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"THE WATERS OF THE CANADIAN ARCHIPELAGO"

BY

ARTHUR E. COLLIN

REPORT B. I. O. 62-2

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B E D F O R D   I N S T I T U T E   O F   O C E A N O G R A P H Y

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The waters of the Canadian arctic archipelago constitute a network of shallow channels connecting the Arctic Ocean with Baffin Bay and Hudson Strait. The archipelago system contains some 16 major passages that range in width from 10 to 120 Km. and in depth to over 700 metres.

Arctic oceanographic observations have been carried out in recent years by the Fisheries Research Board and by the Marine Sciences Branch of the Department of Mines and Technical Surveys. Much of this work has been directed toward fisheries research and has been concentrated in Foxe Basin and Lancaster Sound. Oceanographic observations have been recorded in all the main channels of the archipelago and in such areas as Lancaster Sound the data of 4 oceanographic cruises are now available. Almost all of this information has been obtained during the summer months of July and August there being very few marine data for winter conditions in the archipelago.

Information used in this discussion results largely from observations carried out aboard the icebreaker LABRADOR in the eastern arctic in 1956 and 1957 and at stations established on the sea ice along the western arctic coast and in the north-western channels of the archipelago in the spring of 1960 and 1961. Observations taken from the ice island T-3 during the summer of 1958 have been used in the description of the oceanographic conditions of the Arctic Ocean.

There is considerable variation in the depth and extent of the continental shelf surrounding the archipelago. Along the west coast of Baffin Bay, to the north of Hudson Strait, the width of the shelf seldom exceeds 55 Km. and the depth is about 200 metres. On the Arctic Ocean coast the break in slope of the continental shelf occurs at a depth of 550 metres, 170 Km. off-shore, to the northwest of Ellef Ringnes Island. The seaward edge of the Arctic Ocean continental shelf appears to be remarkably uniform and our most recent data gives little indication of gulleys or canyons indenting the continental slope in the area between M'Clure Strait and Prince Gustaf Adolf Sea.

Recent hydrographic information shows that the greatest depths within the Queen Elizabeth Islands occur in the troughs that have been discovered in Parry Channel and the Prince Gustaf Adolf Sea. These depressions, which in all cases were aligned parallel to the long axis of the channels, may reach a depth of over 700 metres and are believed to be the result of glacial deepening of the valley floor at a period when the land was at a considerably higher elevation than at present (Pelletier, 1962).

According to present information, the threshold depth of the archipelago is no more than 150 metres and occurs in Barrow Strait near Lowther Island, in Smith Sound, between Ellesmere Island and Greenland the limiting depth is 200 metres.

The combined cross sectional area of the straits of the archipelago joining the Arctic Ocean and Baffin Bay can be compared to a waterway 120 Km. wide and 340 metres deep connecting the Arctic Ocean and Baffin Bay at the latitude of 75° north. Such a passage would be about 12 times the cross sectional area of Bering Strait, but would still be only 6% of the total area through which there may be an exchange of water between the Arctic Ocean and the Atlantic and Pacific Oceans.

SEA ICE

The waters of the archipelago are covered by a mantle of sea ice for at least 7 months of the year. Initial freeze-up occurs in all the coastal waters by mid September and the general break-up and discharge of the ice in the eastern arctic does not take place before early July.

Schule and Wittman (1958) have suggested that the summer disintegration of sea-ice in the eastern archipelago follows a recognized pattern. Break-up begins in certain areas of weak ice concentration and expands outwards from these centres during the summer. One such centre of ice removal is located in Barrow Strait just west of Resolute Bay and another is in northern Baffin Bay.

Ice observations in the western channels of M'Clure Strait, Ballantyne Strait and the waters surrounding the Ringnes Islands have shown that there is virtually no movement of ice during the winter and very irregular drift in summer. Topographic surveys carried out across the sea ice in M'Clure Strait, and Prince Gustaf Adolf Sea and Parry Channel in May 1959, 1960 and 1961 revealed that there was no measurable drift of the ice at that time. Throughout the summer the effect of the melt is limited to the formation of extensive shore leads that allow considerable movement of the ice in the coastal waters. Detailed ice reconnaissance at this time has shown that, in general, the movement of this ice follows the expected circulation pattern through the archipelago into Parry Channel.

