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CIRCULATION AND HYDROGRAPHY NEAR KODIAK ISLAND SEPTEMBER TO NOVEMBER 1977

J. D. Schumacher
R. K. Reed
M. Grigsby
D. Dreves

Pacific Marine Environmental Laboratory
Seattle, Washington
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J. D. Schumacher
R. K. Reed
M. Grigsby
Lt. D. Dreves[1]

Conductivity/temperature/depth observations during early September 1977 and from mid-October to early November 1977 near Kodiak Island are presented and discussed. During both periods there was weak, southwestward flow along the outer continental shelf and gyre-like features in the troughs separating the shoal banks. On the inner shelf near the Kenai Peninsula, a well-developed westward flow was present; transport of this flow increased from 0.4×10^6 m^3 s^{-1} in September to 1.0×10^6 m^3 s^{-1} in October.

The horizontal and vertical distributions of properties are influenced by both the circulation and the sharply varying bank-trough topography. Tidal mixing over the banks appears to be an important factor, and local upwelling induced by wind events also exerts influence on water structure. The westward-flowing band of low-salinity water off the Kenai Peninsula appears to be strongly affected by freshwater drainage from land.

1. INTRODUCTION

Since August 1974, the Pacific Marine Environmental Laboratory (PMEL) has participated in field operations supporting NOAA's Outer Continental Shelf Environmental Assessment Program (OCSEAP) in the Gulf of Alaska. Many of the observations were concentrated in the Kodiak Island region (Fig. 1). In this report we present and interpret CTD (conductivity/temperature/depth) data collected during three cruises from September to November 1977.

1.1 Previous Field Studies

Mean circulation in the Gulf of Alaska is dominated by the Alaskan gyre (Dodimead *et al.*, 1963; Roden, 1969; and Ingraham *et al.*, 1976). The northern leg of this gyre is the Alaskan Stream, which flows westward generally paralleling the coastline. Following convention, we refer to the northern and northwestern arm of the Gulf of Alaska gyre as the Alaskan Stream; the Alaska Current is the less organized northward current off British Columbia and southeast Alaska. Royer (1975) discussed seasonal changes of hydrographic properties across the Alaskan continental shelf and related these changes to local wind forcing. In winter, the Aleutian Low causes storms with southeasterly winds (Danielson *et al.*, 1957), which cause increased current speeds along the continental shelf (Hayes and Schumacher, 1976).

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[1] NOAA Corps

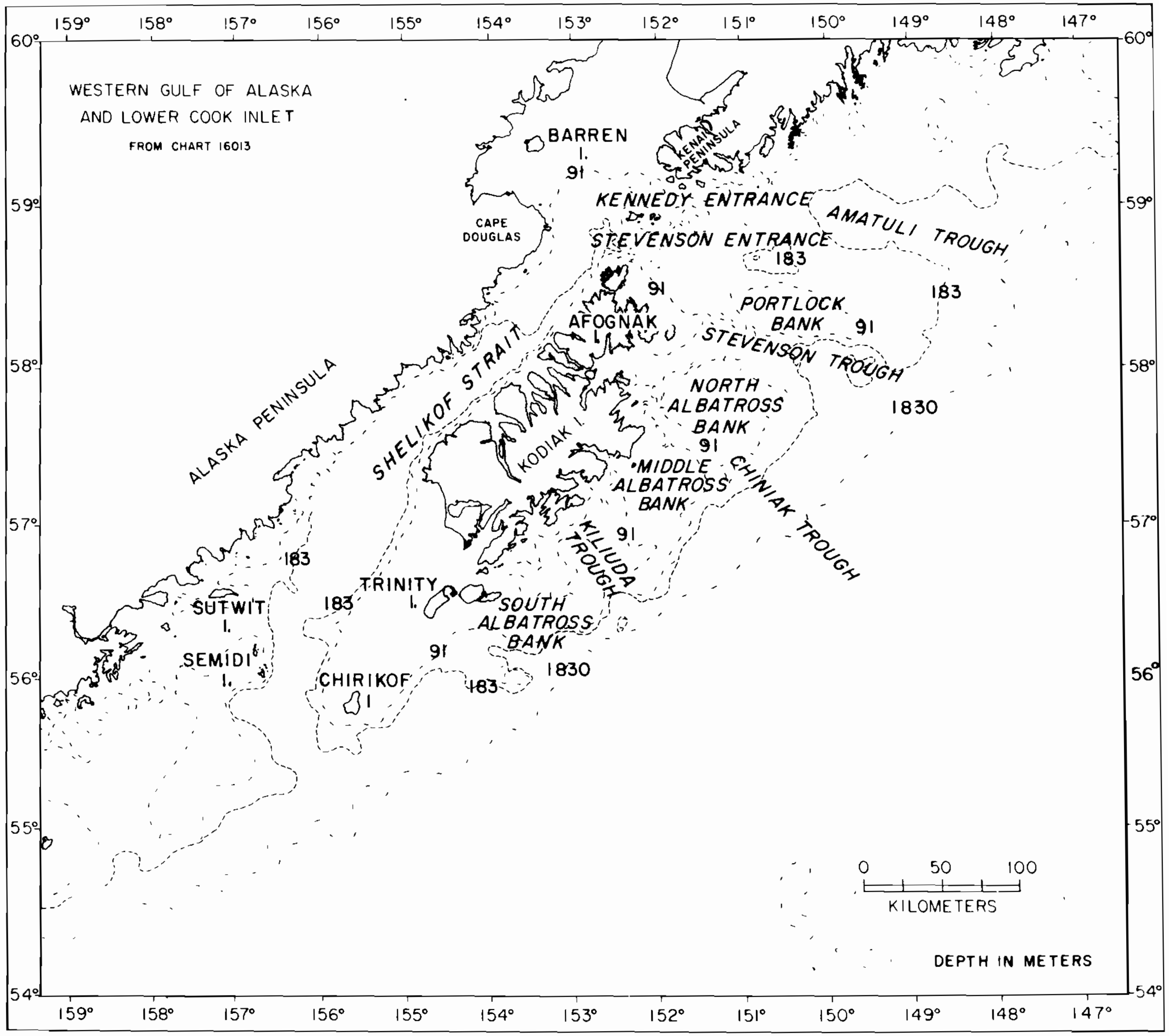

Figure 1. Kodiak Island study area.

Although the existence of a westward flow in the Gulf of Alaska and along the Aleutian Islands has been known for decades, little information has been available on circulation patterns over the continental shelf. Recently, data from two fairly comprehensive surveys off Kodiak Island have been presented (Favorite and Ingraham, 1977; Schumacher *et al.*, 1978), which allow one to infer inshore circulation patterns. The offshore flow (Alaskan Stream), a deep boundary current with peak speeds generally in water depths greater than 500 m (Favorite *et al.*, 1976), may strongly influence circulation over the continental shelf.

