Observations on the Coastal Current of Arctic Alaska[1]

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ABSTRACT

This paper describes characteristics of the warm coastal current in the vicinity of the ice margin in the Chukchi and Beaufort seas. The warm current originates in Bering Strait and is traced around Pt. Barrow to longitude 152°W in the Beaufort Sea. In the Chukchi Sea it is concentrated near the surface, overlying dense relict bottom water trapped by the shallow depths. Eastward, as the bottom deepens, the warm water descends to mid-depth, eventually becoming warmest near bottom in depths of 30 to 50 m. Mechanisms for cooling and dilution of the warm water are discussed.

1. INTRODUCTION. During late July and early August 1971, a group aboard USCGC NORTHWIND carried out salinity-temperature observations in the vicinity of the ice margin in the Chukchi and Beaufort seas. Although not specifically designed for the purpose, the station plan delineated the course of the warm coastal current flowing northeast from Bering Strait (Fig. 1). The current was found to turn sharply to the right about 55 km past Pt. Barrow, after which it followed the coast in the Beaufort Sea at a distance of 55–75 km. It was traced with certainty to longitude 152°W, about 150 km east-southeast of Pt. Barrow, and was lost there probably because the more easterly stations were too near shore. Hufford (1973), working independently in August and September of 1971, traced this same current from longitude 154°30′W to 147°W. The paper describes some interesting characteristics of the current nearer to its source.

2. TECHNIQUES. The measurements were made principally with a Bissett-Berman Model 9006 salinity-temperature-depth recorder (STD) standardized

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with a Nansen bottle sample obtained just above the probe at the greatest depth of lowering. The STD was supplemented by a hand-lowered Beckman Model RS5 conductivity-temperature meter, modified for negative temperatures. The latter meter was used frequently in the upper 15 m of the water column when the salinity was less than 30‰, the lower limit of the STD. It also was used on Stations 72–91 when electrical interference aboard the ship and other problems made the STD inoperative. Although the Beckman instrument is several times less accurate than the STD, the phenomena to be described are sufficiently striking that the probable errors are unimportant. After Station 104, the range of the STD was extended to lower salinities by shunting the conductivity cell with a removable waterproof resistor. Two lowerings were then made, one with the shunt to record the upper layers and one without to record the deeper layers. When the shunt was used, the temperature accuracy was that characteristic of the unshunted instrument whereas the salinities had an estimated error of ± 0.2‰. At salinities less than 30‰ such errors are unimportant; they are smaller than the errors due to the uncertainties in geographic position and depth.

3. Results. The station plan is shown in Fig. 1, which also shows the locations of six vertical sections to be described. The ice distribution is shown in Fig. 2. Ice concentrations are derived from observations on station, so the map is warped by the effects of time during the approximate four-week duration of the cruise. However, the map is more useful in this form than if it were synoptic because the effects of ice are thus more directly correlated with the water properties being measured simultaneously. By comparing the ice distribution with the surface temperature shown in subsequent diagrams, one may see the general coincidence of warm surface water with ice-free areas. The ice-free areas are not always warm; melting may have used all the available heat or the areas may have just recently been freed of ice by the wind. Eventually the temperature maximum descends beneath the surface layer. The distribution of the warm current, therefore, is shown in Fig. 3 as a map of the maximum temperature in the water column.

Figs. 4a, 4b, and 5–9 are longitudinal and cross sections of temperature along the current. They show the warm water generally compressed against the coast in the Chukchi Sea, first as a sharply delineated surficial layer, later dropping toward the bottom while being cooled at the surface. In the Beaufort Sea, beginning at Station 87, the core of the current appears to pass north of Section A–A in Fig. 4, as may also be seen in Section F–F in Fig. 9.

Hufford's data begin, approximately coinciding with ours, at this point. In the region of our Station 129, at longitude 152°W, he penetrated about twenty miles farther to the north, to latitude 71°30′N. His temperature contours suggest that the core is farther north than this. He conclusively demonstrates warm water as far east as 147°W and, at this longitude, there is still the implication

