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The Oceanography of Hudson Strait.

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by

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INTRODUCTION

Two oceanographic surveys of Hudson Strait were made in 1955 and 1956 by the Atlantic Oceanographic Group working from H.M.C.S. "Labrador" (Fig. 1). The first cruise in 1955, provided an opportunity to study the Strait in June and October. During the intervening months, July, August and September, oceanographic surveys were conducted in part of Hudson Bay and most of Foxe Basin. In 1956, oceanographic observations were carried out in Hudson Strait, Foxe Basin, Gulf of Boothia, Prince Regent Inlet and Lancaster Sound.

The three periods of observations in Hudson Strait, June, 1955, October, 1955, and July, 1956, revealed the summer and autumn oceanographic conditions of the Strait. Consequently, the results have largely been considered from the seasonal point of view.

The June survey was limited by heavy ice conditions, but sufficient data were obtained for dynamic computations in the western half of the Strait. The October survey yielded excellent coverage of the whole Strait, eleven cross-sections being completed (Fig. 2). In July, 1956, most of these sections were reoccupied (Fig. 3). Failure to reoccupy a section in July 1956 was not a matter of choice, but of necessity, since ice conditions were so severe in places, that it was impossible to lower instruments into the water.

In the two year period that Hudson Strait was surveyed, other surveys were conducted in and through Foxe Basin to Lancaster Sound via Fury and Hecla Strait, Gulf of Boothia and Prince Regent Inlet.

Early Exploration and Scientific Investigations

Charts dating from 1544 showed the existence of a channel leading westward in the approximate latitude and longitude of Hudson Strait. The possession of these charts by some of the early explorers indicated that at least the existence of Hudson Strait was known. Davis certainly knew. He explored the regions north of Hudson Strait, and in fact named Cape Chidley at the eastern entrance of the Strait (Markham, 1889). The first authoritative account of the exploration of Hudson Strait and Bay however, was that of Henry Hudson and the survivors of the voyage of the "Discovery" in 1610. Following Hudson's route a number of expeditions mapped out large areas of Hudson Strait, Foxe Basin and Hudson Bay. The voyages of Button, Baffin, Bylot, Foxe and James were notable, particularly those of Baffin and Foxe (Markham, 1881; Christy, 1894). The descriptions of navigational hazards and ice conditions that Baffin and Foxe recorded still rank among the best we have at the present time.

Further attempts to discover a Northwest Passage by way of Hudson Bay were laid aside for almost a century while England was involved in wars and revolutions. In 1668 an English expedition entered the Bay for the sole purpose of commercial enterprise. This trading expedition grew into the now famous Hudson Bay Company. The establishment of forts and trading posts in Hudson Bay led to early and not infrequent navigation by the Hudson Bay Company in the Strait. However, navigation and exploration only gained momentum after the Treaty of Utrecht, 1713. For some individuals the goal was still the quest of a Northwest Passage, while for others it was a search for alleged copper deposits rumoured to exist west of Hudson Bay.

Few expeditions, however, sailed into Hudson Bay for the sole purpose of seeking a Northwest Passage. It was not until 1822-1824 that any serious or scientifically rewarding expeditions attempted the route. The work of Parry and Lyon stands out among all others as being undertaken with a definite purpose and goal. Included with their vast amount of work in meteorology, geography, botany and zoology, one finds a series of very early oceanographic observations. Parry directed attention to surface and subsurface temperatures in Hudson Strait and Foxe Basin, and has these results duly recorded in his narrative of the voyage (Parry, 1824).

Further surveys of the route dwindled after Back's near disastrous voyage of 1836 (Back, 1838). From that date the area was virtually forgotten until the arrival of the whalers in 1860. Whaling flourished throughout Hudson Bay and Foxe Basin for the next thirty years. When the whaling declined, it brought to a close the romantic exploration of the Strait and Bay.

Recent Exploration and Scientific Investigations

The development of the Prairie Provinces into a major wheat producing area added new impetus to the establishment of Hudson Strait as a major shipping route. It was proposed late in the nineteenth century to construct a railroad from Winnipeg to a terminus in Hudson Bay, from which western agricultural products could be shipped overseas. The Canadian government consequently undertook a long series of expeditions into Hudson Strait to assess the value and risks of this northern sea route. Reports of the voyages and some of the scientific investigations were published under the Department of Marine and Fisheries (Gordon, 1885; Wakeham, 1898; Bernier, 1909 and 1911).

Many famous Canadian names are associated with these and subsequent expeditions, Wakeham, Gordon, Bell, Bernier and Low. Their published journals and papers cover a wide range of subjects: history, geology, geography, botany, zoology, biology, navigation, hydrography and meteorology. Despite their limited resources of equipment and money, a very thorough scientific and economic survey of Hudson Strait was accomplished. Shore stations were established for continued observations of water temperatures, tides, meteorology and ice conditions, all factors pertinent to navigation of the Strait. To further entice development of the route, Low and Bell studied the geology of the area, and in some regions were responsible for directing and encouraging examination of the fishery potential (Low, 1899; Bell, 1884).

It was not until 1930, however, that detailed information on the hydrography and fisheries of Hudson Bay or Hudson Strait was obtained. The Hudson Bay Fisheries Expedition of 1930 under the direction of H. B. Hachey carried out an extensive survey of hydrography and fisheries in Hudson Strait and Bay (Hachey, 1931; Huntsman, 1931). In 1948, a northern cruise of R.C.N. ships took part in a small oceanographic survey of Hudson Bay and Strait (Bailey and Hachey, 1951). In the same year the C.G.M.V. "Calanus" was built for the Fisheries Research Board of Canada, and in the following year commenced her work in Ungava Bay (Dunbar, 1951). Since then "Calanus" has made observations in Ungava Bay, Hudson Strait, Hudson Bay and recently, Foxe Basin.

In 1955 and 1956, H.M.C.S. "Labrador" carried out a series of oceanographic surveys in Hudson Strait, Hudson Bay and Foxe Basin. Some of the results of these two cruises in Hudson Strait are contained in this report.

PHYSICAL GEOGRAPHY

Origin

Hudson Strait is a submerged valley extending in a northwesterly direction from the Atlantic Ocean to Foxe Channel and Frozen Strait. The overall length of this channel from the Atlantic Ocean to the head of Frozen Strait is approximately 800 miles. The Strait is characterized throughout its length by an uneven bottom topography closely resembling the rugged features of the coastal mountains.

Bell considered that Hudson Strait originated during pre-glacial times, at a period when the northern part of this continent was elevated (Bell, 1895). He believed that the original channel was cut by denudation along decomposing dykes of igneous rocks, and that all the rivers flowing into the plain of Hudson Bay converged and discharged into the Strait as one river near C. Wolstenholme. Bell argued further that during the periods of glaciation, Hudson Bay was a vast reservoir of ice which joined a glacial bed in Hudson Strait (Bell, 1895). Following this argument one would expect Foxe Basin to be similarly formed and altered as Hudson Bay, but with Foxe Channel serving as the glacial bed. Both these glacial centres would have fed the glacial stream of Hudson Strait, which in turn was fed by another glacier originating south of Ungava Bay. The united glaciers are believed to have moved eastward into the Atlantic Ocean.

Coastal Features.

Hudson Strait itself is approximately 400 miles in length and varies from 60 to 130 miles in width. It has an average width of 80 miles. The two narrowest points of the Strait are situated between Resolution Island and the Button Islands, and between Big Island and Quebec. The eastern entrances lead to the Atlantic Ocean through several channels: Baffin Island to Resolution Island, Resolution Island to the Button Islands and Killinek Island to the northern tip of Labrador. The western entrances lead to Hudson Bay and Foxe Channel between the Quebec mainland, Digges, Nottingham, Salisbury and Baffin Islands.

Ungava Bay opens out from the south coast of Hudson Strait near the eastern entrance. This large bay is approximately 130 miles wide at the mouth and 140 miles long.

The southern coast of Hudson Strait is composed mainly of Precambrian rock and rises abruptly from the sea to altitudes of 1000 and 2000 feet. Fiord valleys indent the coast and give access to a rolling interior, which slopes gradually downward to the east and south, forming a lowland area around Ungava Bay (Robinson, 1951). The eastern perimeter of the Bay rises from the lowlands in the south to altitudes of 1500 feet on Killinek Island. The northeastern section of this part of the coast is much indented by fiords and is still virtually unexplored.

Baffin Island forms the northern side of Hudson Strait. It has a barren rocky coast of Precambrian origin with coastal mountains rising to an altitude of approximately 1000 feet (Robinson, 1951). West of Big Island numerous islands and skerries front the rugged coast, making it impossible in many places to distinguish the shore from the islands (Bell, 1901; Smith, 1936). The uplands attain elevations of 2000 to 3000 feet, and slope downwards north and west to a broad, poorly drained tundra plain, bordering the central east coast of Foxe Basin.

Islands

Nottingham, Salisbury and Mill Islands are composed of Precambrian rock and have steep, barren indented coasts. Nottingham

Island exhibits many glacial features indicating that glaciation occurred from west to east and from the southwest (Bell, 1884).

Charles Island is situated off C. Weggs on the southern shore of the Strait. The eastern end of the island is high and bold, rising to heights of 200 and 600 feet, but terminating to the west in a low flat boulder fringe extending into the sea (Sailing Directions for Northern Canada, 1951).

Big Island is situated about midway along the northern coast of Hudson Strait, west of the Resolution Island group, which is located off the southeast tip of Baffin Island. Both island groups exhibit the same basic rock formations as Baffin Island and present high, bold headlands to the sea.

Akpatok Island is located at the mouth of Ungava Bay and is a limestone plateau of Palaeozoic origin. The cliffs rise to a height of 900 feet and present to seaward a high vertical wall of 400 to 600 feet, except along the northeastern coast where the cliffs give way to a low shingle shore-line (Sailing Directions for Northern Canada, 1951).

The common physical characteristics of the whole coastline of Hudson Strait are the rugged well-glaciated mountains that flank the sea boundary.

Bottom Topography

The submarine topographic features of the Strait reflect the uneven and rugged coastal features of the neighbouring land masses. In many places depths within the Strait exceed the heights of the bordering coastal mountains. The main feature of the bottom topography is a long deep channel with depths of 200 fathoms or more, which extends from the eastern entrance to Foxe Channel (Fig. 4).

Three areas of exceptional depths are found in the Strait. The largest and deepest area is located at the eastern entrance where depths exceed 500 fathoms. A sill in this region separates a deep hole at the eastern end of the Strait from the Atlantic Ocean. Off Digges Islands, there is a deep depression of 300 fathoms, which is distinctly separated from the main submerged channel of the Strait by a long shallow ridge connecting Charles Island and Salisbury Island. A submarine passage cuts across the ridge connecting the deep channel off Digges Islands to the main channel of the Strait.

Ungava Bay is on the whole much shallower than Hudson Strait. and for the most part, it resembles a submerged table or plateau. The northern edge of the plateau gives way to the 200 fathom channel in Hudson Strait. A cut extending from the 500 fathom depression at the mouth of the Strait extends into the eastern side of Ungava Bay. The depths are less extreme in Ungava Bay than those in Hudson Strait, but do attain 150 fathoms.

The 100 fathom contour generally lies within a ten mile limit of the coast. The only areas of exception are the shallows at the head of Ungava Bay and the much-indented and island-dotted stretch of coast between Dorset and Fair Ness.

Climate

The climate of Hudson Strait is polar in character and falls within the Koppen classification of a tundra climate (Finch and Trewartha, 1949). According to this classification, the average temperature of the warmest month is no lower than 32°F. and no higher than 50°F.

In Hudson Strait the mean daily temperature varies from -15°F. in January to 45°F. in July. The July 45°F. isotherm approximately parallels the south coast of the Strait and the mouth of Ungava Bay. The mean daily temperature elsewhere in the Strait is about the same, but tends to be slightly lower around the Resolution Island area. A major change in the distribution of the mean daily temperature occurs in October. At this time, temperatures of 20°F. and 25°F. are common in the western half of the Strait, while a slightly higher temperature, 30°F., is found in the eastern area (Thomas, 1953).

January mean daily maximum and minimum temperatures average 5°F. and -15°F. respectively for the central regions of the Strait. Temperatures west of Big Island are more extreme and somewhat typical of continental Arctic conditions, while the milder maritime polar conditions prevail on the Atlantic side of the Strait.

The moderating influences of the Atlantic are clearly evident in the Strait. The eastern half of the Strait exhibits warmer air temperatures for most of the year. The proximity of the ocean also affects the distribution of rainfall. A total mean annual precipitation of 15 to 20 inches is found in the eastern half of the Strait. The mean annual precipitation decreases westwards to 10 inches around Foxe Channel. Of the total precipitation, approximately 10 inches occurs as snowfall. Most of this snow appears during the autumn and spring months rather than in midwinter.

The wind direction for the Hudson Strait area of the Arctic varies considerably. On the average, summer westerly winds predominate at Nottingham Island, but both easterly and westerly winds occur with the same frequency and strength at Resolution Island. Winter winds, however, are predominately westerly and northwesterly at both Nottingham and Resolution Islands. Mean wind speeds are not excessive compared with other parts of Canada. Mean spring, autumn and winter wind speeds are 15 m.p.h., slightly lower than the average for the Maritime areas. Summer mean wind speeds are 10 m.p.h. or less. Computed maximum gust speeds correspond closely with the Maritimes, averaging 90 to 100 m.p.h. for the year. A slightly greater potential maximum gust speed has been calculated for Hudson Strait. This speed represents the maximum for Canada (Thomas, 1953).

ICE CONDITIONS

Hudson Strait

Opinions of ice conditions for Hudson Bay and Hudson Strait have varied considerably over the last 100 years. Some of this difference of opinion stems from the particular interest of the individual and type of ship. A truer picture of ice conditions is obtained from aerial photographs or aerial reconnaissance.

Ice conditions in Hudson Strait are reported to be heavy, but such that the Strait never freezes over (Bell, 1884a; Forward, 1956). These views have been confirmed by aerial observations (Hare and Montgomery, 1949). The fact that Hudson Strait is not frozen over solidly follows from the wind distribution and strong currents, which keep the ice in constant motion. The discharge of water and ice out of the Strait into the Atlantic Ocean prevents an all-winter blockage of ice.

The most severe ice conditions in Hudson Strait and Hudson Bay occur at the narrow western channels leading into the Strait, where the outward movement of ice becomes choked in the narrow channels between Mill, Salisbury and Nottingham Islands. The exodus of ice through the western channels also depends on the prevailing Hudson Strait ice conditions, which in turn are partially dependent on the distribution and movement of the Baffin coast pack ice. If the latter two areas are open, ice conditions within Hudson Bay and Foxe Basin can be quite light.

Winter ice first appears in the western end of the Strait in November. The growth of ice in this region is dependent on previous weather history, surface water temperatures and the ice state of Foxe Basin and Foxe Channel. Normally, ice conditions are more advanced in Foxe Channel than Hudson Strait and these conditions may lead to a belt of heavy ice extending into Hudson Strait between Salisbury and Charles Islands. This formation of ice is generally accompanied by a band of ice extending along the south shore of the Strait. Mid-channel ice usually does not appear until late November and early December.

Once the Baffin pack forms, ice moves into the Strait a short distance west of Resolution Island. By midwinter, ice covers most of the Strait, but it is seldom completely consolidated.

The inflow of ice from Baffin Bay may also be accompanied by icebergs which originate in Greenland and are carried into the Strait by deep currents. The icebergs generally move into the Strait along the south Baffin coast and may be found as far west as Big Island and along the Quebec coast east of C. Prince of Wales. Some of the icebergs are carried by the currents into Ungava Bay, where they either melt in the summer or drift out to the Atlantic Ocean around C. Chidley. (Forward, 1956; Supplement to the Pilot Chart of the North Atlantic Ocean, May 1952).

The break-up of ice takes place in May and June with the advance of warm weather. During this period the landfast ice dislocates from the shore and joins the drifting pack. The Strait is in some years ice-free by July, but ice may still remain in Ungava Bay or off Resolution Island until August. Elsewhere, ice may be encountered between Salisbury and Charles Islands where Foxe Basin ice enters the Strait.

The area between Resolution Island and Big Island along the north coast has shown unusual ice conditions in the past. A long open lead or region of light ice concentration appears at the time of freeze-up and again before break-up. The causes of this phenomenon are not fully understood, but it is believed to be related to the winds. Two additional factors that may contribute to the formation of the open water are the intrusion of water from Baffin Bay and the turbulence of waters west of Fair Ness.

A different situation appears from Digges to Charles Islands where the discharge of water from Hudson Bay influences the ice conditions. Water which has warmed in the shallow regions of Hudson Bay can clear this coast of ice in spring well before other regions of the Strait, or delay freeze-up along the coast in the autumn.

The period of comparatively safe ice navigation in Hudson Strait is roughly from mid-July to mid-October (Sailing Directions for Northern Canada, 1951; Forward, 1956). The dates of ice break-up and freeze-up are roughly May and November, but these periods may vary by a month one way or another.

Hudson Bay

Ice in Hudson Bay was believed to be limited only to the shore, and it was not until 1948 and 1949 that it was finally proved that the Bay did freeze over. The R.C.A.F. undertook a number of reconnaissance flights over the centre of Hudson Bay and their observations confirmed the possibility that Hudson Bay did freeze over solidly (Hare and Montgomery, 1949). These results are not surprising when one considers the climatic and oceanographic conditions of the area - factors, which have been known for a number of years (Hachey, 1931; Hare and Montgomery, 1949a).

The break-up of ice in Hudson Bay begins in May, with the landfast ice breaking free. By June, most of the fast ice is free and the main body of the pack is reduced in concentration and size. In July, the Bay is open with only a few scattered floes remaining.

Approximately 1000 sq. miles of ice can leave the Bay at the daily outflowing rate between Nottingham Island and C. Wolstenholme. At this rate of discharge, it would require about 240 days to clear Hudson Bay of ice when in fact it occurs within 90 days. It thus appears that the largest percentage of Hudson Bay ice melts in the Bay. As a result of this contribution of melt water, the salinity decreases; a phenomenon which can be traced all the way through Hudson Strait in the summer months.

Foxe Basin

Ice conditions in Foxe Basin are normally more severe than the corresponding conditions in either Hudson Strait or Hudson Bay. Foxe Basin ice is much heavier and characteristically identified by its unusual colour and extremely uneven topography (Campbell and Collin, MS, 1957).

Freeze-up in Foxe Basin begins in October and November, but the Basin seldom freezes over completely, owing to the movement of ice by wind, tides and currents (Dunbar and Greenaway, 1956).

The break-up of ice commences in May or earlier, but changes in the distribution of the main pack ice are not noticeable until June. Parts of the northern area of the Basin will open, but Foxe Channel remains clogged with ice at least until July. In August there are generally only a few scattered coastal areas of ice, however, ice may be encountered in one place or another in the Basin throughout the year.

Heavy floes of ice from Foxe Basin appear in Hudson Strait during the ice season, but they are particularly prevalent in the late summer, when the locally formed Hudson Strait ice has disappeared. An example of such ice discharge can often be observed off Charles Island in July and August. This peculiar concentration of Foxe Basin ice is believed to be that commonly referred to years ago as the "Charles Island Patch", (Parry, 1824).