1.2 Bathymetry

Bathymetry southeast of Kodiak Island is dominated by a series of four relatively shallow (∿90 m) shoal areas (Fig. 1). These are, from north to south: Portlock, North, Middle, and South Albatross Banks. They are separated from each other by narrow channels that cleave the shelf in a direction roughly normal to the coastline.

Stevenson Trough extends from Stevenson Entrance southeasterly, separating Portlock and North Albatross Banks. At its shallowest point, in the narrow passage west of Portlock Bank, the trough is 110 m deep. Chiniak Trough, separating North and Middle Albatross Banks, has an apparent sill depth of 145 m. Kiliuda Trough, southernmost of the three cuts, lies between Middle and South Albatross Banks and has a sill depth of 150 m. Amatuli Trough, the most northerly of the features in the study area, lies north of Portlock Bank and is a large, deep (∿200 m) cleft cutting the shelf from east to west. The westward extension of Amatuli Trough bifurcates at the Barren Islands to form Kennedy Entrance north of the islands and Stevenson Entrance between the Barren Islands and Afognak Island. Kennedy Entrance is the narrower of the two and has depths of almost 200 m; the maximum depth in Stevenson Entrance is slightly more than 120 m.

1.3 Data Acquisition and Reduction

Temperature and salinity data were collected from the NOAA ships SURVEYOR and DISCOVERER using Plessey model 9040 CTD systems with model 8400 data loggers. This system sampled five times per second for values of conductivity, temperature, and depth. Data were recorded during the down-cast using a lowering rate of 30 m min^{-1}. Nansen bottle samples were taken at each station to provide 1-m temperature and salinity values from which the other parameters were then computed.

2. OBSERVATIONS (5-11 SEPTEMBER 1977)

Figure 2 shows the location of CTD casts taken off the Kenai Peninsula-Kodiak Island area from the NOAA ship SURVEYOR.

2.1 Circulation

The 0/500-dB dynamic topography (Fig. 3) indicated that the Alaskan Stream flowed southwestward paralleling the 1830-m (1000 fathom) depth contour. The

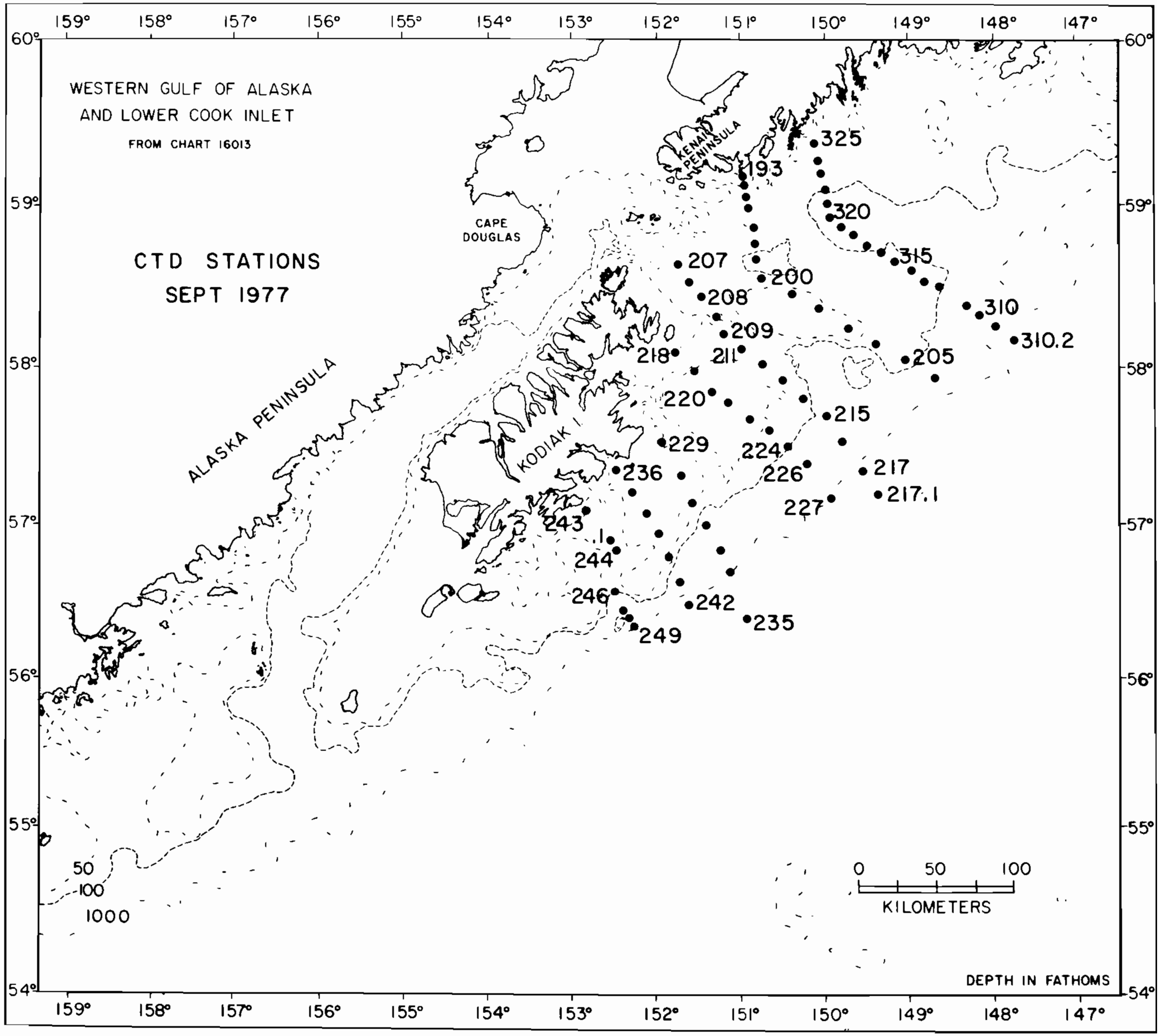

Figure 2. Location of CTD stations occupied during 5-11 September 1977.

