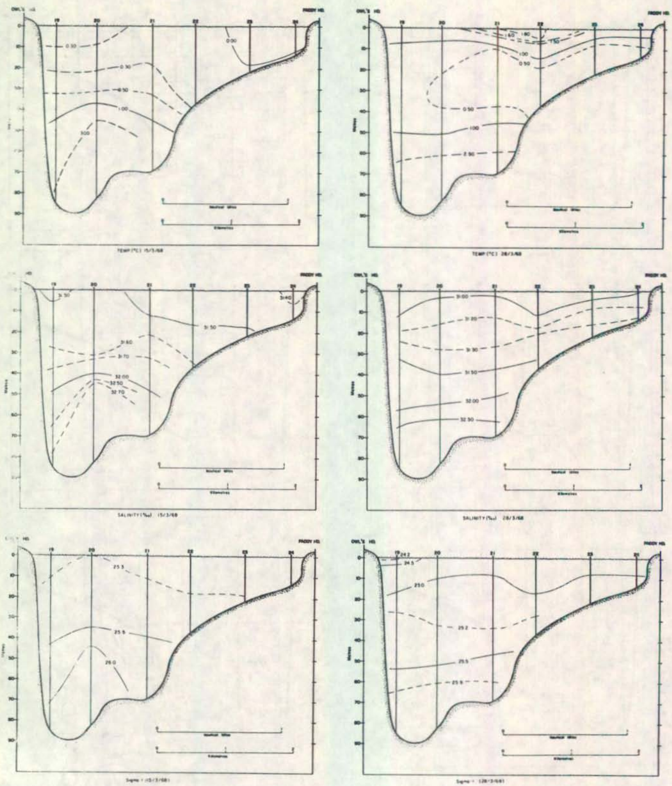


Fig. 3.12.11. Temperature, salinity and density structure with a cross-section near the mouth of the Bay for cruises on 15 March and 28 March 1968.

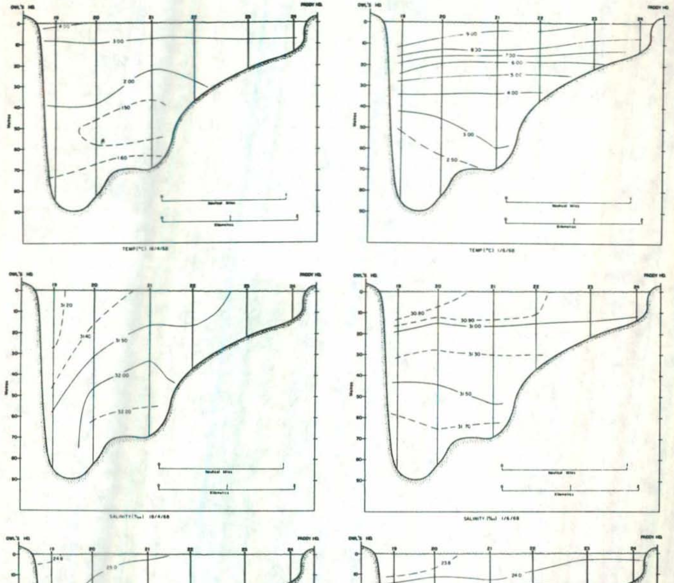


Fig. 3.12.12. Temperature, salinity and density structure with a cross-section near the mouth of the Bay for cruises on 18 April and 1 June 1968.

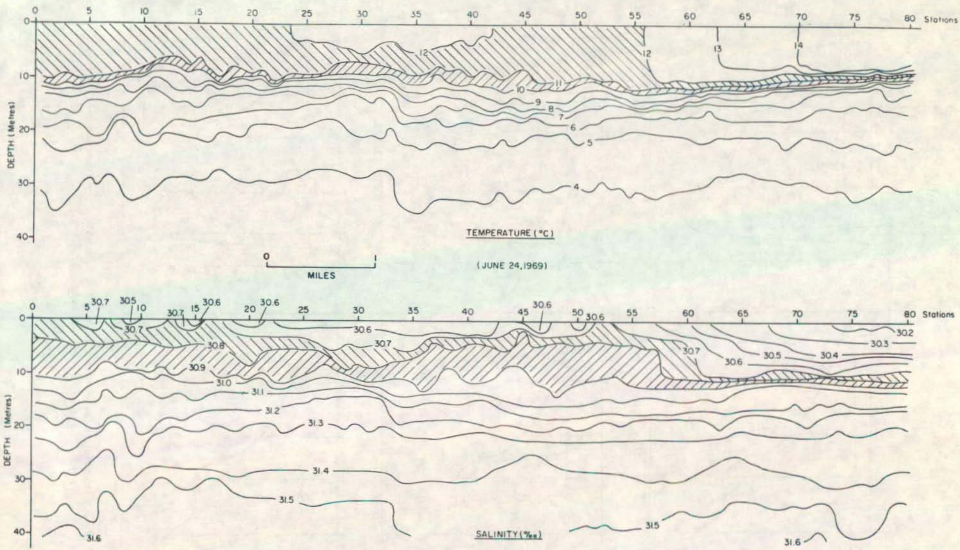


Fig. 3.13.1. Temperature and salinity structure at longitudinal section in the Bay on 24 June 1969.

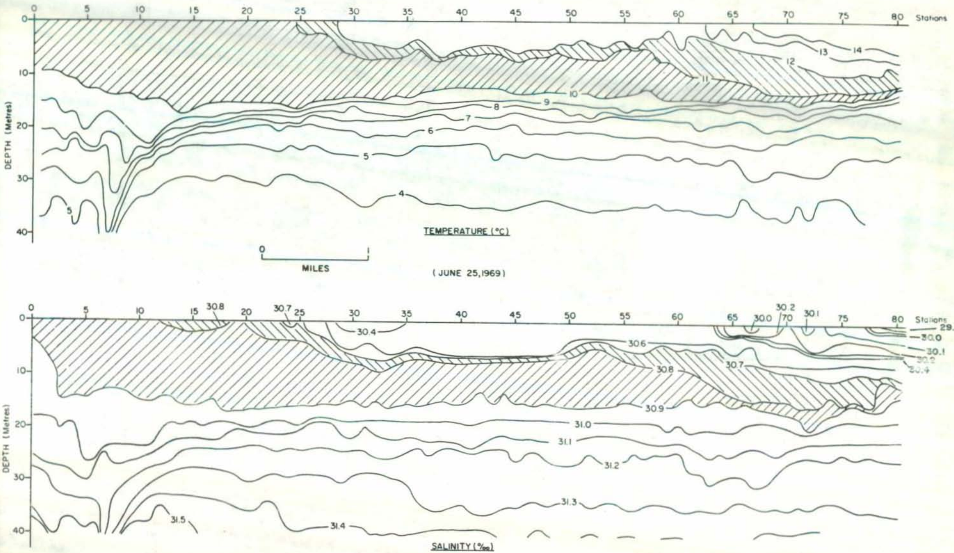


Fig. 3.13.2. Temperature and salinity structure at longitudinal section in the Bay on 25 June 1969.

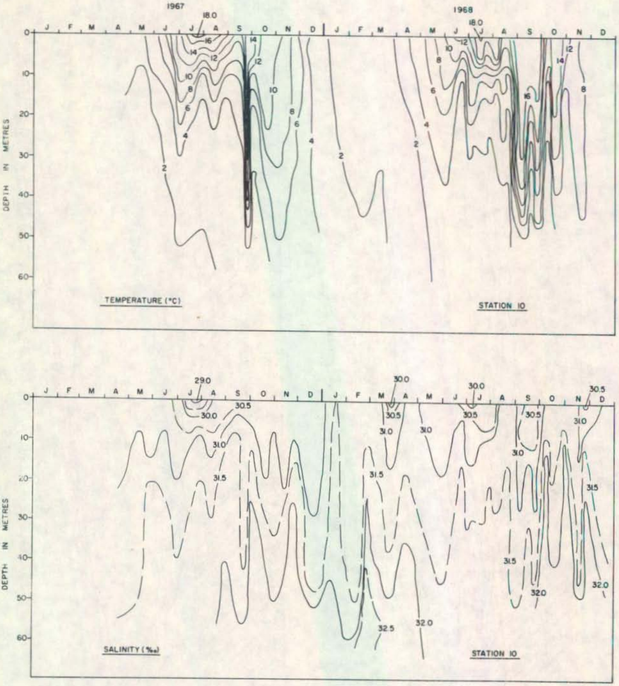


Fig. 3.14. Seasonal variation of temperature and salinity with depth at Station 10.

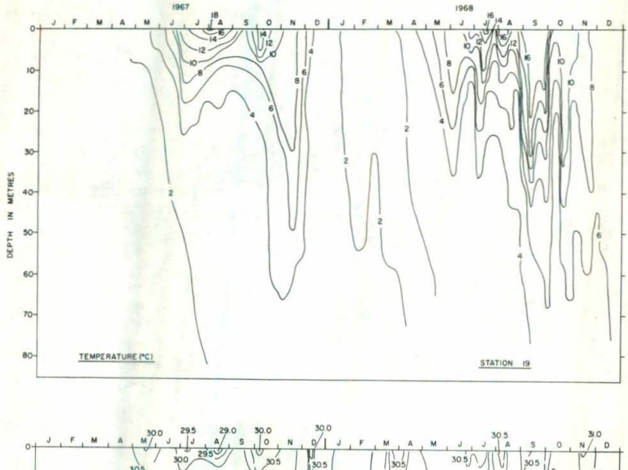


Fig. 3.15. Seasonal variation of temperature and salinity with depth at Station 19.

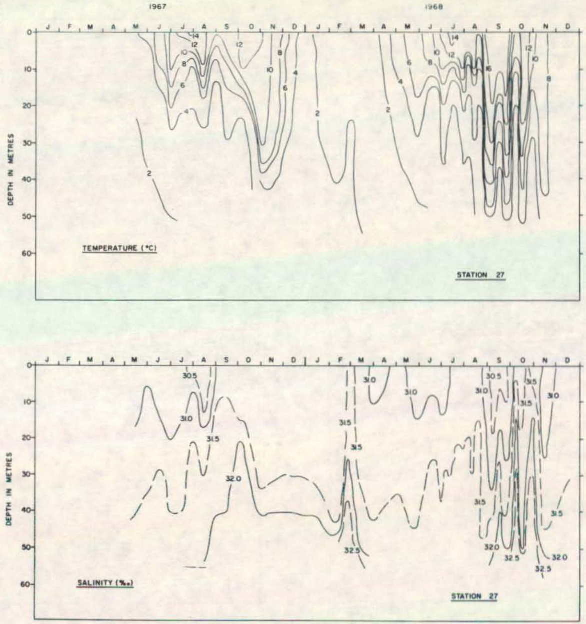


Fig. 3.16. Seasonal variation of temperature and salinity with depth at Station 27.

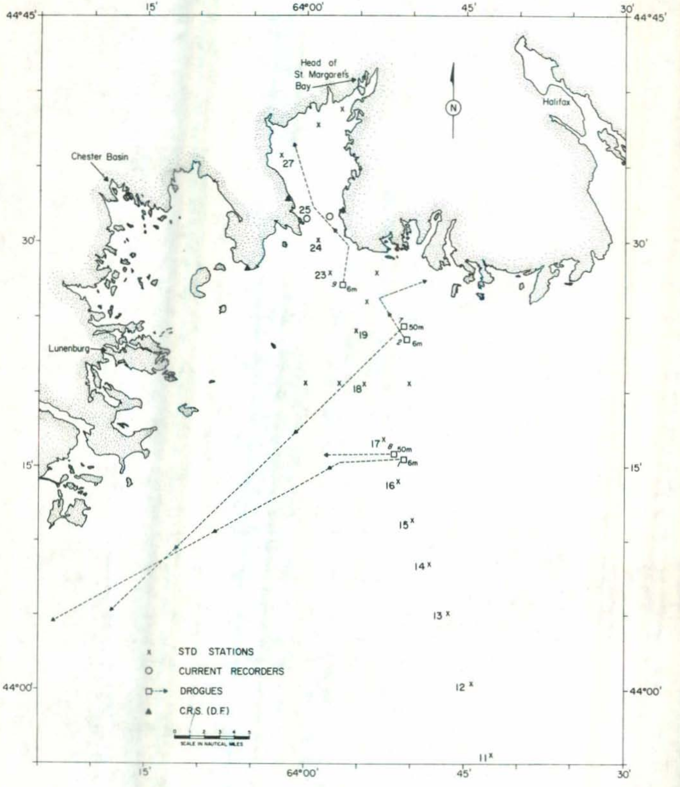


Fig. 3.17.1. Chart of St. Margaret's Bay showing location of sampling stations taken on 19-20 November 1968.

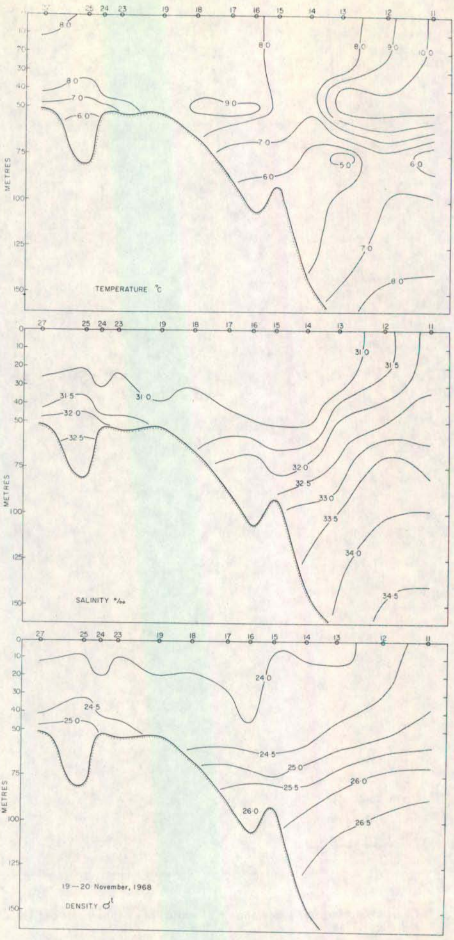


Fig. 3.17.2. Temperature, salinity and density structure along a section from St. Margaret's Bay to LaHave Basin on 19-20 November 1968.

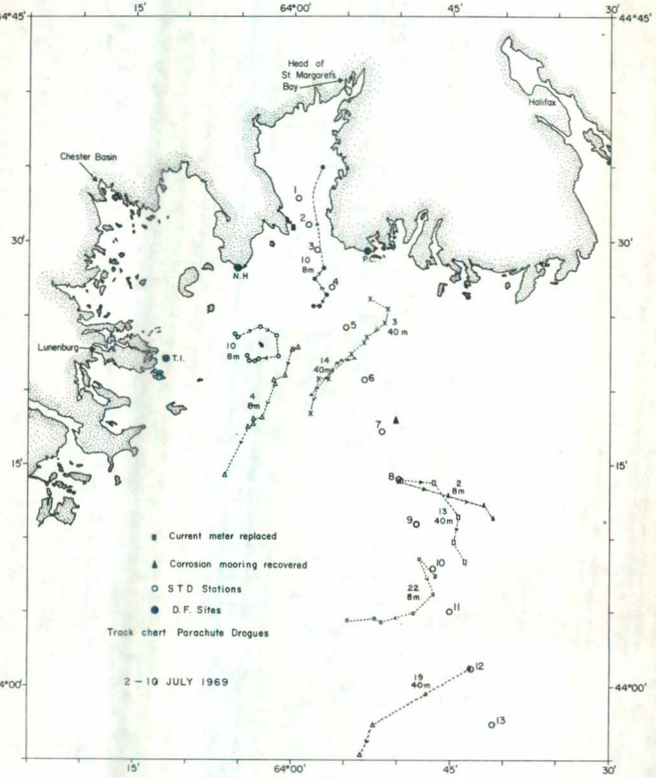


Fig. 3.18.1. Chart of St. Margaret's Bay showing location of sampling stations taken on 2-10 July 1969.

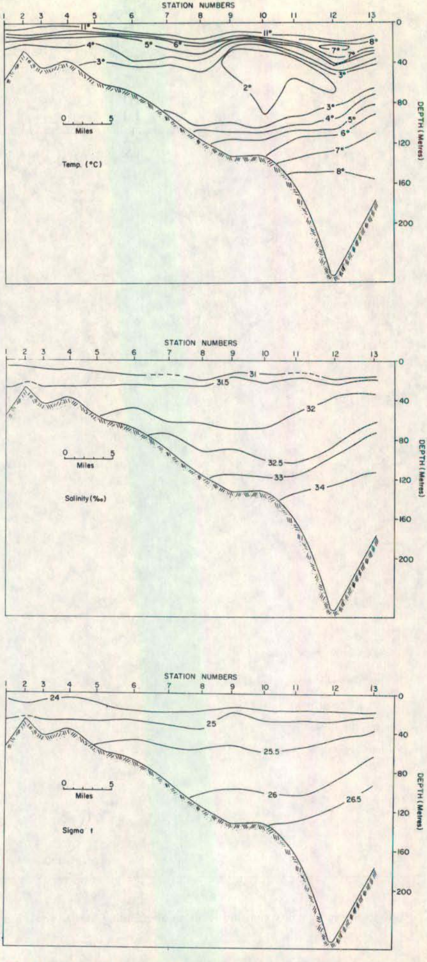


Fig. 3.18.2. Temperature, salinity and density structure along a section from St. Margaret's Bay to LaHave Basin on 2 July 1969.

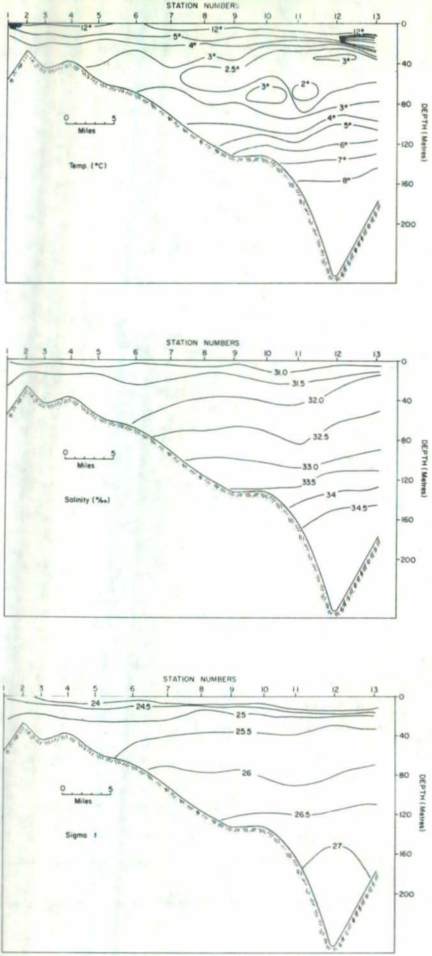


Fig. 3.18.3. Temperature, salinity and density structure along a section from St. Margaret's Bay to LaHave Basin on 10 July 1969.

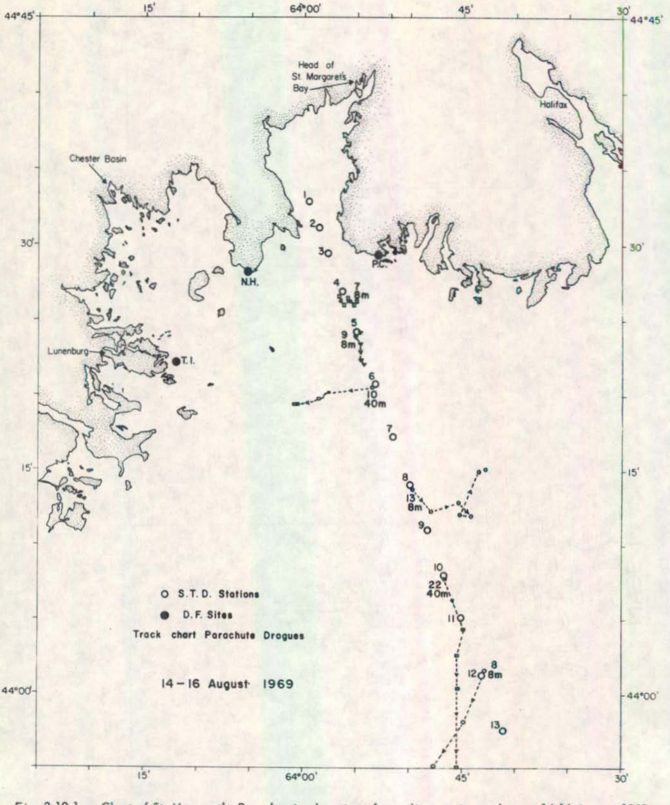


Fig. 3.19.1. Chart of St. Margaret's Bay showing location of sampling stations taken on 14-16 August 1969.