PHYSICAL OCEANOGRAPHY

Horizontal Distribution of Temperature and Salinity

The data from the two cruises, October, 1955 and July, 1956 were plotted at a number of depths. The one striking feature of the distribution of temperature and salinity was the uniformity at all depths except for surface anomalies arising from ice cover. Late summer conditions are marked by comparatively warm low saline water along the south coast. For example, in October, 1955 and July, 1956, surface water temperatures were high, 1.0°C. to 3.0°C. between Nottingham and Charles Islands (Figs. 5 and 7), while the salinities were about 30.00‰ for the same area (Figs. 6 and 8). Residual early summer conditions (ice and open water) are evident in Fig. 5 with temperatures below 0.0°C.

The three surveys in the Strait, June, 1955, October, 1955 and July, 1956 have all shown the existence of low saline water along the south side of the Strait, and where open water conditions appeared, relatively warm water. These conditions appear to be directly related to the oceanographic conditions in Hudson Bay. On the northern side of the Strait, temperatures are lower and salinities higher than along the southern coast (Figs. 5 to 8). These conditions are related to a number of factors occurring in late summer, advection of ice and cold water into the Strait from either Foxe Channel or Davis Strait and turbulent conditions in both the northwestern and northeastern areas of the Strait. These factors seem to eliminate most of the evidence of seasonal variation along the north side of the Strait.

The inward intrusion of water from the Baffin coast is characterized by its comparatively high surface salinities, however, the temperatures are on the whole the same as those of the Foxe Channel waters in the northwestern area of the Strait.

The water characteristics and patterns of the distribution of temperature and salinity indicate the intrusions of other waters in the Strait. The surface pictures are inconclusive (Figs. 5 to 8), but there are typical tongue-like patterns of distribution which are related to intrusions of water from Hudson Bay, Foxe Channel and the Atlantic Ocean.

The discharge of Hudson Bay water into the Strait occurs mainly between Nottingham Island and C. Wolstenholme. East of Nottingham Island, a large body of Hudson Bay water appears to "eddy" on the way out along the south side of the Strait. The isohalines and isotherms (Figs. 5, 6, 7, and 8) show part of the eddy off Nottingham Island and parallel extensions along the Quebec coast. In the northwestern section of the Strait a clear picture is not too evident, but the isohalines and isotherms generally extend directly from Salisbury Island to Charles Island. Another feature of the salinity and temperature distributions is the appearance of tongue-like patterns extending from Mill and Resolution Islands to Big Island. These characteristics are found in the surface distributions of temperature and salinity. Variations are, however, evident in the July observations in local regions of ice (Figs. 7 and 8).

The autumn observations in 1955 showed that warm surface waters, temperatures of 1.0°C. to 4.5°C., were limited to the Nottingham-Charles Island region (Fig. 5). Salinities for the same area were low, 29.00‰ to 32.00‰ (Fig. 6). The distribution of the isopleths again indicate the cellular formation of water in this locality. The eddy is deep, but confined laterally by the coast and bottom topography (Fig. 4).

Autumn conditions also feature a band of warm surface water, 1.0°C. to 1.5°C. extending along the Quebec coast (Fig. 5). This phenomenon appears to be common earlier in the year, judging from the thermal conditions in July 1956, but the pattern is interrupted by pack ice approximately delineated by the -0.5°C. isotherm (Fig. 7). This ice barrier has caused a northward displacement of the warm surface water (Fig. 7).

The surface width of the outflowing stream on the south side of the Strait is approximately the same for both periods of observation. The outgoing stream in July, 1956, lies south of the 31.00‰ isohaline, while in October, 1955, the 32.00‰ isohaline separates the main stream from the waters on the north side of the Strait. The seasonal difference in the salinity can be traced to the slightly higher percentage of fresh water in the surface layers in the summer than in the autumn.

Temperatures and salinities for the summer and autumn off Resolution Island can be expected to vary from -1.0°C. to 1.0°C. and from 32.50‰ to 33.00‰. In the northwest sector of the Strait for the same periods, temperatures may be found lower than -1.0°C., but on the whole, they occur within the same range as those at Resolution Island. Salinities, however, seldom exceed 33.00‰.

Extreme fluctuations of surface temperature and salinity are limited to the southern half of the Strait. Variations of the temperature and salinity may be of the order of five degrees Centigrade and three or four parts per thousand respectively. Local alterations of temperature and salinity may occur in the presence of an ice field anywhere in the Strait.

The distribution of temperature and salinity at 20 metres (Figs. 9 to 12) shows the same basic patterns as the distribution of the surface isopleths.

The relatively warm water conditions found for the surface in October, 1955, (Fig. 5) were also common at 20 metres (Fig. 9). These features are primarily due to an outflow of a warm surface layer from Hudson Bay which develops and expands into the Strait as the summer season progresses. Within the Strait the warm body of water appears as a wedge thinning to the north and east. The deepest depths of the warm layer have always been found off Digges Islands and between Nottingham and Charles Islands. The deepening of the wedge by mixing results in small subsurface thermal differences, which appear to be normal for the late summer conditions in the Strait. Marked thermoclines were only observed in the southwestern approaches to Hudson Bay in June of 1955 and July of 1956. These conditions were apparent in July, 1956 (Fig. 11) where the temperatures east of Digges Islands were below 0.0°C. although immediately off Digges Islands, warm subsurface summer temperatures were located. Presumably these thermoclines are related to the discharge of both surface heated waters and the remnant cold winter waters from Hudson Bay. Throughout the remainder of the Strait, temperatures are well below surface values (Figs. 7 and 11), except the extensive region of warm water off Big Island. This mass of warm water probably originated in Hudson Bay, although the salinity is unusually high for water originating in Hudson Bay, both at the surface and 20 metres, (Figs. 8 and 12). The only possible explanations of the origin of the warm water in this locality are an intrusion of warm water from the Atlantic Ocean or from Hudson Bay prior to the period of significant ice or river dilution.

Seasonal variations of salinity at 20 metres are not as apparent as the variation of temperature, although there is still a close relationship of the salinity conditions in the Strait to the salinity of the waters discharging from Hudson Bay (Fig.10). This phenomenon is particularly evident along the southern side of the Strait in both October and July (Figs. 10 and 12).

Dilution of the water by ice melting is not too evident at 20 metres. A conspicuous example of surface dilution was found off C. Hopes Advance, where the salinity had dropped to 20.00‰, but at 10 and 20 metres, the salinity remained relatively unchanged (Figs. 8 and 12).

The main features of the surface temperature and salinity distributions were not only the same for each cruise, but repeated at subsurface depths. In addition to this rather stable condition, the salinity at 20 metres along the Quebec coast was found to remain at approximately 31.00‰, increasing across the Strait to 33.00‰ for both series of observations (Figs. 10 and 12).

October temperatures at 50 metres were 0.00°C. and 2.50° C. off Digges Islands and 0.50° C. along the Quebec coast. These regions are within the area of the warm water wedge. However, across the mouth of Ungava Bay, there is no further evidence of the wedge as temperatures varied only slightly above and below 0.00° C. A uniform decrease of autumn temperatures appeared across the Strait with slightly colder water located east of Big Island. July thermal conditions at 50 and 100 metres revealed very cold water conditions through the Strait. Temperatures as low as -1.40°C. and -1.50° C. were found along the south shore, while across the Strait, temperatures were -0.60°C. and -1.25° C.

The salinities at 50 metres ranged from 30.00‰ to 33.00‰ for the two cruises. The small fluctuations common to the shallower depths were also repeated relatively at the deeper levels, however, salinities in July were slightly greater than in October.

Seasonal climatic influences were quite apparent at 50 metres and at greater depths. The July 1956 data indicated that at sub-surface depths typical winter conditions of higher salinities and colder water still prevailed. October 1955 observations on the other hand, were typical of summer conditions of lower salinities and warmer water.

The patterns of the distribution of temperature and salinity are strikingly uniform at the surface and 20 metres and also at 50 and 100 metres. These characteristics indicate rather clearly some of the features of the circulation to which reference has been made. The main features of the horizontal circulation which can be deduced from these diagrams are the Atlantic inflow along the Baffin coast to Big Island and the outflow of waters from Hudson Bay paralleling the Quebec coast, but first "eddying" off Nottingham and Charles Islands. The only regions where there is some doubt as to the manner of the circulation is the northwestern area of the Strait, where there is considerably vertical movement of waters, and the mouth of Ungava Bay. The circulation in this latter area will be referred to later, but it is pertinent to mention here that the distribution of property in this locality exhibits features which do not appear to be consistent with the accepted direction of flow.

Vertical Distribution of Temperature and Salinity.

The cross-sectional diagrams of temperature and salinity show a number of characteristics common to each cruise, regardless of time differences. The major oceanographic features are shown by three sections, occupied in 1955 and 1956. The stations are located in the narrows of the Strait, northeast of C. Weggs, C. Prince of Wales, and C. Hopes Advance (Figs. 1, 2 and 3).

The outflowing waters along the south side are clearly defined by the salinity distribution for both cruises. On this side of the Strait, the salinity is consistently lower than elsewhere and the isohalines slope sharply downwards to deep water at the southern stations. For example, Figs. 13, 14 and 15, October, 1955, show the 31.00‰ to 32.00‰ isohalines intersecting the surface about mid-channel and sloping downwards to depths of 50 and 100 metres at the coastal stations 212, 220 and 225.

In July, 1956, these three sections were re-occupied (Figs. 16, 17 and 18) and similar distributions of salinity were observed as before (Figs. 13, 14 and 15). Salinities in July, 1956 were slightly higher at intermediate depths, while the surface and bottom salinities were slightly lower than the October, 1955, results.

The two sections east and west of Big Island (Figs. 13, 15, 16 and 18) show a concave curvature of the isohalines below 50 and

100 metres. This feature is believed to be related to the deep water circulation which is outgoing along the south side of the Strait and incoming along the north side. The northern current, however, does not appear to be completely continuous across the section off Big Island. Part of the current turns south east of Big Island and joins the main outgoing stream, while part may continue westwards close inshore. The outflowing stream from the west continues to Ungava Bay, but some water branches northward, west of Big Island, and forms a west moving current. Indications of the deep water movements are lacking in the cross-sectional Figures at Big Island (Figs. 14 and 17) and it is presumed that this section lies between the opposing cross-channel flows.

The temperature sections for the autumn survey, 1955, (Figs. 19, 20 and 21) show a downward slope of the isotherms on the south side corresponding to that of the salinity sections (Figs. 13, 14 and 15). In July, however, the slope of the isotherms in the upper layers, (Figs. 22, 23 and 24), is the reverse to that obtained in October, 1955 (Figs. 19, 20 and 21). The reversed slope of the isotherms and the low temperatures are typical of remnant winter conditions in Hudson Strait. The change from winter conditions to summer conditions appears concurrently with the reversal of the isothermal slopes.

The summer appearance of warm water, of approximately 2.00°C. and the typical summer distribution of the isotherms is illustrated between stations 24 and 25 off C. Weggs (Fig. 22). Further east, at C. Prince of Wales, the typical winter slope is present with temperatures less than 0.00°C. (Fig. 23). The development of warm water conditions in the Strait are almost complete by autumn. During this period, the high temperatures and the typical slope of the isotherms are fully developed along the south side of the Strait (Figs. 19, 20 and 21).

The two surveys in Hudson Strait revealed an extensive cold water mass or core at approximately 150 metres depth. In October, 1955, the core extended mainly along the southern coast (Fig. 20), but in July, 1956, it was much more extensive (Fig. 23). Temperatures varied slightly for the two periods. In October, temperatures were -0.75°C. and -1.00°C., while in July, colder water was found with temperatures between -1.25°C. and -1.50°C.

Evidence of the gradual dissipation of the core in the autumn is seen from the increase of temperature in the sections, C. Weggs to C. Hopes Advance (Figs. 19 and 21). However, the re-appearance of the core in the following year suggests two distinct and separate processes involving winter cooling of Hudson Strait and Bay, and subsequent warming of Hudson Bay waters and movement into Hudson Strait during the summer. These phenomena imply that the core appears in the summer when the warm surface waters encroach on the Strait. The autumn dissipation occurs with the mixing of the cold waters with the warm waters both from Hudson Bay and the Atlantic Ocean.

Bottom temperatures follow the growth and decay of the minimum temperature layer or core which is confined to intermediate depths.

Consequently, July bottom temperatures -1.00 to -0.50° C. are slightly lower than in October, when the temperatures range from 0.00° C. to 0.40° C.

Similar oceanographic conditions were found in the outer cross-sections of the Strait. The main features of those sections, which are not shown here, are lower salinities and deep water temperatures at Nottingham Island than at Resolution Island.

One line of stations, however, occupied in October, 1955, across Ungava Bay is worthy of mention for several reasons (Figs. 25 and 26). Water conditions in this section were characterized by comparatively high temperatures and salinities, quite unlike the conditions found in Hudson Strait. Below 200 metres there was a significantly higher vertical increase of temperature and salinity than had been found in Hudson Strait. Bottom temperatures were as high as 1.75° C. and salinities 34.25‰.

Water conditions in the western half of the section above 200 metres were similar to those of Hudson Strait, but the deeper water and the surface water near the eastern entrance were characteristic of water from the Atlantic Ocean. The deep water intrusion from the Atlantic Ocean into Ungava Bay seems to be largely confined to the area east of Akpatok Island. However, the movement of Atlantic water probably can extend further west in the Bay in the summer and autumn, when the discharge from Hudson Bay decreases.

The wave-like appearance of the distribution of temperature and salinity may indicate the existence of internal waves. Dynamic computations of current speed and direction, based on the observations taken in this section, are so varied that the results appear at the present time to be of questionable value. A time series study across the Bay would be most valuable to fully ascertain the complexities of the currents and suspected existence of internal waves.

The longitudinal sections of temperature and salinity (Figs. 27 and 28), October, 1955, and (Figs. 29 and 30), July, 1956, for the two cruises give some further insight into the deep water movements of the Strait and the distribution of property.

Temperature fronts appear at the eastern entrance of the Strait, separating Hudson Strait water from Atlantic water (Figs. 27 and 29). The same frontal formation is also evident in the distribution of salinity, October, 1955 (Fig. 28) and to a less extent in the Figure for July, 1956 (Fig. 30).

The position of the fronts probably vary in the Strait depending on the seasonal variations of discharge from Hudson Bay. During peak Hudson Bay discharge periods in the Strait, the inward movement of Atlantic water is confined to the eastern entrance, while in the winter, there is a gradual intrusion, at depth, of Atlantic water.

The deep intrusion of Atlantic water is shown by the positions and distribution of the 33.50‰ and 33.75‰ isohalines (Figs. 28 and 30). In October, 1955, the bottom salinity is slightly greater with the 33.75‰ isohaline occupying the same depth as the 33.50‰ isohaline in July of 1956 (Figs. 28 and 30). There is, however, a remnant patch of high saline water located well within the

Strait in July, 1956 (Fig. 30). It appears then that in July and August, most of the deep Atlantic water has been flushed out of the Strait, while in September and October, there is a return of high saline water from the Atlantic Ocean.

The uplift of the isopleths at the eastern entrance of the Strait indicates the extent the waters from the inland seas override the heavier Atlantic water. This phenomenon might suggest flow along the lines of constant property, but at the entrance of the Strait, there are such indications of turbulence that flow along the isopycnal surfaces seems impossible.

The major movements of water in Hudson Strait can be depicted by the conditions represented in these sections. A wedge of deep warm high salinity water intrudes into Hudson Strait and Ungava Bay from the Atlantic Ocean. This body of water is generally confined to the deeper levels, but moves far into the Strait through the deep channels. The outbound waters from Hudson Bay and Foxe Channel in the summer are made up of a surface warm water wedge and a deeper cold water wedge. The opposing flows in the Strait form two distinct bodies of water, the one originating in the Atlantic Ocean and the other from inland seas. The extent to which one finds either water mass in the Strait depends on the season, but the fresher water from Hudson Bay will always override the heavier water from the Atlantic Ocean.

During the periods of maximum fresh water content, July and August, the waters from Hudson Bay and Foxe Channel will predominate

(Figs. 29 and 30). At other times of the year, particularly autumn and winter, Atlantic conditions will be more prevalent as the system attempts to recover dynamic stability and salt balance.

Average Salinities and Temperatures.

Salinities and temperatures were averaged in four sections along the south coast of the Strait and two along the north coast. The southern sections were divided into the areas between Nottingham and Charles Islands; Charles Island and C. Hopes Advance; and C. Hopes Advance to Akpatok Island and the eastern entrance of the Strait. The northern areas were divided into only two sections, the eastern and western approaches within the Strait.

The data analyses were carried out for both the October, 1955 and the July, 1956 cruises. Tables I and II list the data from the 1955 cruise for the respective areas on each side of the Strait, while Tables III and IV list the results for the 1956 observations. The standard deviation is small for each table, so that realistic physical conditions can be interpreted from these data.

A small increase in salinity occurs from the western sector to the eastern entrance of the Strait for any designated depth (Tables I and III). The only anomalous salinity values appear in the W. Ungava region where there is a marked decrease of salinity in the upper 50 metres. The decrease could be explained by the presence of ice in the early summer, but such an explanation could not be considered in October. Further, there are no large rivers in the C. Hopes Advance region to effect local dilution of waters. The only possible source of low saline water that could be forced offshore is brackish coastal water confined to the coast of Quebec. The presence of brackish water close inshore is presumed from the steady shoreward decrease of salinity (Figs. 6 and 8). At the eastern end of the Strait the salinity increases sharply owing to the influx of Atlantic water (Tables I and III).

Some indication of the seasonal changes in salinity are apparent in Tables I and III. Salinities in October are slightly lower in the western section than the corresponding salinities in July. However, the standard deviations overlap for these data, and a conclusion that fresh water has mixed to deeper layers must be regarded with some reservation. In Tables I and III, a salinity of 33.00‰ is found at depths of about 150 and 200 metres in the western area, while in the eastern area the depth of this isohaline is only 16 metres in October and 60 metres in July. The change in slope of the isohalines results from the seasonal variations of the fresh water run-off and the volume of discharge from Hudson Bay.

The temperature variations are even more marked than the salinity gradations. Sub-zero water temperatures are featured in July, with high temperatures appearing only in the upper 10 metres in the western area (Table III). Table I (October, 1955) depicts typical summer conditions with warm water predominating throughout the main body of the Strait. The depth of this warm water layer is limited to approximately 50 metres.

Along the north shore, the salinities are slightly higher than on the south side, however, a minimum salinity occurs off Big Island where cross-channel mixing occurs. The higher salinities north of Salisbury Island and west of Resolution Island are associated with respective movements of water into the Strait from Foxe Channel and Gabriel Strait (Tables II and IV). The salinities and temperatures on the northern side of the Strait reveal very slight changes from east to west for July and October (Tables II and IV). In July, there is a slightly lower average salinity and temperature than in October. Both longitudinal and vertical differences in salinity are small along the northern half of the Strait. Longitudinal variations of one part per thousand are extreme for the surface waters and vertical variations are limited to less than two parts per thousand.

The differences in water temperatures in July and October have been considered as indicative of seasonal changes in the water conditions. The most significant indication of summer is the break-up of ice. At such times, surface and subsurface temperatures are generally below 0°C. Once open water regions appear, warming of the water progresses rapidly, followed by wind mixing of the surface layers. The effects of advection of warm surface and subsurface water from Hudson Bay are most noticeable in the Strait in the summer. The warm water appears as a layer which varies in thickness throughout the Strait, but generally it is deeper in the southern half of the Strait than in the northern half.