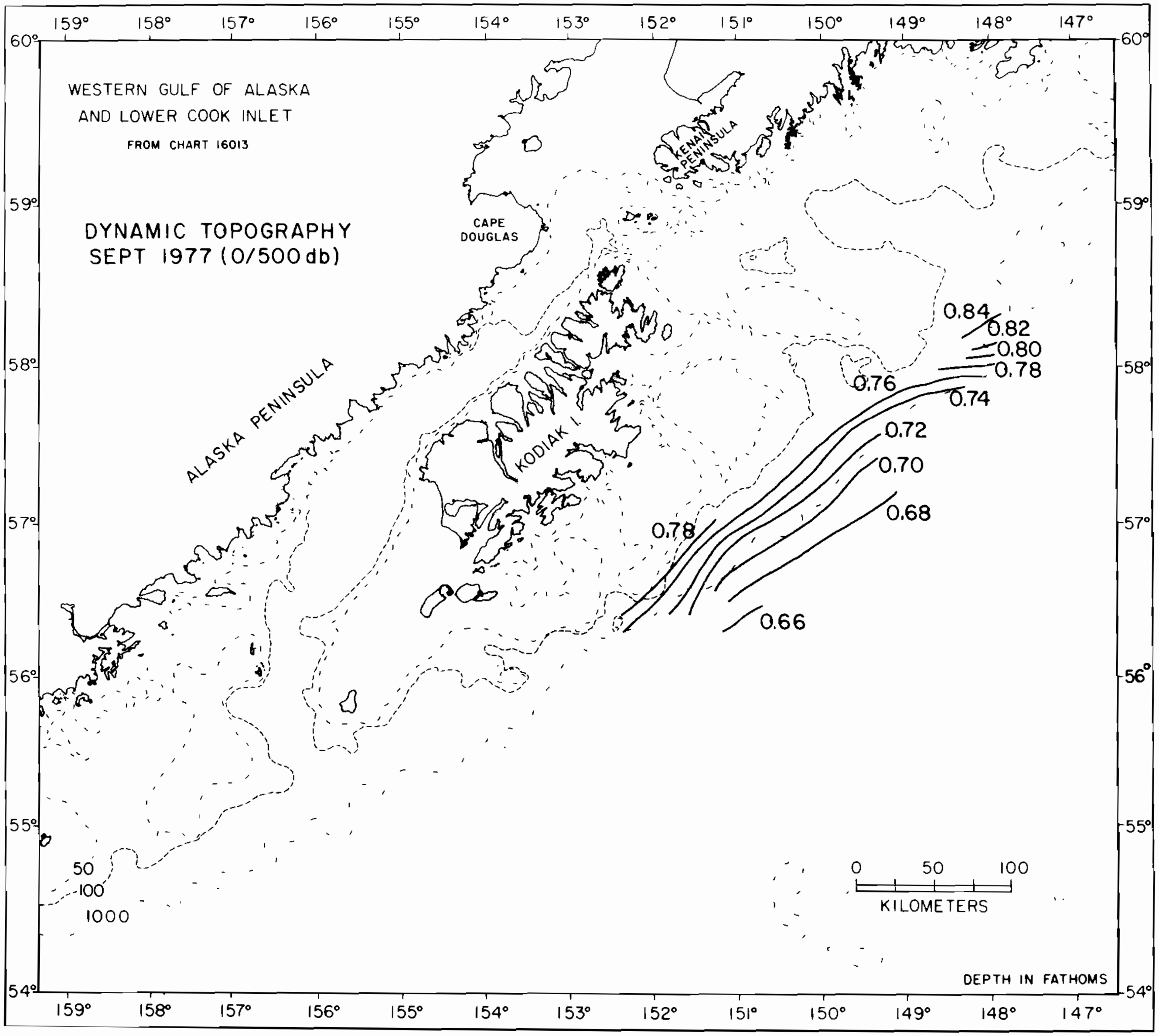

Figure 3. The 0/500-dB geopotential topography for September 1977. Contour interval is 0.02 dynamic meters.

flow had no major perturbations, but was somewhat further offshore in the northern part of the area than to the south. We estimated the baroclinic geostrophic transport (0/1500 dB) to be 11.9 x 10^6 m^3 s^{-1} using data from stations 235, 249, and 311.

We use the 0/100-dB dynamic topography (Fig. 4) to infer circulation over the shelf. Although we do not imply that absolute velocities can be obtained, there is evidence that the direction of flow is realistically depicted in shallow areas (Smith, 1974; Reed, 1978). Further, flow patterns inferred from the 0/100-dB dynamic topography were supported by the distribution of temperature and salinity to be described in Section 2.2 below.

Three major features were apparent in the inferred circulation. First, the longshore flow shown in Fig. 3 was also seen here and extended over the edge of the continental shelf in a weakly developed manner. Second, a westward flow was present off the Kenai Peninsula; because of its salinity structure, this appeared to be at least partially a result of freshwater drainage from land. This flow had easily identifiable boundaries, and it was possible to estimate volume transport; 0.4 x 10^6 m^3 s^{-1} flowed westward between stations 193 and 197 using the deepest common depth between the various stations as a reference level. Third, there was a well-developed clockwise gyre centered near 58°N, 151°W.

At first, the third feature appeared very puzzling; it was difficult to envision what might initiate and maintain such a system. Close comparison of the data with the bathymetry suggested that the flow was constrained by the bathymetry, which exerted control on the shape of the gyre. The gyre was situated between Portlock and North Albatross Banks, with eastward flow along the former and westward flow along the latter. We noted that the hydrographic properties of this water were similar to those observed to the north and unlike those observed over the neighboring banks (cf. Fig. 9 to 11). We suggest that the flow may have been initiated by a southward branch of the westward coastal flow off the Kenai Peninsula; the water could not move out of the trough onto the continental slope because of the southwest flow near the shelf edge. Instead, it turned westward and presumably flowed southwestward near Kodiak Island (Favorite and Ingraham, 1977). The March 1977 data analyzed by Schumacher *et al.* (1978) did not indicate a gyre between Portlock and North Albatross Banks. Instead, it appeared that the westward coastal flow moved into Shelikof Strait without a portion of it turning south. The existance of such gyral features in mid-shelf circulation clearly varies with time; two factors which influence shelf circulation are intensity of the southwestward shelf-edge flow and of the westward coastal flow along the Kenai Peninsula.

2.2 Hydrography

Surface waters were relatively warm (11-14°C) throughout the region as a result of summer warming due to insolation and a lack of intense evaporative cooling (Fig. 5). The warmest waters (>13°C) were offshore and inshore near the Kenai Peninsula; surface temperatures between these areas were generally 1-2°C lower. The lower temperatures were probably due in part to enhanced mixing over the shoal areas; however, surface temperature patterns were not entirely consistent with enhanced mixing over banks. Factors such as daily