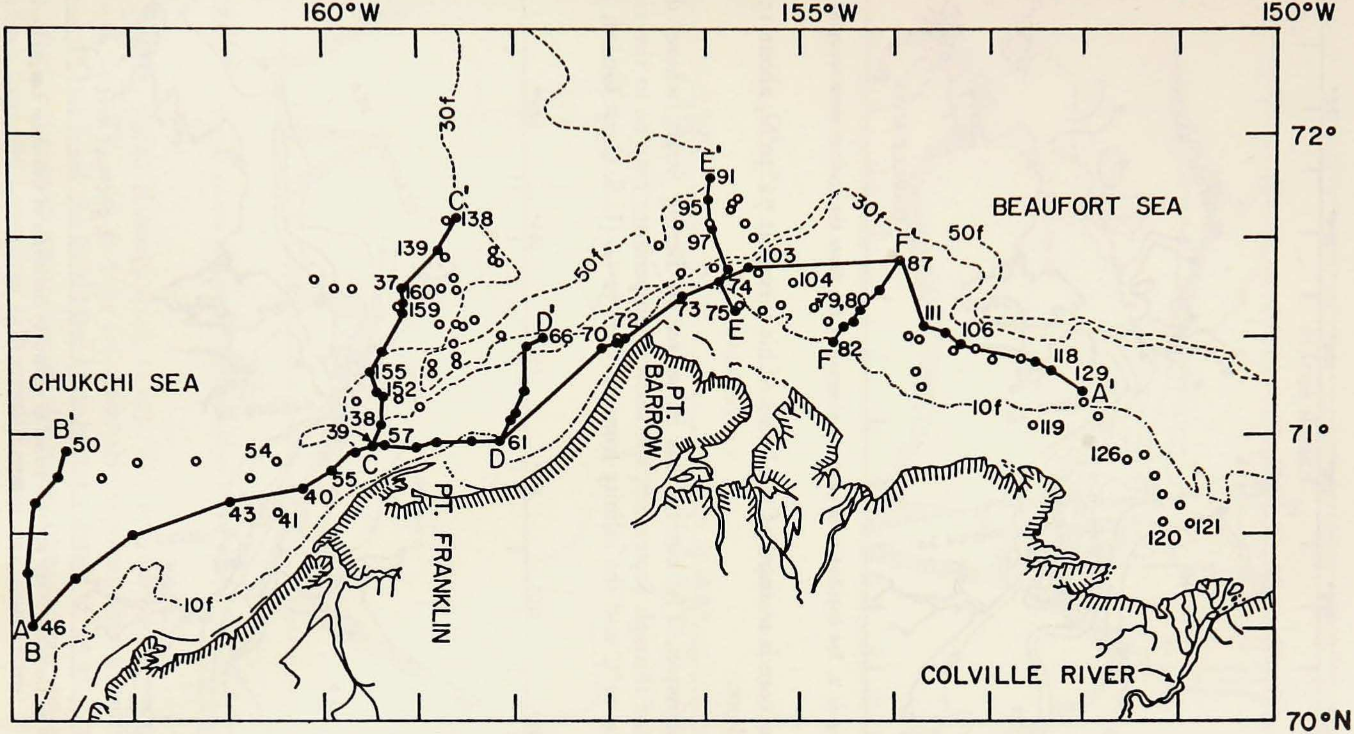

Figure 1. Station plan and locations of vertical sections.

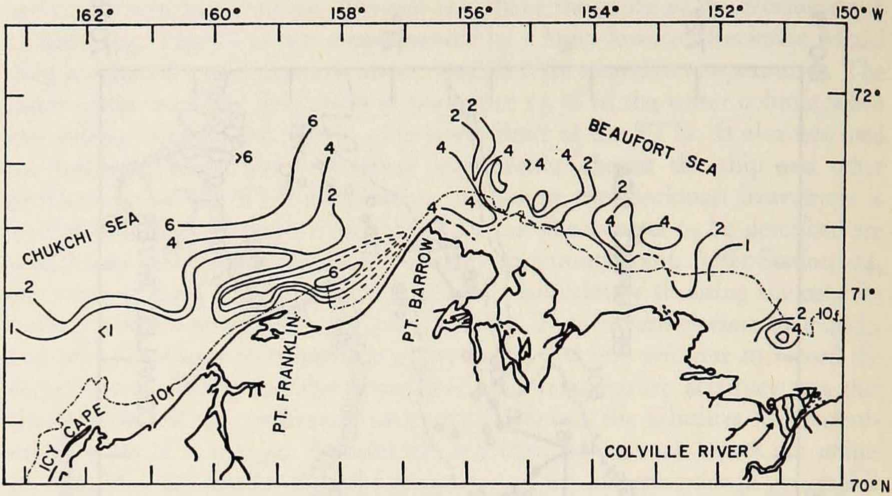

Figure 2. Ice distribution in oktas, as observed at the times the stations were occupied.

that the core is seaward of the limits of his survey at 71°30′N, about 175 km from shore.