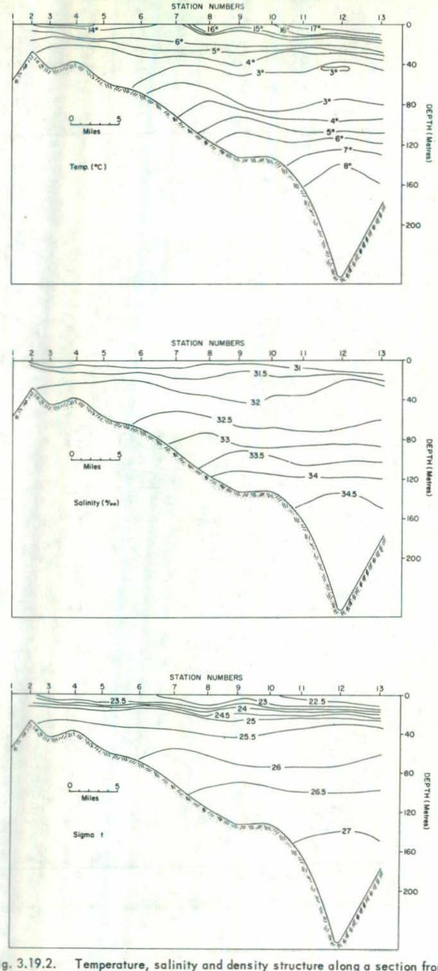


Fig. 3.19.2. Temperature, salinity and density structure along a section from St. Margaret's Bay to LaHave Basin on 14-16 August 1969.

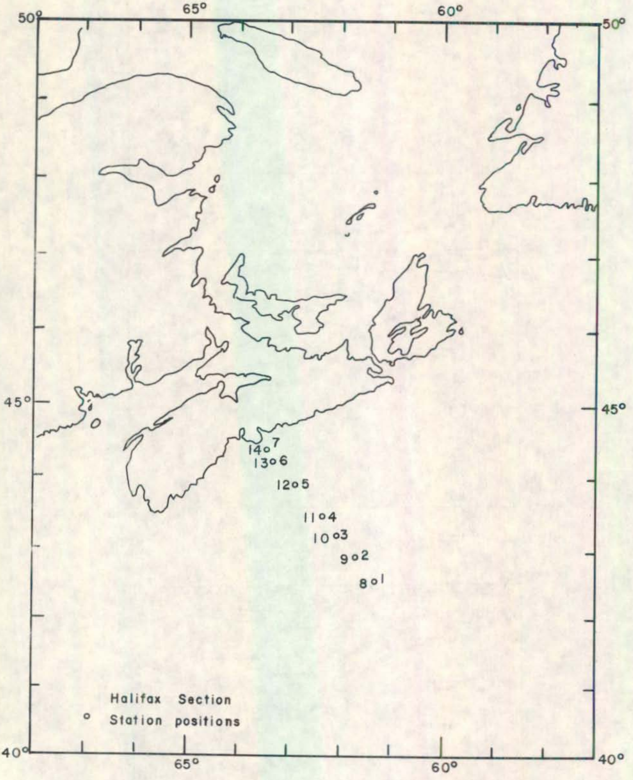


Fig. 3.20.1. Chart of Nova Scotia showing location of sampling stations for Halifax Section.

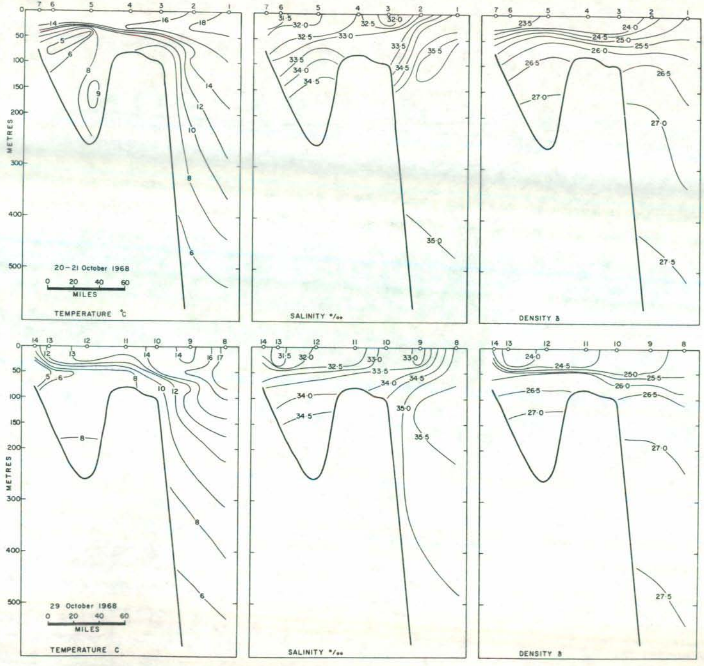


Fig. 3.20.2. Temperature, salinity and density structure along Halifax Section during October 1968.

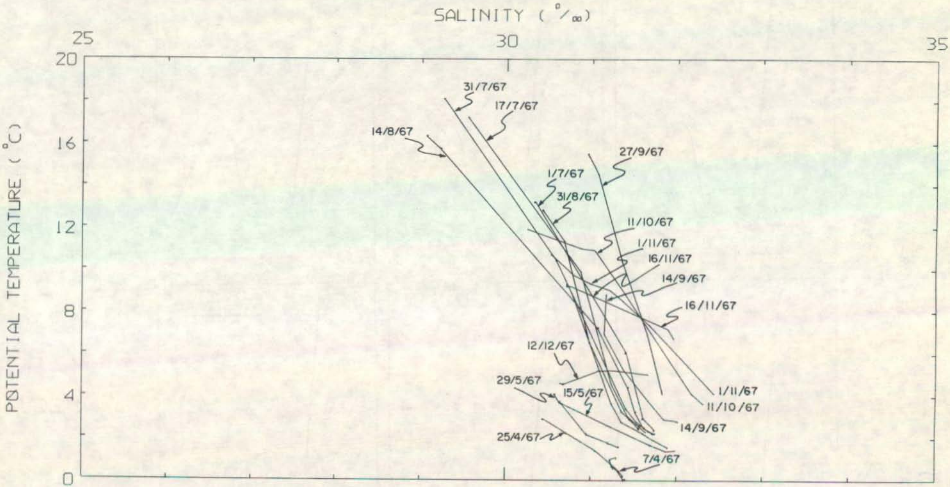


Fig. 3.21.1. T-S diagrams for Station 12.

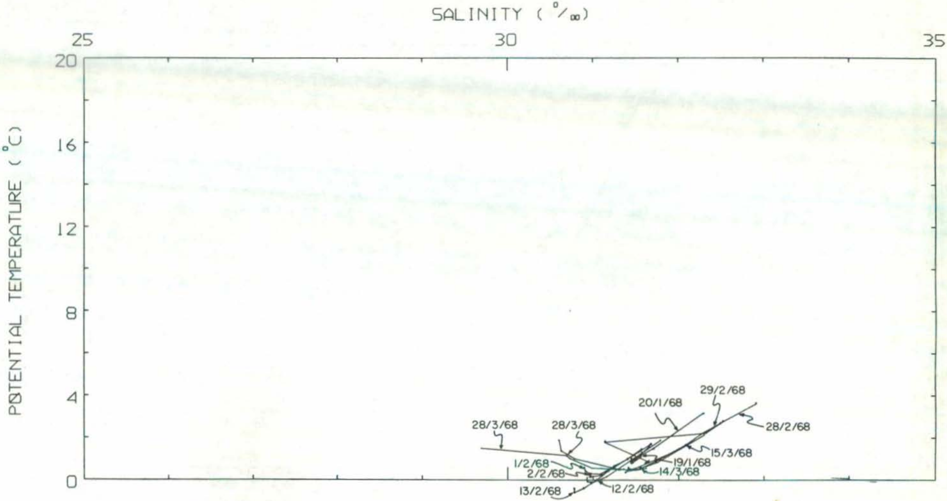


Fig. 3.21.2. T-S diagrams for Station 12.

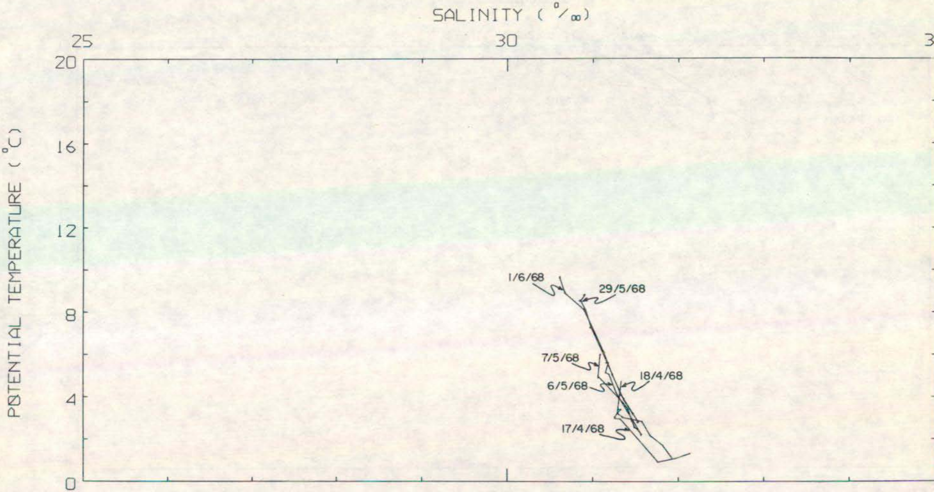


Fig. 3.21.3. T-S diagrams for Station 12.

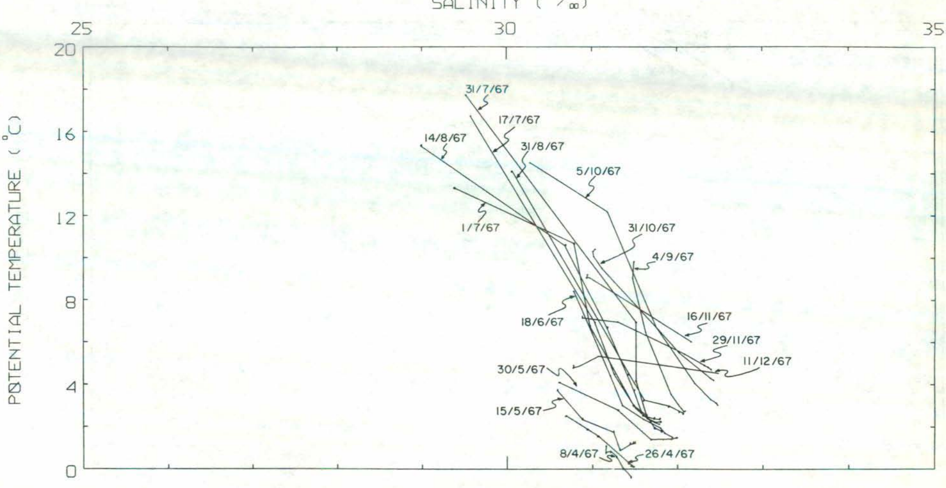


Fig. 3.21.4. T-S diagrams for Station 21.

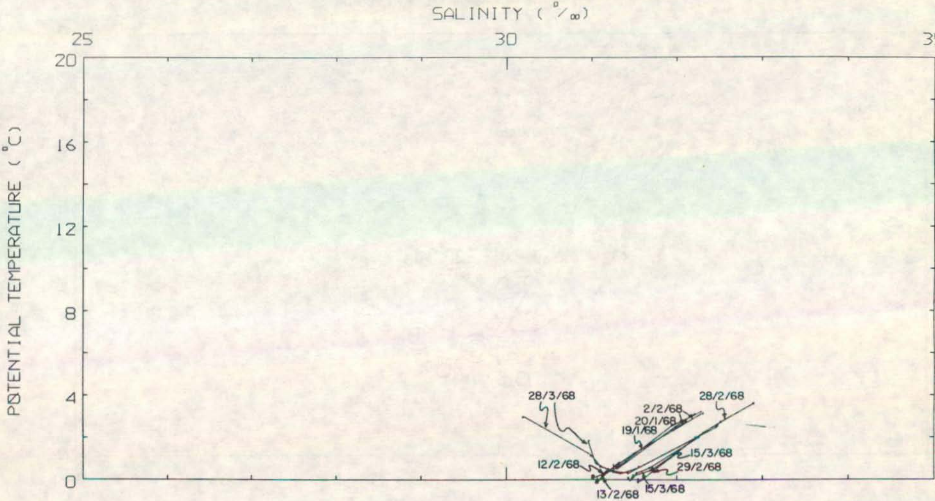


Fig. 3.21.5. T-S diagrams for Station 21.

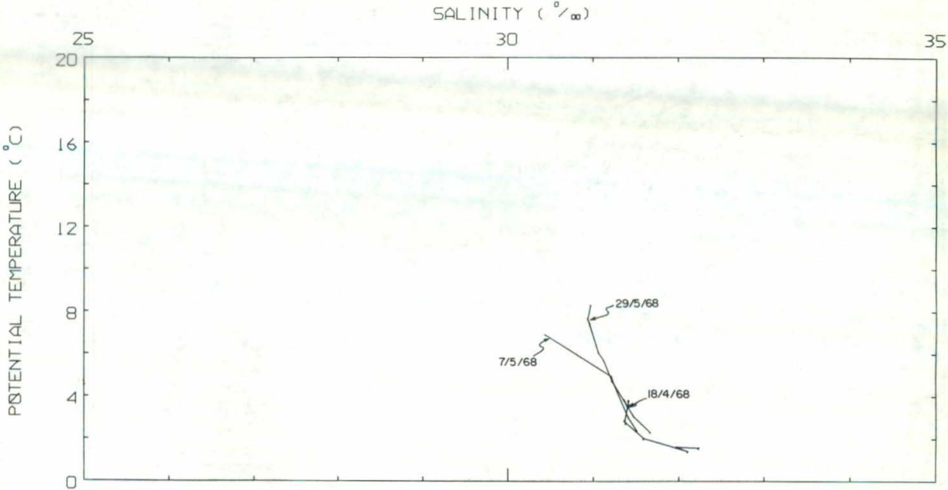


Fig. 3.21.6. T-S diagrams for Station 21.

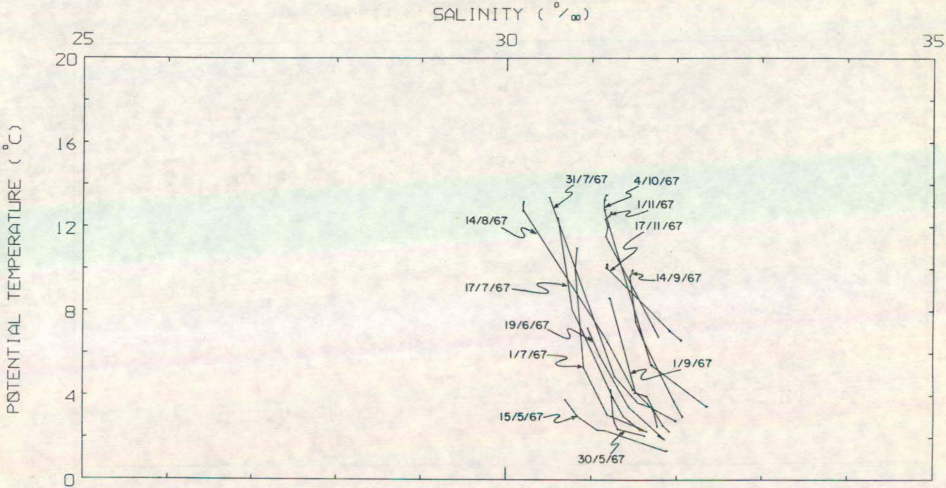


Fig. 3.21.7. T-S diagrams for Station 28.

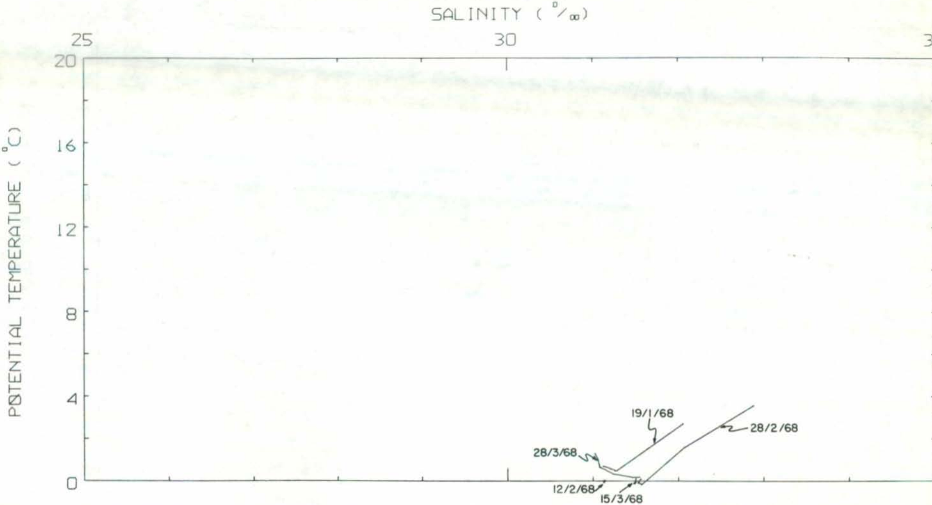


Fig. 3.21.8. T-S diagrams for Station 28.

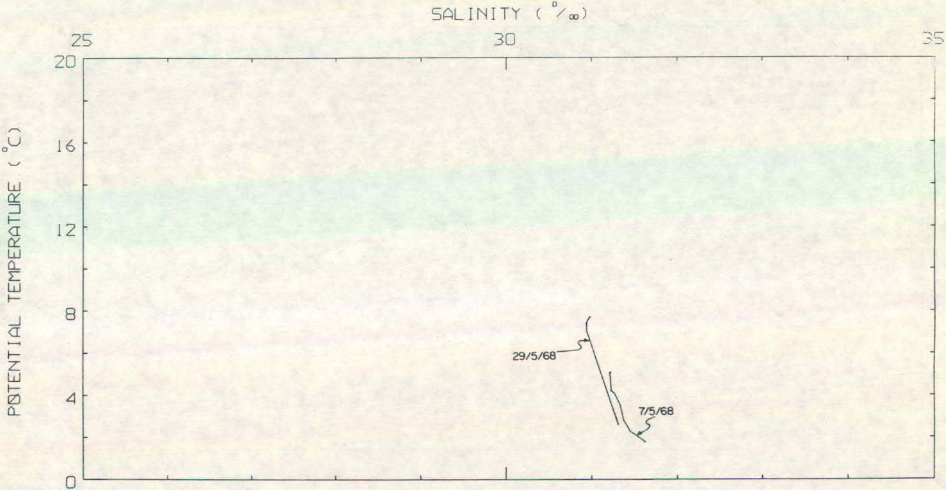


Fig. 3.21.9. T-S diagrams for Station 28.

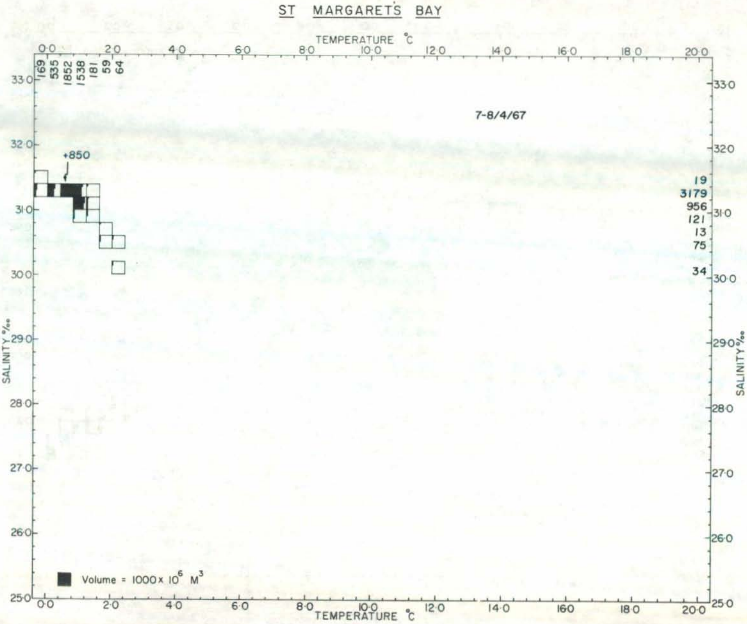


Fig. 3.21.10. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 7-8 April 1967.