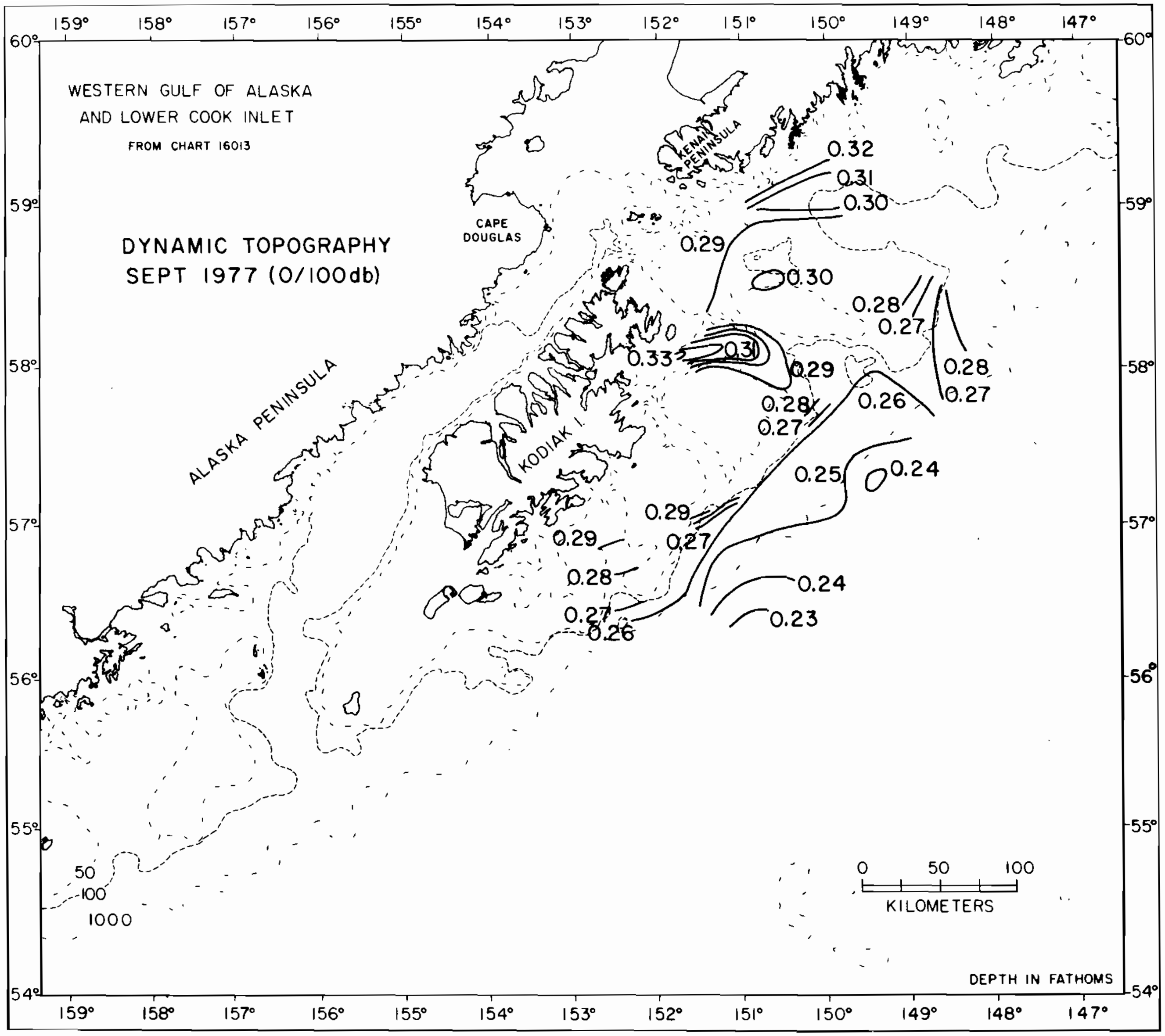

Figure 4. The 0/100-dB geopotential topography for September 1977. Contour interval is 0.01 dynamic meters.

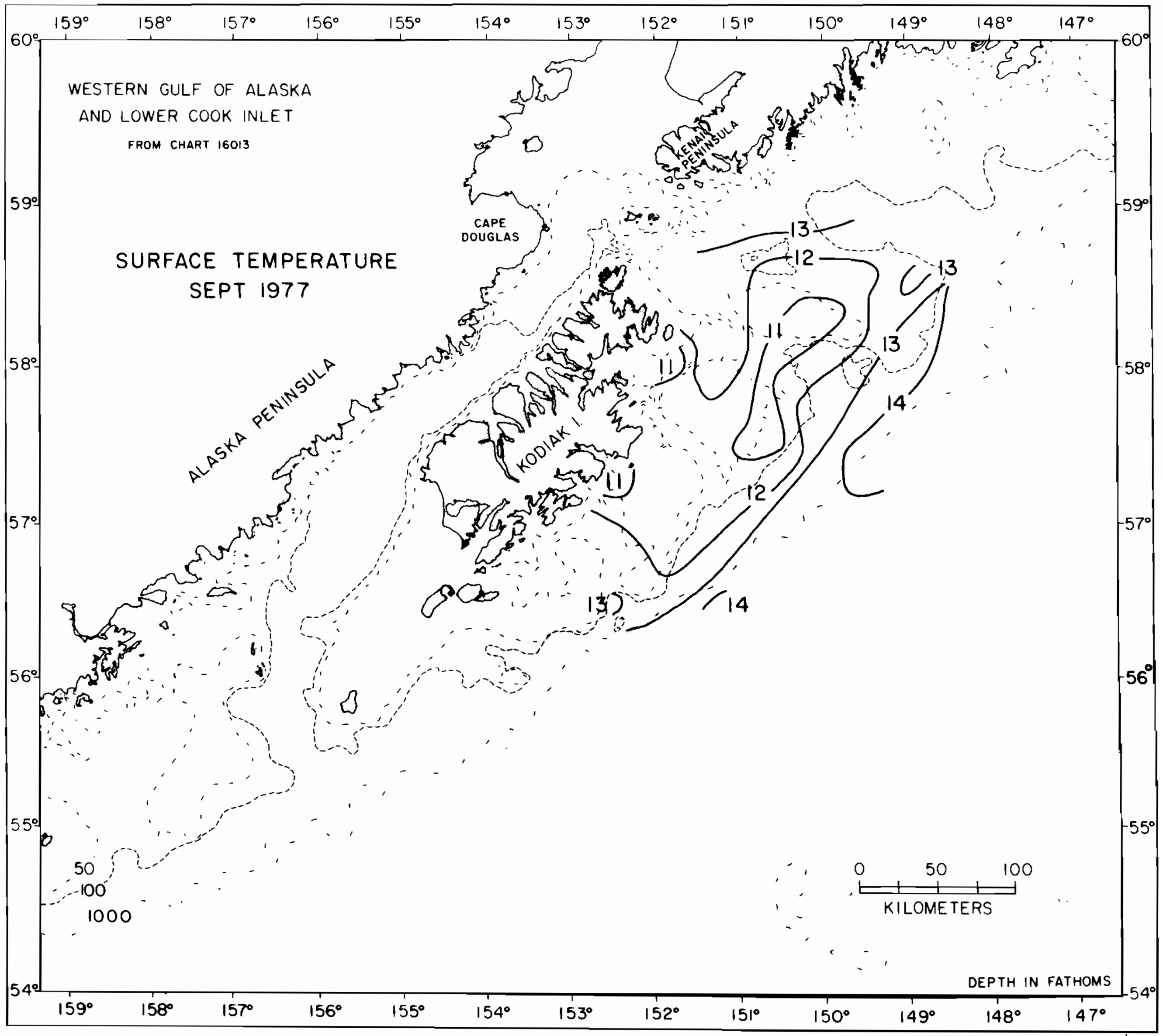

Figure 5. Distribution of surface temperature for September 1977. Contour interval is 1°C.

variations in heating and cooling and spatial variations in the tidal energy dissipation rate (a function of depth and tidal speed) may also have been important. Storm events also had a pronounced impact on hydrographic structure (see Section 4.1).