CIRCULATION

For the purpose of this discussion the Canadian arctic archipelago is considered to be that area of Canada to the north of the arctic mainland coast including Foxe Basin and Hudson Strait. The circulation through this system of shallow channels is weak and appears to be influenced by three circulatory systems, (1) the Arctic Ocean, (2) Baffin Bay and (3) Hudson Strait such that the dominant movement of water is easterly through the Barrow Strait-Lancaster Sound passage. The general pattern of the surface water movement is shown in Figure 1.

Observations recorded on the ice island T-3 when it was in the vicinity of the western archipelago show that along the northwest coast the surface water movement is to the southwest at a rate of about 2 Km. per day in summer and slightly over 1 Km. per day in winter.

The circulation pattern in Baffin Bay consists of the West Greenland Current that passes northward through the eastern section of Davis Strait and the Baffin Current which moves southward along the Baffin Island coast. The West Greenland Current is composed of a mixture of the East Greenland Current and the comparatively warm Irminger Current that impinges on the southeast coast of Greenland. Thus, the West Greenland Current appears as a relatively temperate contribution to the circulation of Baffin Bay. The Baffin Current is formed of the outflow of cold Arctic Ocean water from the channels of the archipelago and the northern, cooled remnant of the West Greenland Current. From a theoretical treatment of the oceanographic observations of the Goodthaab Expedition of 1928 Kiilerich (1939) determined that the dominant current along the east Ellesmere coast of the archipelago moves in a southerly direction at a rate of 17 Km. per day. Small branches from this current enter Jones Sound and Lancaster Sound.

The predominant flow through the archipelago is in a south and easterly direction through the main passages of Parry Channel, Prince Regent Inlet and Jones Sound. This flow is disturbed by a significant permanent eddy circulation in the eastern end of Lancaster Sound and a consistent, westward current that is confined to the northern side of Lancaster Sound. This westward current appears to be a constant feature of the circulation and is continuous from Baffin Bay to Barrow Strait.

The water movement in Lancaster Sound has been calculated from the geostrophic equation based on a reference level of 600 metres to allow comparison with the earlier calculations of this current by Kiilerich in 1928 and Bailey in 1954. The calculated summer velocities in Lancaster Sound indicate a westward current along the northern side of the passage of 19 Km. per day and an eastward flow of 17 Km. per day along the south coast of the channel. These figures are slightly higher than those presented by Bailey (1957) but are in fair agreement with Kiilerich's results (Kiilerich, 1939).

In Prince Regent Inlet and Wellington Channel the predominant current is to the south, however, in both passages a comparitively weak northerly drift has been observed along the eastern coast.

Surface currents in Foxe Basin form a cyclonic pattern with a net southward set of 13 to 50 Km. per day along the western side of Foxe Basin and Foxe Channel (Campbell and Collin, 1956). In Hudson Strait the strength of the eastward flow appears to vary seasonally whereas the westward current along the north side of the strait remains as a persistent feature of the circulation. Campbell (1958) has determined the summer rate of the eastward current in Hudson Strait from dynamic analysis of the oceanographic data to be about 17 Km. per day and Farquharson (1960) has arrived at a similar result using recording current metres.

CHARACTERISTICS OF THE WATER MASSES

The Parry Channel system including Lancaster Sound, Barrow Strait, Viscount Melville Sound and M'Clure Strait forms a zone of transition between the waters to the west, characteristic of the Polar Basin, and those to the east that are formed through an interchange of Arctic water with that of the west Greenland current in Baffin Bay. The western water, which extends from the Beaufort Sea into M'Clure Strait is identical in physical properties to that which has been described further off-shore in the Arctic Ocean. As this water moves eastward into Parry Channel only water of the surface layer (0-150 metres) can pass eastwards over the sill into Lancaster Sound. In Lancaster Sound the temperature and salinity characteristics at depth are determined by the relative contributions of water of Baffin Bay and Arctic Ocean origin.