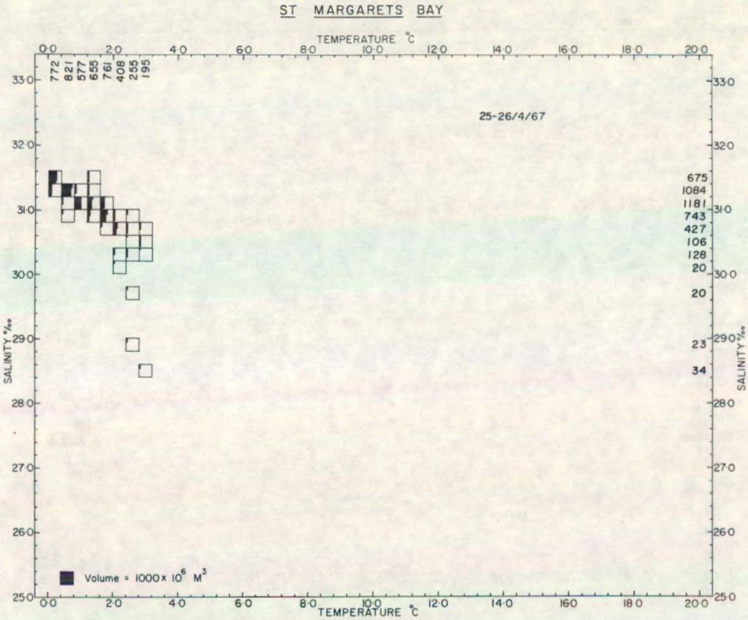


Fig. 3.21.11. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 25-26 April 1967.

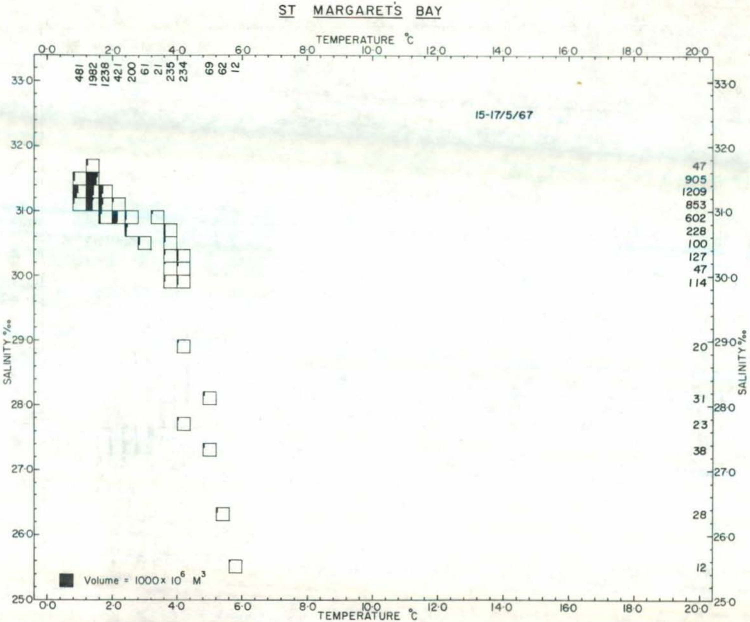


Fig. 3.21.12. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 15-17 May 1967.

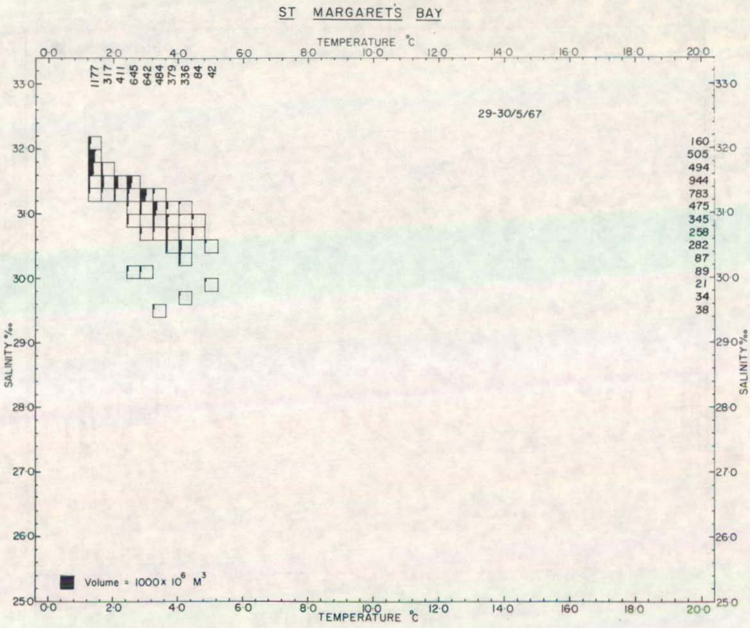


Fig. 3.21.13. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 29-30 May 1967.

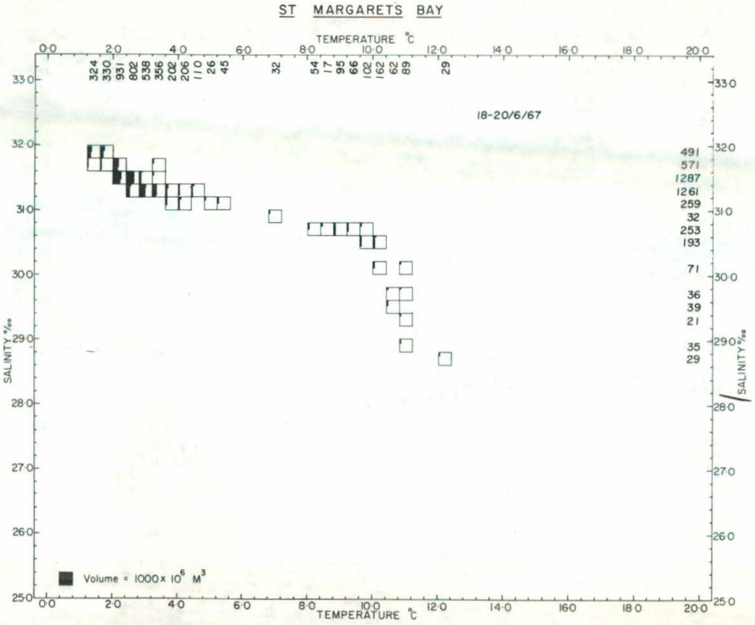


Fig. 3.21.14. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 18-20 June 1967.

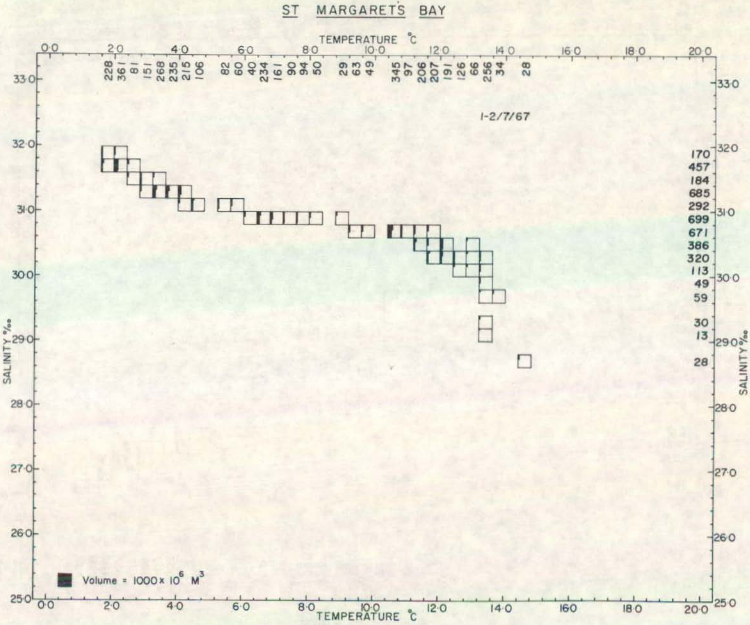


Fig. 3.21.15. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 1-2 July 1967.

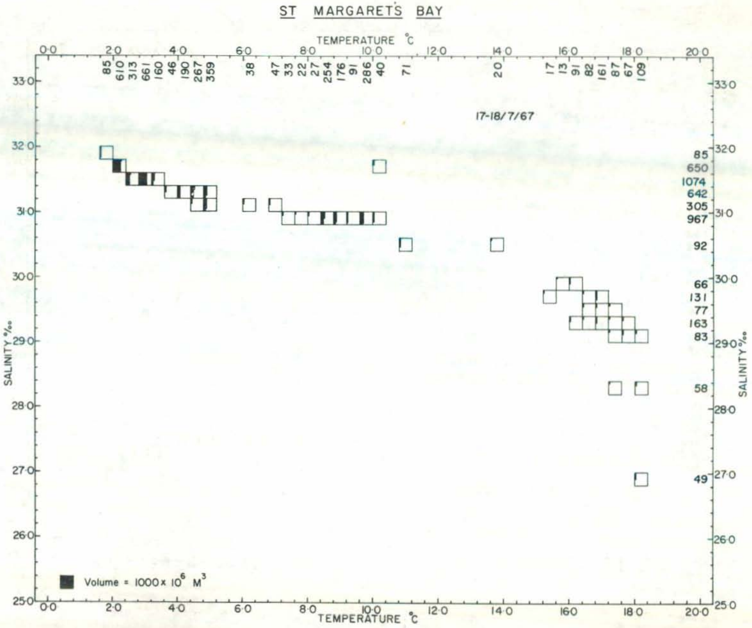


Fig. 3.21.16. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 17-18 July 1967.

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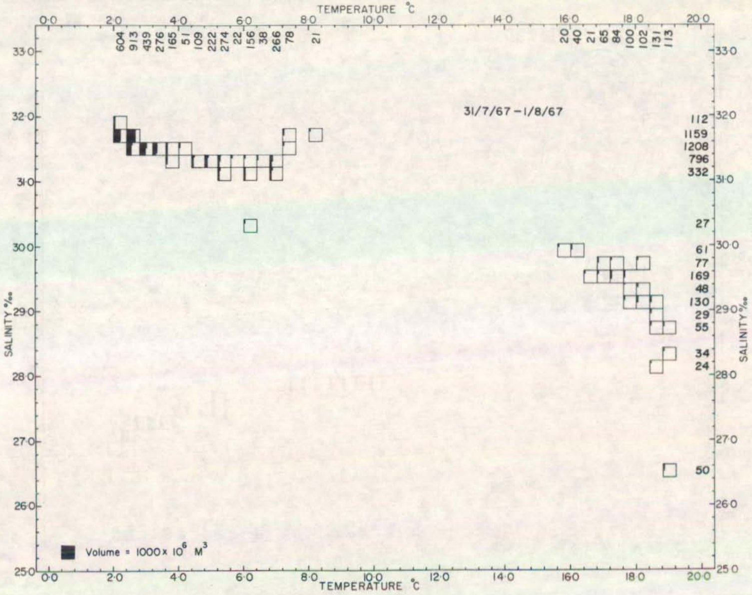

Fig. 3.21.17. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 31 July-1 August 1967.

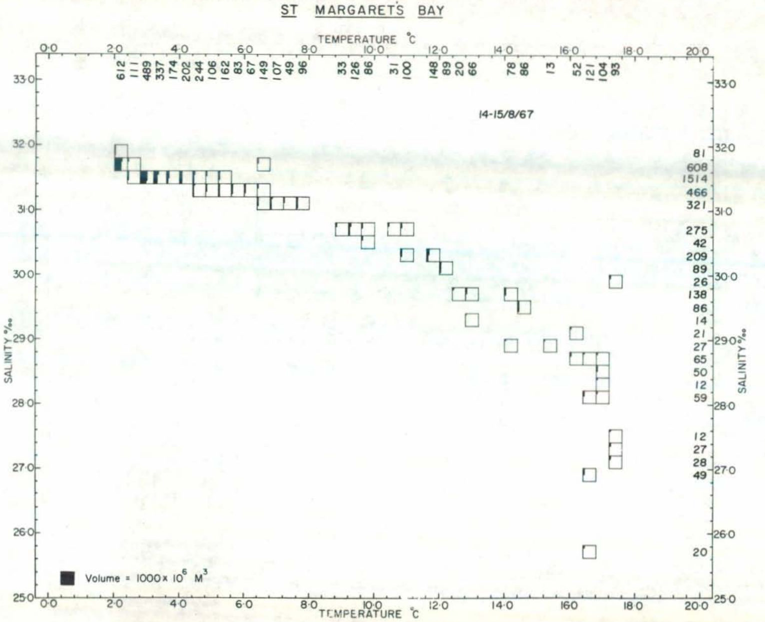

Fig. 3.21.18. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 14-15 August 1967.

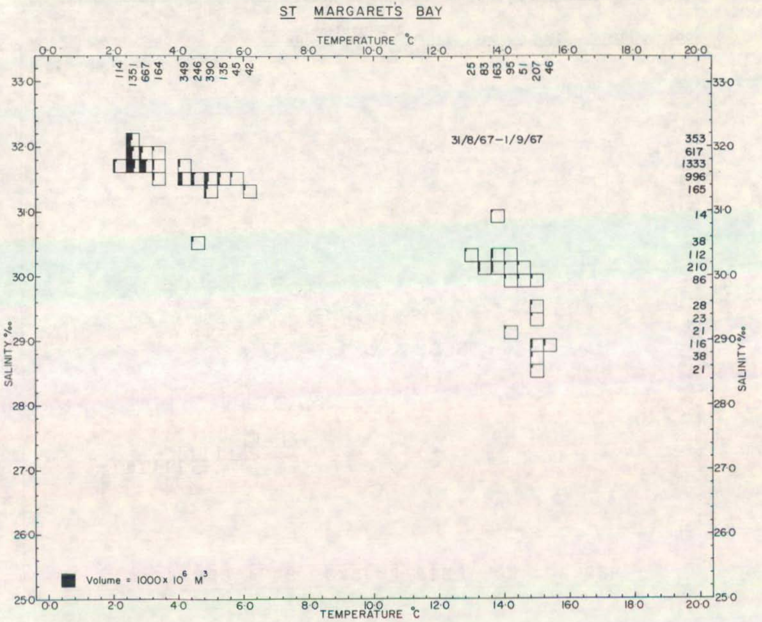

Fig. 3.21.19. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 31 August-1 September 1967.

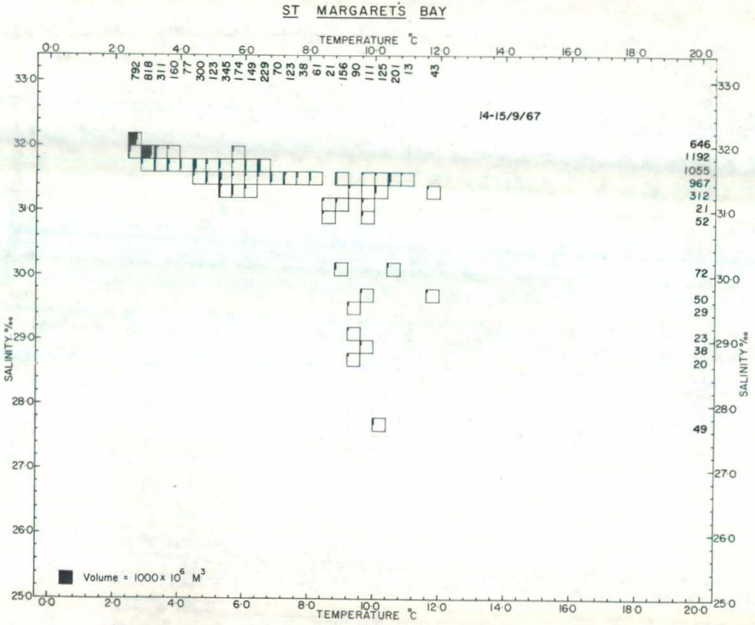

Fig. 3.21.20. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 14-15 September 1967.

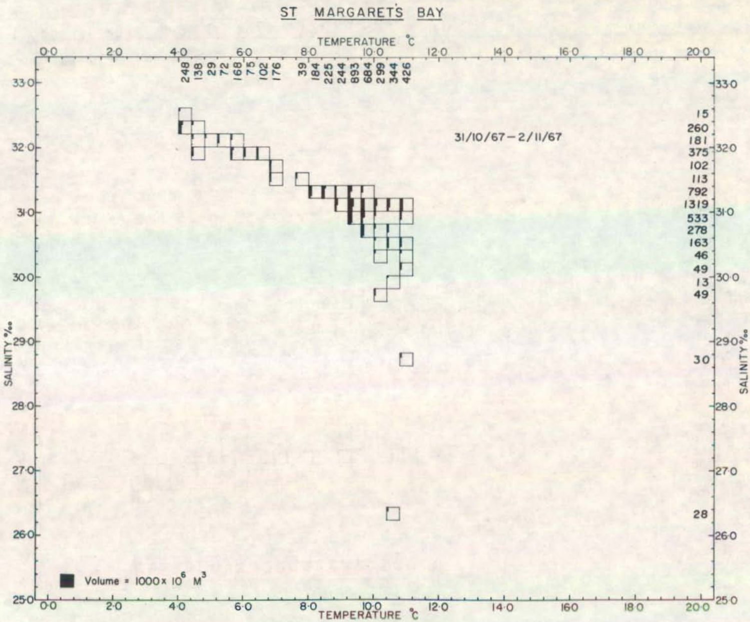

Fig. 3.21.21. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 31 October-2 November 1967.

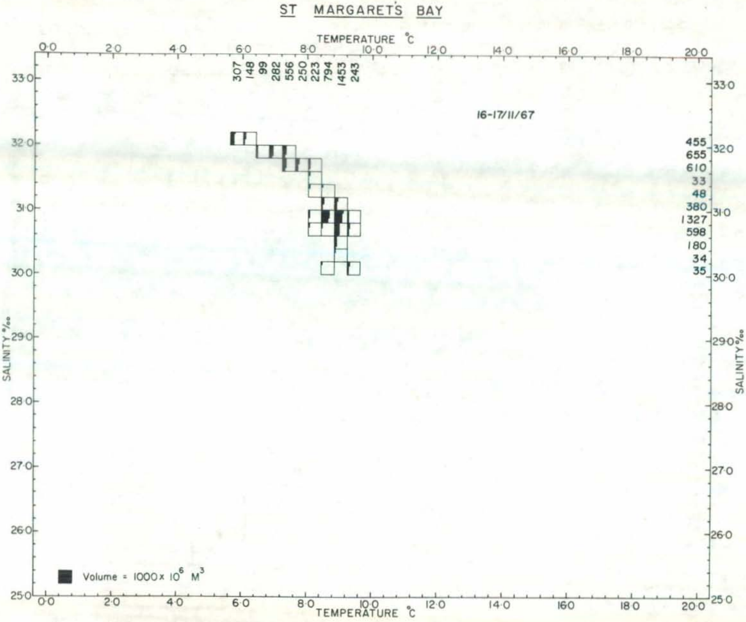

Fig. 3.21.22. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 16-17 November 1967.

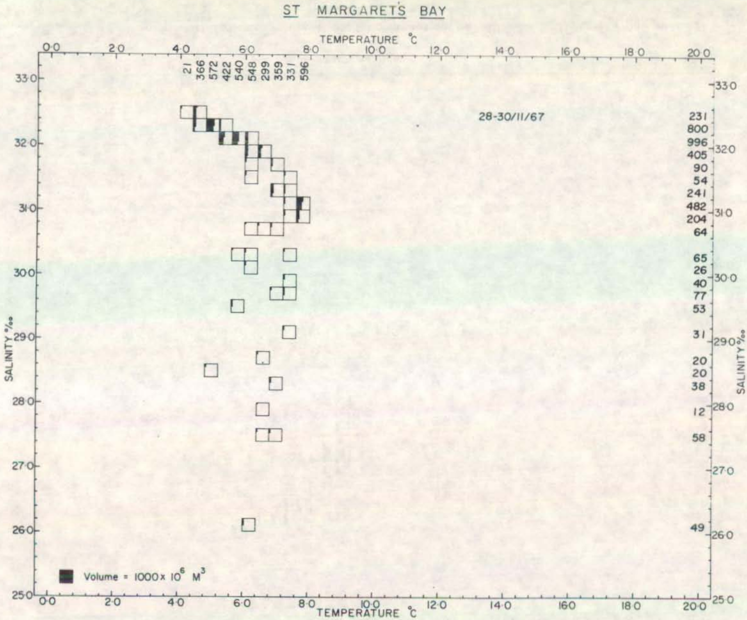

Fig. 3.21.23. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 28-30 November 1967.

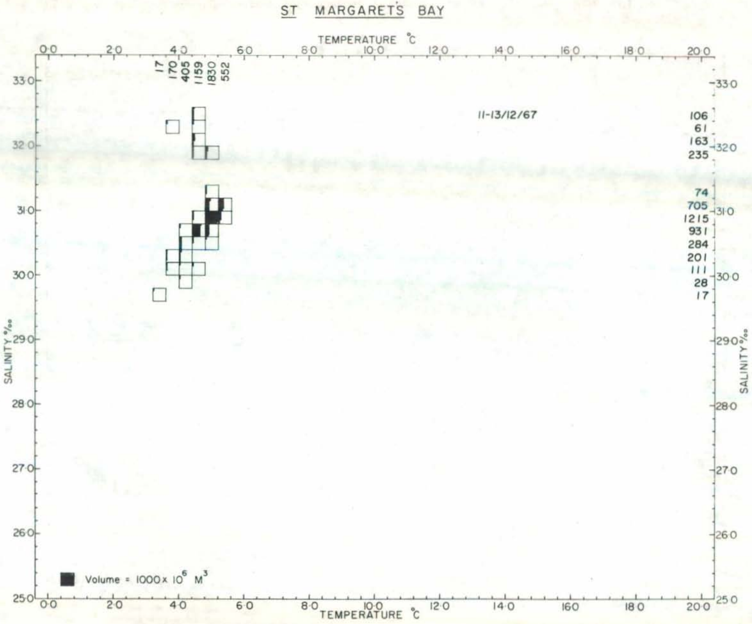

Fig. 3.21.24. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 11-13 December 1967.