Surface salinity values varied from about 28.5 g kg^{-1} to 32.5 g kg^{-1} (Fig. 6). The lowest values occurred near shore in the region of warmer surface waters; this area must have been strongly influenced by rivers and coastal drainage. There was a nearly uniform increase of salinity offshore in contrast with the distributions seen earlier in summer. During May 1972 there was a surface salinity maximum offshore, a low-salinity band near the Kenai Peninsula, and another minimum offshore from the maximum (Favorite and Ingraham, 1977). These two features, however, resulted in 1972 from well-developed, relatively large-scale cyclonic and anticyclonic gyres that were absent during our survey. Surface salinity patterns are highly variable and reflect features of circulation more strongly than surface temperature. The temperature distribution at 50 m (Fig. 7), which is near the minimum depth of the banks, appeared to be influenced primarily by water depth and circulation. The temperatures were generally higher over banks than over troughs, as evidenced by temperatures above 8°C over the Portlock and Albatross Banks and cooler water in Stevenson Trough. This was due to enhanced mixing over banks that resulted in cooler near-surface layers and warmer deep layers. Temperatures at 50 m decreased seaward, in agreement with the offshore upward slope of isotherms in the Alaskan Stream. The region of cool water west of Amatuli Trough coincided with a low in geopotential associated with westward flow along the Kenai Peninsula. Features in the temperature distribution generally paralleled those in the salinity distribution (Fig. 8). However, mixing over banks lowered the salinity at 50 m because salinity increased toward the bottom whereas temperature decreased with depth. Lows in geopotential were associated with more saline water. Finally, the distribution of sigma-t at 50 m (not shown) was virtually identical to that of salinity, because of the dominance of salinity over temperature in controlling the density of subarctic water.

Figures 9, 10, and 11 present the temperature, salinity, and sigma-t difference between the values observed at the surface and at 50 m. This permits an areal presentation of the material usually treated in vertical sections, and one can assess the stratification and the processes that affect it. The distribution of surface to 50-m temperature difference shows the effects of mixing over the banks, where differences were less than 3°C. The large temperature differences offshore resulted from the steep rise of isotherms in the seaward portion of the Alaskan Stream. Nearshore, the zone showing differences greater than 6°C resulted mainly from the relatively cool 50-m water associated with a low in geopotential. The distribution of 50 m to surface salinity differences was unlike that for temperature except that low values were caused by mixing over the banks. The maximum differences occurred just off the Kenai Peninsula, whereas temperature differences there were intermediate. This was due to low values of surface salinity (with large horizontal gradients) near the peninsula. Offshore, the salinity differences did not increase significantly because the steepest part of the halocline was below 50 m; the steepest part of the thermocline, however, was above 50 m. The sigma-t differences generally reflected the dominant influence of salinity on density except off-

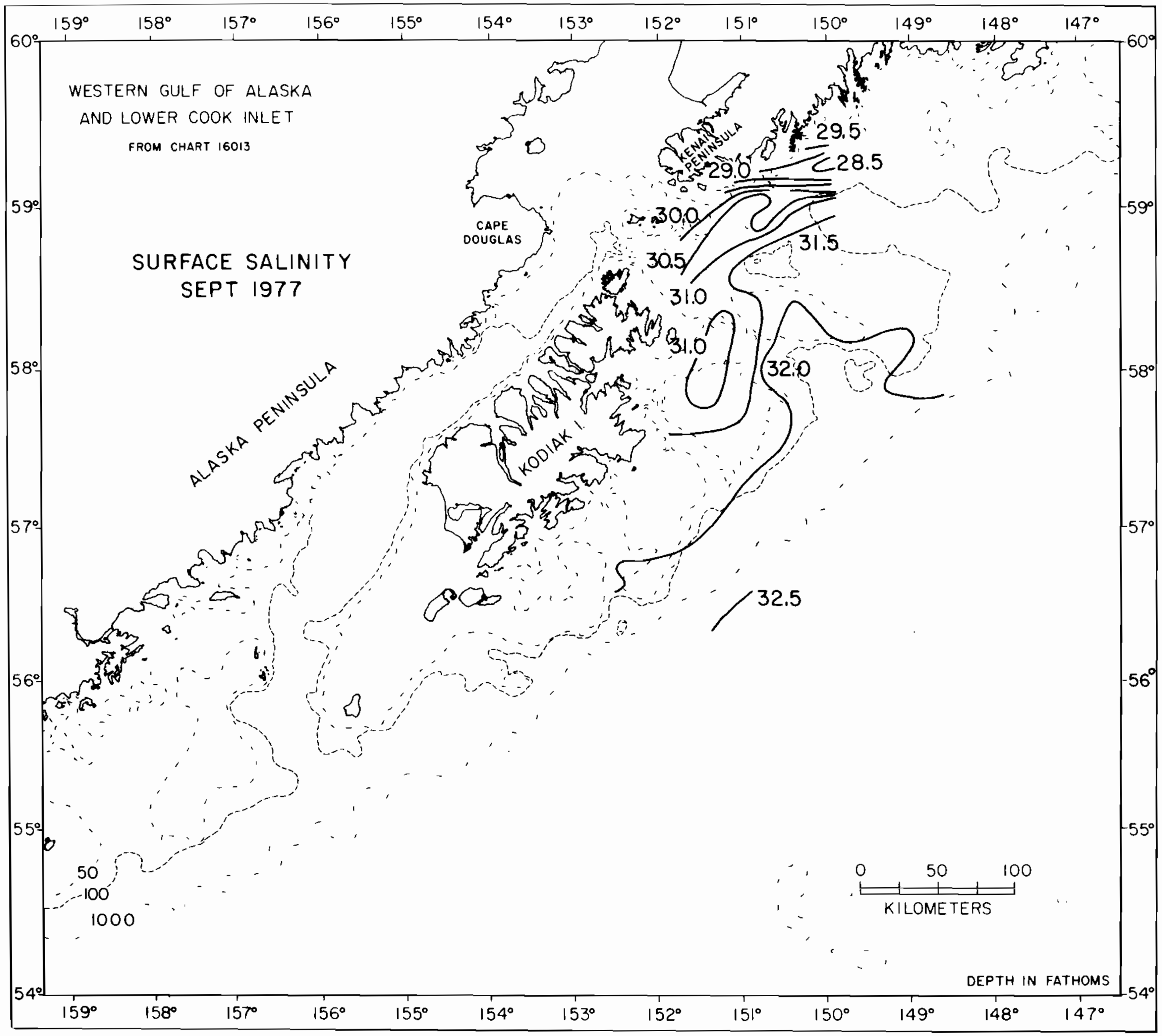

Figure 6. Distribution of surface salinity for September 1977. Contour interval is 0.5 g kg^{-1}.