The water masses of the archipelago are shown graphically in the temperature-salinity diagrams in Figure 2. The curves are drawn from a series of summer observations considered to be representative of each of the areas in question and only those data from depths greater than 50 metres have been plotted.

In the region of M'Clure Strait the Arctic Cold water layer, identified by a range in temperature of -1.2°C. to -1.4°C. and salinity 32.2°/oo to 33.5°/oo occurs between 70 and 140 metres.

Evidence of the shallow temperature maximum or Pacific Inter-layer described by Worthington (1953) and Godkavich (1955) does not appear to any extent in the in-shore waters of the western continental shelf. Coachman and Barnes (1961) have shown that this feature is weakest in the region along the western coast of the Canadian archipelago.

Between 150 and 250 metres there is a uniform increase in temperature and salinity below which lies the Polar Atlantic water first described by Nansen in 1902. The defining characteristics of this water are positive temperatures between 250 and 100 metres and a distinct temperature maximum between 400 and 600 metres. This water, according to Timofeyev (1957) is of Atlantic origin and constitutes a permanent feature of the Polar Basin. On the western continental shelf the Polar Atlantic water occurs between 250 and 1000 metres with a temperature maximum of 0.43°C. and salinity of 34.9°/oo at 500 metres.

The T-S curve for Baffin Bay illustrates the summer conditions of the water off Lancaster Sound and shows the influence of both the Arctic and Atlantic contributions.

Surface water with temperatures ranging from -1.0°C. to 5.0°C. and salinities 30.0°/oo to 33.5°/oo is identified within the upper 50 metre layer. This layer owes its variable characteristics to the local effects of summer heating, winter chilling, and changing ice concentration.

A distinct cold water mass with temperatures to -1.6°C. and salinity less than 33.8°/oo occupies the depth interval 50 to 200 metres. Kiilerich (1939) identified this layer as Cold Arctic water and deduced from the 1928 Baffin Bay observations that this water type could possibly form at the surface during the winter. The higher salinity at this depth as compared to water at the same level in the archipelago or Arctic Ocean indicates that this water does not enter Baffin Bay from the north but must be the result of local conditions of climate and circulation.

The warm Intermediate layer of Baffin Bay is characterized by temperatures greater than -0.5°C. and salinity 34.2°/oo to 34.5°/oo. Off Lancaster Sound this layer is found between the depths of 200 and 1000

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metres and may have a maximum temperature of 1.0°C. at 500 metres. Smith, Soule and Mosby (1937) have shown that during the summer the main channel of Davis Strait may be filled with water of this type from the West Greenland Current.

At depths greater than 1000 metres the temperature decreases to less than -0.5°C. and salinity is practically constant at 34.45°/oo. This deep Baffin Bay water was, at one time thought to be formed by freezing at the surface and consequent sinking. However, Bailey (1956) has suggested that it is far more likely that the deep water is of Arctic Ocean origin and enters Baffin Bay through Smith Sound. The low oxygen content of the deep Baffin Bay water, 3.6 ml./l. at 2000 metres, suggests that this water does not contribute to the general circulation in Baffin Bay and that the renewal of the deep water takes place only at infrequent intervals.

The waters of the Queen Elizabeth Islands exhibit conditions typical of the Arctic Ocean and Baffin Bay. Water of Arctic Ocean origin can be recognized by the exceptionally low surface temperature and salinity and an intermediate temperature maximum of 0.4°C. with a corresponding salinity of 34.9°/oo at 500 metres. Water of Baffin Bay origin can be identified by considerably higher surface temperatures and sub-surface maximum of 1.0°C. between 300 and 600 metres with salinity of 34.5°/oo.