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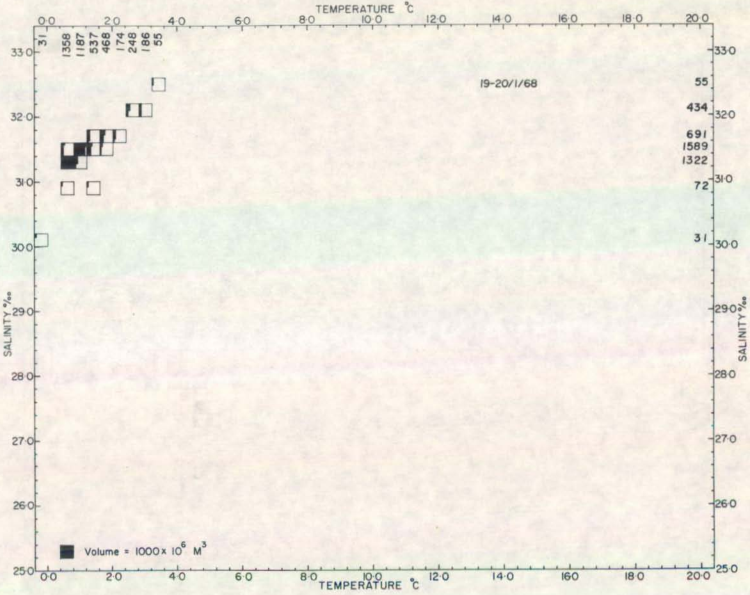

Fig. 3.21.25. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 19-20 January 1968.

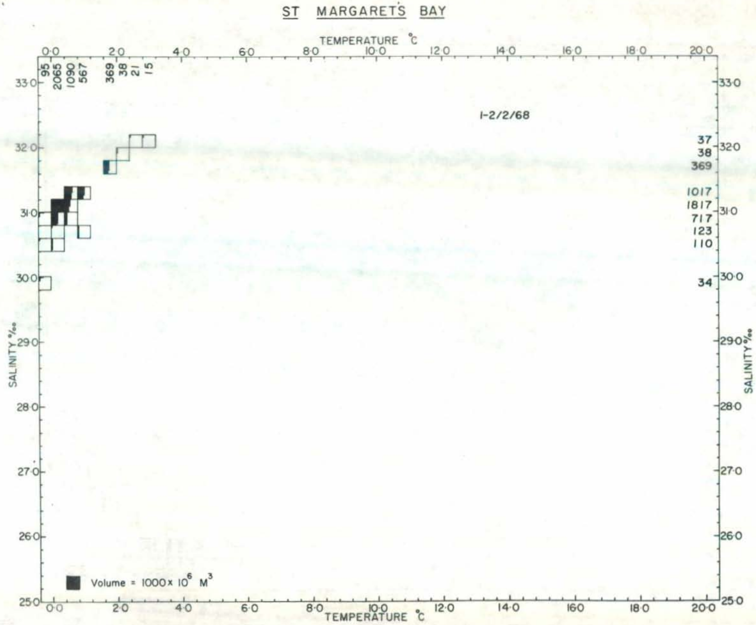

Fig. 3.21.26. **Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 1-2 February 1968.**

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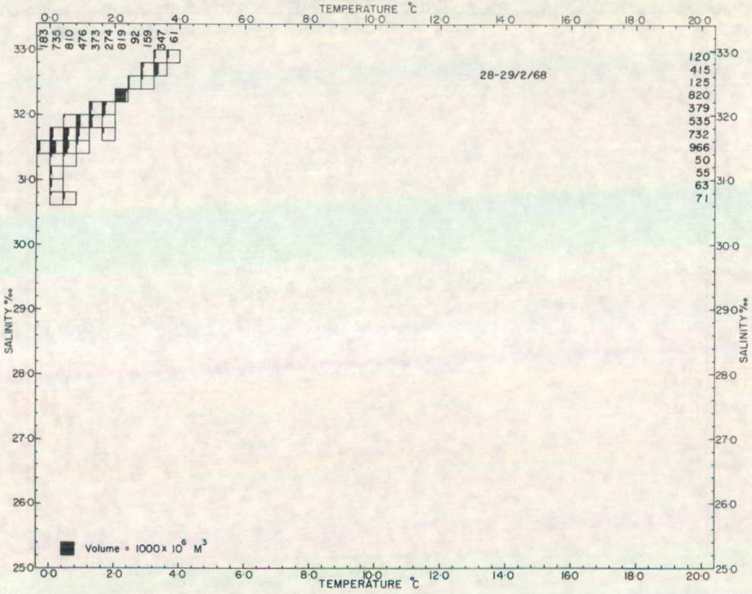

Fig. 3.21.27. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 28-29 February 1968.

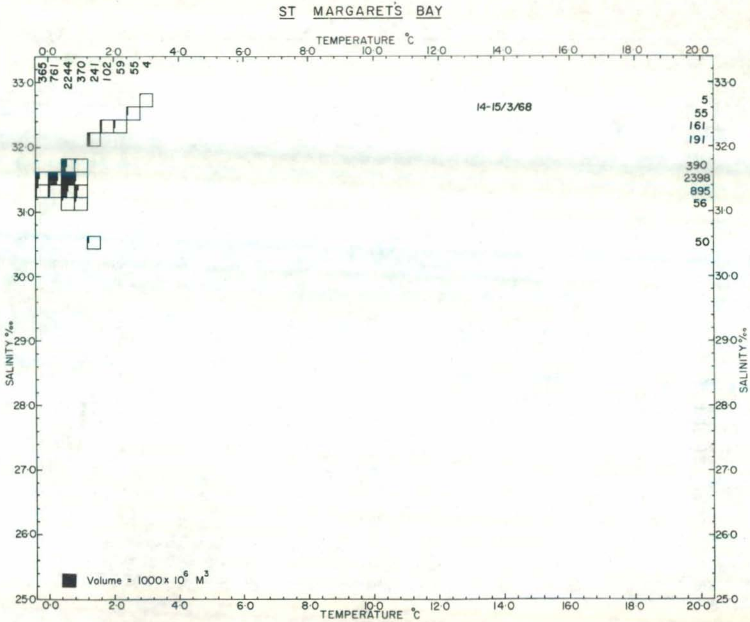

Fig. 3.21.28. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 14-15 March 1968.

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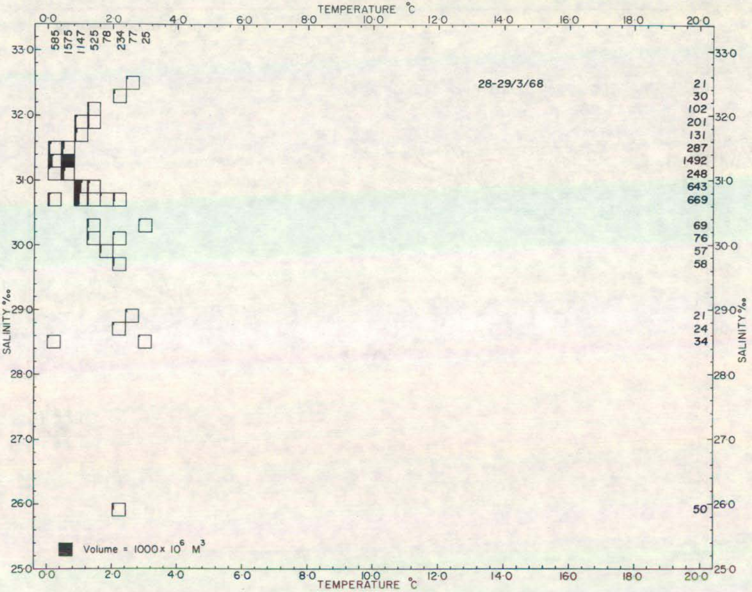

Fig. 3.21.29. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 28-29 March 1968.

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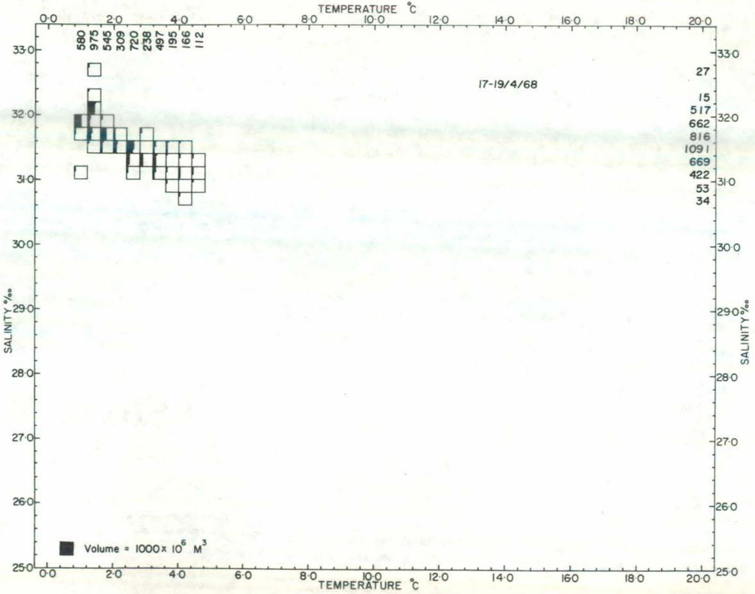

Fig. 3.21.30. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 17-19 April 1968.

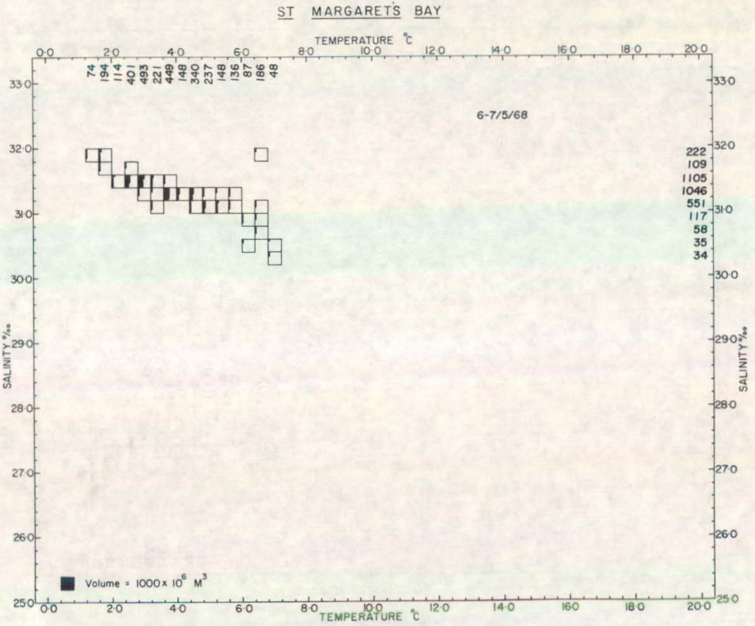

Fig. 3.21.31. Bivariate distribution of volume among temperatures and salinities for St. Margaret's Bay on 6-7 May 1968.

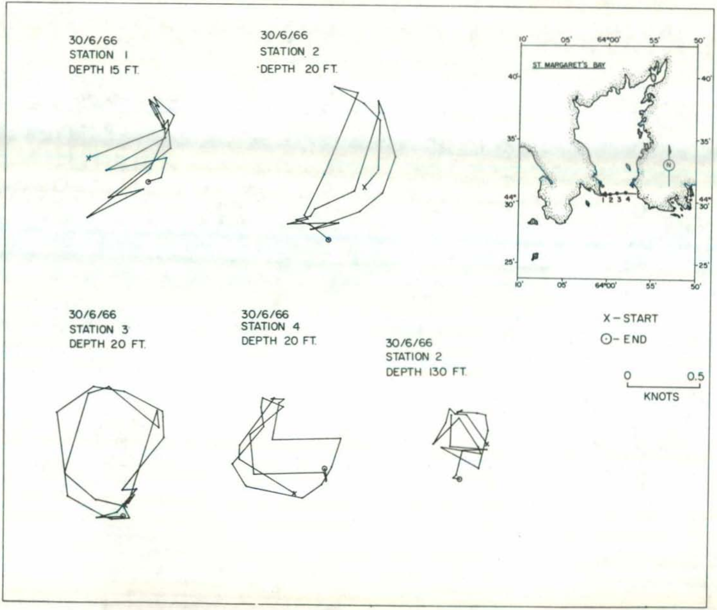

Fig. 3.22. Progressive vector diagram of observed currents at hourly intervals during 1966.

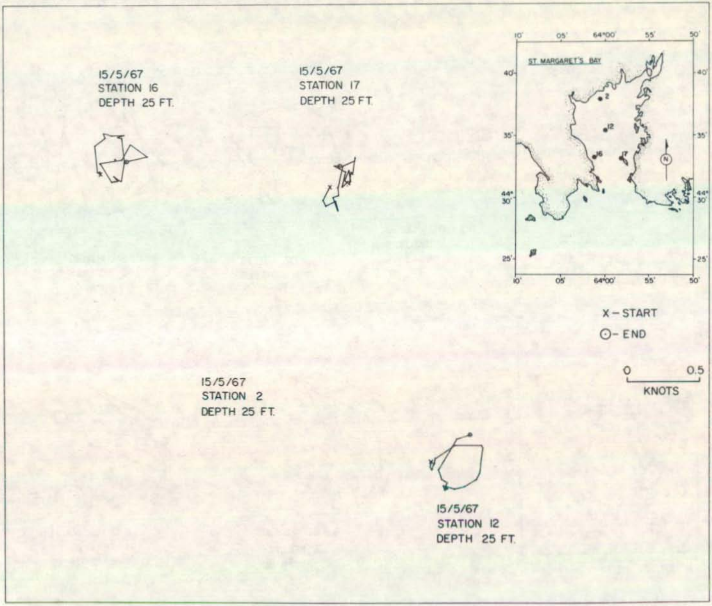

Fig. 3.23. Progressive vector diagram of observed currents at hourly intervals during 1967.

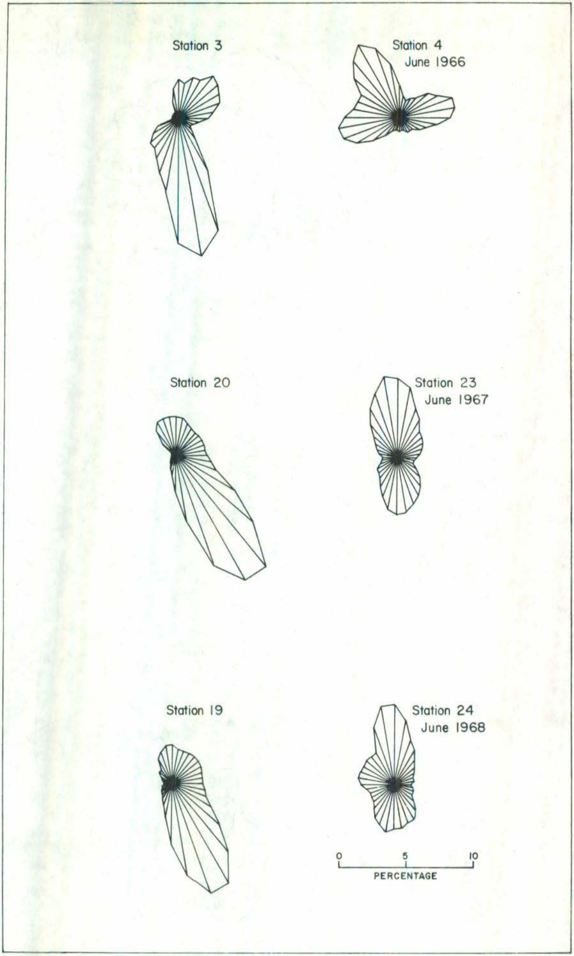

Fig. 3.24.1. Percentage distribution of current direction at depth of 20 feet, 1966-1968.

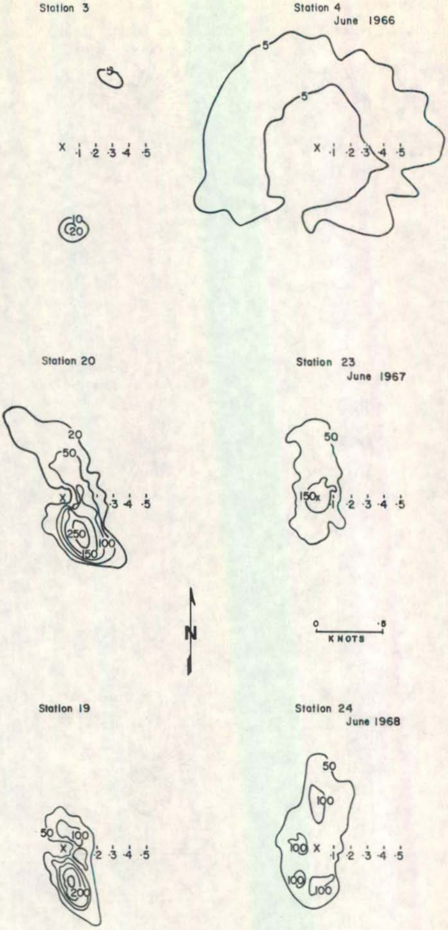

Fig. 3.24.2. Frequency density of current at depth of 20 feet, 1966-1968.

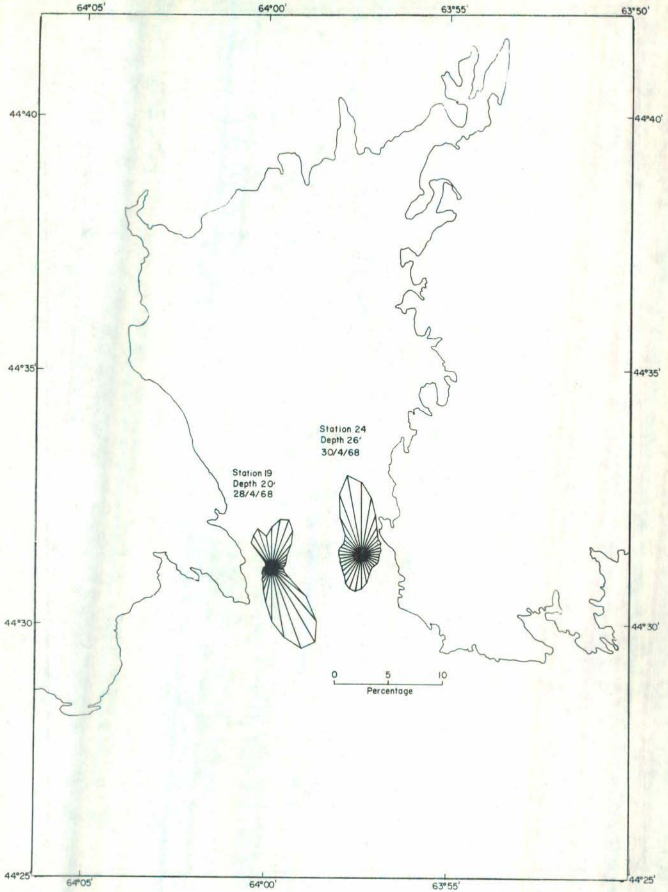

Fig. 3.25.1. Percentage distribution of current direction at the surface at the sides of the mouth of the Bay during April 1968.