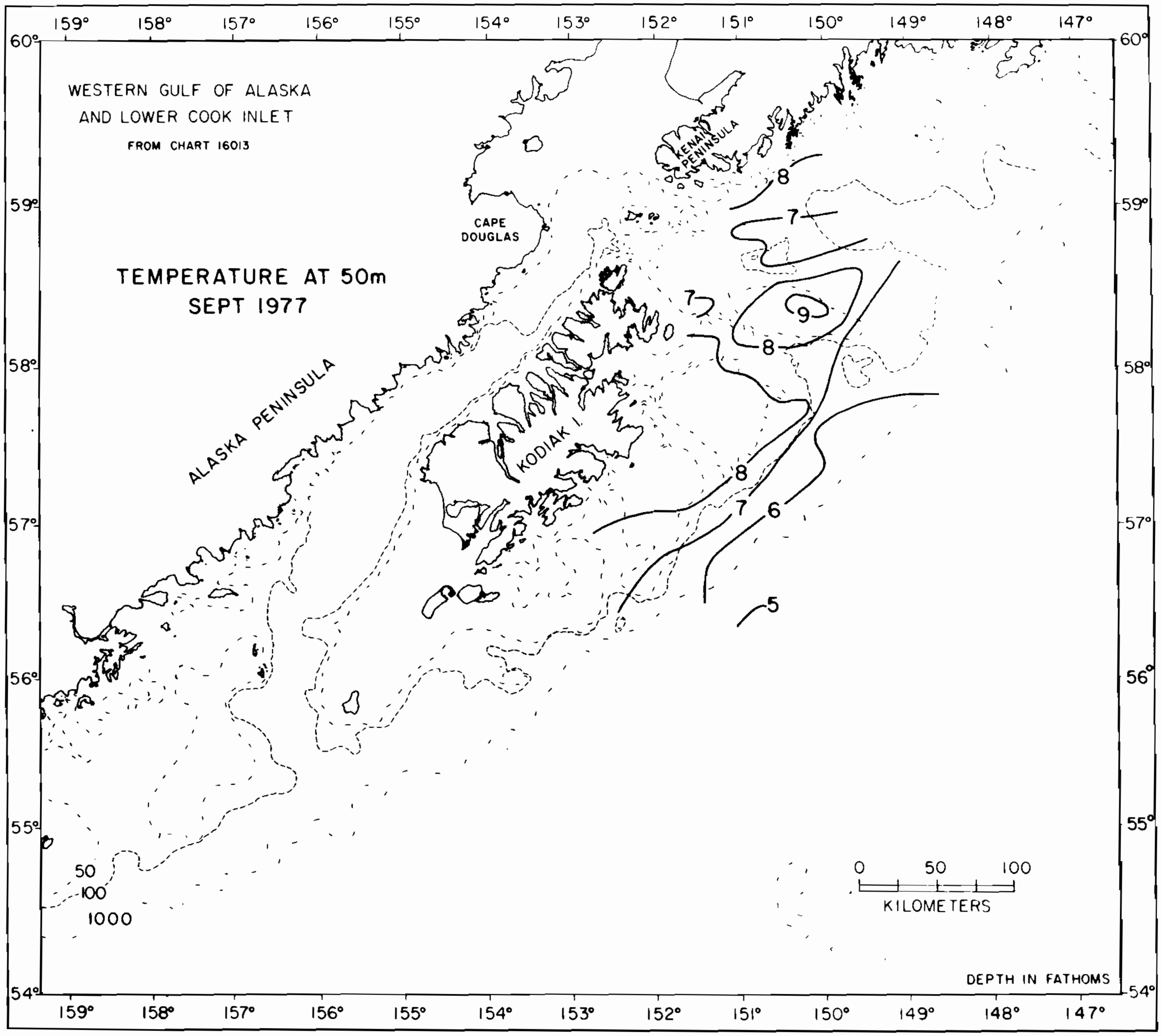

Figure 7. Distribution of temperature at 50 m for September 1977. Contour interval is 1.0°C.