4. Discussion. The current has its source in Bering Strait, where, during late June through September, the surface temperature may be in the vicinity of 5° to 11°C and the salinity from 28.5 to 32‰ (U.S. Coast Guard, 1964,

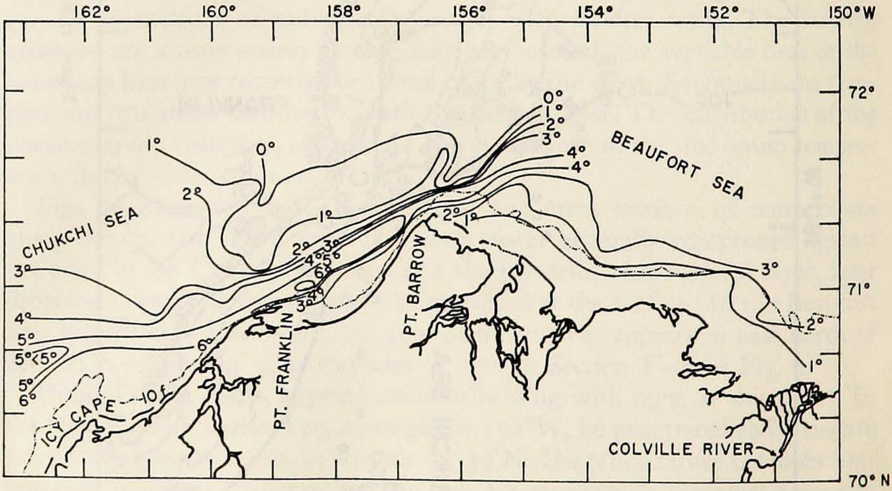

Figure 3. Location of the coastal current as shown by isotherms of maximum temperature in the water column. Temperatures in degrees C.