Following the break-up of ice, surface salinities may drop as low as 20.00‰ or lower in ice-enclosed areas. However, the average minimum salinity does not appear in the Strait until late July or early August, when the combined sources of melt water and river drainage from Hudson Bay are brought into the Strait. Not all of the brackish water is flushed out of the Strait in August or September, because a major amount of the rainfall occurs in the autumn. However, it would seem that more stable salinity conditions are attained in the Strait shortly after freeze-up when fresh water is stored over the drainage basin of Hudson Bay.

The cold deep water conditions in July indicate that winter conditions are still prevalent in the Strait, although warm water from Hudson Bay appears off Digges Islands. In October, peak summer thermal conditions are reached in the main body of the Strait, while cooling may begin in the inshore waters. Ice generally forms along the shore in October, indicative of the onset of winter cooling conditions.

T-S Characteristics

The water masses found in Hudson Strait originate in Hudson Bay, Foxe Basin and the Atlantic Ocean. Temperature and salinity characteristics alone were not sufficiently different to permit positive identification of all the water masses. T-S curves were drawn for all stations by cruise and areas, and it was found that the T-S relationships were generally limited, but with sufficient variation so that no single T-S curve could adequately represent the water conditions. The tables of salinity and temperature give some indication as to the variation of conditions in the Strait with time (Tables I, II, III and IV).

The most useful information that is gained from the TS curves is a representation of the extreme conditions that are likely to appear in the Strait by season and area. The broken lines in Fig. 31 depict the water conditions at the eastern end of the Strait for June, July and October. The solid lines represent typical water conditions in the western approaches of the Strait for the same three months. No data above 30 metres have been included in these curves.

The temperatures decrease initially with depth, but in the western regions there is no significant rise of temperature near the bottom or below 300 metres, as is the case at the eastern end of the Strait (Fig. 31). The limiting or minimum temperatures in the western area are -1.20°C. to -1.50°C. In the eastern area, temperatures rise to 0.30° C. and 1.50°C. below 300 metres. Salinities are restricted as well to a maximum value of approximately 33.30‰ in the western area, while they may increase to values of 34.30‰ or greater in the deeper waters at the eastern entrance.

The salinity and temperature ranges for the respective regions, east and west, can be markedly different. Thermal and haline conditions partially overlap by area for June, but spread significantly later on in the year. In June, the temperatures are the lowest in both the eastern and western areas. A progressive seasonal warming is evident at each entrance of the Strait. The minimum June temperatures may increase by one and one-half degrees off Resolution Island, but in the western area, the increase of the minimum temperature is usually less than half a degree. The salinity at the minimum temperatures observed in the eastern part of the Strait was almost constant at 33.20‰. This value corresponds very closely to the maximum salinity in the western end of the Strait.

Distribution of Dissolved Oxygen and Phosphate.

Average values of oxygen concentration and percent saturation were found for the periods of sampling, June, 1955, October, 1955 and July, 1956. Early summer concentrations ranged at the surface from 8.3 to 10.4 ml/l. compared with autumn values of 7.7 and 8.3 ml/l. The average percent saturation decreased also from 120% in June and July to 97% in October.

The high oxygen concentrations in July of 8.0 to 11.0 ml/l are not unusual in the Arctic. A sharp increase in oxygen concentration generally follows with the disappearance of ice. At such times, the phytoplankton populations appear to be at, or near, a maximum. An oxygen maximum is common for the area and for the most part is located at 10 metres, but instances occurred of maximum values being found at the surface and 20 metres. Below 20 metres the oxygen content decreased to average minimum values of 7.0 and 7.6 ml/l. near the bottom.

Surface oxygen concentrations were found to fluctuate considerably from station to station and little information was gained by treating the geographic distribution at this depth. The distribution of oxygen at 20 metres for October, 1955 and July, 1956 show few corresponding features (Figs. 32 and 33). However, both diagrams exhibit some of the characteristics of the distribution of temperature and salinity at 20 metres. For the main part, lower values of oxygen are found at the eastern and western approaches of the Strait, while higher values appear in the central area. This situation exists for both periods of observation although the values of concentration differ slightly (Figs. 32 and 33).

It is possible to trace the waters from Hudson Bay by the concentration of oxygen (Figs. 32 and 33). The concentration in October varies from 6.5 ml./l. to 8.0 ml./l. as compared to 8.0 and 9.0 ml./l. in July. The highest July concentrations of oxygen were located in the eastern regions where the ice concentration varied from 40% to 80% of the total area.

Percent saturation is a useful parameter for characterizing the waters seasonally. The July survey revealed that on the average percent saturation was well above 100%. The high concentration of oxygen is no doubt due to the existence of phytoplankton, but also to the cold water conditions. The autumn figures of percent saturation showed a marked decrease in oxygen, resulting possibly from reduced biological activity and warm water.

Oxygen determinations were made at most stations during the two larger surveys, October, 1955 and July, 1956, to obtain comparative information, but only two sections are presented here. The sections are those off C. Weggs and C. Hopes Advance (Figs. 34 and 35) and (Figs. 36 and 37) for 1955 and 1956 respectively. There is virtually no similarity of the oxygen distribution from the one cruise to the other. There are, however, recognizable features between sections for each cruise.

The results of the October survey of 1955 (Figs. 34 and 35) show a slightly lower oxygen content along the south coast in the autumn than indicated by the summer observations. The autumn oxygen concentration was quite uniform for the Strait with a maximum variation of only two millitres per litre. The results for July of 1956 are quite different, and marked variations of the oxygen concentration were evident at all depths. The oxygen content was slightly lower on the average along the south side, as found the year before, but the gradation from the surface to the bottom ranged from 10.00 ml./l. to 7.50 ml./l. (Fig. 37).

There appears to have been only a slight change of the amount of dissolved oxygen in the deep water. Oxygen values range from 7.00 ml./l. to 7.50 ml./. Above 200 metres there is a considerable variation of the oxygen concentration. The results of the three surveys in the Strait indicate that higher oxygen concentrations and larger variations can be expected in early summer than in the autumn. The summer values of the oxygen concentration in the upper 200 metres vary from 7.25 ml./l. to 10.00 ml./l., while the autumn variation appears to be limited from 7.25 ml./l. to 8.25 ml./l.

A limited study of the phosphate content was undertaken in 1956 to obtain some indication of the average nutrient content of these waters. The observations revealed that within the upper 30 metres the average phosphate content was 0.63 ug. atoms /l., but below this depth the phosphate concentration increased to values of 0.96 ug. atoms /l. at the bottom. The data were not sufficient to consider a geographical distribution of this parameter.

Circulation

Sigma-t surfaces were contoured for the Strait and the analyses of the distribution of the density revealed several interesting dynamic relationships. The vertical and horizontal variation of the density was limited to sigma-t values of 25.00 at the surface, and 27.50 at the bottom. The 26.50 sigma-t surface extended throughout most of the Strait and was selected for partial isentropic analysis following the technique employed by Montgomery (Montgomery, 1938).

Two charts of the 26.50 sigma-t surface (Figs. 38 and 39) were prepared by contouring the depth of this surface (depth in metres). Complete isentropic analyses were not possible for several reasons. It was found that the range of the salinity was less than 0.5‰ and that vertical mixing was prevalent in some areas within the Strait.

The configuration of the density topography is fairly consistent for both cruises, but major differences appear in some localities. Both Figures show the depression of the isopycnal surfaces along the whole extent of the Quebec coast (Figs. 38 and 39). In other regions, such as Ungava Bay, Big Island, Nottingham and Charles Islands, differences in configuration and slope are apparent.

The density topography in the Ungava Bay region is the least reliable for reasons mentioned. The water movements revealed by the October survey point to a strong southerly flow into Ungava Bay off Akpotak Island (Fig. 38). The following survey in July, 1956, revealed a southeasterly directed movement off C. Hopes Advance and an easterly directed flow north of Akpatok Island (Fig. 39). Both these differently directed flows could be real, but the dynamic interpretations must be questioned in view of strong tidal mixing and the possible existence of internal waves.

Variations of the density topography off Big Island also reveal different current features in October and July. The cross-sectional slope of the 26.5 sigma-t surface indicates an outflow across the Strait during both cruises, but the longitudinal slopes reveal in October on offshore component of current west of Big Island, and an onshore current in July (Figs. 38 and 39).

The configuration of the density surfaces in the Nottingham-Charles Island region suggests a deepening of the sigma-t surface towards the Quebec coast in the autumn (Fig. 38), while in the summer, the maximum depth (Fig. 39) of the density surface is centred off the coast. The dynamic interpretation is quite different in each case. The results from the October cruise indicate a cyclonic sweep of the water from Digges Islands to Charles Island, while in July an anticyclonic movement prevails throught this locality.

For the main part, the slope of the isopycnal surfaces was consistent for the two periods of observations, but the depth of the density surface was much greater in October, 1955, than July, 1956.

The dominant feature of the circulation is the outflowing current along the Quebec coast. This current remains as an outgoing stream from Hudson Bay to Ungava Bay, despite seasonal changes. The current streams on the northern side of the Strait are much weaker and appear to be influenced by minor disturbances, such as variations in the volume discharge and atmospheric conditions.

Dynamic computations of the data were undertaken by the data processing centre of the United States Navy Hydrographic Office. The computed data were used to prepare two charts showing the surface currents relative to the 200 decibar level. The selection of the 200 decibar level is partly arbitrary because it is doubtful that a surface of no motion exists through the Strait. In some sections, however, the 200 decibar level corresponded to a shear zone which was considered to be the closest approximation of a surface of no motion. Dynamic heights were studied with reference to other depths, and it was found that for depths less than 200 metres, the main current patterns were reproduced. Unfortunately, an insufficient number of stations were occupied with depths exceeding 200 metres, and it was not possible to prepare a representative dynamic height chart of the Strait for deeper levels.

The agreement in direction and speed of the currents is reasonably good (Figs. 40 and 41). However, there are the differences in current direction for the Nottingham-Charles Island area and Big Island. The results of the autumn survey show a strong current of water with speeds of 0.41 knots, between Nottingham Island and the mainland. Part of this circulation possibly takes part in the cyclonic sweep of the water west of Charles Island, but the main stream extends north and east between Salisbury Island and Charles Island. However, the series of observations taken in the same area in July, 1956, indicate an anticyclonic gyre. Probably this flow is associated with the strong flow of water entering the Strait between Nottingham and Salisbury Islands.

The dynamic heights in the southwestern section of the Strait are considerably greater than those calculated for other regions. As a result of this phenomenon, the slope of the dynamic topography is downwards from this locality to all other regions of the Strait. There is no indication from either of these two cruises that extreme dynamic heights should be found along the Quebec coast, although this possibility cannot be excluded. The occurrence of the warm low saline water in the southwestern sector of Hudson Strait is reflected by the low density of the water. The subsequent transport and associated mixing of the water results in an increase of salinity and decrease of temperature. These changes bring about a marked alteration of dynamic topography throughout the Strait.

Some of the minor differences in the slope of the dynamic height are revealed by the current directions off Big Island. The results show that in July, 1956, an onshore westerly-directed movement of water took place along the northwestern sector of the Strait, in contrast to an offshore current that appeared in October, 1955. However, despite the differences of the cross-channel flows, the main set of the currents on the northern side of the Strait was westward in each case. This movement of water may be sporadic, but the June observations of 1955 revealed a westerly current extending as far as Salisbury Island. The speed of this current in June was of the order of 0.33 knots.

The net movement of water along the northern coast is difficult to access on the basis of these data, because the waters are turbulent and disturbed by the action of strong tides running over a rugged and uneven bottom. Other evidence, however, supports at least the periodic existence of the westbound current, icebergs have been reported grounded on the northeastern side of Salisbury Island, and Dunbar reports the occurrence of biological indicators of Atlantic water in Hudson Strait and Hudson Bay (Sailing Directions for Northern Canada, 1951 , (Dunbar, 1951).

The differences in the patterns of the secondary circulations are marginal, although it is felt that the evidence presented should be considered in view of possible differences in seasonal variations of the circulation.

The important feature of the circulation is the outgoing current along the Quebec coast. Speeds are variable but range from 0.15 to0.34 knots. In all probability, a net current speed of 0.5 knots or better occurs closer inshore.

The inflowing waters from the Atlantic do not appear as a rule to extend as far west as Big Island, but turn south short of the Island and join the main flow into Ungava Bay. The net current speeds of this circulatory branch were calculated to be less than 0.30 knots. The outflowing stream from Hudson Strait to the Atlantic Ocean is believed to be largely confined to the southern limits of the eastern entrance. The speed of this current is estimated at 0.30 to 0.40 knots.

Volume Transport

Calculations of the volume transport were made from all sections in Hudson Strait. Additional sections were examined in Hudson Bay, Rose Welcome Sound, Frozen Strait and Foxe Channel, to obtain an overall picture of the exchange of waters in the Hudson Bay-Foxe Basin region. In order to estimate the volumes of exchange through Hudson Strait and the western passages, a number of gross assumptions were required to obtain reasonable agreement. It was found necessary to weigh the results more in certain areas than in others, owing to the difficulties encountered with the assumption of a steady state, and the choice of a depth of no motion.

The initial inconsistencies of the rate of discharge ranged from values of $0.2 \times 10^6 m^3/sec.$ to $0.7 \times 10^6 m^3/sec.$ with reference to the 200 decibar level. It was reasoned that two major sources of error were possible, namely that the depth of no motion varied laterally and longitudinally, and that the transport of water between the southern stations and the coast could be as high as the transport within the station cross-sections.

The cross-sectional distributions of temperature and salinity were studied in order to approximate a depth of no motion. The interpretation of the data led to a sloping surface of no motion which was deeper on the southern coast of the Strait than on the northern coast. The approximate depth of no motion on the northern side was found from current reversals. Extrapolation from both sides of the Strait to the central area selected the depth of no motion in the intervening gap.

This method is not void of difficulties because it is dependent on the maximum depth of sampling. However, it is felt that the error involved in determining the volume transport on this basis is less than an artificial selection of a level of no motion at 150 or 200 metres.

At each section, an attempt was made to determine both the eastward and westward transports of water as well as the net transport. Using this approach, fairly consistent results were obtained for the respective periods of observation, but differences occurred for the two surveys. Consistent agreement on an eastward transport was obtained from three sections, C. Weggs, C. Prince of Wales and C. Hopes Advance. The only section where a westward transport was obtained was that between Nottingham Island and Digges Islands. In this area, sampling extended almost to the bottom.

Very little evidence of a westward moving current was found in the three central sections of the Strait. Some minor indications of a deep westerly set to the current were obtained for the sections off C. Weggs and C. Hopes Advance, but none were found from the section off Big Island. It must be presumed then that cross-channel flows referred to earlier exist, or the westward movement of water is confined to the bottom, or along the north coast in a region where sampling was not carried out.

The transport of water through the Strait is related to the influx of Atlantic water, the discharge of water through Fury and Hecla Strait, and rainfall. The net volume transport must therefore closely approximate the excess of water originating from land drainage and the eastward transport of water through Fury and Hecla Strait.

The Hudson Bay - Hudson Strait - Foxe Basin drainage system includes a large part of Canada. Rivers that drain into this vast system originate as far south as the United States and as far west as the Canadian Rockies (Fig. 42). The total area of the drainage system including the areas of Hudson Bay and Foxe Basin is approximately 1.8 x 10^6 square miles. The rainfall over the area varies from 30 inches per year in northern Ontario to less than 10 inches per year in Foxe Basin. Most of the rain and snow will be stored over the drainage areas of Hudson Bay and Foxe Basin from November until May. Maximum discharge of the southern rivers draining into Hudson Bay takes place in late May, while the minimum discharge usually occurs in November or March. For the more northern regions, the period of peak discharge will be delayed by a few weeks.

It would be expected that the net volume discharge in Hudson Strait would reflect the rise and fall of the river runoff with a time delay of perhaps several weeks. On this assumption, an increase in the volume discharge through the Strait would be expected in June, lasting until the end of August. In addition to the discharge of fresh water from the rivers, there is an additional source of fresh water in June and July from the melt waters of ice. The volume of such water stored in the form of ice is quite considerable, being approximately one-tenth of the total annual rainfall over the drainage basin. The release of this water or even a small percentage of it, results in an additional flood of fresh water to that of river discharge. The result is a large stored potential of brackish water which can mix and quickly upset the previous winter's "dynamic stability" of the waters in Hudson Bay. The effect of the sudden release of fresh water is to increase the rate of exchange of water. This would be expected to take place at a faster rate than if mixing and discharge of river water occurred independently of melting ice. The rate of flushing or net discharge in Hudson Strait is estimated to be approximately $0.3 \times 10^6 m^3/sec.$ for July (Fig. 44).

In October, the net eastward transport of water in Hudson Strait was computed at approximately $0.2 \times 10^6 m^3/sec.$ (Fig. 43). The net volume loss of water in the inland seas, Hudson Bay and Foxe Channel can only be related to the discharge of water from Fury and Hecla Strait and rainfall over the Hudson Bay-Foxe Basin drainage system. The winter storage of snow and ground water for almost a five month period suggests a considerably reduced net transport through Hudson Strait in the winter months. An estimate of this rate of discharge is of the order of $0.1 \times 10^6 m^3/sec.$

roughly equivalent to the calculated transport through Fury and Hecla Strait.

The net volume discharge $0.3 \times 10^6 m^3/sec.$ computed for July, 1956, is believed to represent a maximum figure, the largest percentage of which would be related to fresh water runoff. The runoff would be well above normal in June and it is calculated to be of the order of $0.25 \times 10^6 m^3/sec.$ for Hudson Bay. A figure of this order will maintain volume continuity in the Bay (Fig. 44). The net loss of water in Hudson Bay in October, 1955 (Fig. 43) requires a fresh water input of approximately $.15 \times 10^6 m^3/sec.$

The agreement of the net volume transport figures with those of rainfall are remarkably good, although the estimates of land drainage require that most of the ground water be stored over the winter months and released within a short period of time in the summer. The autumn estimate also appears high, and it is suggested that the net volume transport through the Strait possibly passes through a summer minimum in late August and early September. Following this decline, there would be a secondary increase in the net volume discharge as the autumn rains and snow would cause a significant increase in river discharge before freezing conditions are established on the land.

Differences in the net volume transport of water appear in the northern part of Hudson Bay and Foxe Channel (Figs. 43 and 44). An outward flow of $0.9 \times 10^6 m^3/sec.$ confined to the upper 150 metres, was calculated for October, 1955, between Nottingham and

Digges Islands (Fig. 43). Below this depth, a compensating westward transport of 0.5 x $10^6 m^3$/sec. appeared flowing into Hudson Bay. Part of the net outflow through this section passes through the Strait, and part sweeps northward and enters Foxe Channel. The eastward outflow extends almost to the bottom along the south coast of the Strait, while on the northern side, the outflow is limited to a thin surface layer of 75 metres or less. The westward compensating flow of water is confined to the deeper depths and the coastal areas along the northern side of the Strait.