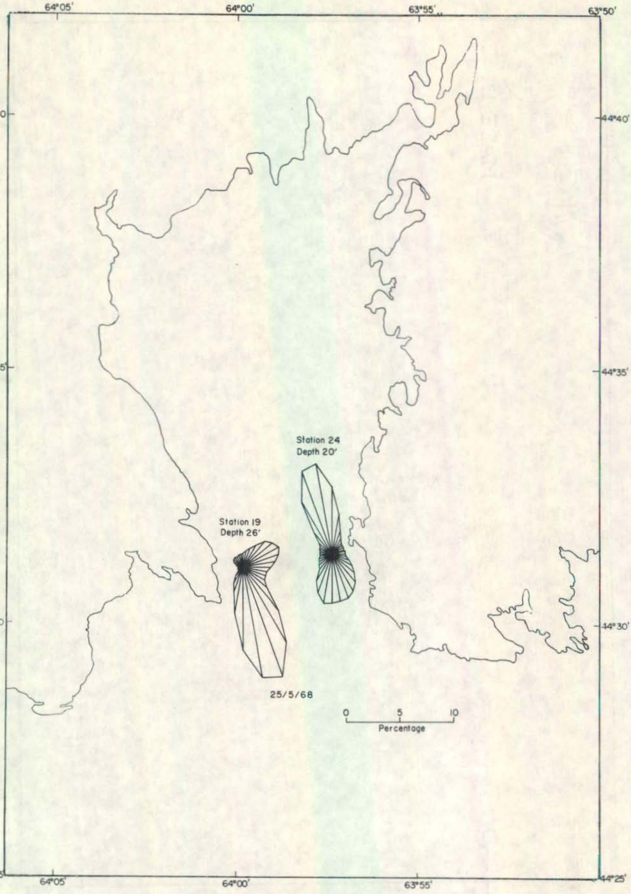

Fig. 3.25.2. Percentage distribution of current direction at the surface at the sides of the mouth of the Bay during May 1968.

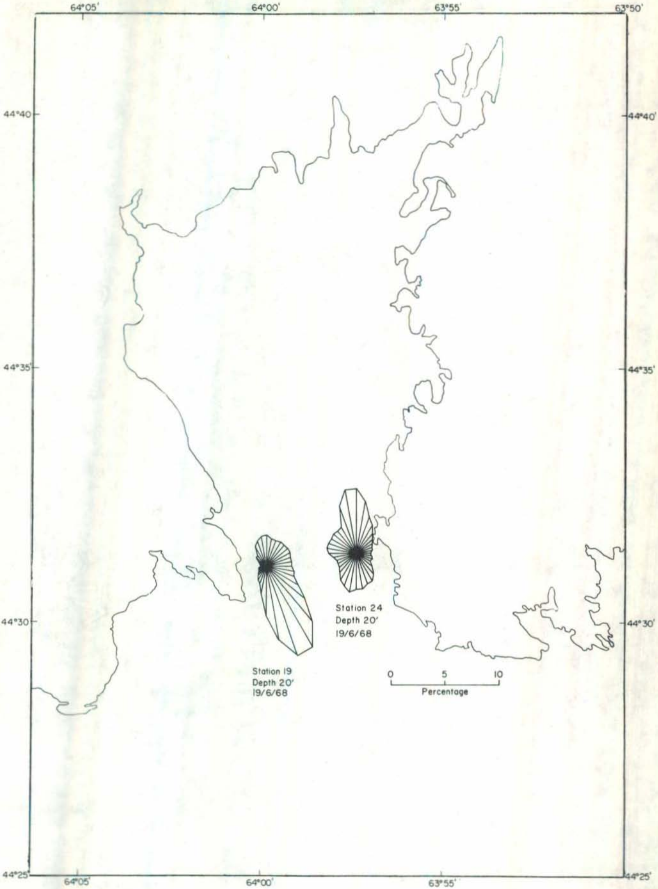

Fig. 3.25.3. **Percentage distribution of current direction at the surface at the sides of the mouth of the Bay during June 1968.**

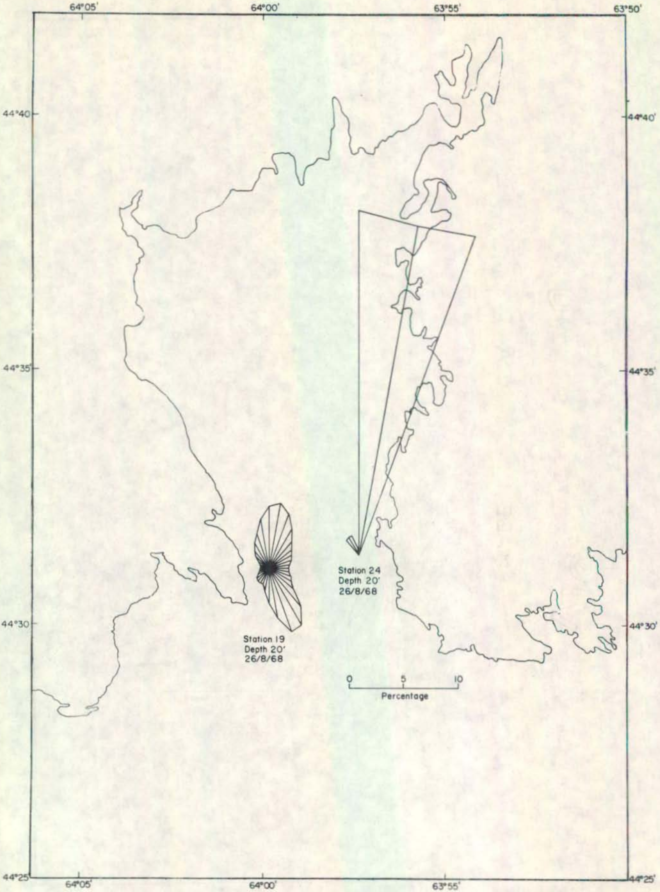

Fig. 3.25.4. **Percentage distribution of current direction at the surface at the sides of the mouth of the Bay during August 1968.**

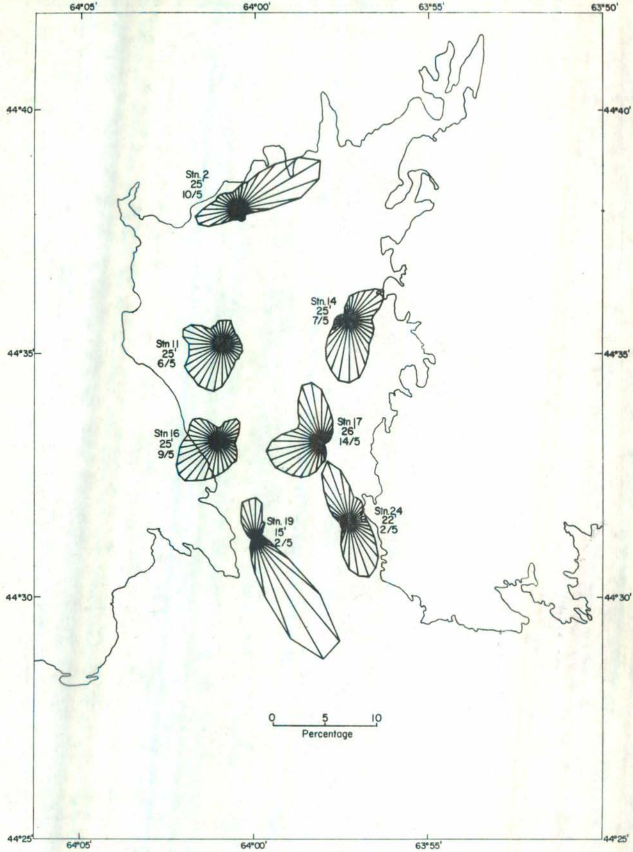

Fig. 3.26.1. Percentage distribution of current direction at the surface layer during May 1967.

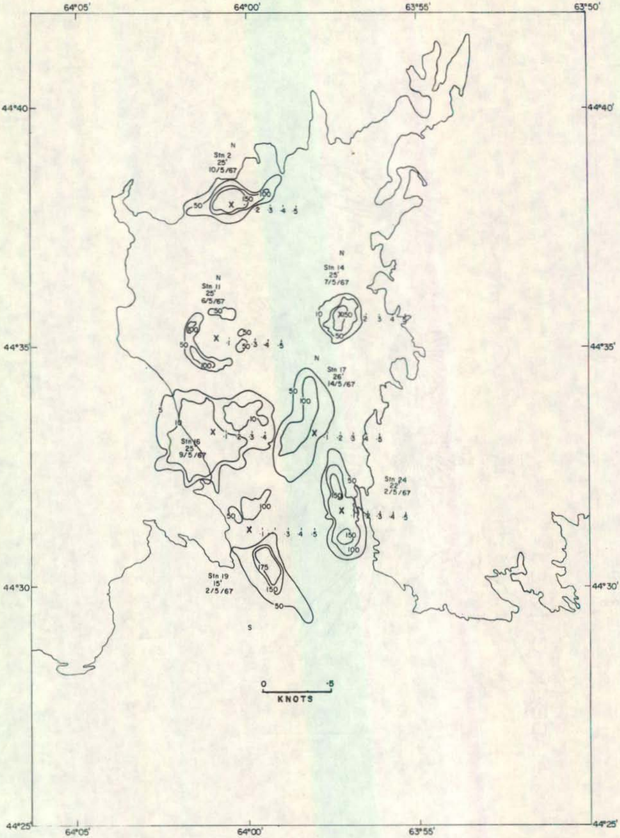

Fig. 3.26.2. Frequency density of surface current during May 1967.

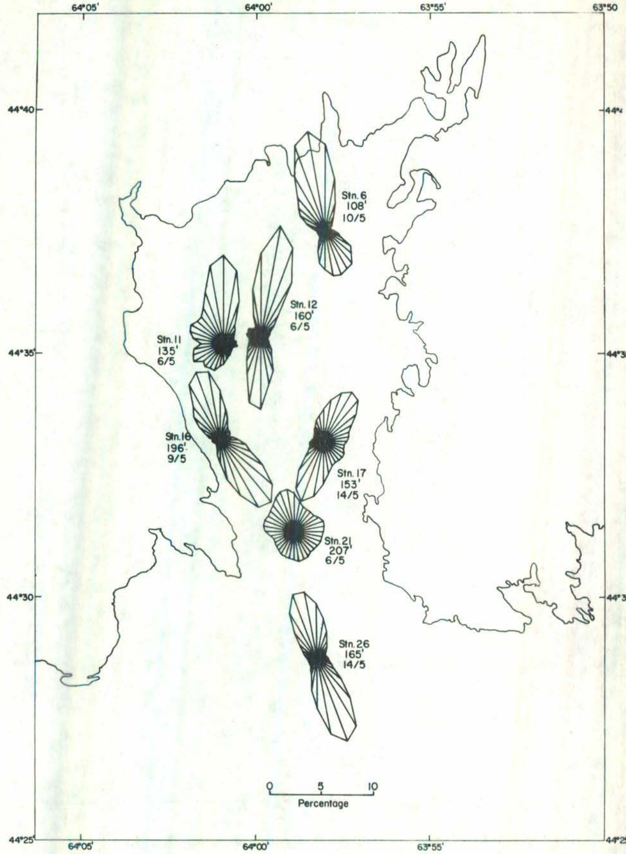

Fig. 3.26.3. Percentage distribution of current direction at the bottom layer during May 1967.

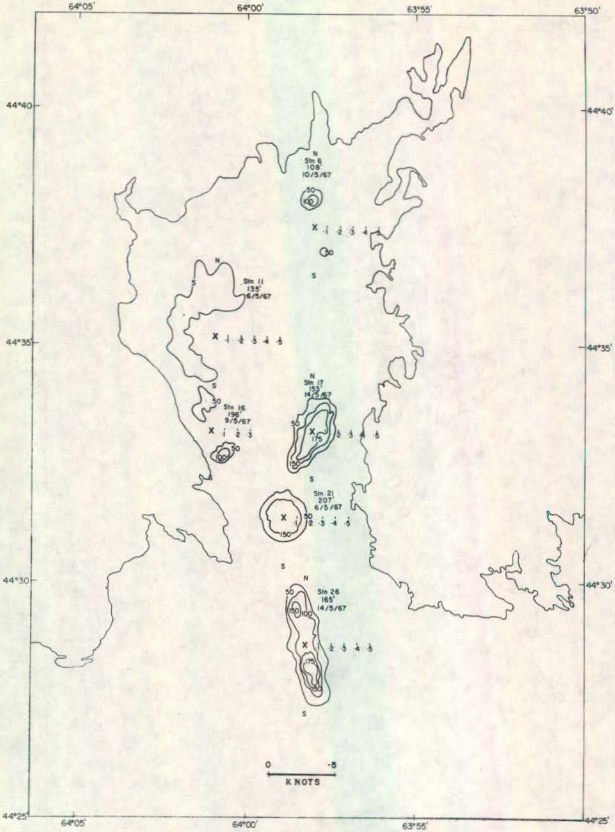

Fig. 3.26.4. Frequency density of bottom current during May 1967.

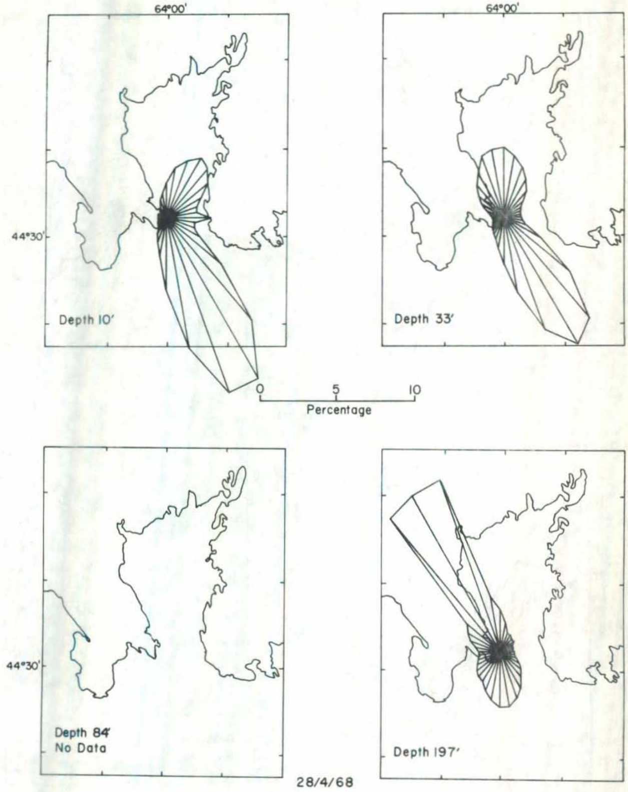

Fig. 3.27.1. Percentage distribution of current direction at Station 19 at different depths on 28 April 1968.

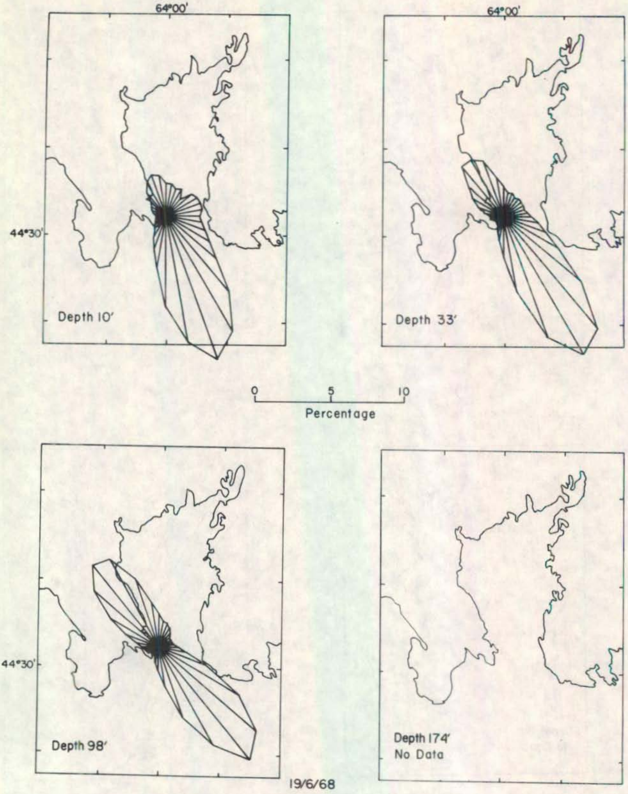

Fig. 3.27.2. Percentage distribution of current direction at Station 19 at different depths on 19 June 1968.

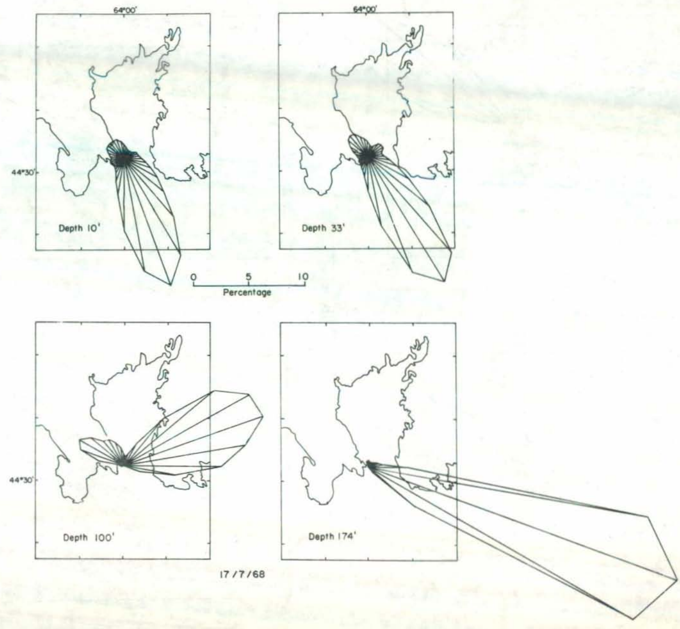

Fig. 3.27.3. Percentage distribution of current direction at Station 19 at different depths on 17 July 1968.

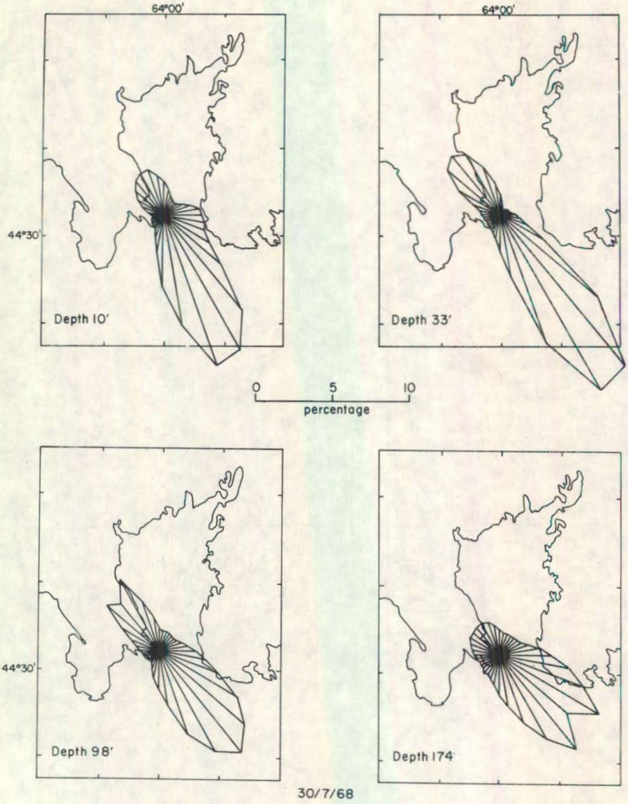

Fig. 3.27.4. Percentage distribution of current direction at Station 19 at various depths on 30 July 1968.

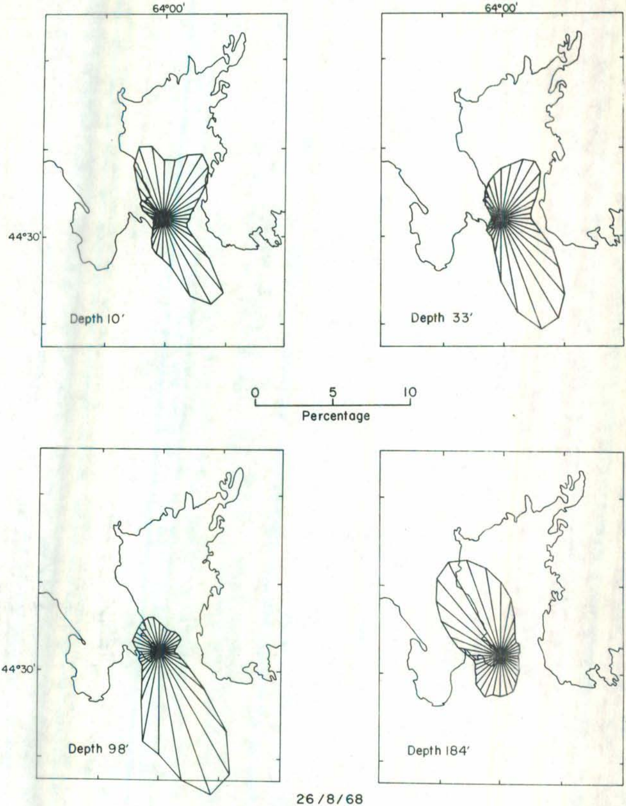

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Fig. 3.27.5. Percentage distribution of current direction at Station 19 at different depths on 26 August 1968.