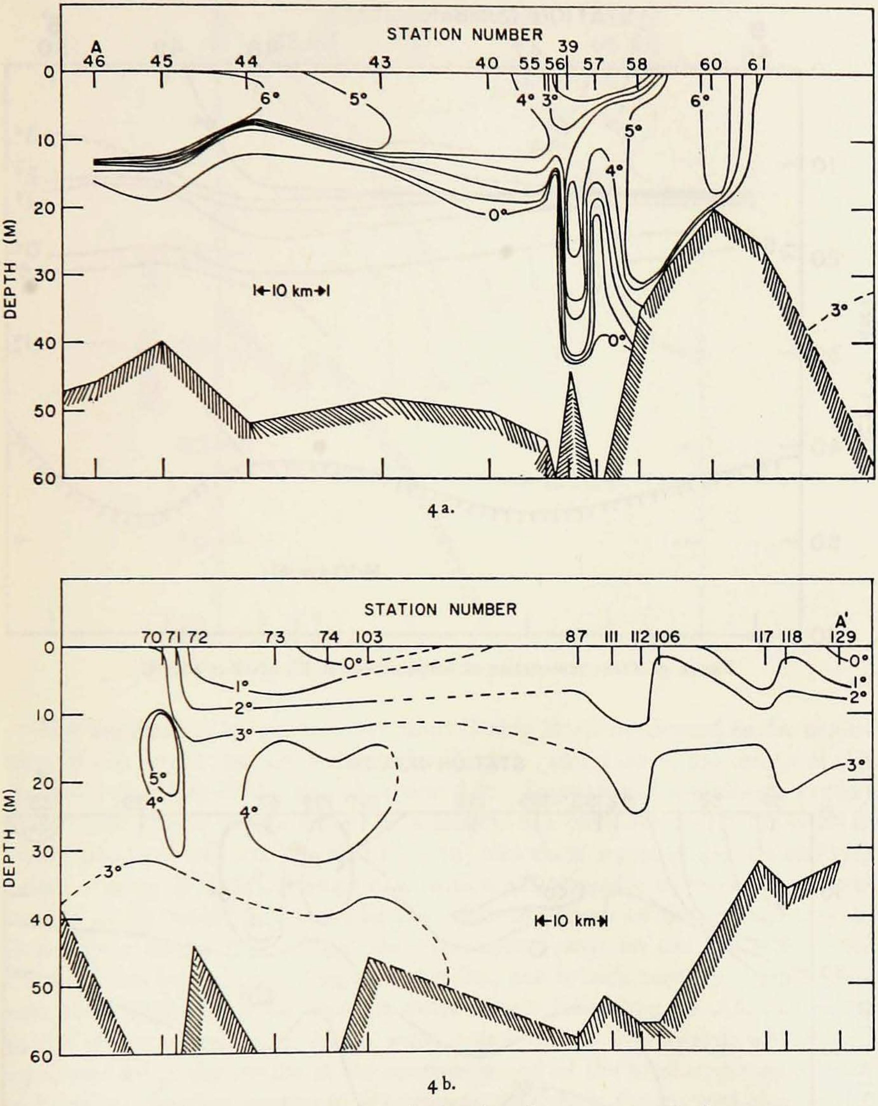

Figure 4a and 4b. Longitudinal section of temperatures, *A–A'*.

1965, 1968, 1969; Kinney, *et al*, 1970). The low salinities seem atypical. Perhaps 7° to 8°C and 31.5‰ are reasonably representative for the July–August period. Near the Strait the warm water extends to 35 m or more of depth. Within the warm water column, the temperature decreases with depth, sometimes little and sometimes substantially.

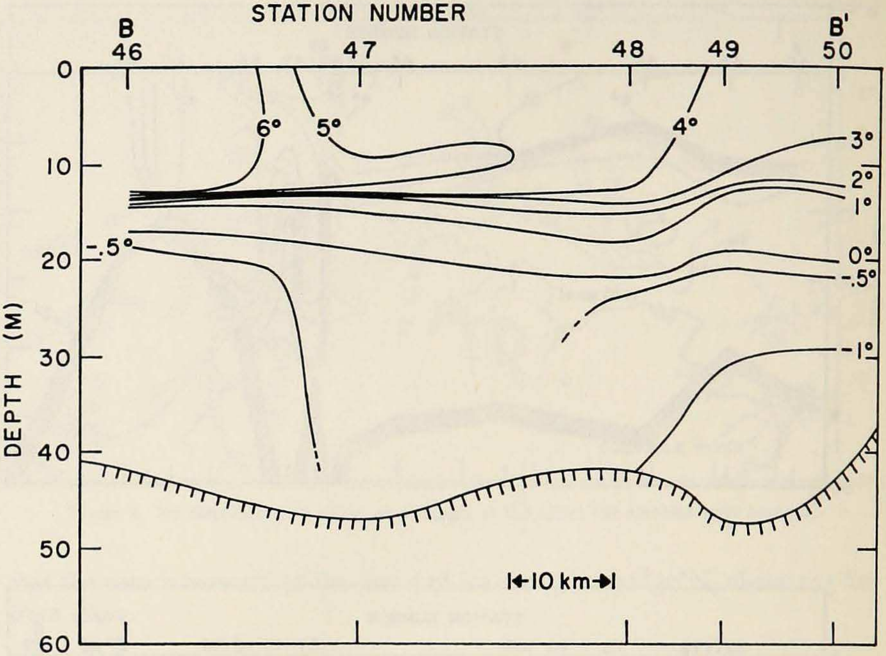

Figure 5. Transverse section of temperatures, B–B′, Stations 46–50.

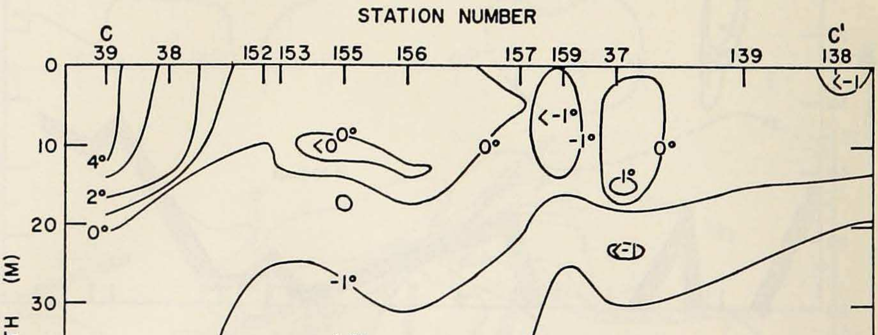

Figure 6. Transverse section of temperatures, C–C′.