From Southampton Island across to Digges Islands, an exchange of water takes place in and out of Hudson Bay, through the sections, Southampton Island to Coats Island, Coats Island to Mansel Island, and Mansel Island to Digges Islands. A net westward flow of water between Southampton Island and Coats Island appears with a volume transport of 0.1 x $10^6 m^3$/sec. The source of this water is probably the strong southerly flow found on the western side of Foxe Basin and Channel. A north-south exchange of water occurs through the two sections between Coats Island and Digges Islands. West of Digges Islands, a northern movement of water exists in October with a transport of 0.5 x $10^6 m^3$/sec. between the surface and 250 metres, but below 250 metres, there is a compensating southerly flow of 0.2 x $10^6 m^3$/sec. (Fig. 43). A northern flow was also found in the upper 250 metres between Coats Island and Mansel Island. This transport was determined at the rate of 0.3 x $10^6 m^3$/sec. However, in order to maintain volume continuity in Hudson Bay, an inflow of 0.2 x $10^6 m^3$/sec. was presumed to exist near the bottom (Fig. 43).

The exchange of waters between Foxe Channel, Hudson Strait and Hudson Bay appears to be subject to seasonal fluctuations. In October, there was a transport of water from Hudson Strait to Foxe Channel at approximately 0.2 x $10^6 m^3$/sec. (Fig. 43). The influx of water from Fury and Hecla Strait has been calculated to be of the order of .05 to 0.1 x $10^6 m^3$/sec. The combined transports from Fury and Hecla Strait and Foxe Channel are transported out through Frozen Strait to Rose Welcome Sound and Hudson Bay.

A slightly different picture of net transport was obtained in July, 1956, for the whole area, but particularly the Hudson Bay-Foxe Channel region (Fig. 44). A northern transport of water from Hudson Bay to Foxe Channel was found with part of this transport, 0.1 x $10^6 m^3$/sec. moving out into Hudson Strait north of Nottingham Island and part flowing into Foxe Channel. The northern extension of the flow is restricted to the central and eastern half of Foxe Channel.

The difference in the net transport calculated for October, 1955 and July, 1956, are believed to be predominately dependent upon the percentage of fresh water in Hudson Bay. Consequently, during the summer period of peak river discharge and ice melting, the net transport increases to what is believed to be a maximum for the year.

The potential energy and volume of the outflow is so great at the time of maximum river discharge and ice melting that it regulates the circulation in Hudson Strait. Later, in the autumn and winter, when the volume discharge has waned, the influx of water from the Atlantic becomes the controlling dynamic factor and the circulation may readjust or alter significantly.

SUMMARY

1. Three oceanographic surveys were carried out in Hudson Strait in June, 1955, October, 1955 and July, 1956.

2. Hudson Strait ice is in a continuous state of motion from the effects of wind, tides and currents. The pack ice in the Strait includes local ice and ice from Baffin Bay, Hudson Bay and Foxe Basin. Of the four types of ice encountered in the Strait, the Foxe Basin ice is much heavier and is characteristically discoloured in the summer by brown dirt deposits.

3. The horizontal distribution of temperature and salinity clearly indicates the influence of the outflowing waters from Hudson Bay. In the summer, the outflowing waters are warm and of low salinity.

4. Seasonal differences in thermal conditions are evident at both the surface and subsurface depths. The encroachment of warm low saline water from Hudson Bay into the Strait is first evident along the south shore of the Strait. With the advance of the summer season, the water from Hudson Bay spreads out to cover almost one half the width of the Strait. At the same time the depth of the Hudson Bay water increases at the western end and along the southern shore.

5. Remnant winter or spring conditions remain in the Strait for most of the summer. These conditions disappear first at the surface

and may be almost absent by the end of July, however, winter conditions of cold and high salinity water may still be evident between 100 and 200 metres.

6. In the summer, the waters from Hudson Bay and Foxe Basin are the most dominant in the Strait, as these waters override an intrusion of Atlantic water from the eastern end of the Strait. The Atlantic water is largely confined to this area of the Strait, but it may appear further west in the Strait along the bottom.

7. Surface oxygen concentrations fluctuate geographically and seasonally, but for the main part they fall within a range of 7.0 to 11.0 ml./l. Bottom oxygen concentrations appear to be fairly uniform 7.00 to 8.00 ml./l. The phosphate concentration varies approximately from 0.60 ug. atoms /l. within the upper 30 metres to 0.96 ug. atoms /l. at the bottom.

8. The circulation in the Strait is dominated by almost a steady outflow from Hudson Bay to Ungava Bay along the south shore of the Strait. Atlantic water enters the Strait around Resolution Island and appears to extend almost as far west as Big Island, where it turns south and joins the outflowing stream from Hudson Bay. Part of the water from the Atlantic inflow may continue on west of Big Island, but this movement may only take place occasionally.

9. Evidence of Atlantic water in Ungava Bay indicates that both a deep and shallow intrusion of water takes place between the eastern entrance and the Bay.

10. Waters from Foxe Basin and Foxe Channel enter Hudson Strait

around Salisbury and Mill Islands and join the outgoing stream along the south side of the Strait. West of Big Island, a return circulation of water is evident. However, the conflicting results revealed by the two cruises in this area leave the current picture somewhat in doubt.

11. The nature of the currents between Nottingham and Salisbury Islands is also doubtful, due in part to tidal effects and seasonal changes.

12. Estimates of the volume exchange of waters in the Hudson Strait-Hudson Bay-Foxe Basin area have been presented. The net volume transport through the Strait is related to the fresh water drainage and discharge through Fury and Hecla Strait. The net volume transport for July, 1956, was determined at $0.3 \times 10^6 m^3/sec.$ while the transport for October, 1955 was $0.2 \times 10^6 m^3/sec.$

13. The differences in the rate and direction of the volume transport in the Hudson Bay-Hudson Strait and Foxe Channel areas are believed to be related to the seasonal variation of fresh water content in Hudson Bay.

ACKNOWLEDGMENTS

Much of the success and interest of the Hudson Strait surveys is owed to the Commanding Officers, officers and men of H.M.C.S. "Labrador" in the two year period of investigations. Assistance in the field operations was efficiently and cheerfully tended by Messrs. J. G. Clark and N. A. Clarke, 1955, and Messrs. A. E. Collin and C. C. Cunningham, 1956, all members of the Atlantic Oceanographic Group on board H.M.C.S. "Labrador". Many skilled services were kindly rendered by the staff of the Atlantic Oceanographic Group, in particular Mr. F. Forgeron, who assisted with some phases of the data analyses.

Table I.

Average Temperature and Salinity Conditions

South Coast, Hudson Strait

October, 1955.

	West		Central		W. Ungava		East	
Depth m	Sal. ‰	Temp. °C.	Sal. ‰	Temp. °C.	Sal. ‰	Temp. °C.	Sal. ‰	Temp. °C.
0	29.82	2.68	31.41	0.76	31.00	1.50	32.96	0.55
10	30.06	2.28	31.49	0.75	31.00	1.14	32.98	0.15
20	30.31	2.13	31.76	0.65	31.12	1.13	33.16	-0.04
30	30.61	1.77	32.04	0.50	31.47	0.94	33.18	-0.07
50	31.28	1.17	32.33	0.22	32.28	0.34	33.27	-0.03
75	31.85	0.07	32.67	-0.22	32.79	-0.09	33.53	-0.07
100	32.45	-0.25	32.86	-0.36	33.01	-0.33	33.69	-0.53
150	32.91	-0.54	33.13	-0.46	33.29	-0.30	33.85	-0.66
200	33.11	-0.91			33.55	-0.17	33.92	-0.76

Table II.

Average Temperature and Salinity Conditions

North Coast, Hudson Strait

October, 1955.

	Northwest		Northeast	
Depth m	Sal. ‰	Temp. °C.	Sal. ‰	Temp. °C.
0	32.83	0.31	33.21	0.50
10	32.87	0.15	33.24	0.27
20	32.89	0.17	33.21	0.28
30	32.92	0.21	33.23	0.19
50	32.94	0.12	33.34	0.12
75	33.03	-0.13	33.37	-0.08
100	33.07	-0.42	33.44	-0.19
150	33.20	-0.85	33.60	-0.25
200	33.25			

Table III.

Average Temperature and Salinity Conditions

South Coast, Hudson Strait

July, 1956.

	West		Central		W. Ungava		East	
Depth m	Sal. ‰	Temp. °C.	Sal. ‰	Temp. °C.	Sal. ‰	Temp. °C.	Sal. ‰	Temp. °C.
0	30.10	2.22	31.12	1.93	30.57	-0.78	32.42	-0.80
10	30.35	1.41	31.41	1.37	31.10	-0.05	32.62	-0.89
20	31.19	-0.38	32.01	-0.18	31.78	-0.62	32.73	-0.98
30	31.55	-0.88	32.38	-0.73	32.20	-0.93	32.82	-0.69
50	32.09	-1.49	32.69	-1.32	32.70	-1.39	32.96	-1.04
75	32.49	-1.46	32.86	-1.41	32.98	-1.42	33.10	-1.15
100	32.67	-1.56	32.98	-1.48	33.08	-1.54	33.22	-1.10
150	32.94	-1.61	33.20	-1.45	33.31	-1.33	33.50	-0.27
200	33.06	-1.72						

Table IV.

Average Temperature and Salinity Conditions

North Coast, Hudson Strait

July, 1956.

	Northwest		Northeast	
Depth m	Sal. ‰	Temp. °C.	Sal. ‰	Temp. °C.
0	31.66	-0.64	32.64	-0.38
10	32.21	-1.18	32.72	-0.44
20	32.59	-1.33	32.78	-0.53
30	32.71	-1.32	32.96	-0.65
50	32.85	-1.33	33.14	-1.13
75	32.98	-1.34	33.19	-1.16
100	33.08	-1.26	33.22	-1.18
150	33.19	-1.24	33.28	-1.10

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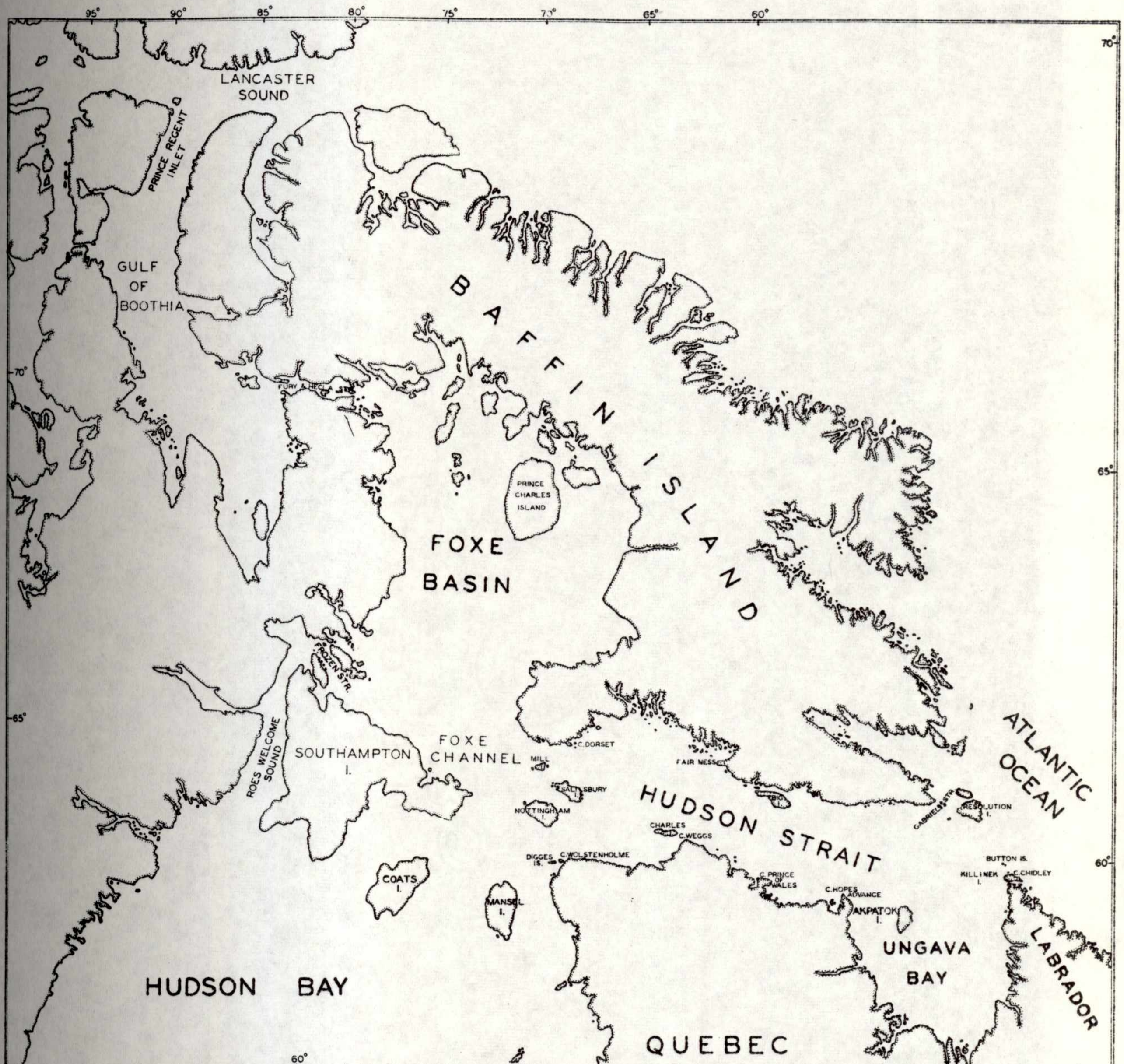
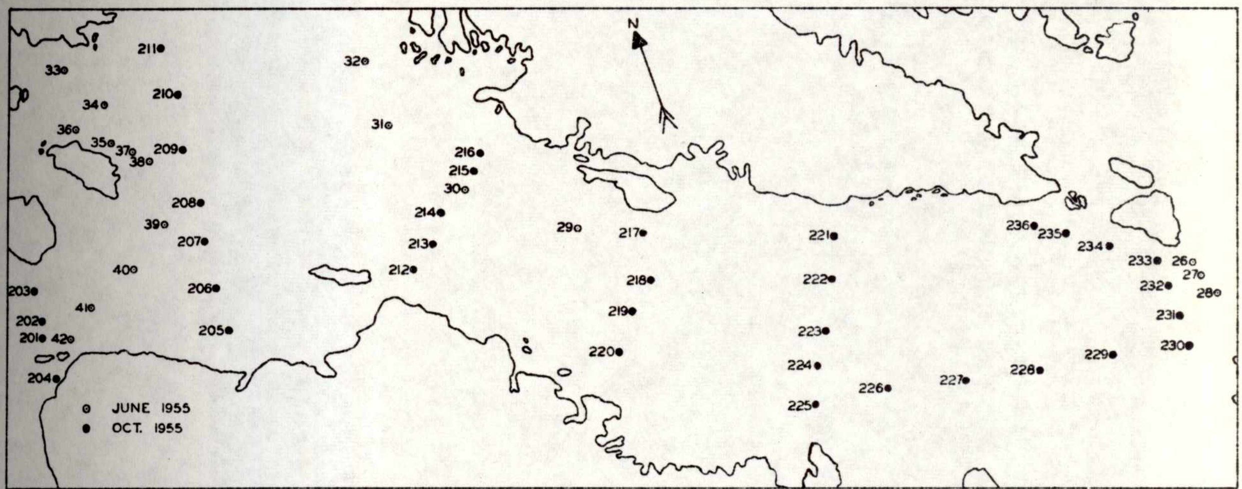


Fig. 1. Hudson Strait, Foxe Basin and Hudson Bay.



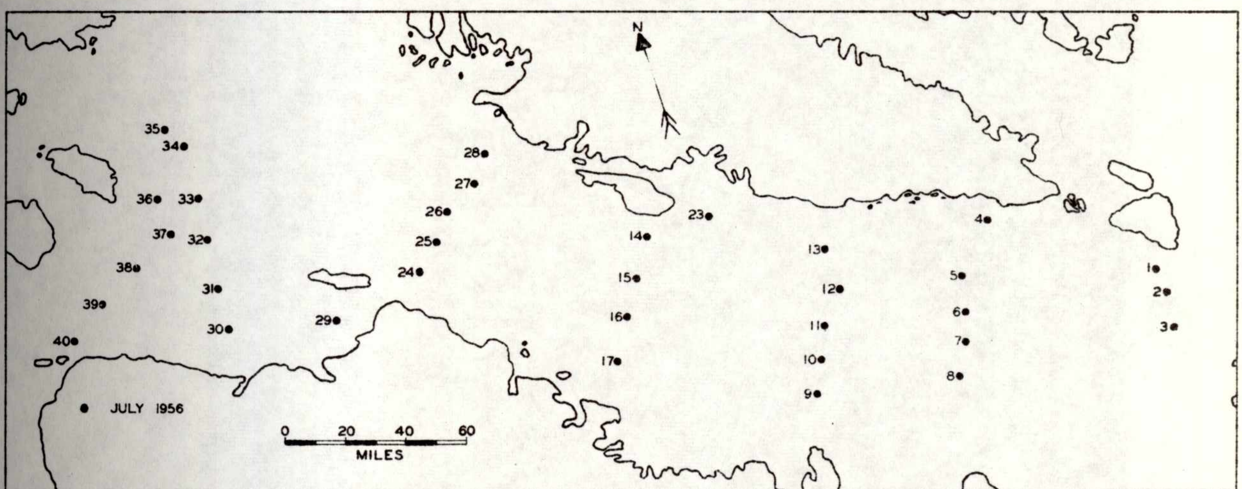


Fig. 2. June and October oceanographic stations, Hudson Strait, 1955.

Fig. 3. July oceanographic stations, Hudson Strait 1956.