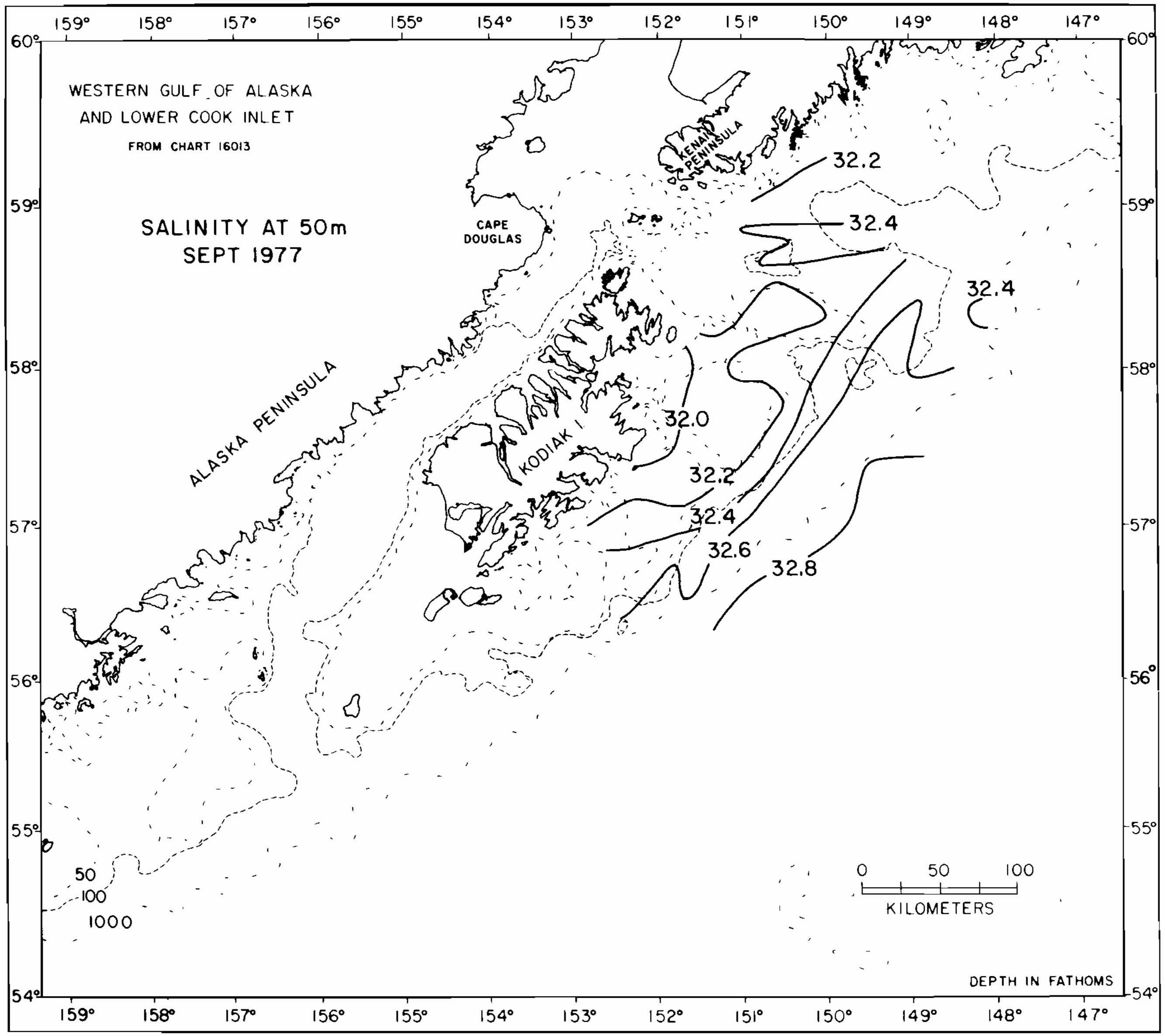

Figure 8. Distribution of salinity at 50 m for September 1977. Contour interval is 0.2 g kg^{-1}.

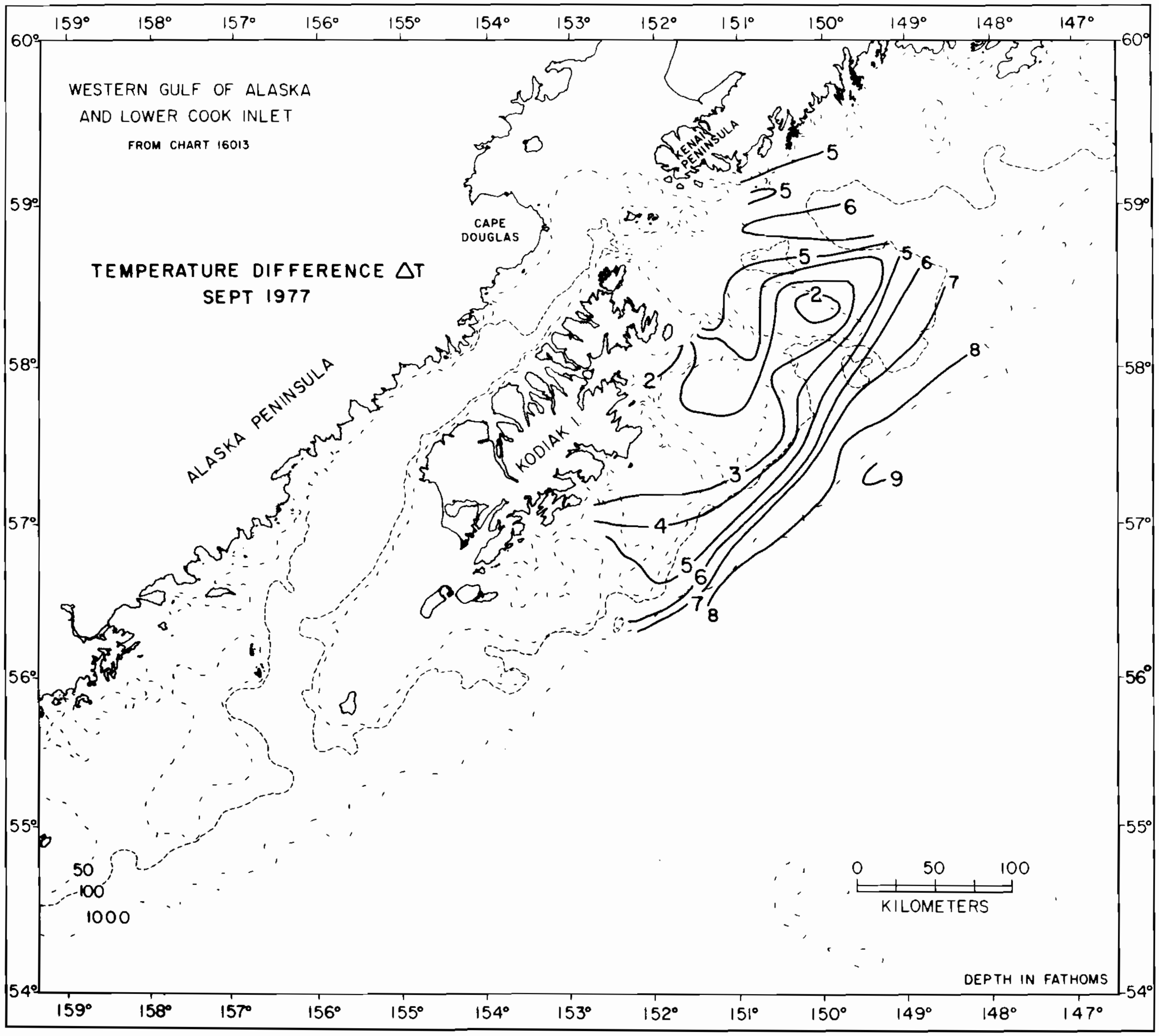

Figure 9. Temperature difference ΔT between the surface and 50 m for September 1977. Contour interval is 1°C.