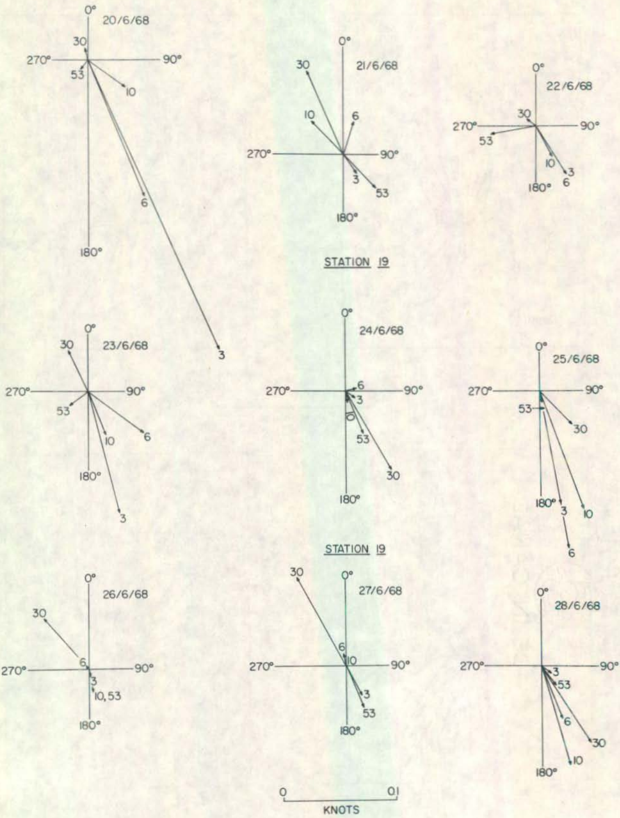

Fig. 3.28.1. Variation of residual currents at each depth for Station 19 during period 20 June 1968 to 28 June 1968.

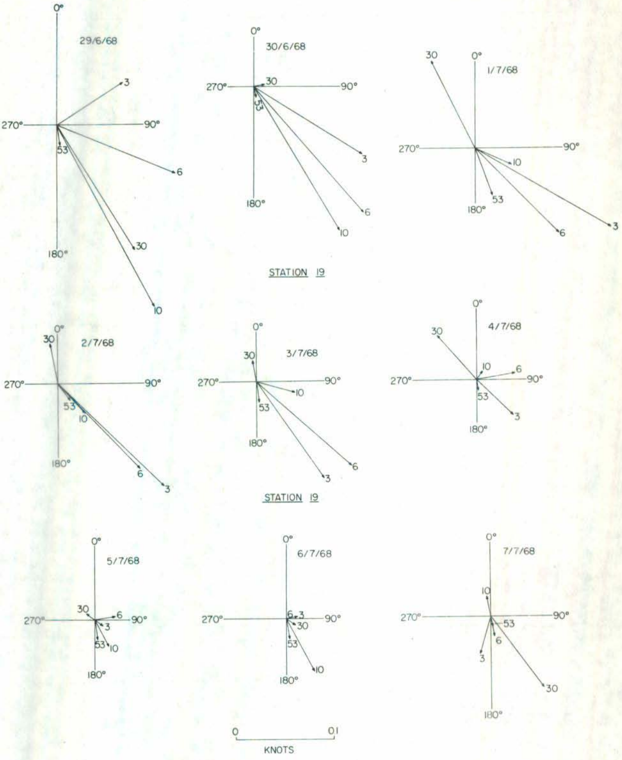

Fig. 3.28.2. Variation of residual currents at each depth for Station 19 during period 29 June 1968 to 7 July 1968.

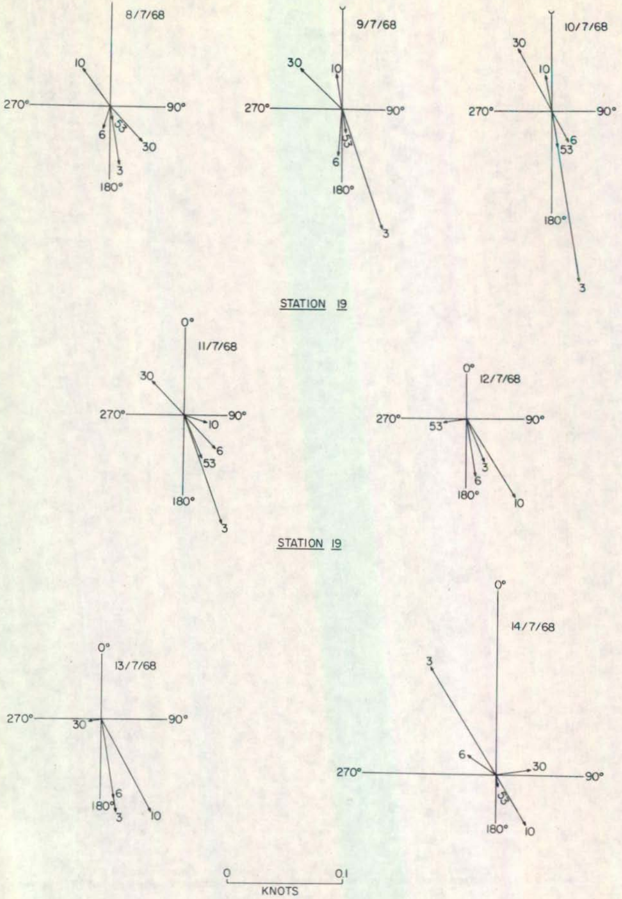

Fig. 3.28.3. Variation of residual currents at each depth for Station 19 during period 8 July 1968 to 14 July 1968.

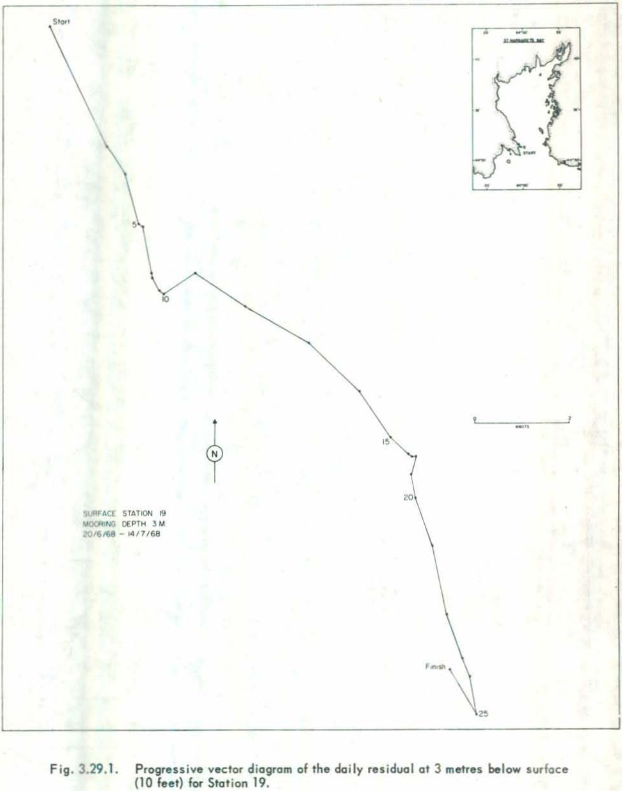

Fig. 3.29.1. Progressive vector diagram of the daily residual at 3 metres below surface (10 feet) for Station 19.

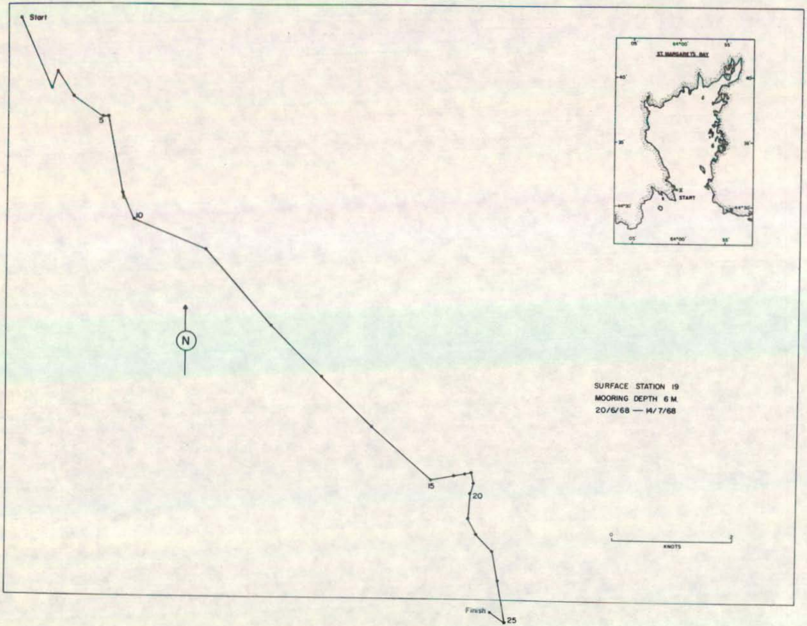

Fig. 3.29.2. Progressive vector diagram of daily residual at 6 metres below surface (20 feet) for Station 19.

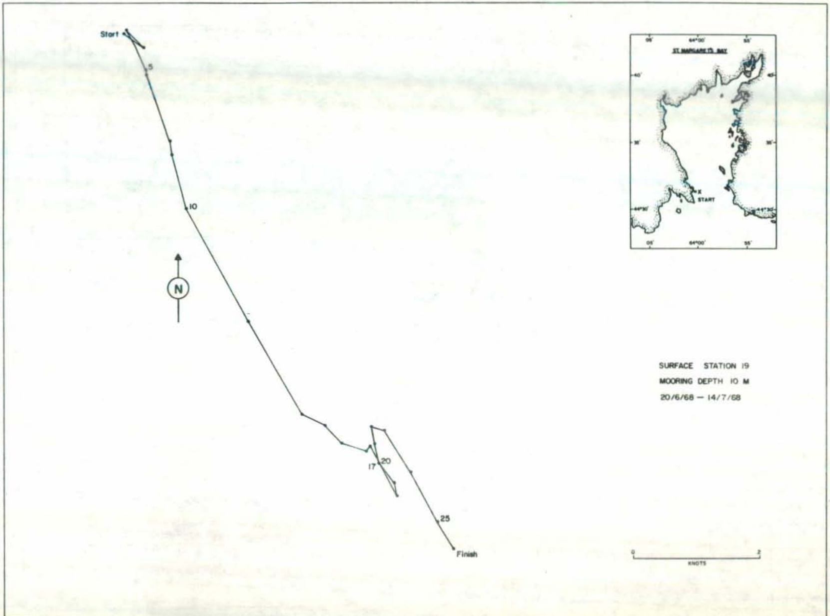

Fig. 3.29.3. Progressive vector diagram of daily residual at 10 metres below surface (33 feet) for Station 19.

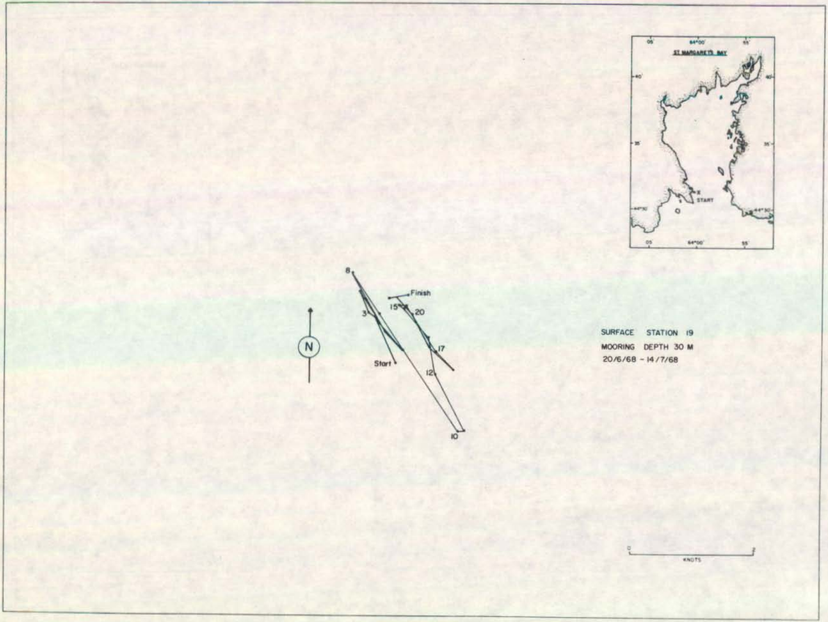

Fig. 3.29.4. Progressive vector diagram of daily residual at 30 metres below surface (100 feet) for Station 19.

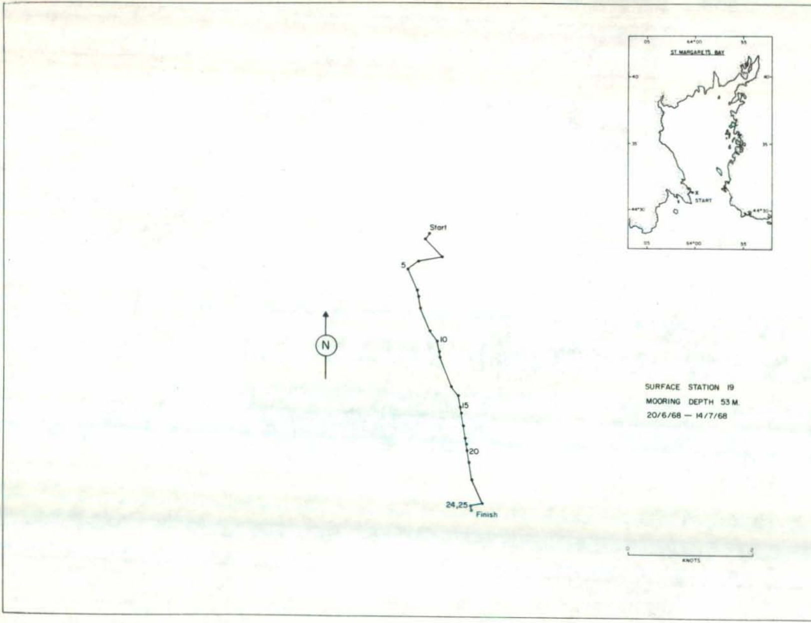

Fig. 3.29.5. Progressive vector diagram of daily residual at 53 metres below surface (174 feet) for Station 19.

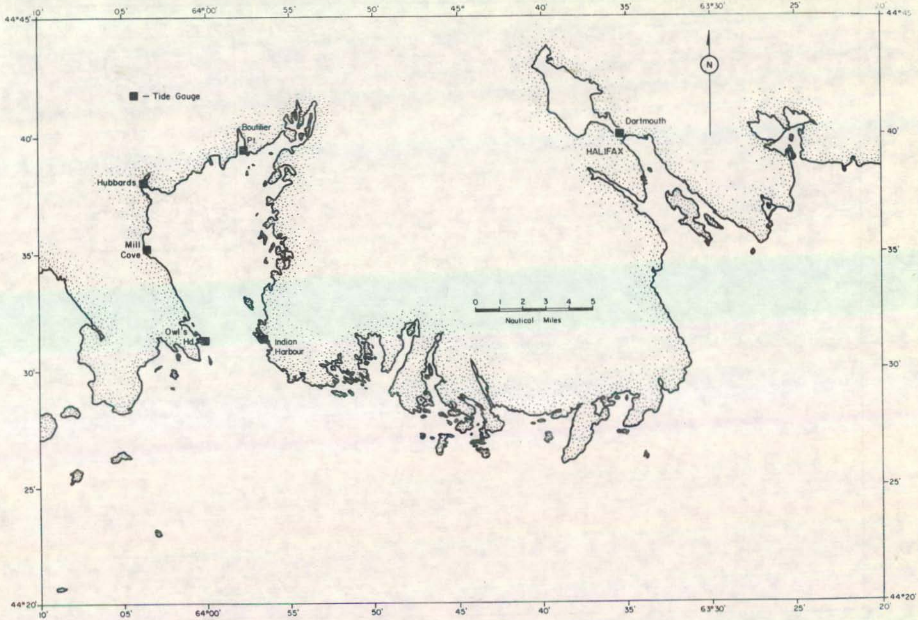

Fig. 3.30. Location of tide gauges in St. Margaret's Bay and Halifax Harbour.

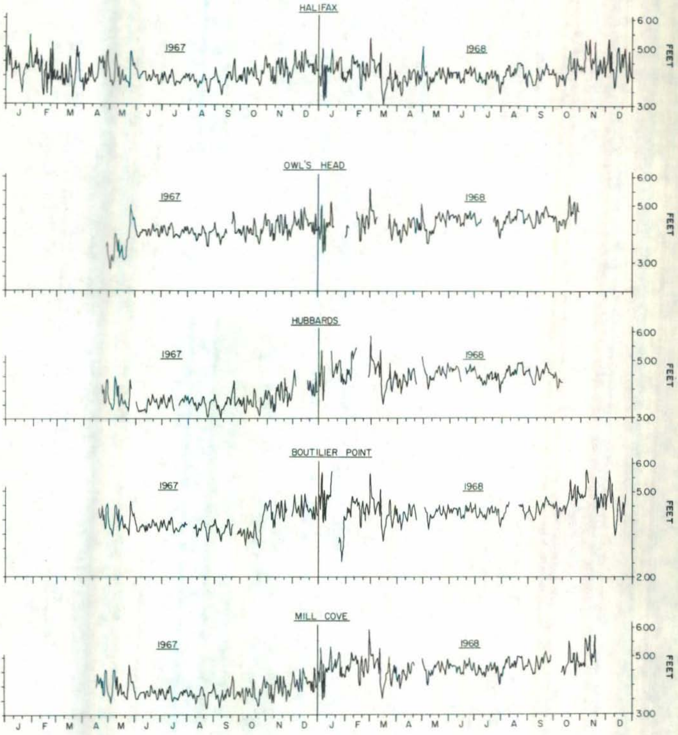

Fig. 3.31. Daily mean sea level for St. Margaret's Bay and Halifax Harbour.

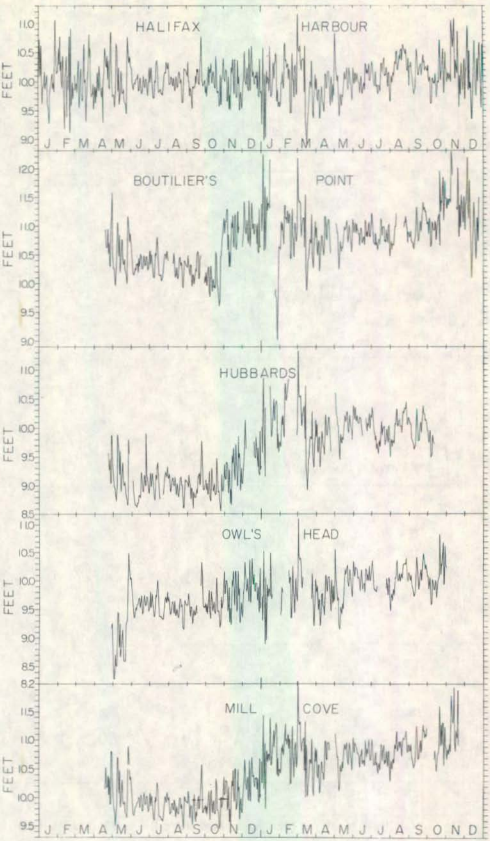

Fig. 3.32. **Daily residual heights of sea level for St. Margaret's Bay and Halifax Harbour.**

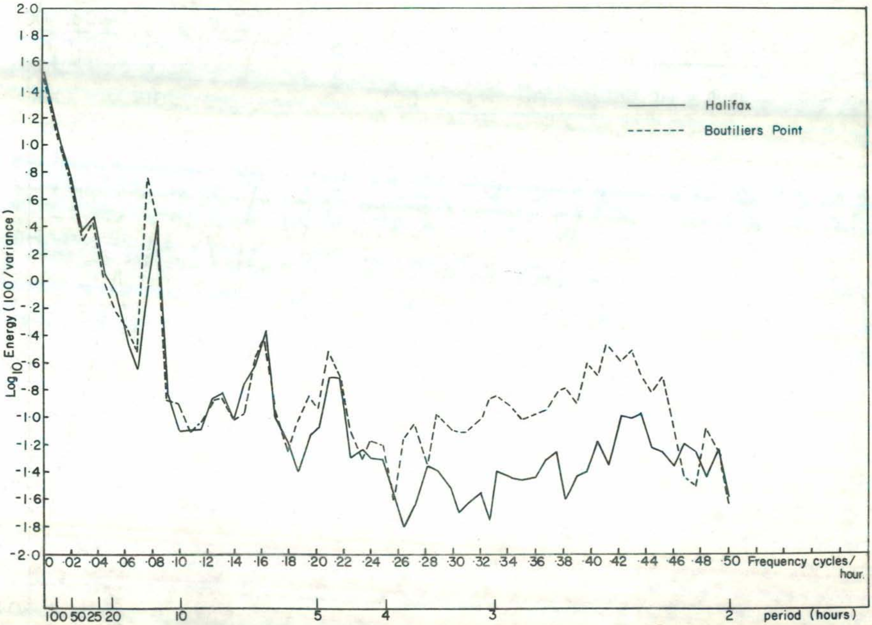

Fig. 3.33. Power spectrum of residual heights at Boutilier's Point and Halifax Harbour.