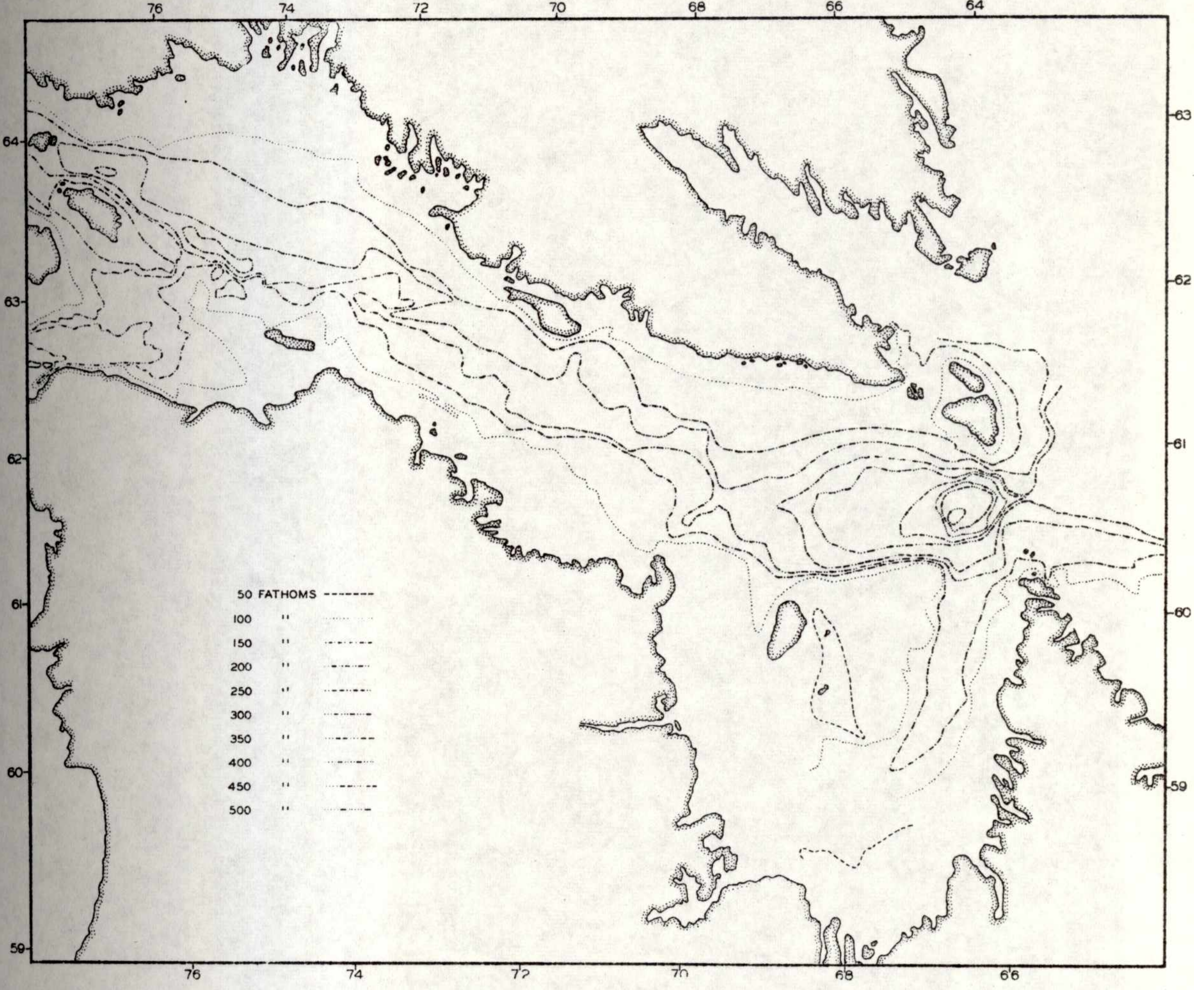
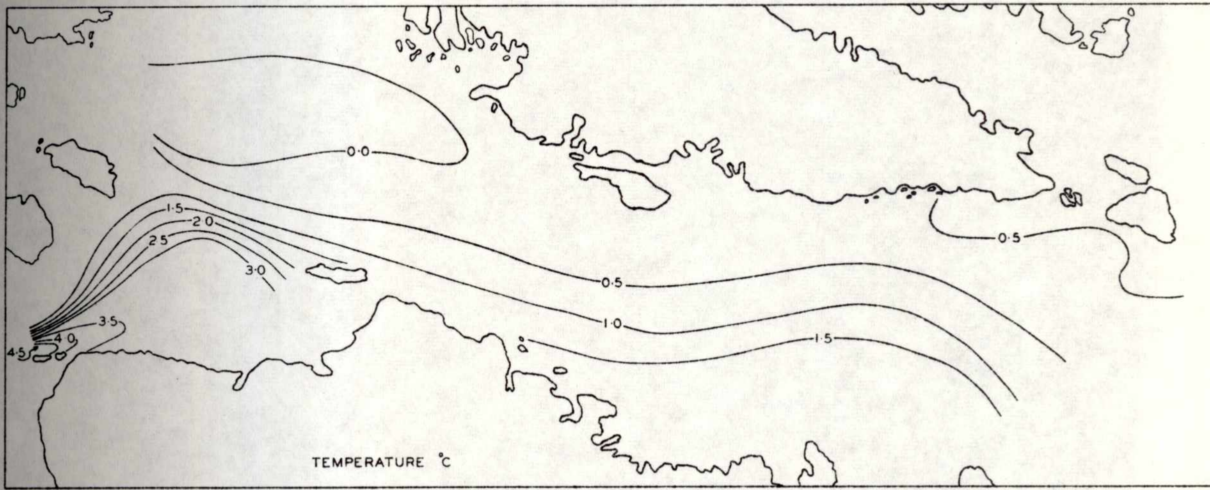


Fig. 4. Bottom topography, Hudson Strait.



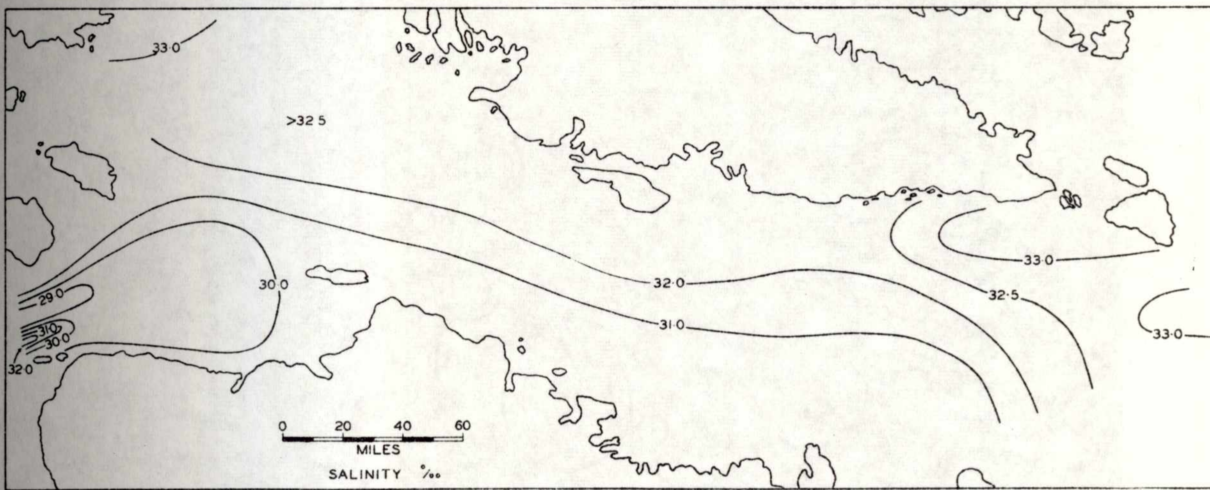


Fig. 5. Distribution of surface temperature, Hudson Strait, October, 1955.

Fig. 6. Distribution of surface salinity, Hudson Strait, October, 1955.

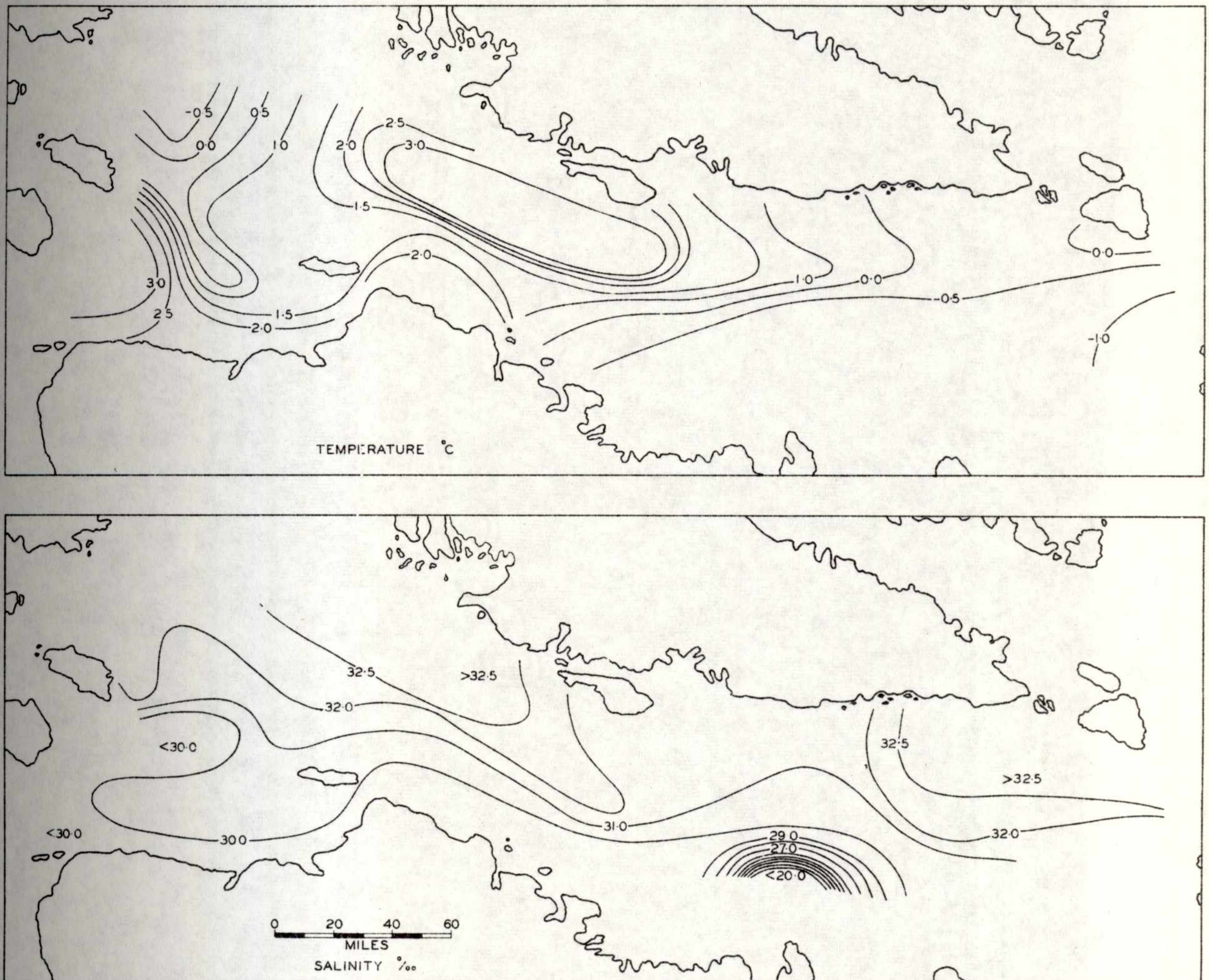
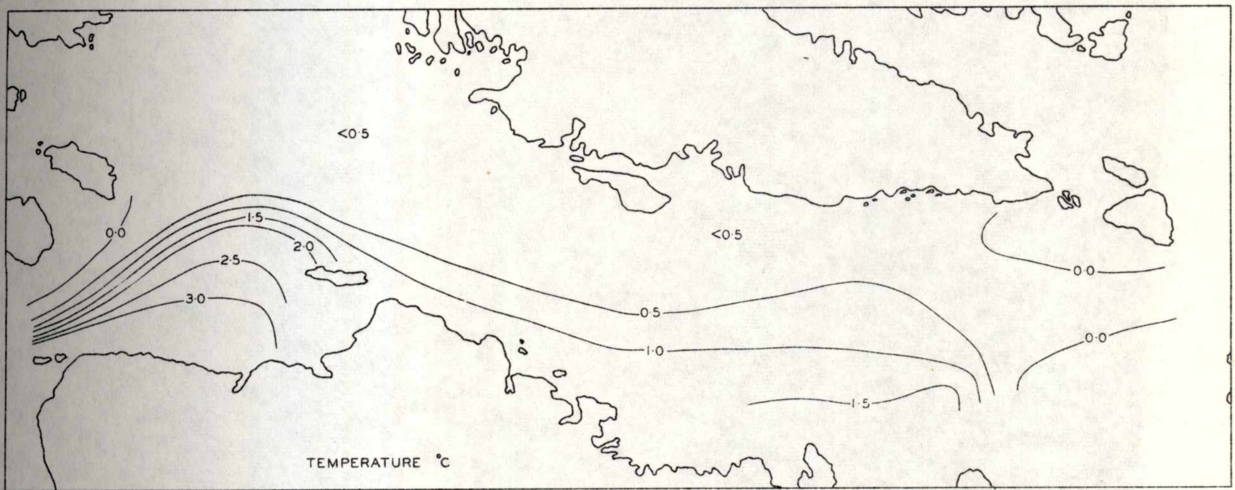


Fig. 7. Distribution of surface temperature, Hudson Strait, July, 1956.

Fig. 8. Distribution of surface salinity, Hudson Strait, July 1956.



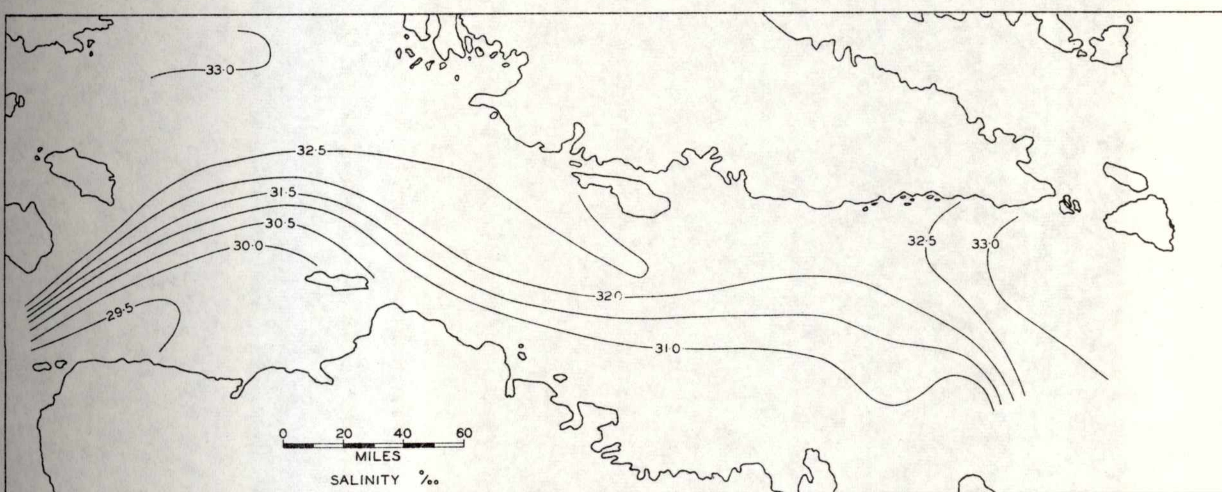
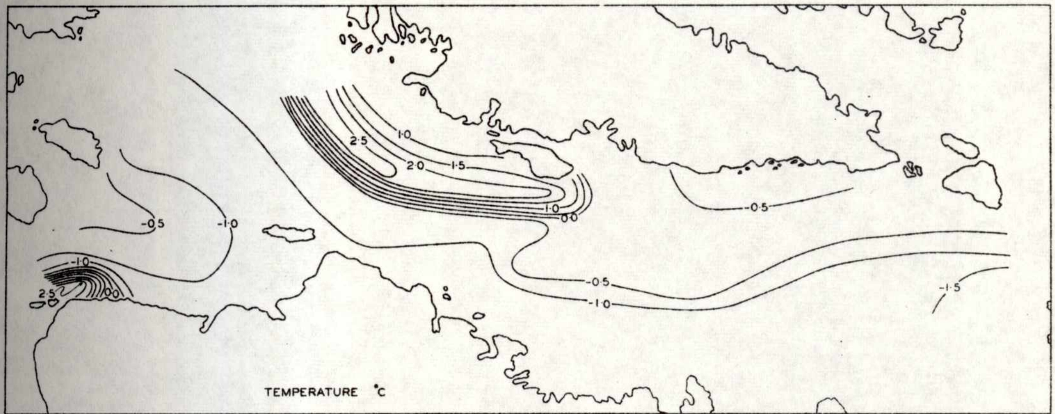


Fig. 9. Distribution of temperature, 20 metres, Hudson Strait, October, 1955.

Fig. 10. Distribution of salinity, 20 metres, Hudson Strait, October, 1955.