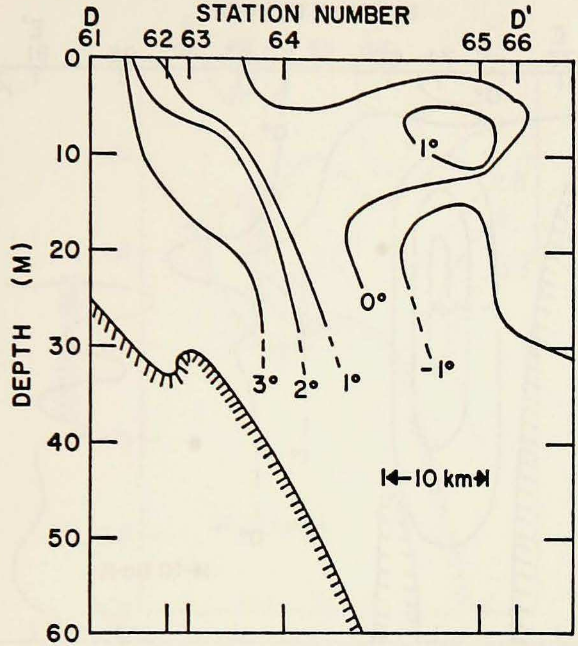

Figure 7. Transverse section of temperatures, D–D′, Stations 61–66.

The distribution of warm water from Bering Strait northward to the beginning of the present survey is shown by English (1963) using the results of the August 1960 BROWN BEAR cruise data. Aagaard and Coachman (1964) show a circulation diagram for the Chukchi Sea based on NORTHWIND 1962 data. LaFond and Pritchard (1952) also show water properties and circulation using NEREUS 1947 data which are adequate to show the coastal current as far north as Cape Lisburne, just southwest of the present survey. From these results it is evident that the current stays on the east side of the Chukchi Sea but at Cape Lisburne it splits, one branch turning north-northwest toward Herald Shoal and the other closely following the Alaskan coast. In the region of the split, warm water exists farther to seaward, which is in agreement with the results at the southwest end of the present survey as seen in Figure 3. Farther northeast, the present data show the current close to the coast and narrow, as Aagaard and Coachman suggested in their diagram. It is as narrow as 37 km in places and even narrower 40 km north of Pt. Barrow.

From a point northeast of Pt. Barrow at least part of the warm current turns east, more or less parallel to shore. From here eastward only its southern edge is demonstrated by the data. It is notable, in this region, that the temperatures are highest toward the bottom.

Referring now to the longitudinal section, Fig. 4, and the T-S diagram,

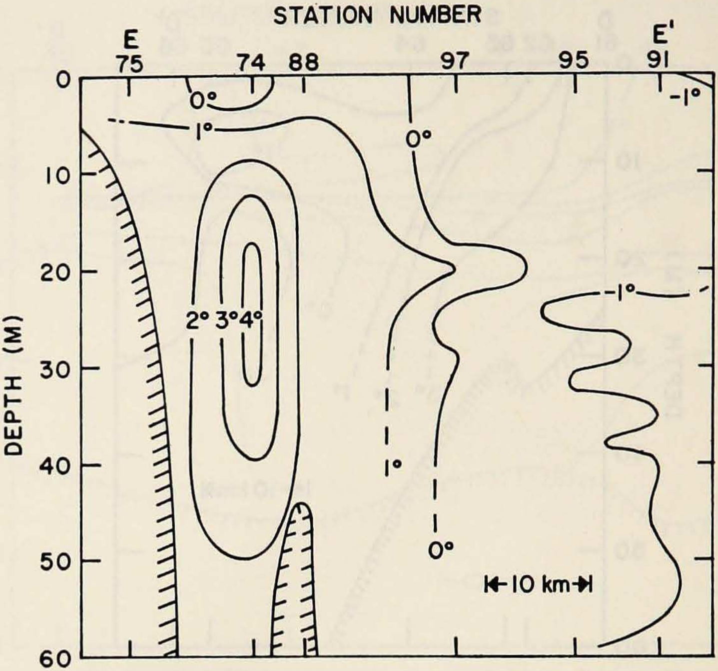

Figure 8. Transverse section of temperatures, E–E′, Stations 75–91.

Fig. 10, one sees the current first at Station 46 (72°20′N) as a mixed layer at 6.5°C riding atop an extremely sharp temperature gradient. The temperature at Station 46 decreases from about 6° to 1°C in 1.5 m. The maximum gradient is about 7°C/m. Gradients such as these have devastating effects on the conductivity-to-salinity conversion circuit of the STD. The resulting salinity anomalies have been ignored in converting the data.