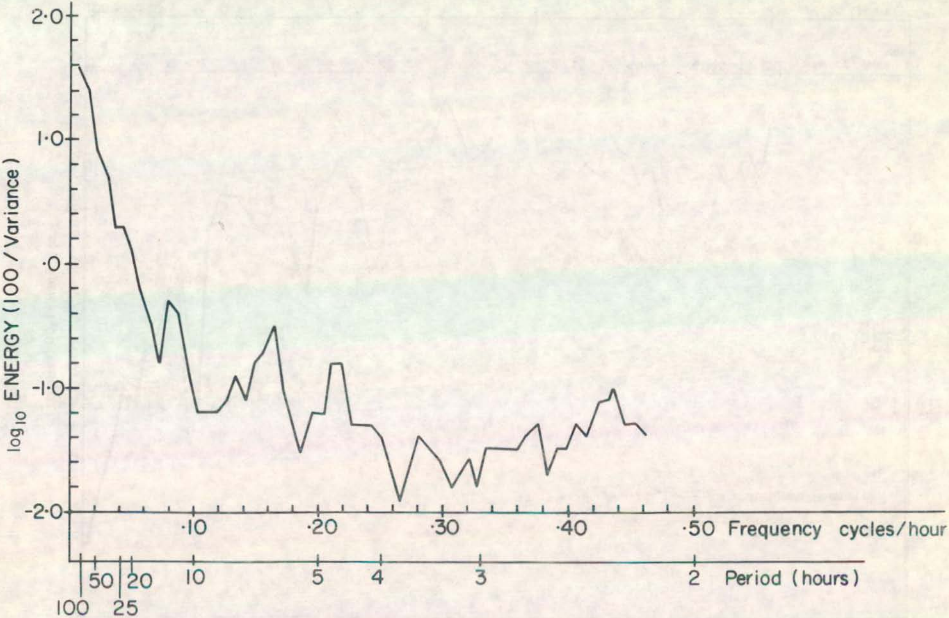

Fig. 3.34. Power spectrum of residual heights at Halifax Harbour for one year's data.

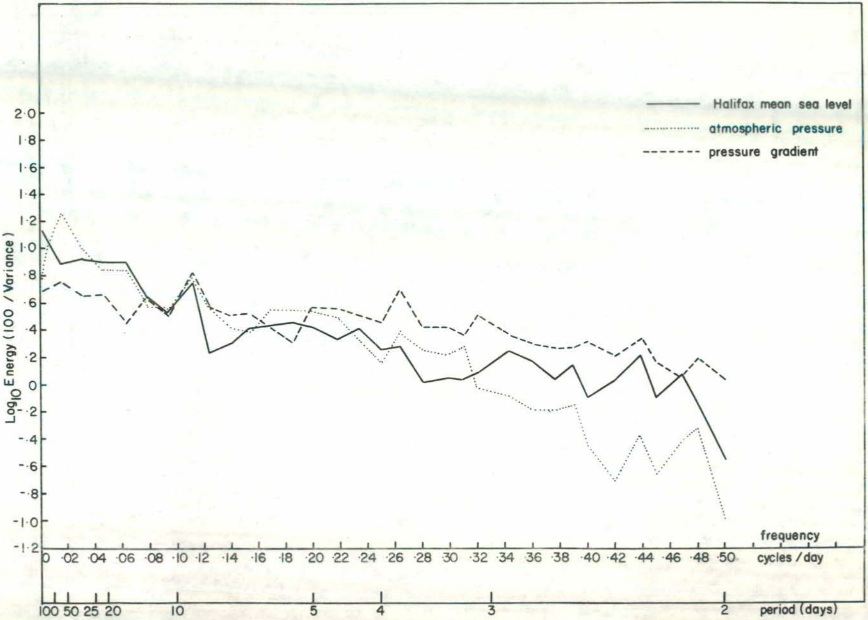

Fig. 3.35. Power spectrum of daily mean sea level at Halifax Harbour, atmospheric pressure at Shearwater and pressure gradient between Shearwater and Western Head.

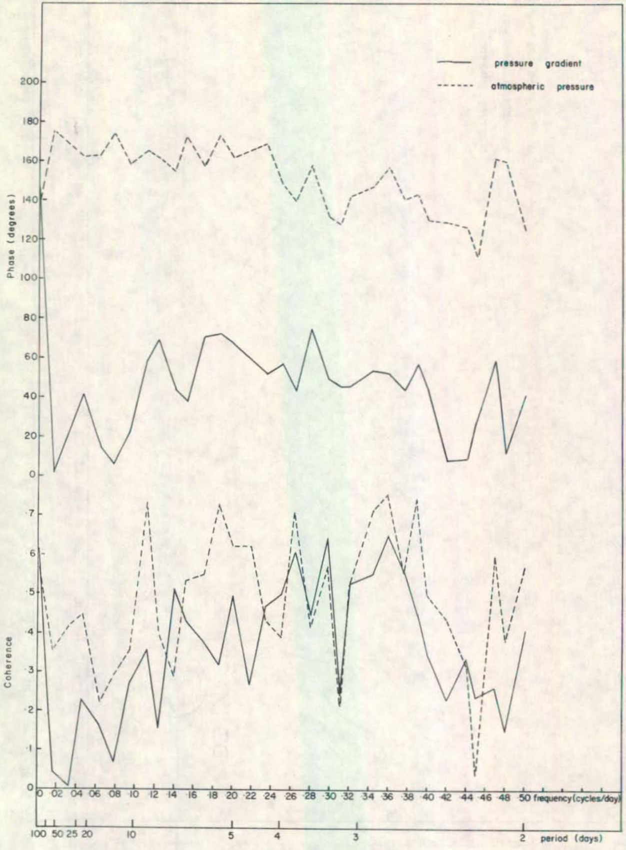

Fig. 3.36. Coherence and phaselag between daily mean sea level at Halifax and atmospheric pressure at Shearwater, and pressure gradient between Shearwater and Western Head.

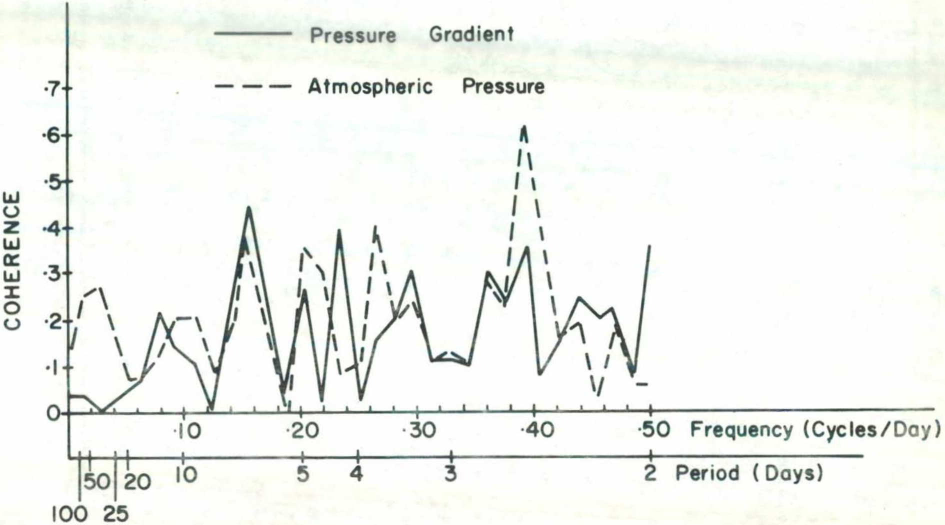

Fig. 3.37. Coherence between daily residual heights at Halifax and atmospheric pressure at Shearwater, and pressure gradient between Shearwater and Western Head.

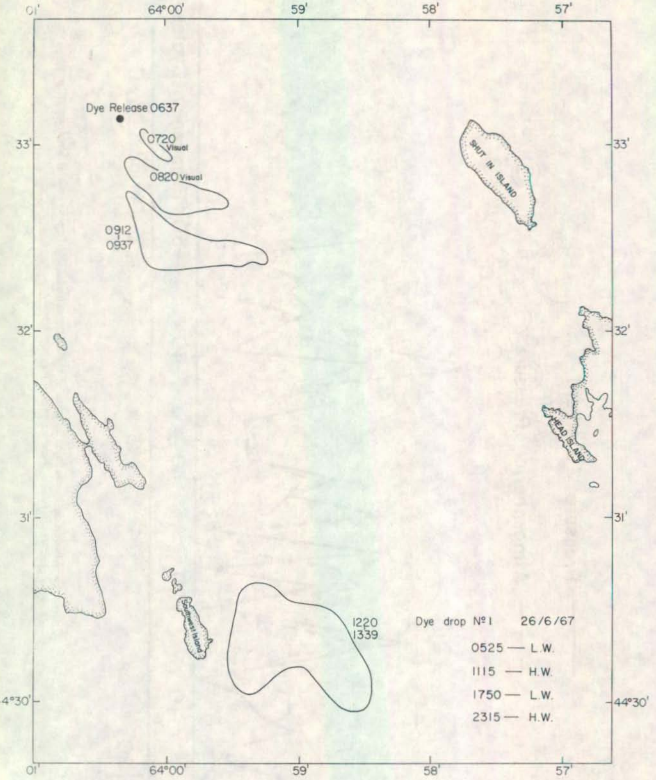

Fig. 3.38. Sketches of dye patches based on visual and fluorometer measurements of experiment No. 1 on 26 June 1967.

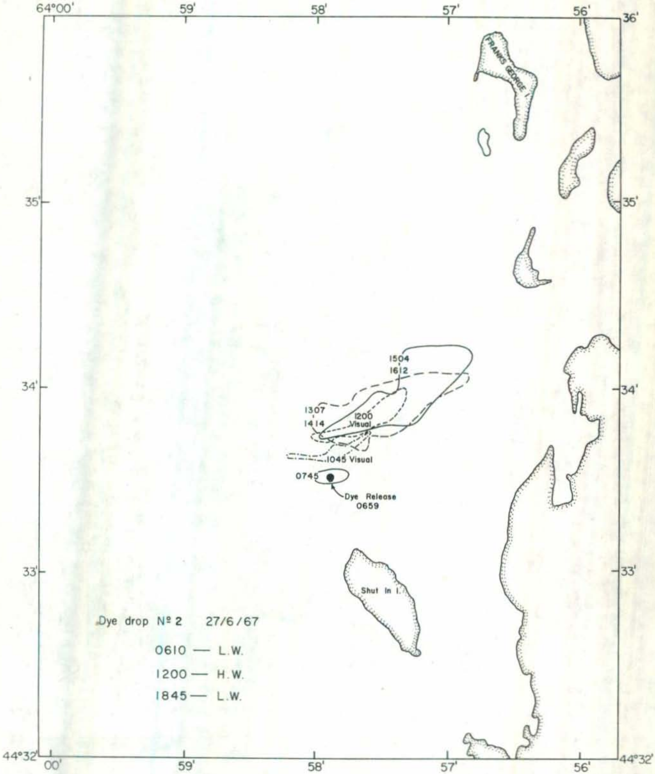

Fig. 3.39. Sketches of dye patches based on visual and fluorometer measurements of experiment No. 2 on 27 June 1967.

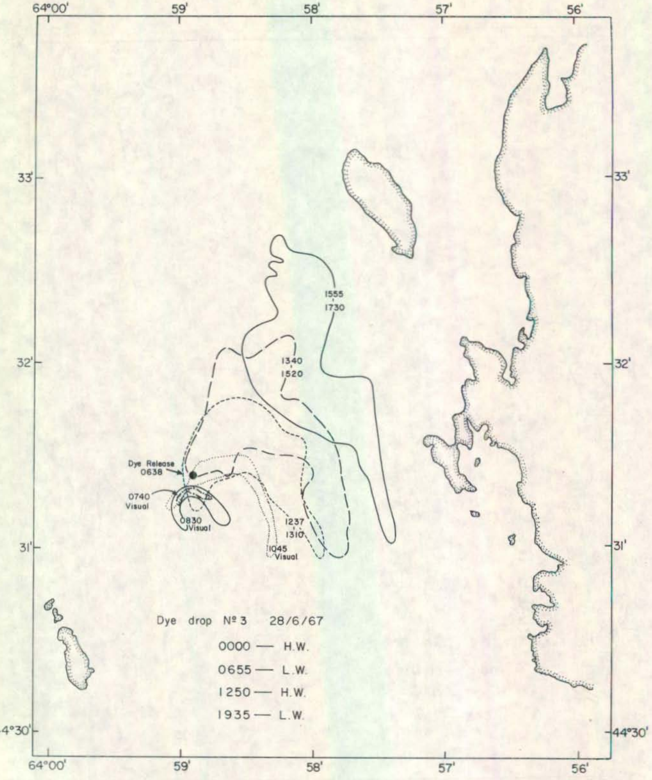

Fig. 3.40. Sketches of dye patches based on visual and fluorometer measurements of experiment No. 3 on 28 June 1967.

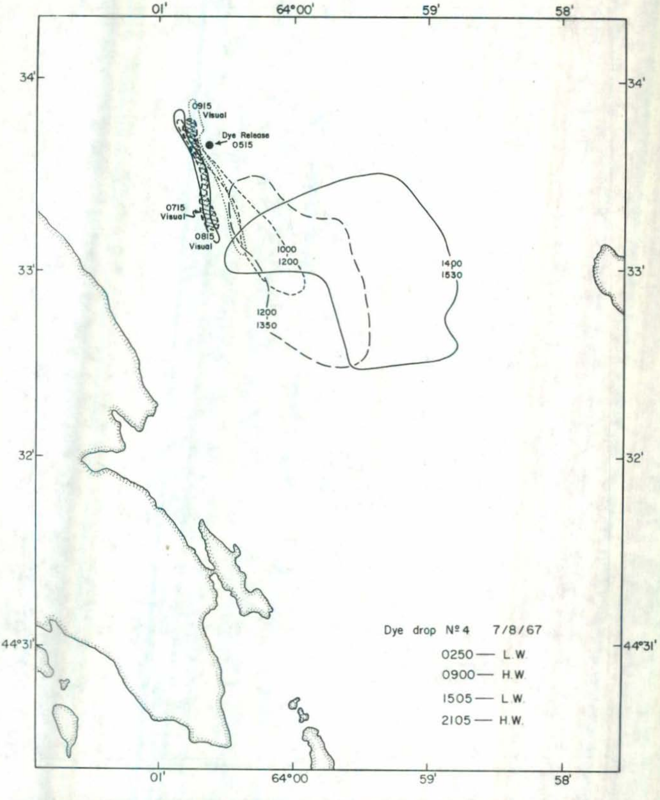

Fig. 3.41. Sketches of dye patches based on visual and fluorometer measurements of experiment No. 4 on 7 August 1967.

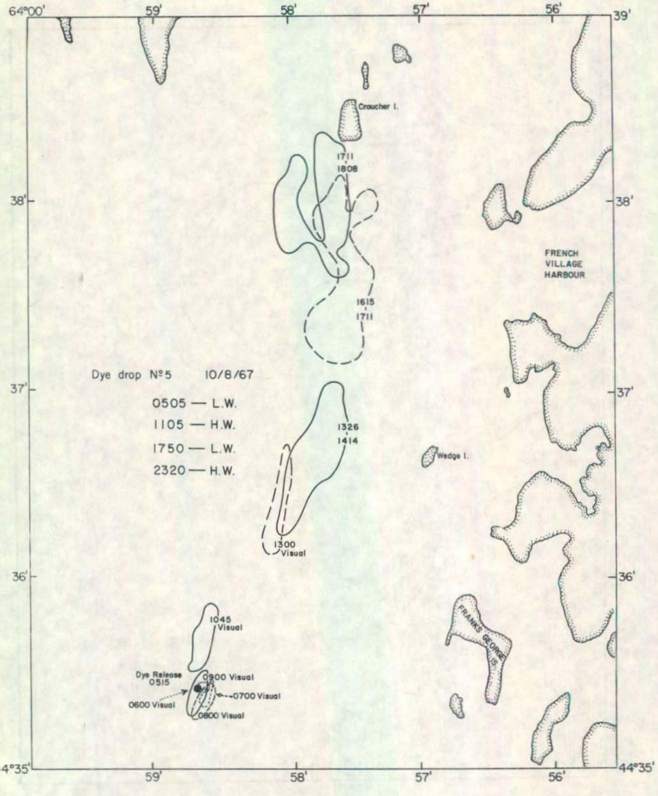

Fig. 3.42. Sketches of dye patches based on visual and fluorometer measurements of experiment No. 5 on 10 August 1967.

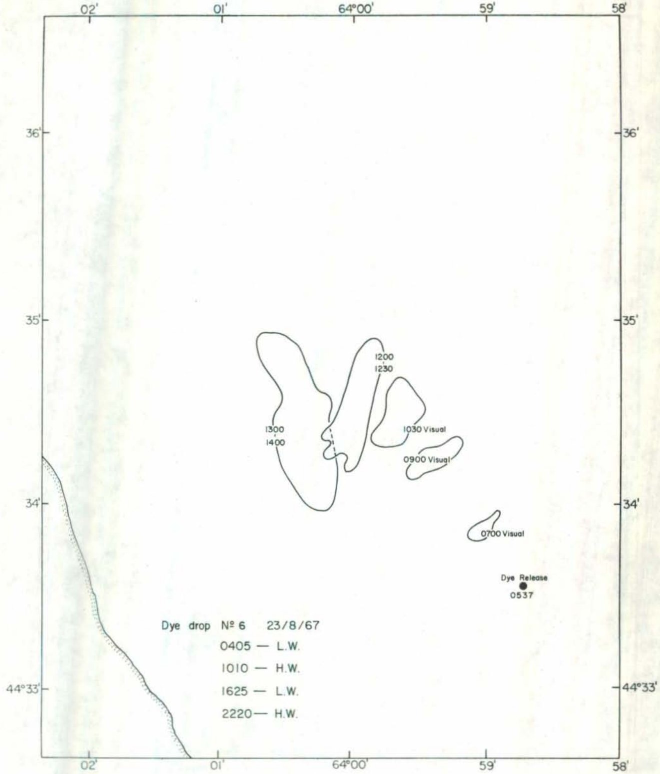

Fig. 3.43. Sketches of dye patches based on visual and fluorometer measurements of experiment No. 6 on 23 August 1967.

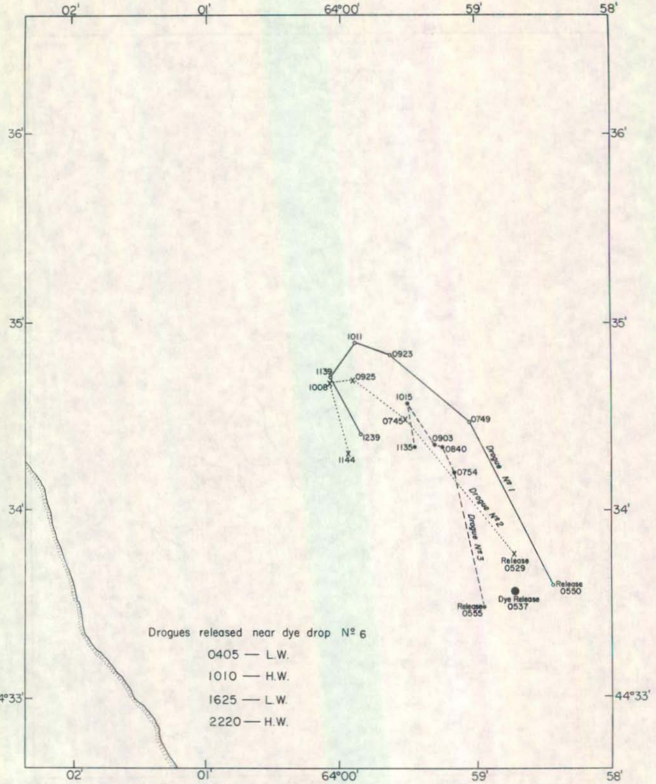

Fig. 3.44. Plots of drogue trajectories on 23 August 1967.