The T-S diagrams of the two principal water masses of the Arctic Ocean and Baffin Bay indicate a boundary, coincident with the thresholds in Barrow Strait, the Norwegian Sea and Kane Basin. The limiting depth in Kane Basin permits a free exchange of water only within the upper 200 metres. Nevertheless, under extreme meteorological conditions it is possible that Arctic water to a depth of 250 metres could enter Baffin Bay through Smith Sound as an irregular discharge. Bailey (1956) has suggested that the deep water of Baffin Bay is formed in this manner.

The T-S curve for Lancaster Sound illustrates the marked contrast in the temperature and salinity of waters of eastern and western origin at depths greater than 150 metres. The Lancaster Sound graph shows the effects of surface warming to a depth of almost 100 metres but between 100 and 150 metres the curve is identical to the Arctic Ocean T-S curve. In comparison, at depths greater than 150 metres the T-S curve for Lancaster Sound becomes progressively similar to the T-S curve for Baffin Bay until, at depths greater than 250 metres temperature and salinity characteristics are identical.

Figure 3 represents a longitudinal section through Parry Channel illustrating the topographic features of the passage and the vertical distribution of temperature and salinity recorded during the summer months of August and September.

Within the surface layer Baffin Bay water of temperature greater than -1.0°C. and salinity less than 33.5°/oo forms a conspicuous intrusion that extends from Baffin Bay to Barrow Strait. To the west of Barrow Strait cold, less saline water typical of the Arctic Ocean forms the surface layer. Between 200 and 250 metres the temperature and salinity structure is relatively uniform throughout the channel. At depths greater than 250 metres temperatures increase to 0.5°C. and salinity reaches a maximum of 34.7°/oo in M'Clure Strait and 34.5°/oo in Lancaster Sound.

The spread of the western Arctic water eastwards through Barrow Strait has been traced by Grainger (1961) using the plankton indicator Calanus glacialis. This species, typical of Arctic Ocean water has been found in Lancaster Sound, Prince Regent Inlet and western Foxe Basin. On the basis of these investigations Grainger (1962) has suggested that the southernmost limit of unmixed arctic water in the archipelago possibly occurs in Foxe Basin.

VOLUME TRANSPORT

Estimates of the net volume transport through the major eastern channels of the archipelago have been made by Kiilerich (1939) and Bailey (1957). Additional calculations of the summer flow through Lancaster Sound and Jones Sound based on observations recorded in Lancaster Sound in 1956 and 1957 and in Eureka Sound and Parry Channel in 1960 and 1961 have been carried out and are presented in Table 1.

TABLE 1

Calculated volume transport through channels leading into northern Baffin Bay for 1928, 1954, and 1957.

Section	1928 m^3/sec	1954 m^3/sec	1957 m^3/sec
Lancaster Sound	0.64×10^6	1.48×10^6	1.00×10^6
Jones Sound	0.29×10^6	-0.39×10^6	0.27×10^6
Smith Sound	0.47×10^6	-0.42×10^6	0.47×10^6 (Kiilerich, 1939)
	1.40×10^6	0.67×10^6	1.74×10^6

The eastward transport through Jones Sound of 0.27 million cubic metres per second was determined from dynamic calculations of the southern transport through Parry Channel and estimates of the southward flow through Eureka Sound based on winter current observations. No recent observations suitable for transport analysis have been recorded in Smith Sound thus the figure of 0.47 million cubic metres per second determined by Kiilerich (1939) has been used in the 1957 calculations.

Transport calculations for the channels contributing to the circulation through Lancaster Sound have been attempted with limited success. Analysis of the 1956 data showed considerable variation in the transport through successive hydrographic sections in Prince Regent Inlet and Wellington Channel and calculations based on the 1957 data indicated a southerly transport of water through Prince Regent Inlet of the same magnitude as that determined for the easterly transport through Lancaster Sound. On the basis of the two surveys of 1956 and 1957 it is estimated that the easterly flow through Lancaster Sound in summer is of the order of 1 million cubic metres per second.

These results suggest that the volume transport from the Arctic Ocean through the archipelago and Smith Sound may be reasonably estimated at 0.67 to 1.74 million cubic metres per second.