Just north of Station 46, Station 47 shows distinct cooling and dilution at the surface. There is little or no ice at Station 47, but the water must recently have been in contact with ice. Farther along the warm core the general processes taking place are cooling near the surface accompanied by a dilution generally somewhat greater than would occur if pure, water-free ice were melted with the sensible heat. This may be seen in the T-S plot, Fig. 10.

The surface coordinates for Stations 46, 47, 61, 74, and 129 lie fairly close to the dashed line which shows the T-S relation resulting if the surface water of Station 46 were cooled exclusively by the melting of pure ice, with the consequent dilution. The surface water at these stations is slightly more dilute than the melting-dilution curve. Station 87 is anomalous in that it is slightly more saline. These small deviations from the curve may be due to various causes, most likely to lateral mixing with water which is usually less saline or, possibly,

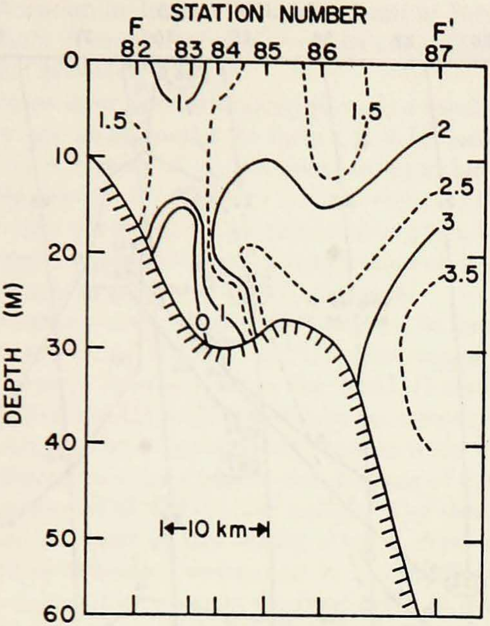

Figure 9. Transverse section of temperatures, F–F′, Stations 82–87.

to some contribution of heat or melt water by solar heating. The fact that the data follow the melting-dilution curve as well as they do is evidence that the dominant factor in the melting of ice along the course of the current is the heat in the water itself.

In the ice, outside the margins of the current, the principal cause of melting is solar heating which yields a melt water with a temperature close to the ice-seawater equilibrium temperature. This is the case at Station 138 which is well within the ice pack. Station 91 probably would have been similar except for the evident mixing with more saline deeper water forming a mixed layer 10 m thick.

The behavior of subsurface water in the current may be seen in Figs. 4 and 10. The warm water, which at first was atop a denser layer, suddenly deepened near Station 39 to nearly fill the water column and, beyond Station 61, the dense layer disappeared. One asks why the dense layer was there in the first place and why it disappeared. Examining the lower portions of the T-S diagrams for Stations 46, 47, 91, and 138, one sees that the bottom waters are fairly saline and not much warmer than that corresponding to the ice-seawater equilibrium at that salinity. The bottom ends are clustered together with roughly the same properties and a sigma-t of 26.3. These two facts suggest that bottom water in the northeastern Chukchi Sea away from shore is a relic of winter freezing. LaFond and Pritchard drew this conclusion also. It is readily

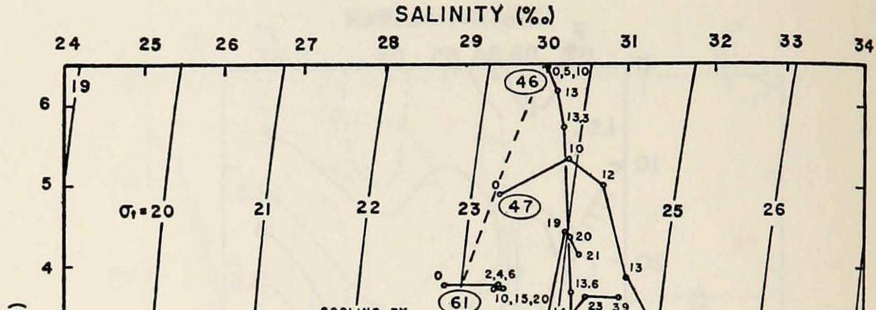

Figure 10. Temperature-salinity diagram for selected stations. Station numbers are in ovals. The numbers along the curves are depths in meters.

seen to be a plausible conclusion from the well-established concepts of removal of fresh water from the water column during winter freezing. Let us assume that 1.5 m of ice are frozen, somewhat less than the 2 m frozen during winter in the central Arctic, and that the average depth of water is 45 m. The average salinity would then rise 3.4 percent above the late summer average. In our data, the average salinity in a 45 m column is about 32‰; this would increase to 33.1‰, which is about what was found.