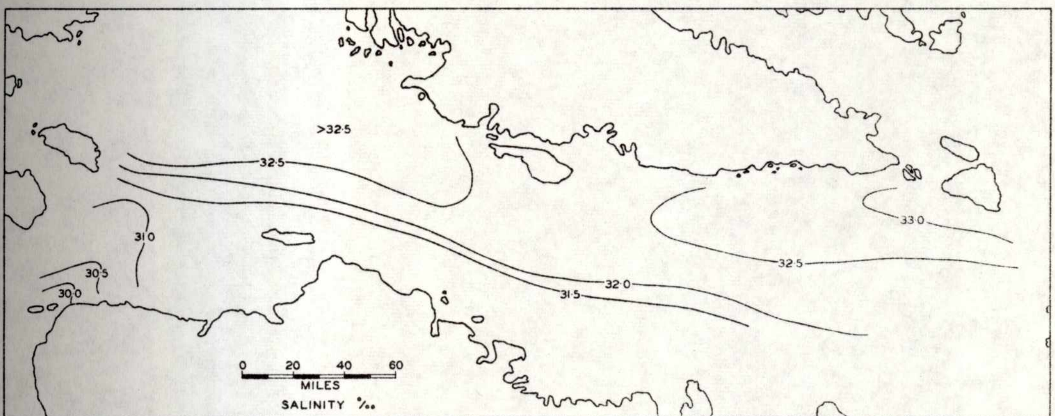
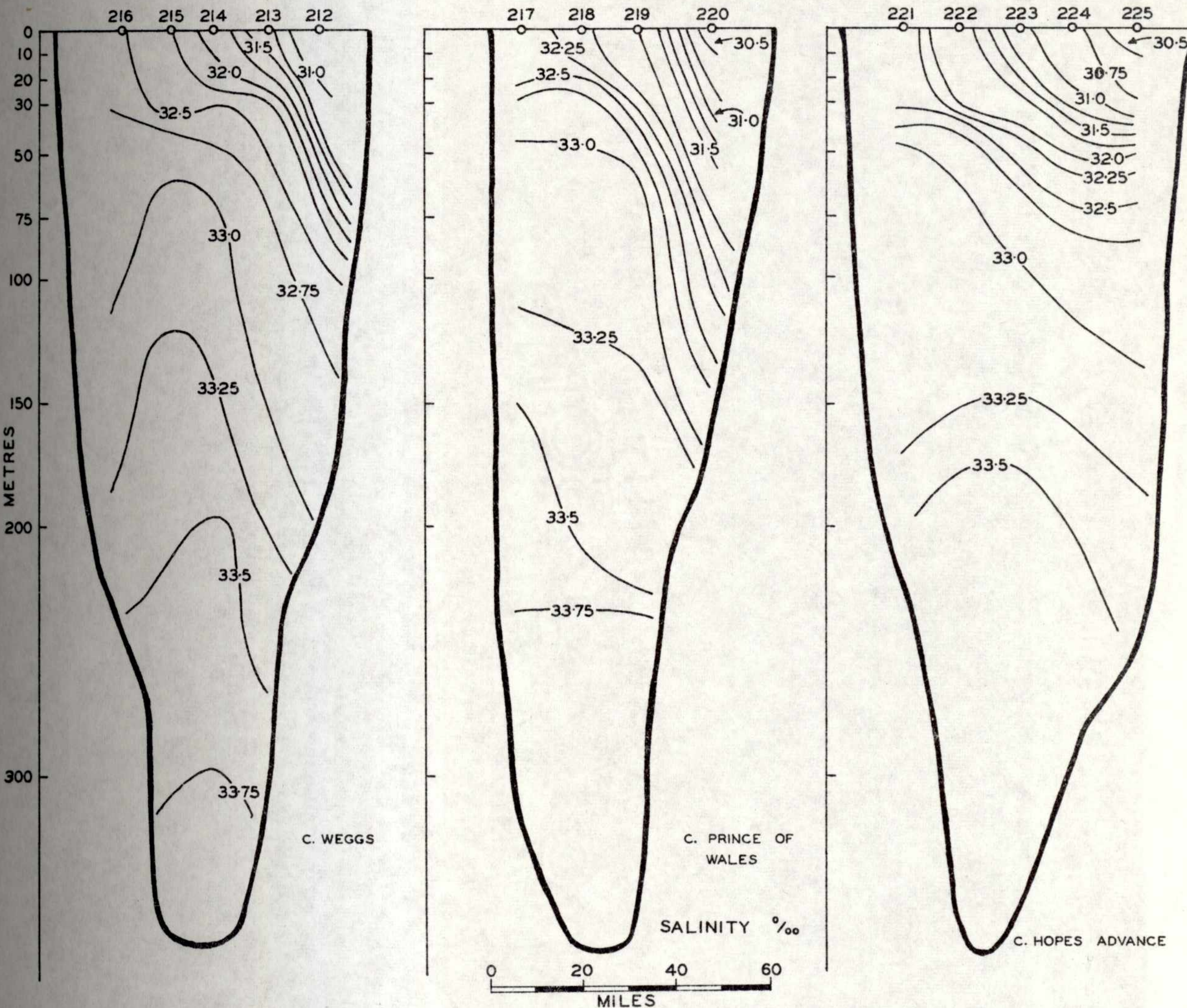
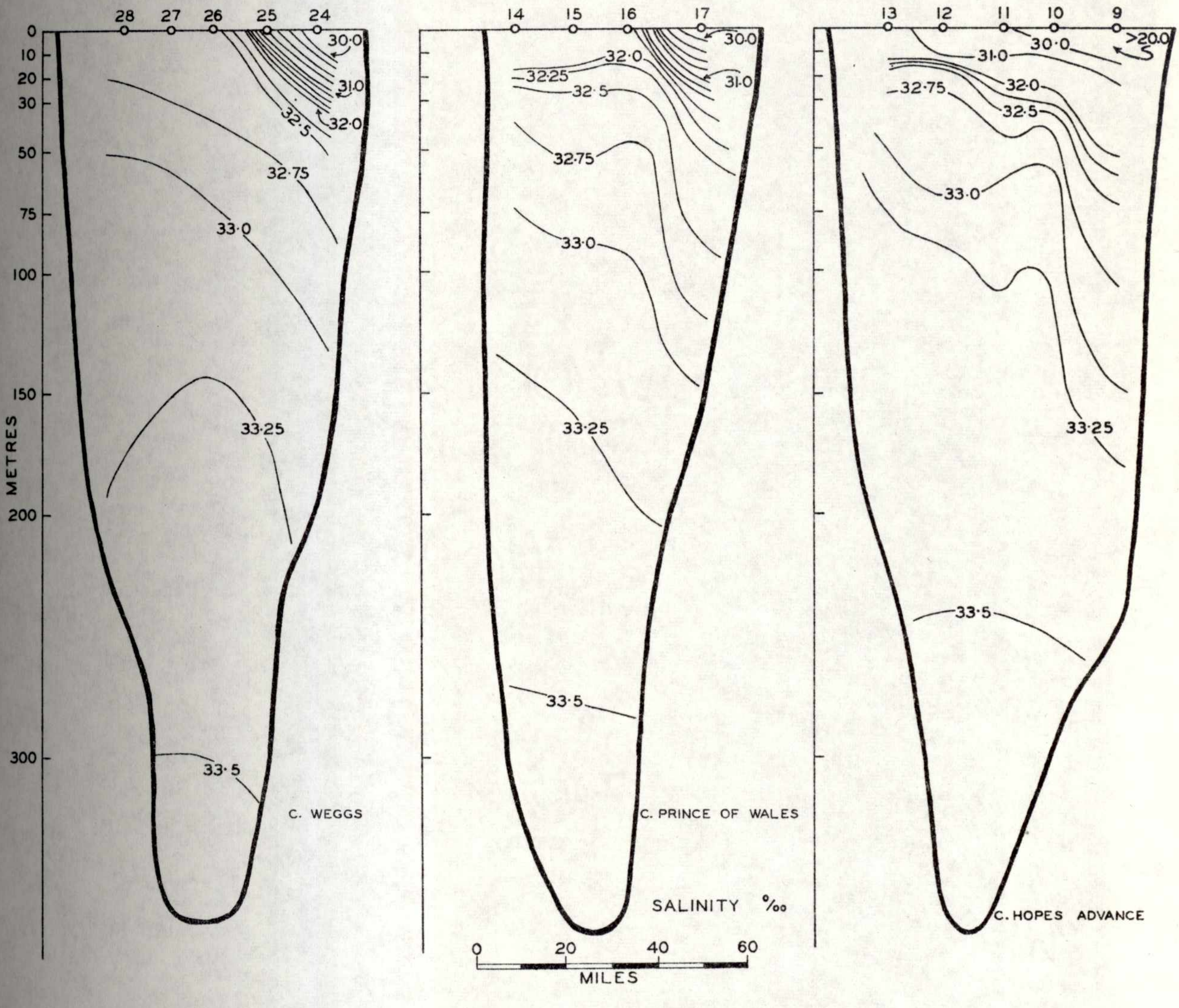


Fig. 11. Distribution of temperature, 20 metres, Hudson Strait, July 1956.

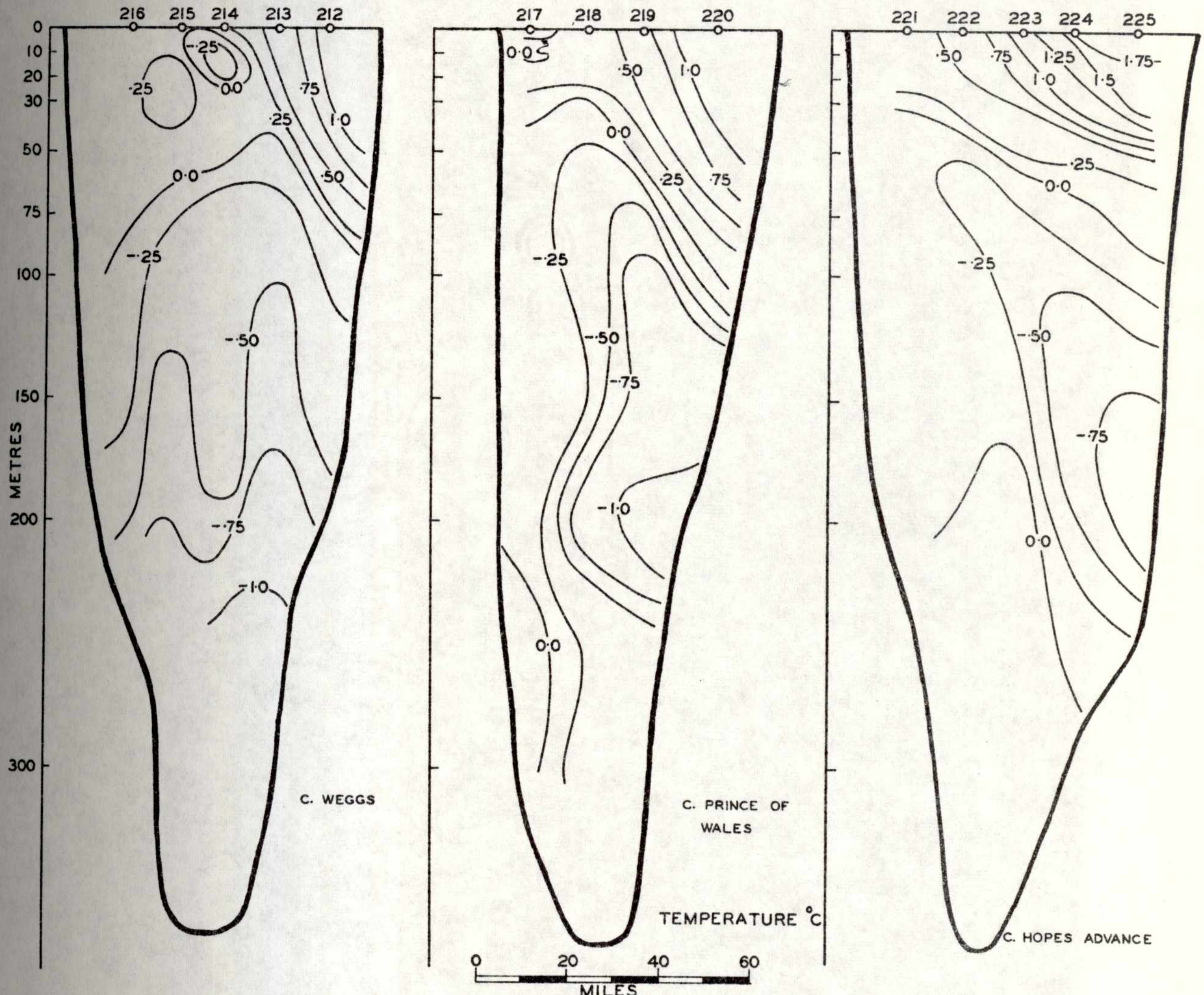
Fig. 12. Distribution of salinity, 20 metres, Hudson Strait, July, 1956.



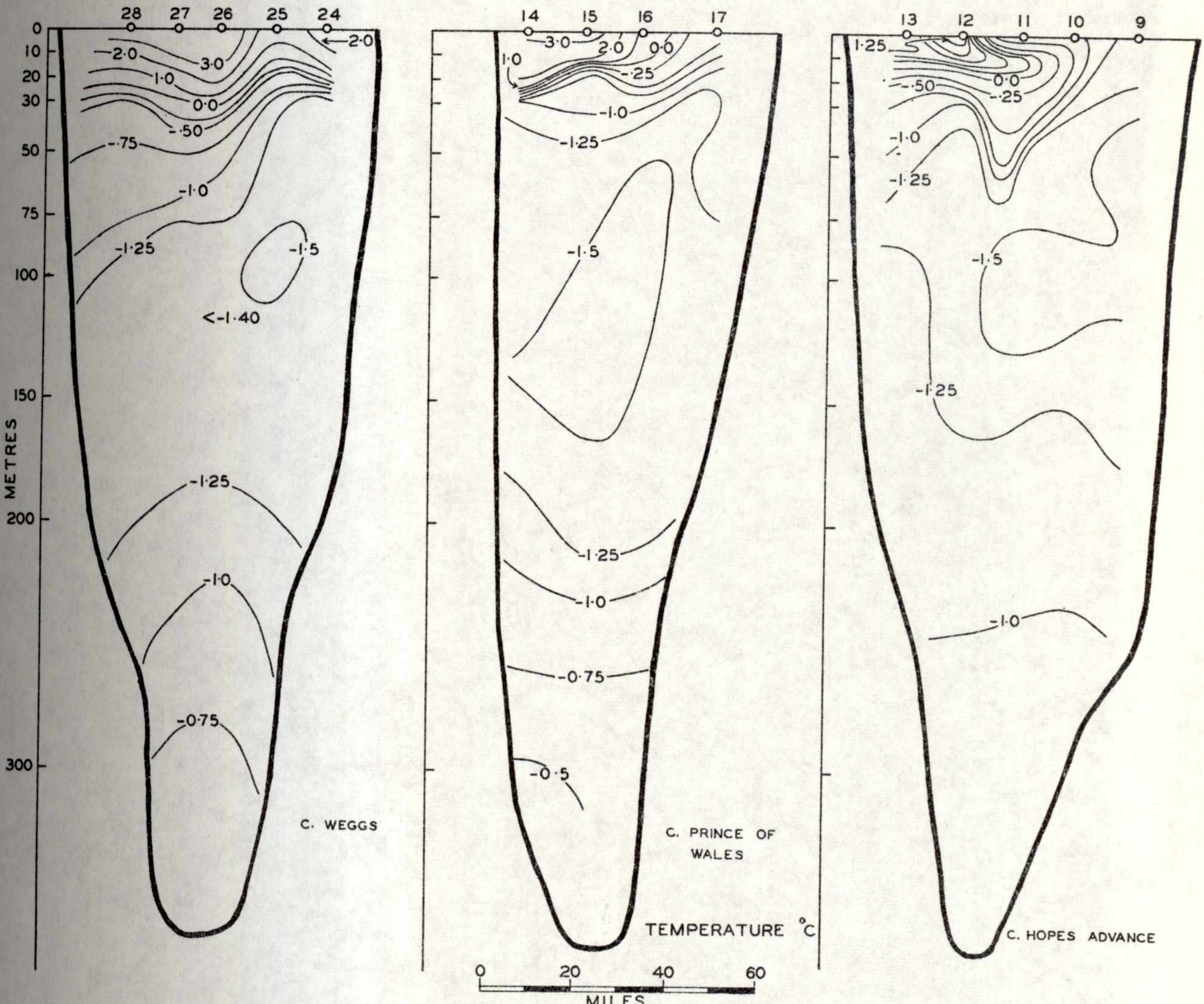
Figs. 13, 14, 15. Cross-sectional distributions of salinity, Hudson Strait, October, 1955.



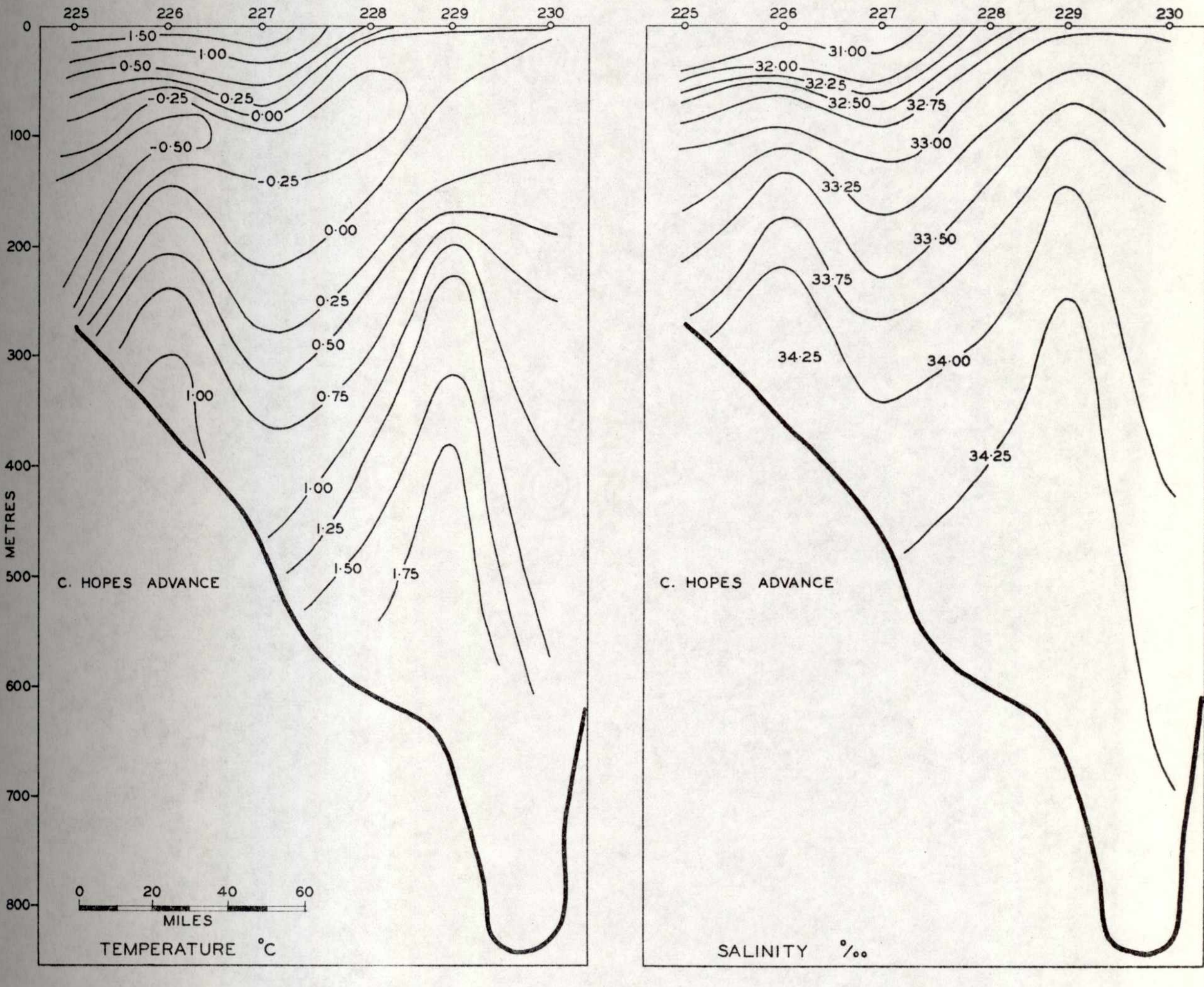
Figs. 16, 17, 18. Cross-sectional distributions of salinity, Hudson Strait, July, 1956.



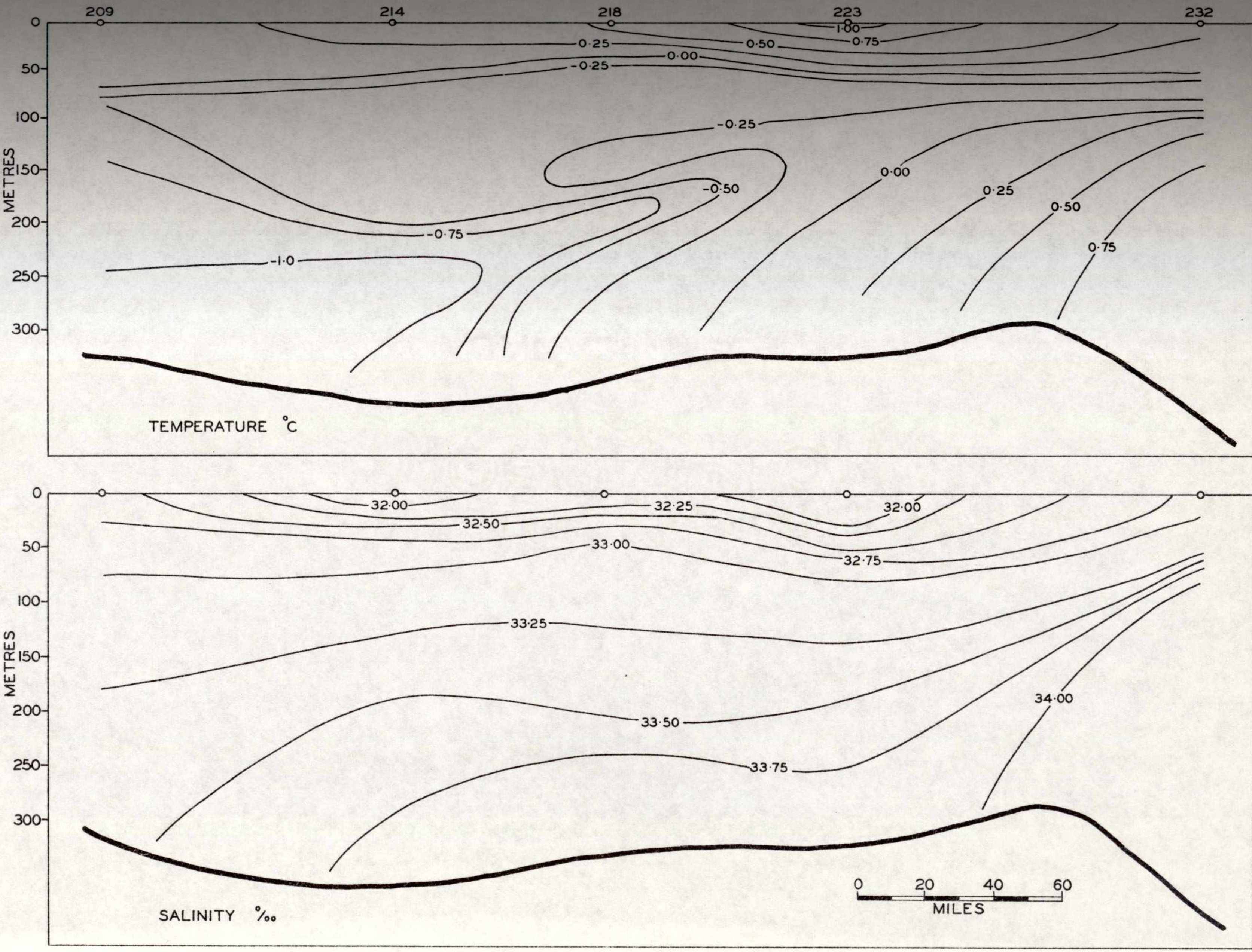
Figs. 19, 20, 21. Cross-sectional distributions of temperature, Hudson Strait, October, 1955.