The figures for the total southerly transport into Baffin Bay agree with the net southward transport across Davis Strait determined by Kiilerich (1939) and with Timofeyev's (1960) recent estimate of 3×10^4 cubic Kilometres per year for the total discharge from the Arctic Ocean through the arctic archipelago.

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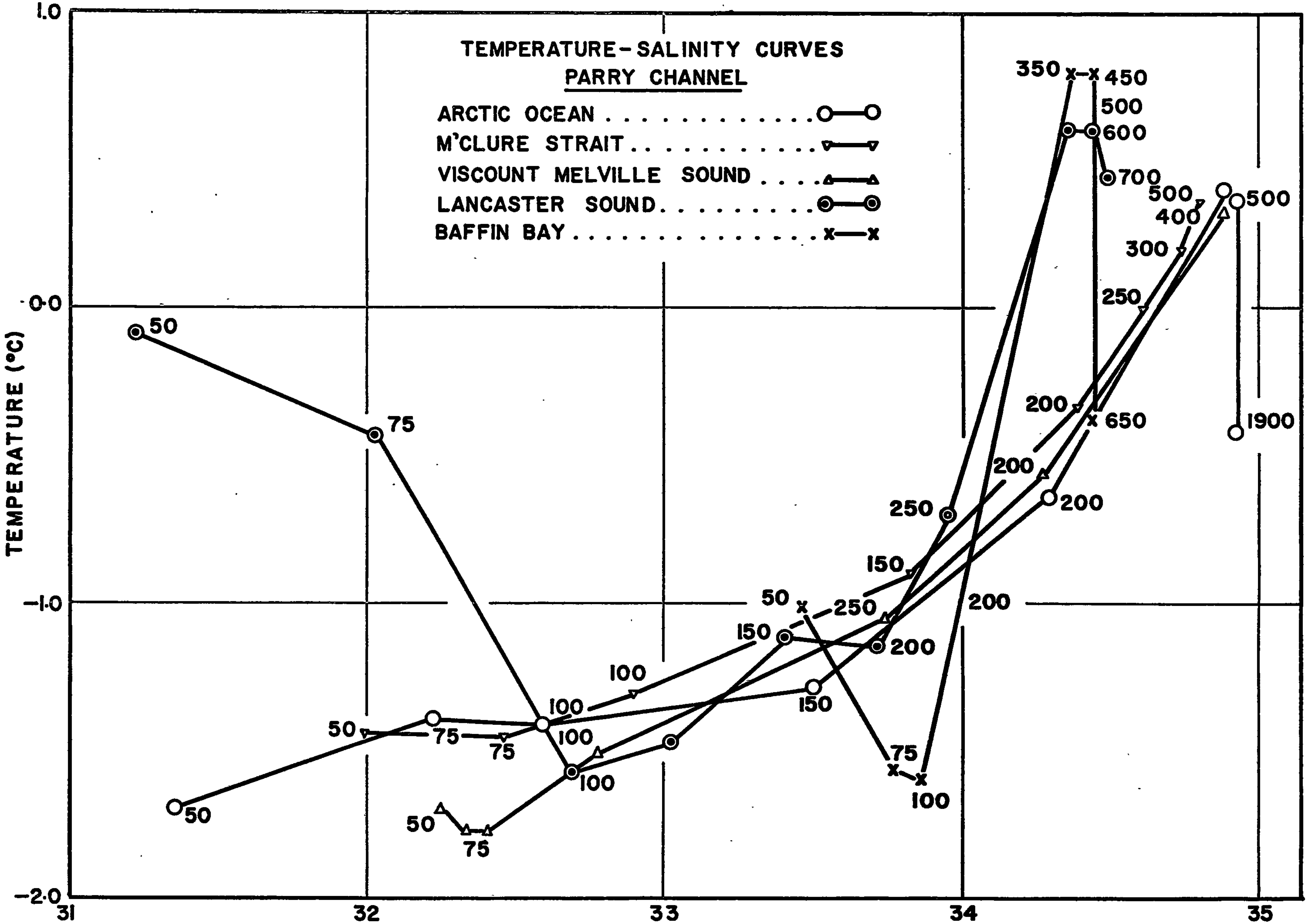

FIG. 2 Temperature-Salinity curves, Canadian arctic waters.