We explored historical measurements to find evidence of the formation of Chukchi bottom water in winter. Appropriate data are sparse; we used a number of the MAUD stations in winter 1922–23 on the Chukchi shelf at longitudes about 172°E, T-3 stations in winter 1965–66 near 76°N and 155°W, and a line of NORTHWIND 1960 stations from latitude 72°23′N to 70°15′N in the eastern Chukchi Sea in early November (National Oceanographic Data Center, 1973). The more southerly NORTHWIND stations show bottom water being formed. The most northerly shows freezing and overturn but not yet sufficient increase in density to form bottom water as dense as 26.3. A station in deeper water farther east in July shows a density of 26.3 at 95 m depth. A number of similar results are available in other summer data, e.g., NORTHWIND (1955).

The T-3 stations show overturn taking place to a depth of about 35 m, but the densities are not great enough to form Chukchi bottom water like that observed in 1971. A density of 26.3 is found at 95 m but the temperature is −1.2°C, not cold enough for Chukchi bottom water. The MAUD stations show a bottom water present at depths greater than 35 m, but it is older water, having a low oxygen concentration and a temperature of −1.5°C. Bottom water was not being formed in that area during that year.

It is clear from these results that bottom water can be formed in the Chukchi Sea at points not too far north. The MAUD data suggest that it may not be renewed every winter. However, since the MAUD stations were near the northern boundary of the Chukchi Sea, it is by no means clear that the bottom water was not being renewed farther south; bottom water may not be continuous and similar throughout the Chukchi Sea. Because of the 95 m depth of the 26.3 isopycnal in the NORTHWIND and the T-3 data, it seems unlikely that Chukchi bottom water of this density at 30 m depth can come from the Arctic Ocean. Flow of bottom water must be toward the Arctic Ocean. The bottom water is denser than water at the same depth in the Arctic Ocean because the shallow flat bottom of the Chukchi Sea is a barrier to free downward convection of brine in winter and retards flow into the Arctic Ocean.

The reason for the abrupt change near Station 39 is not clear. The head of the Barrow Sea Valley is near this point; this valley may be a drain, extending well south of the continental slope, by which the dense water recedes to greater depths and flows northward. The anomaly could also be due to geostrophic tilting of isopycnals by the current, which near here has been observed to flow at a speed of 100 cm/sec or more. However, some exploratory calculations of dynamic heights in the region of the coastal current show that the current is only weakly demonstrated. Therefore, the first explanation is favored.

The decrease in the maximum temperature in the water column as the current proceeds is readily seen to be due mainly to surficial cooling. Once this has occurred, the maximum temperature is located rather stably between 3° and 4°C as is typified by the bottom ends of T-S diagrams 74, 87, and 129. It is notable that the water has retained its identity for so great a distance under conditions of relatively rapid flow and large property gradients.

Early in this investigation it had been considered possible that the warm water in the Beaufort Sea might have its source in the solar heating of shelf water. Probably this is already seen to be an untenable assumption. Additional evidence may be found in the properties of surface water at Stations 120 and 121 on the shelf. These stations had temperatures between −0.7° and +0.7°C and salinities between 24 and 27‰, too cold and too fresh to be considered as a source of the warm water at Station 129.

5. Conclusions. The warm coastal current of northwestern Alaska has been found to turn eastward into the Beaufort Sea and to run more or les parallel to shore to longitude 152°W in August 1971. Hufford, in this same year and at nearly the same time, followed it farther east to 147°W. The current generally hugs the shore in the Chukchi Sea and is centered perhaps 50–75 km seaward in the Beaufort Sea. Befoie it turns east, it is as narrow as 20–40 km in places.

The warm water is first concentrated near the surface because of the relatively high density of relict water in the shallow Chukchi Sea. As deep water is approached, the relict water apparently flows down slope permitting the warm water to find a deeper equilibrium level. The surface, meanwhile, has been cooled and diluted by the melting of ice so that the warm core is eventually found near bottom in 30–50 m depth near the break of the Beaufort Sea shelf. It is possibly at mid-depth to seaward as the bottom drops away.

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