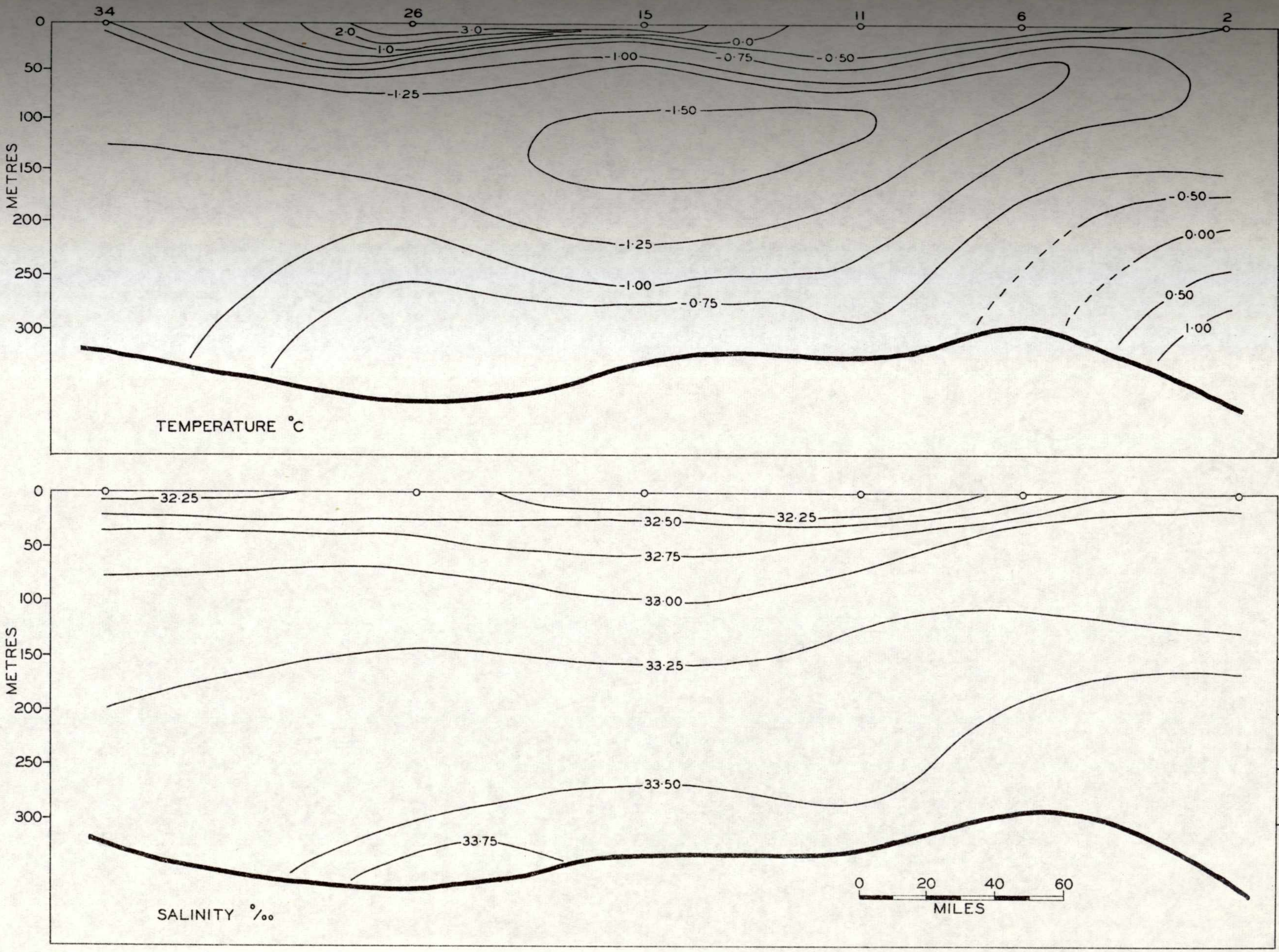
Figs. 22, 23, 24. Cross-sectional distributions of temperature, Hudson Strait, July, 1956.



Figs. 25, 26. Cross-sectional distributions of temperature and salinity across the mouth of Ungava Bay, Hudson Strait, October, 1955.



Figs. 27, 28. Longitudinal distributions of temperature and salinity, Hudson Strait, October, 1955.



Figs. 29,30. Longitudinal distributions of temperature and salinity, Hudson Strait, July, 1956.

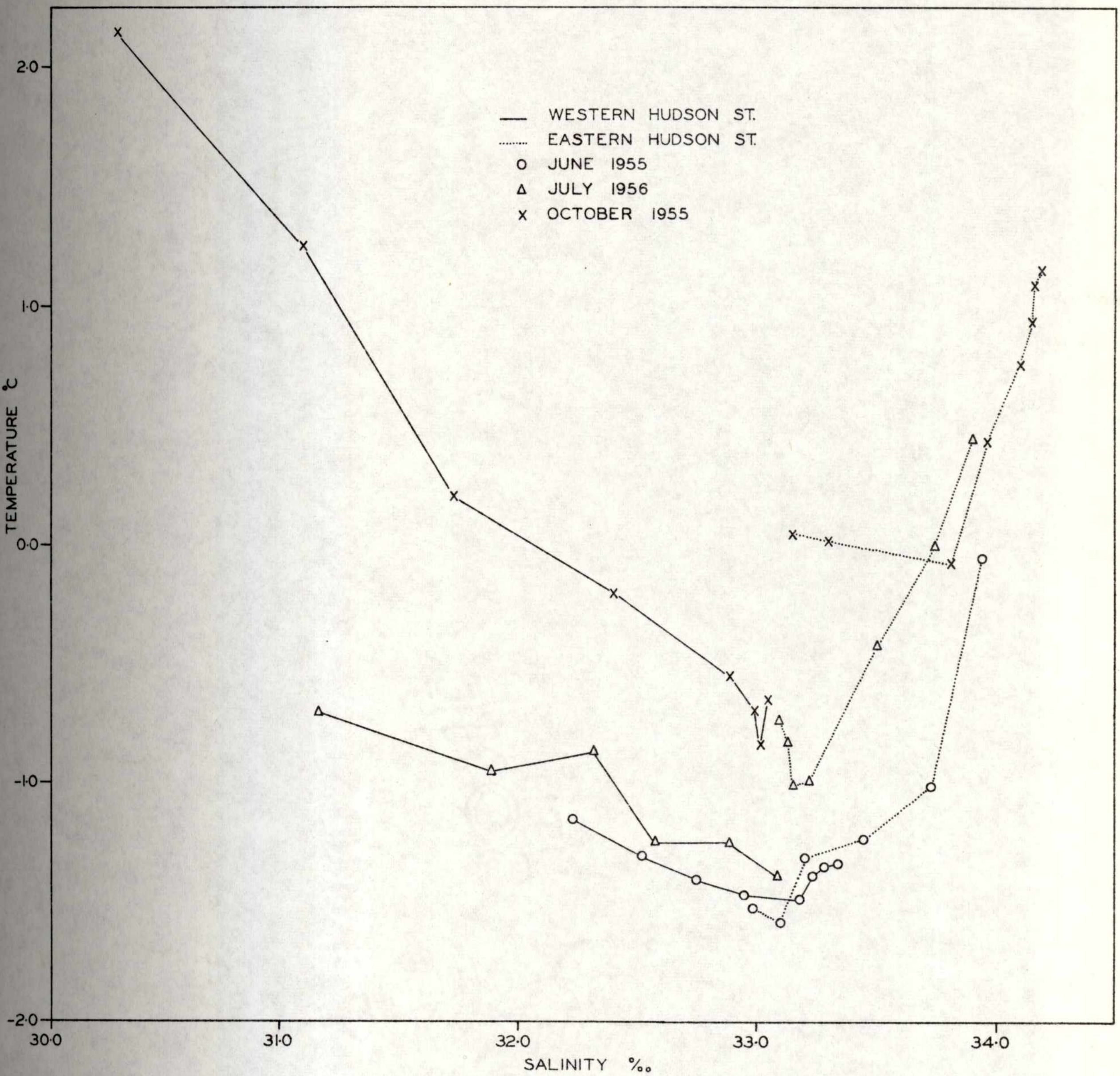
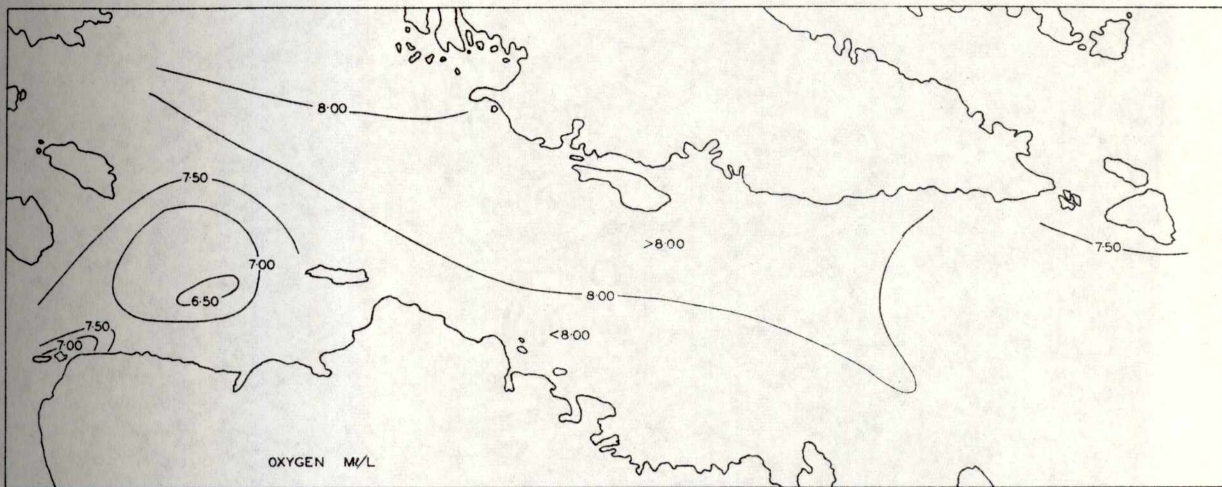


Fig. 31. **TS characteristics, Hudson Strait.**



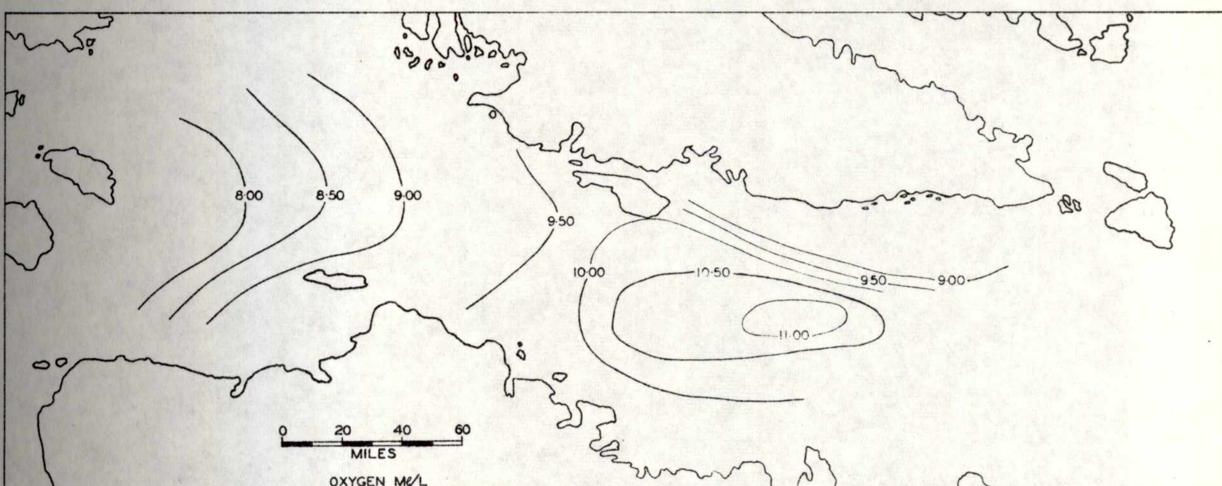
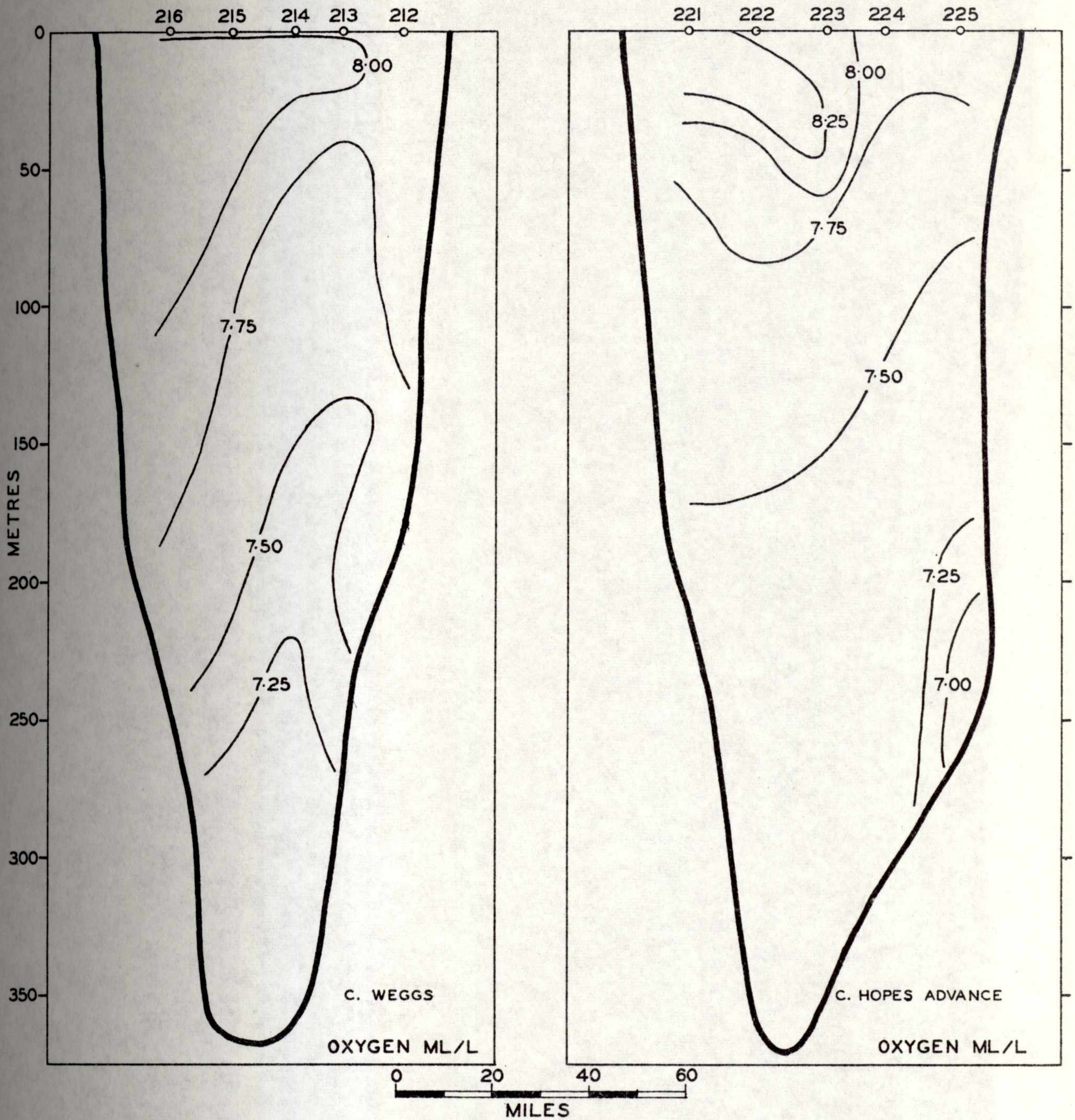
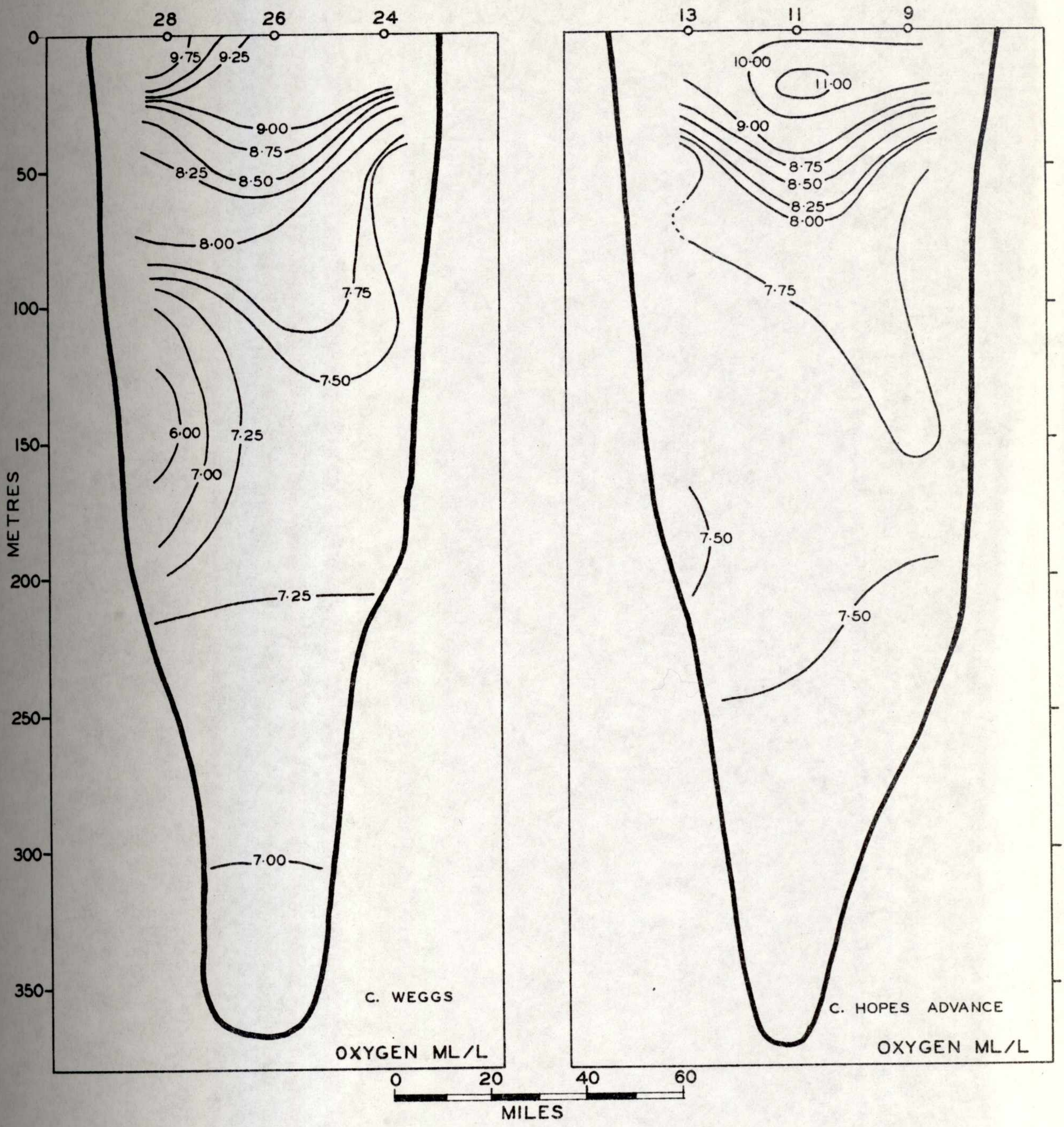


Fig. 32. Distribution of dissolved oxygen, 20 metres, Hudson Strait, October, 1955.