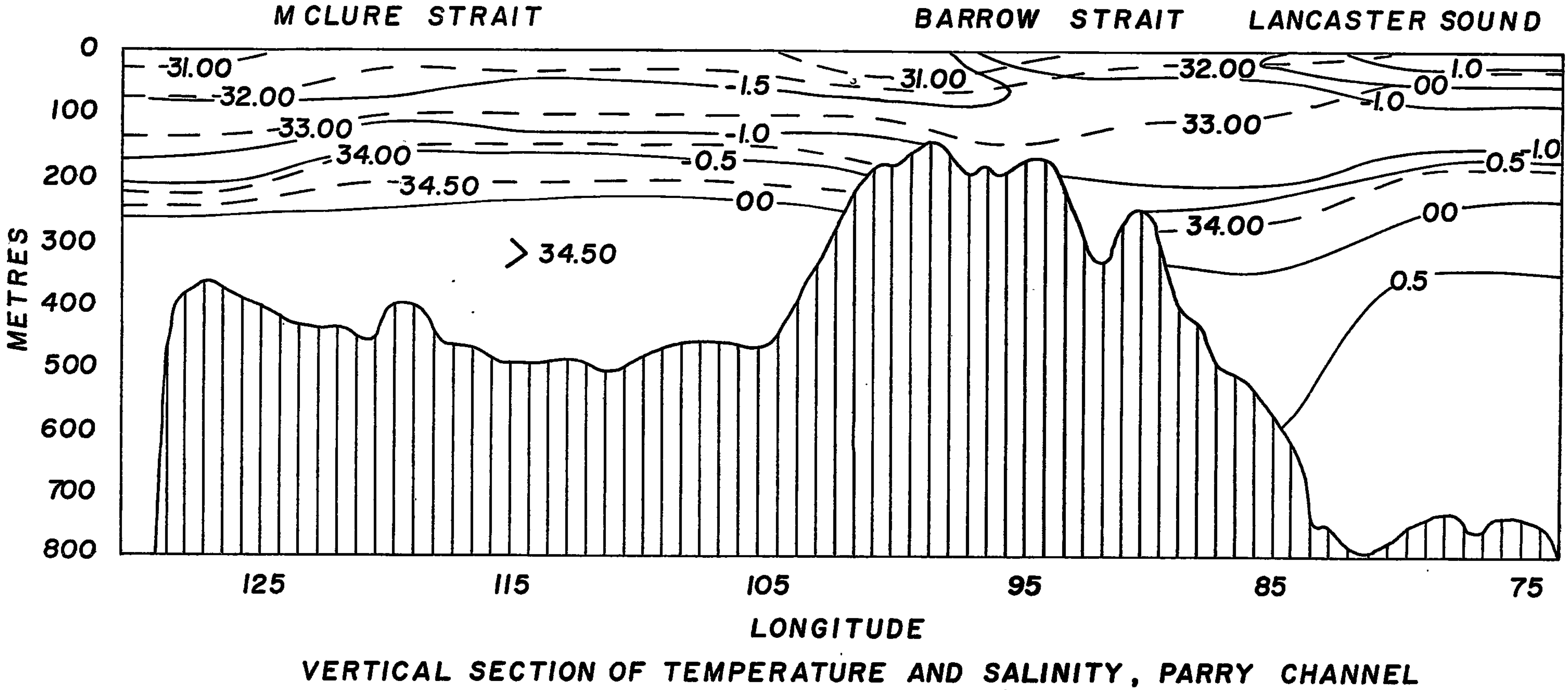

FIG. 3 Vertical section of temperature and salinity through Parry Channel, arctic Canada.