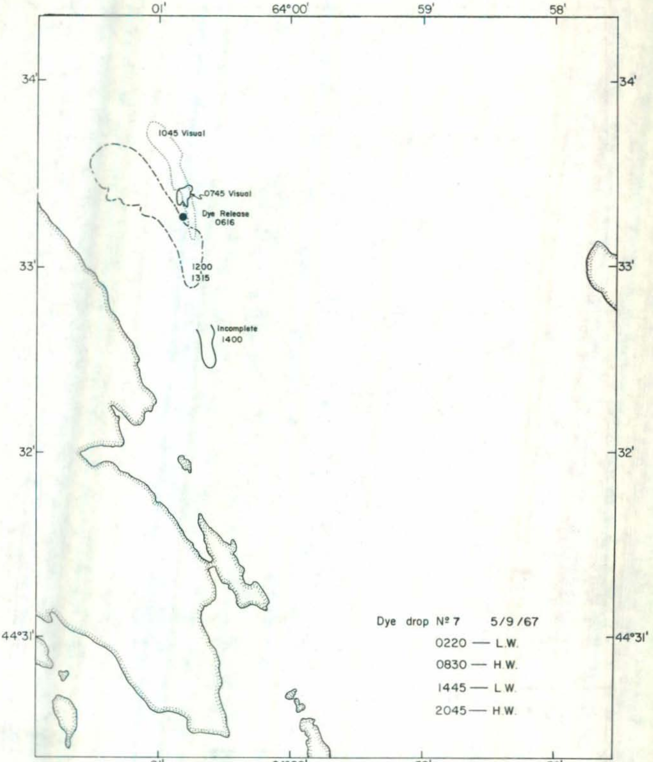

Fig. 3.45. Sketches of dye patches based on visual and fluorometer measurements of experiment No. 7 on 5 September 1967.

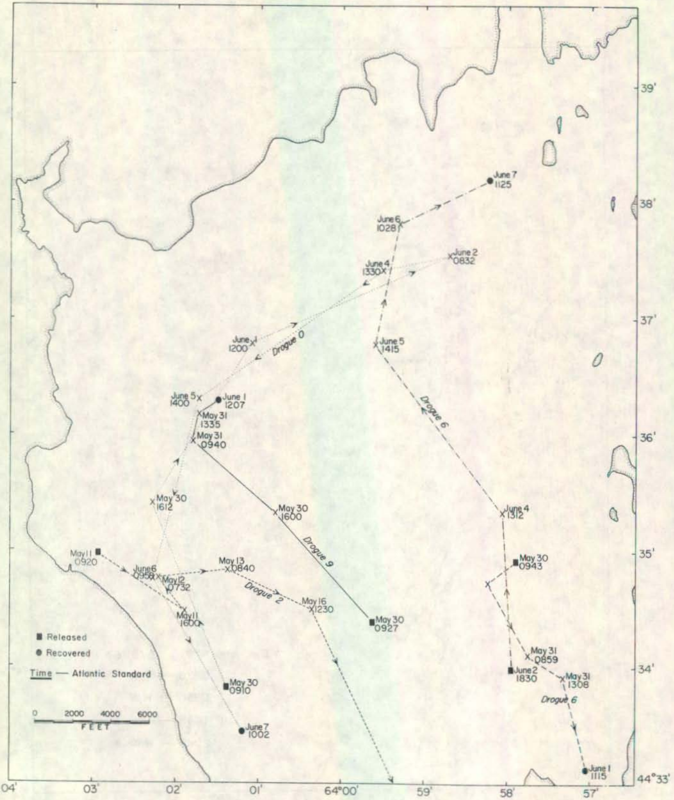

Fig. 3.46.1. Plots of drogue trajectories during May and June 1967.

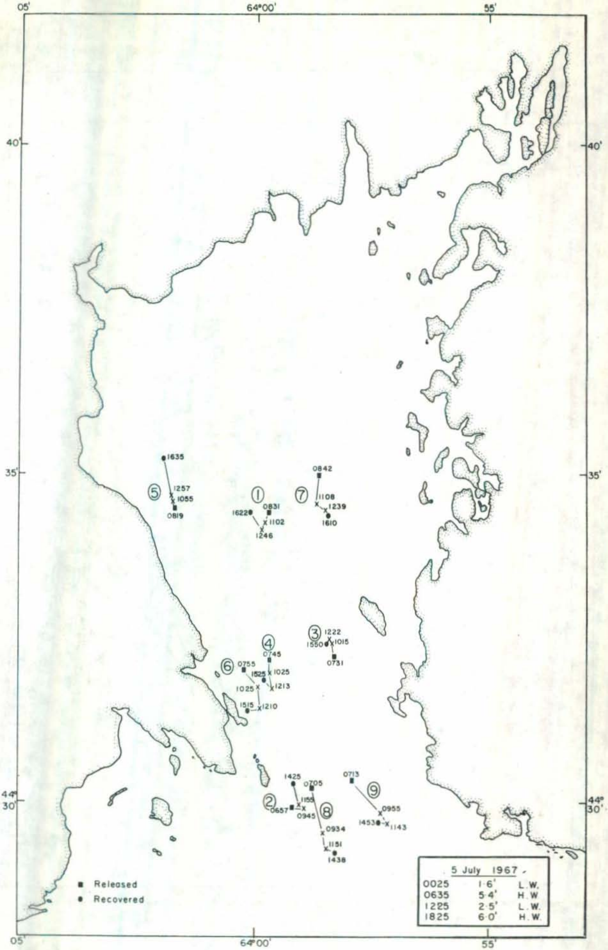

Fig. 3.46.2. Plots of drogue trajectories on 5 July 1967.

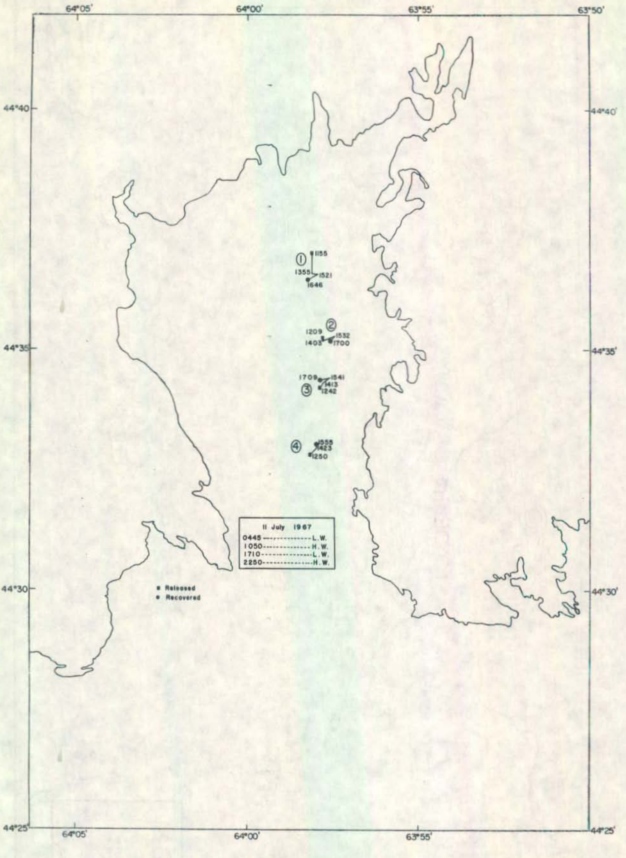

Fig. 3.46.3. Plots of drogue trajectories on 11 July 1967.

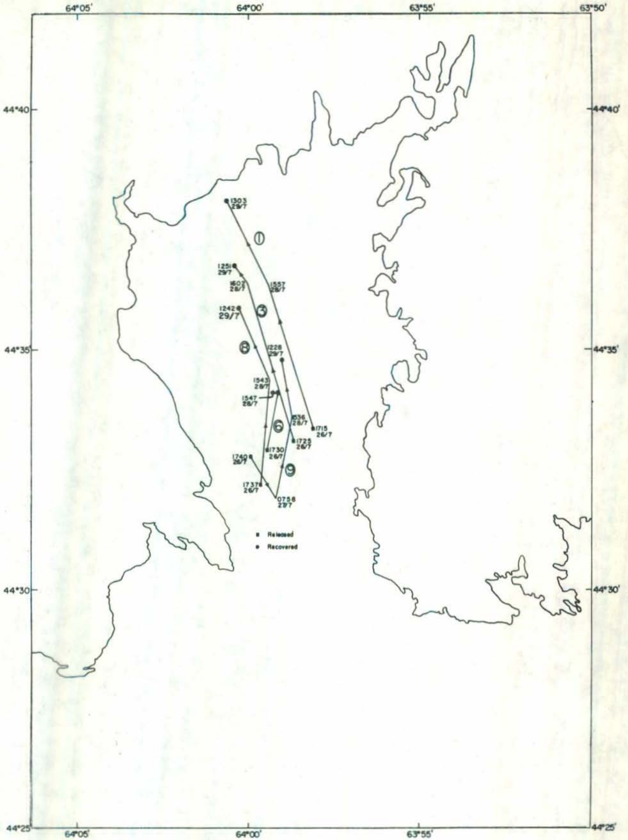

Fig. 3.46.4. Plots of drogue trajectories during 26-29 July 1967.

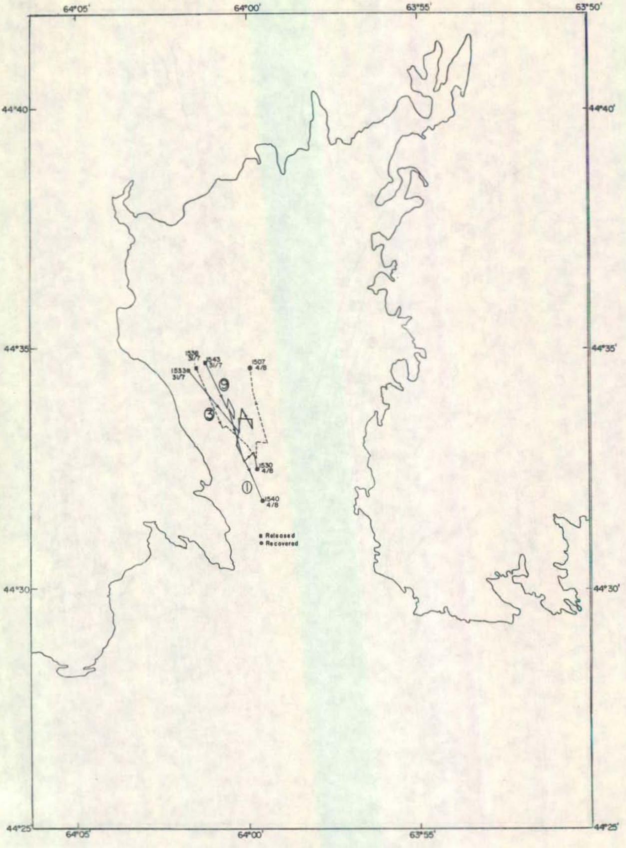

Fig. 3.46.5. Plots of drogue trajectories during 31 July to 4 August 1967.

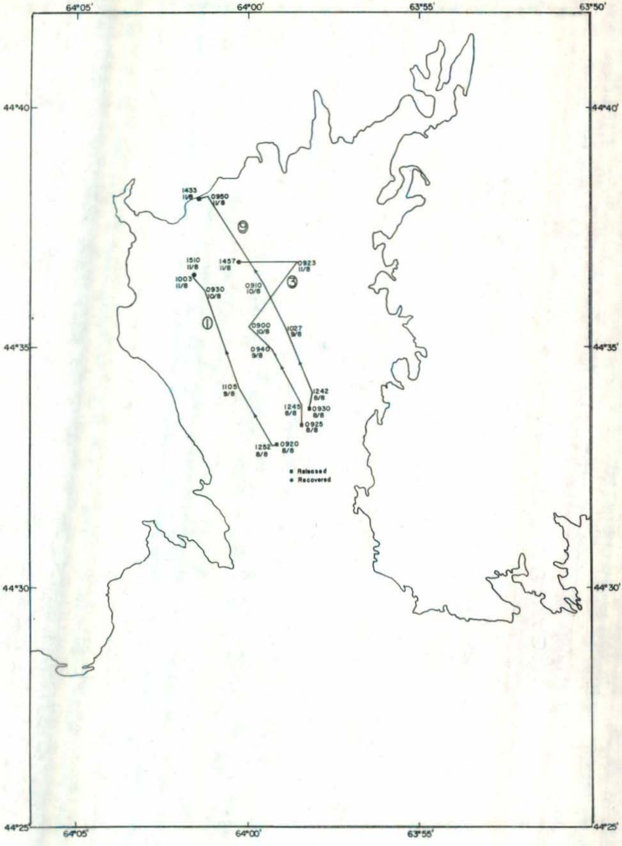

Fig. 3.46.6. Plots of drogue trajectories during 8-11 August 1967.

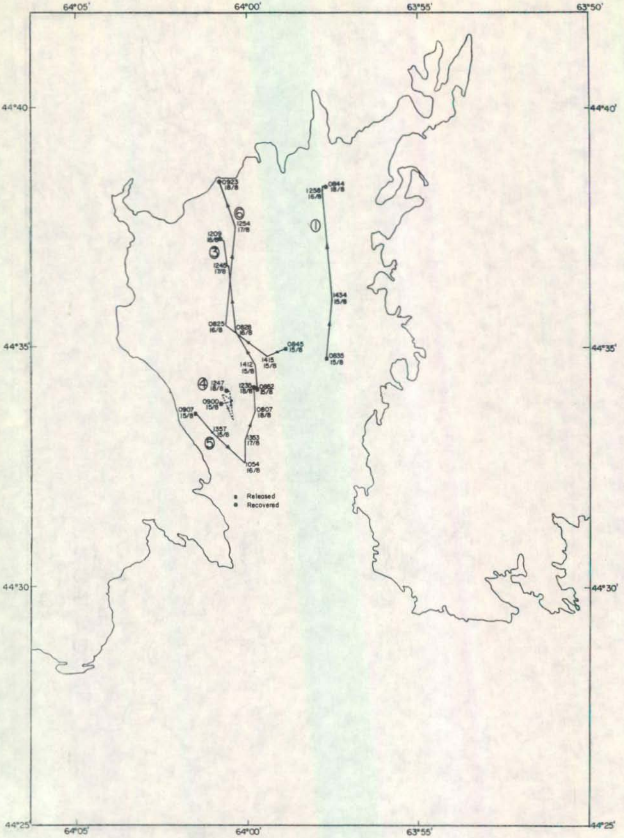

Fig. 3.46.7. Plots of drogue trajectories during 15-18 August 1967.

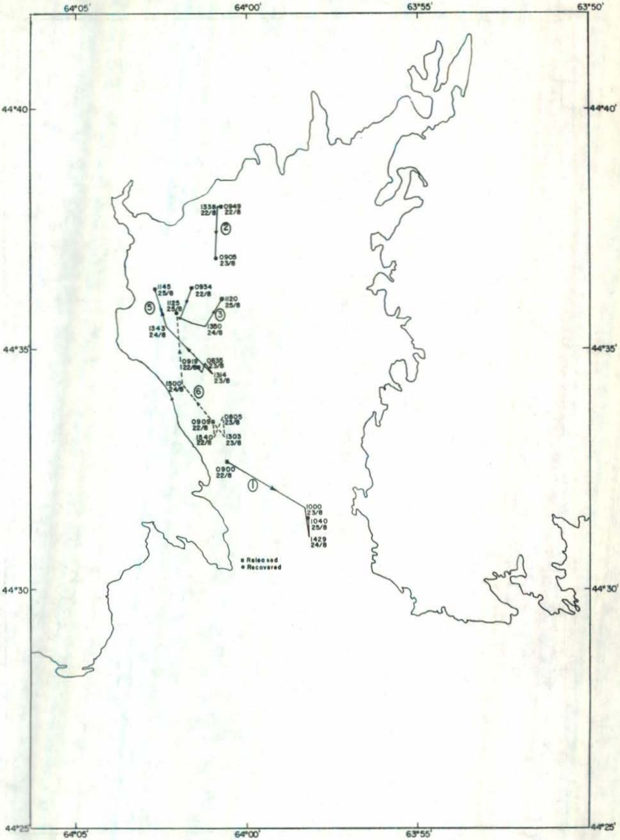

Fig. 3.46.8. Plots of drogue trajectories during 22-25 August 1967.

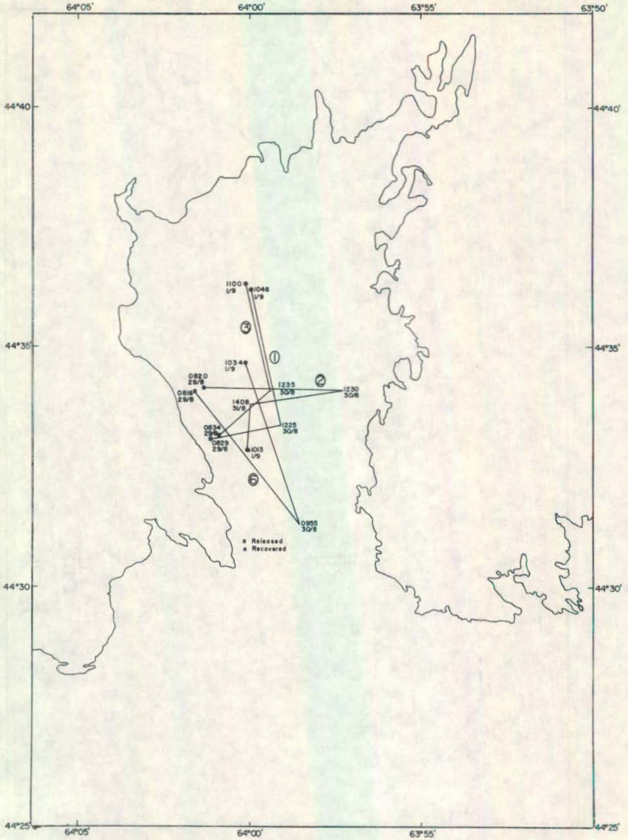

Fig. 3.46.9. Plots of drogue trajectories during 29 August to 1 September 1967.

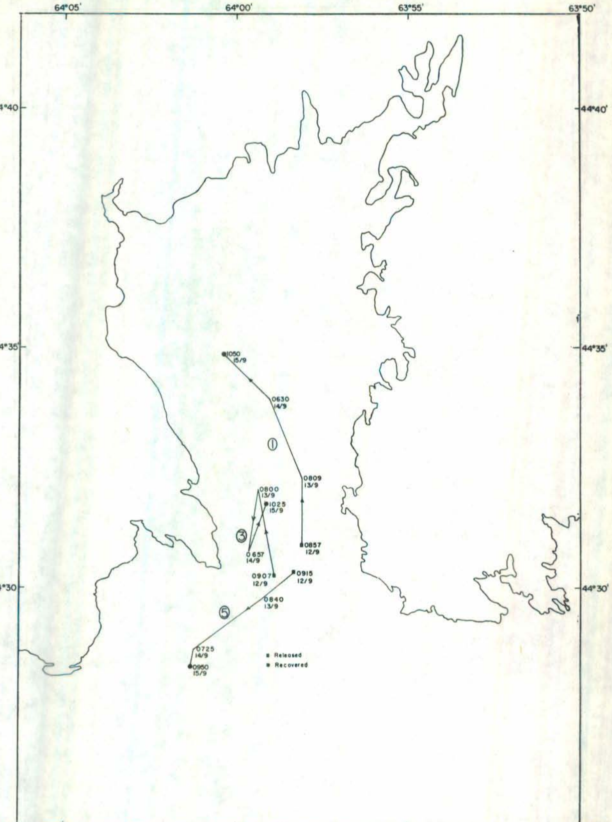

Fig. 3.46.10. Plots of drogue trajectories during 12-15 September 1967.

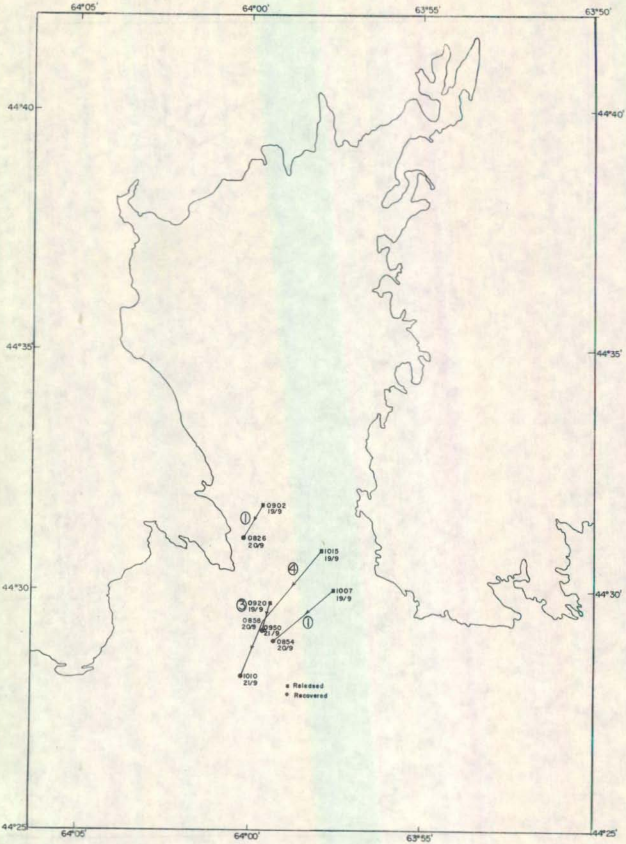

Fig. 3.46.11. Plots of drogue trajectories during 19-21 September 1967.