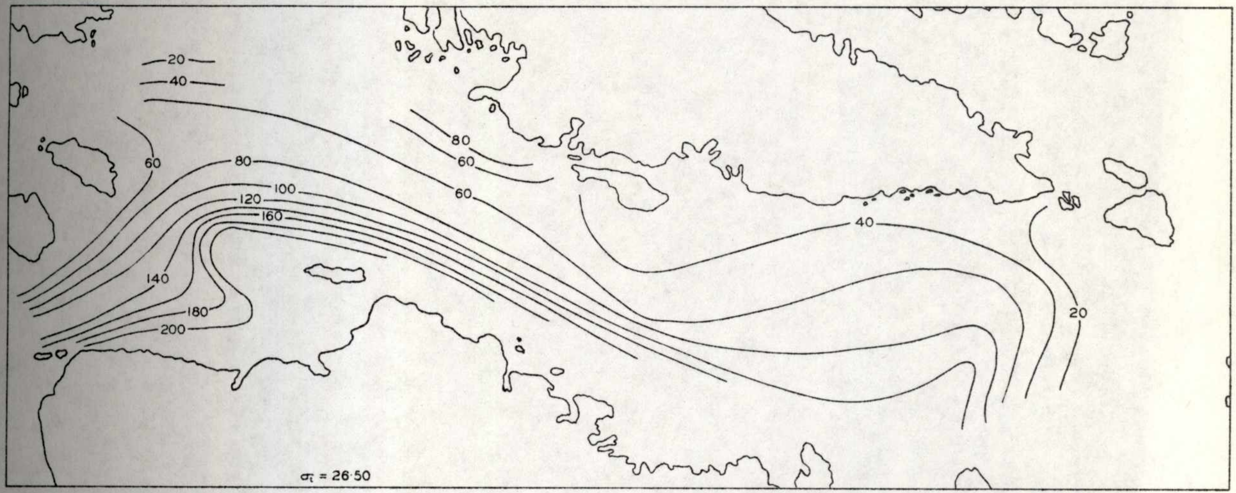
Fig. 33. Distribution of dissolved oxygen, 20 metres, Hudson Strait, July, 1956.



Figs. 34, 35. Cross-sectional distributions of dissolved oxygen, Hudson Strait, October, 1955.



Figs. 36, 37. Cross-sectional distributions of dissolved oxygen, Hudson Strait, July, 1956.



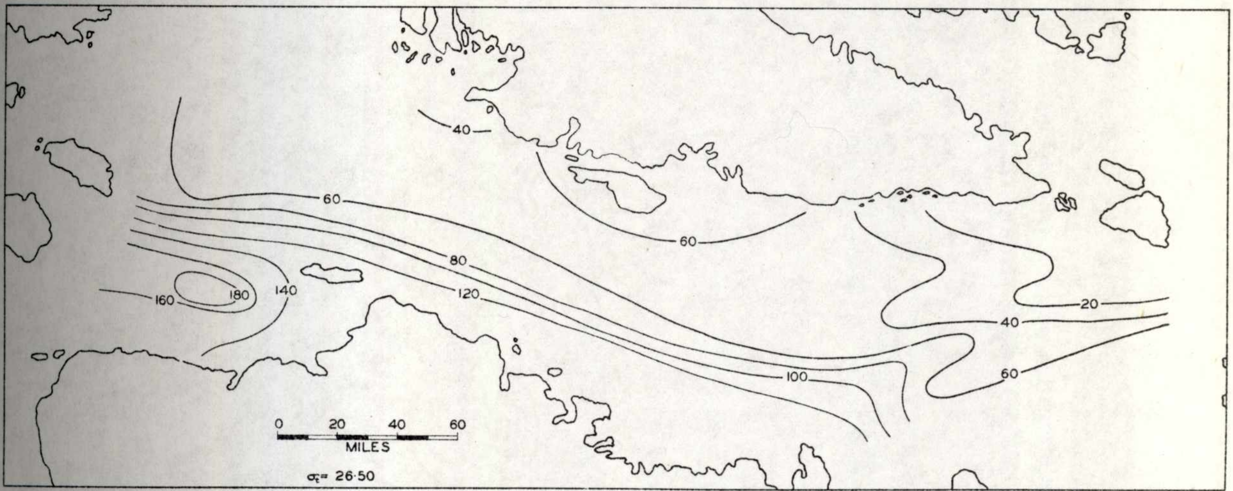
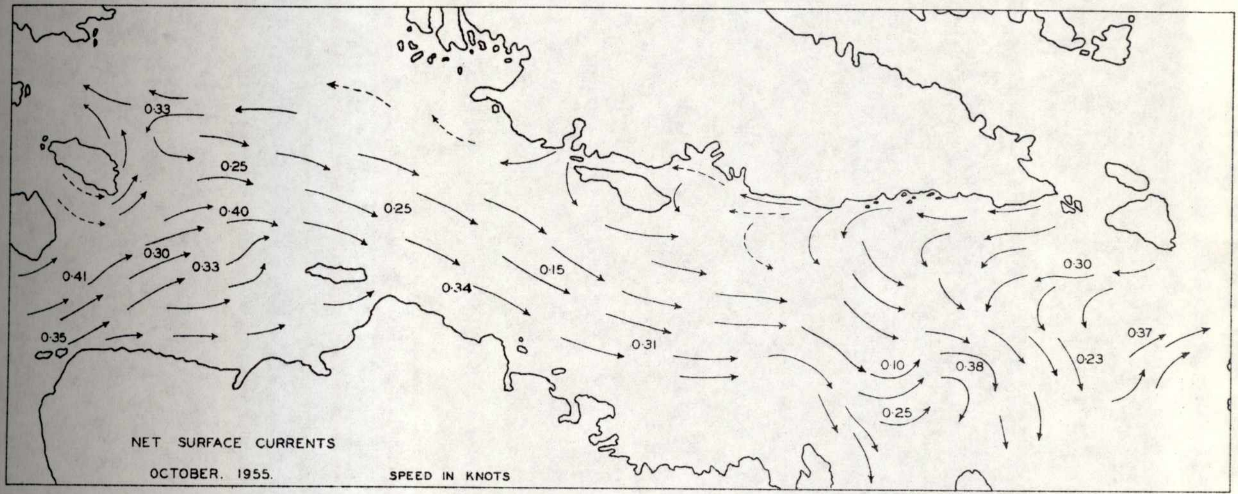
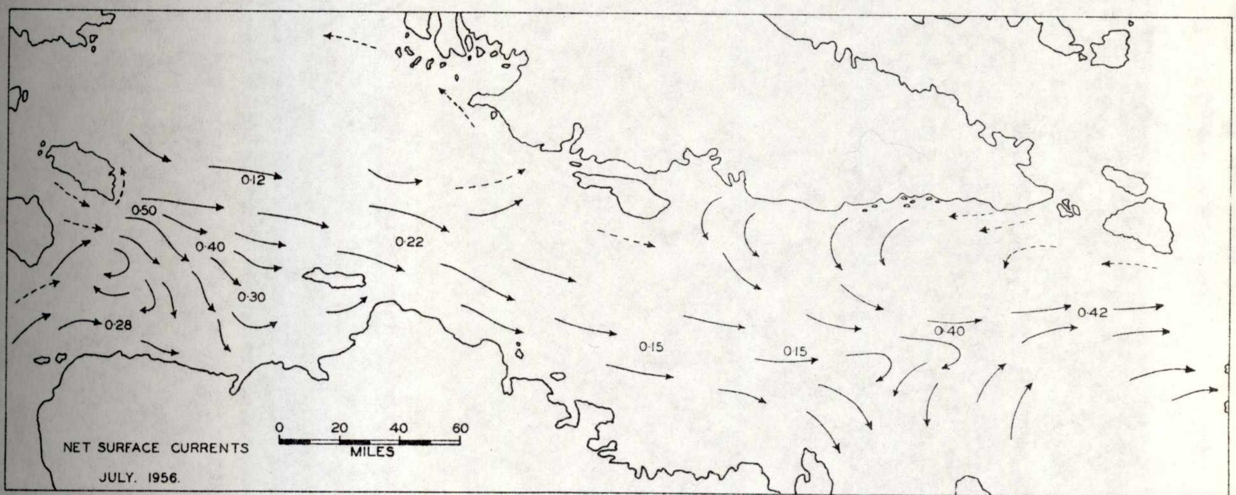


Fig. 38. Depth contours of the 26.5 sigma-t surface, Hudson Strait, October, 1955.

Fig. 39. Depth contours of the 26.5 sigma-t surface, Hudson Strait, July, 1956.





Figs. 40, 41. Net surface currents, Hudson Strait.

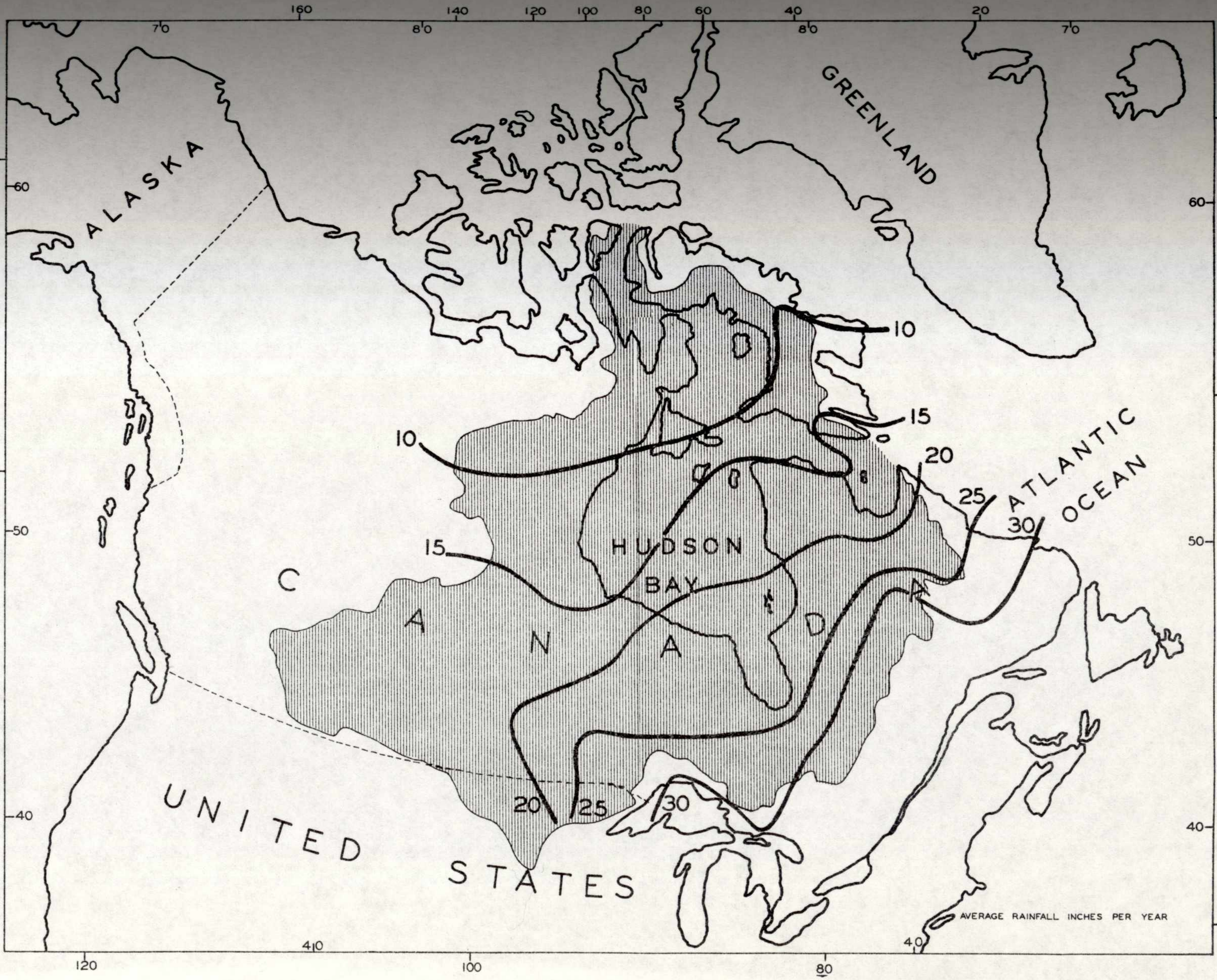
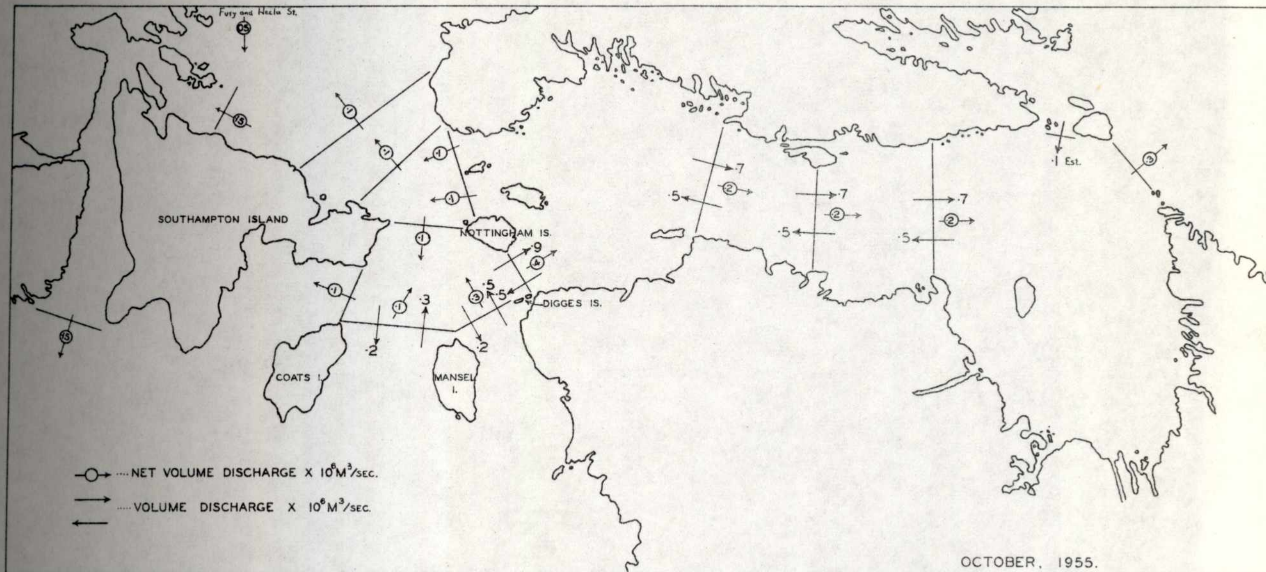
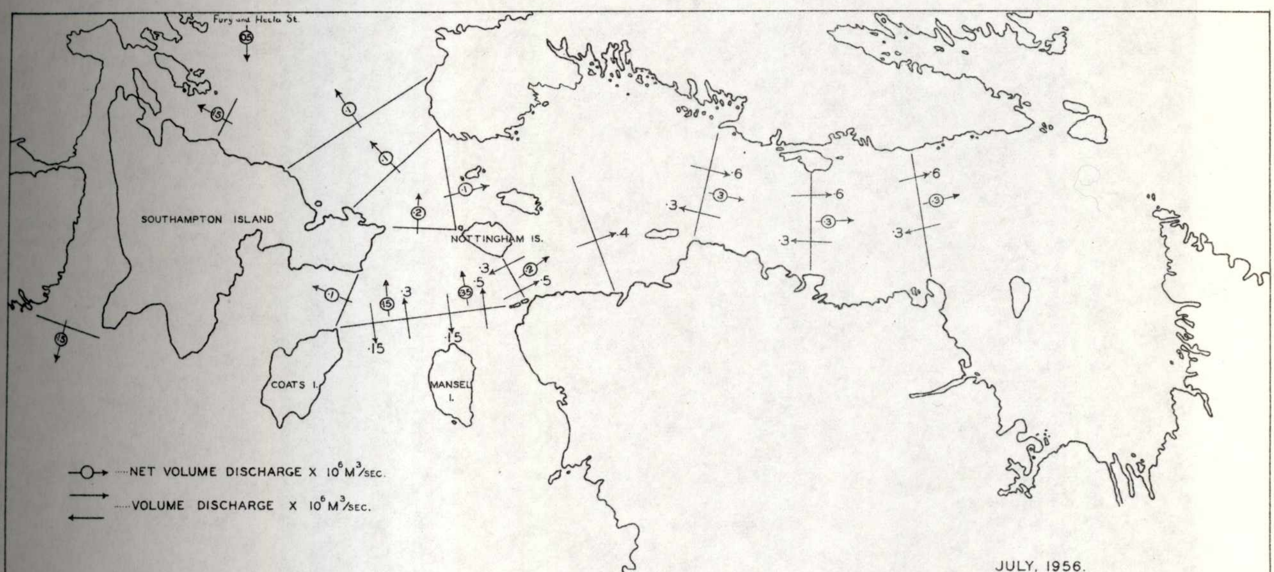


Fig. 42. Average annual rainfall and drainage system of Hudson Bay, Foxe Basin and Hudson Strait.





Figs. 43, 44. Volume transports, Hudson Strait.