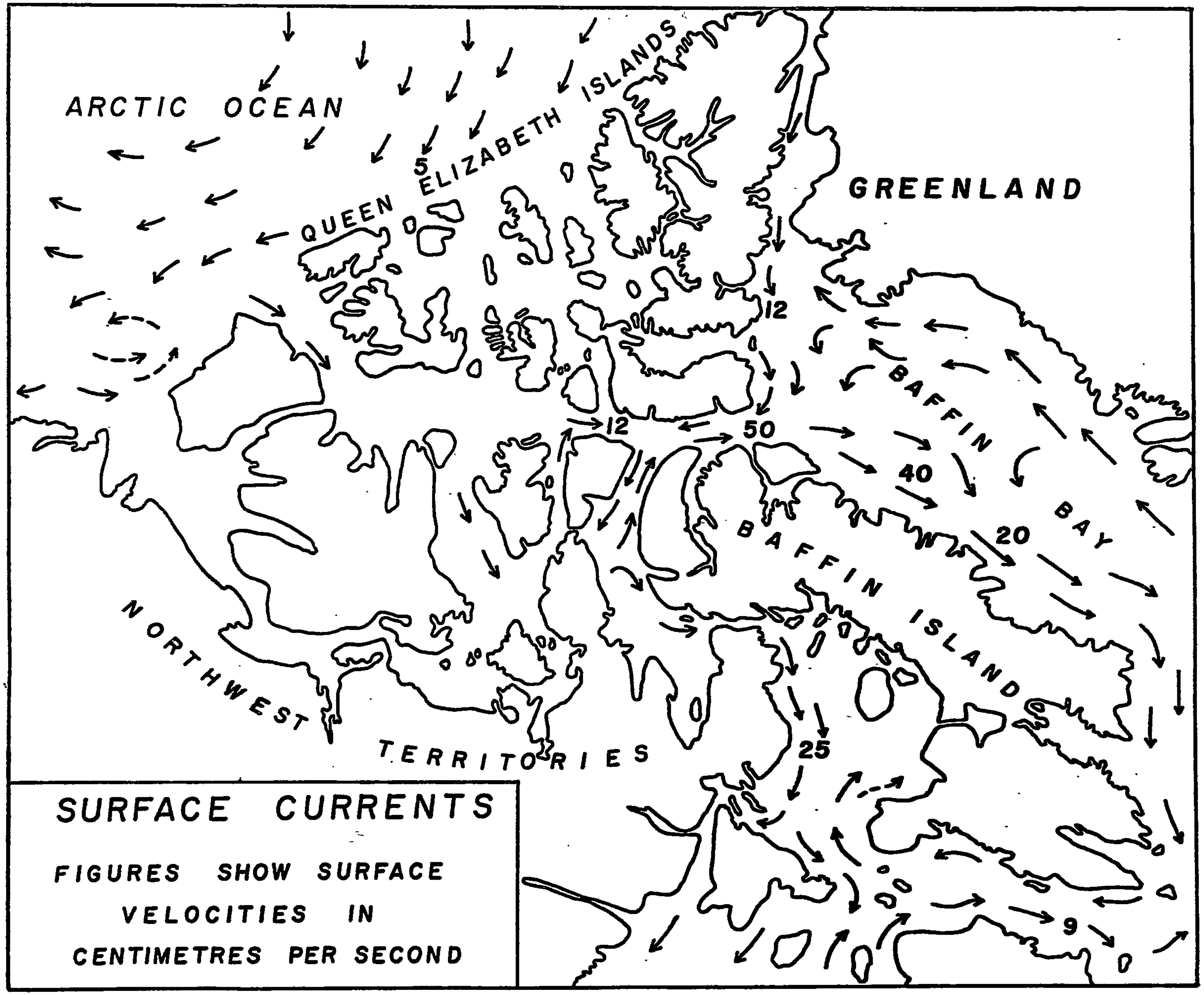

FIG. 2. Surface currents, (After Kiilerich, 1939; Dunbar, 1951; Campbell and Collin, 1956; Campbell, 1958; Timofeyev, 1960).