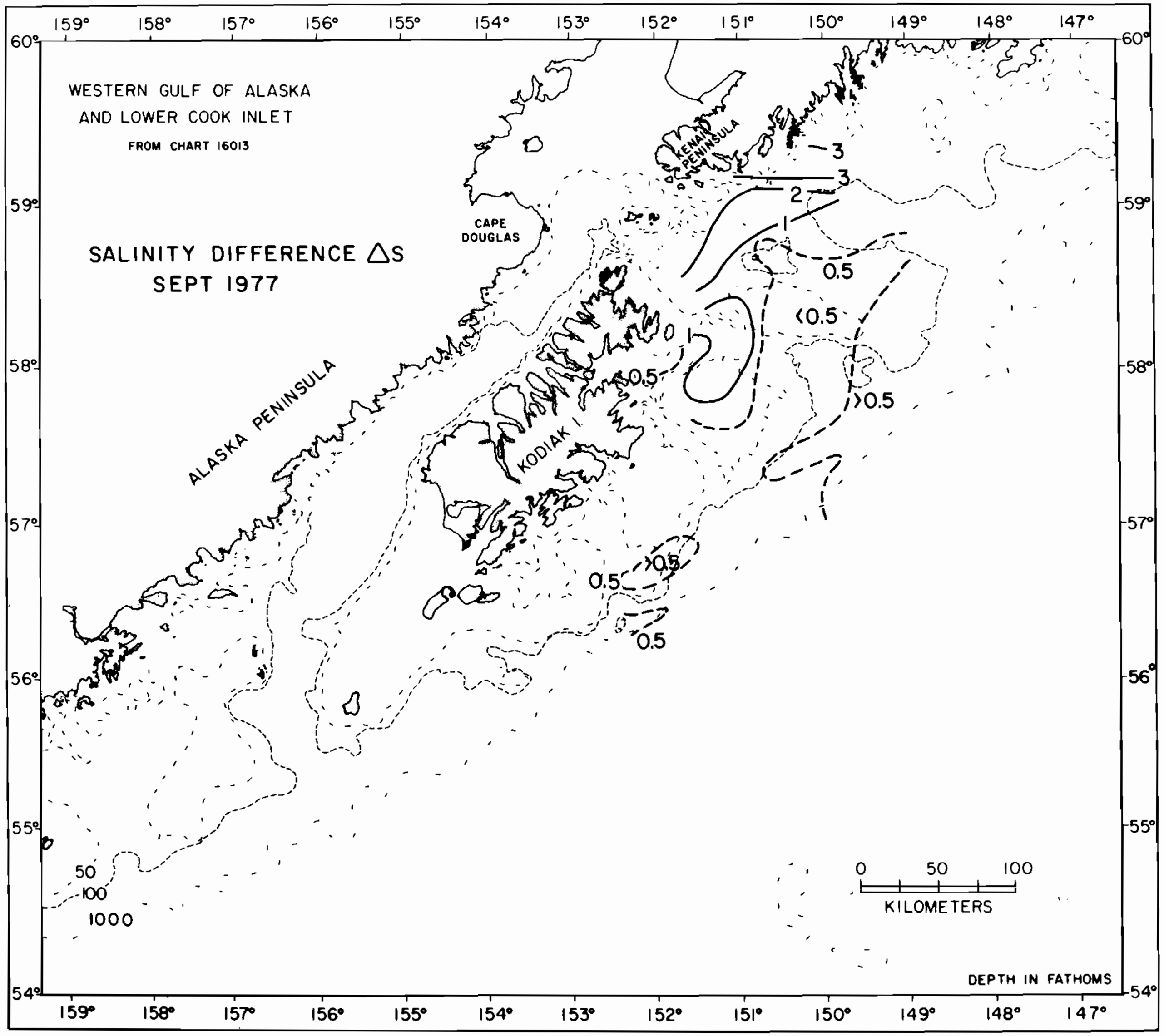

Figure 10. Salinity difference ΔS between 50 m and the surface for September 1977. Contour interval is 1.0 g kg^{-1} and the ΔS = 0.5 g kg^{-1} contour (dashed) is presented since vertical structure was weak.

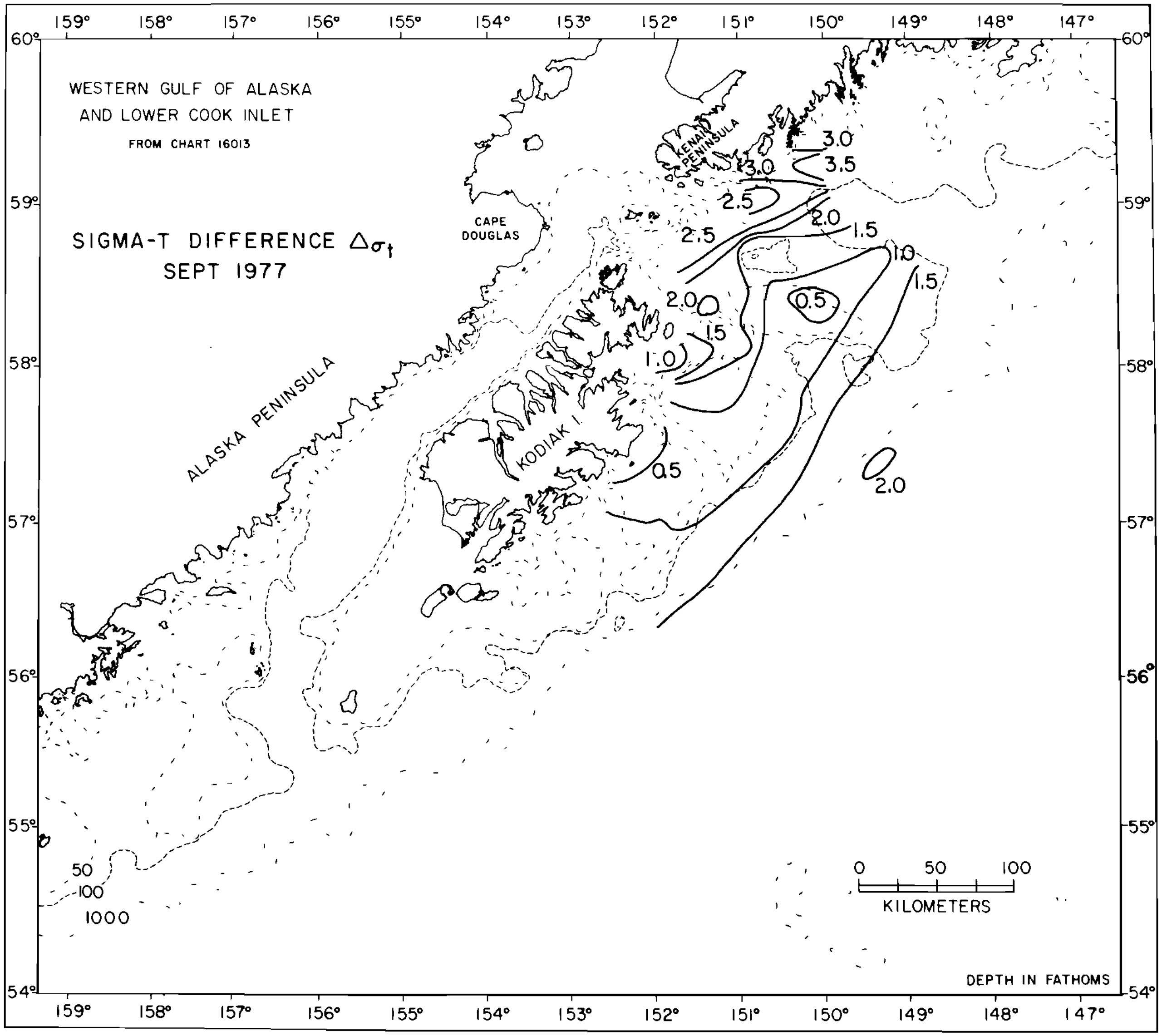

Figure 11. Sigma-t difference $\Delta\sigma_t$ between 50 m and the surface for September 1977. Contour interval is 0.5 units.

shore, where vertical gradients of density were greater than those of salinity because of the strong thermal gradient above 50 m (Fig. 11).

In order to further elucidate hydrographic features, we present vertical sections of temperature, salinity, and sigma-t from stations along four lines, A through D (Fig. 12). Section A (Fig. 13) includes station 235, whose properties indicate that it was near the seaward edge of the southwest-flowing Alaskan Stream. Note the strong depression toward the shelf edge of all but the shallowest (<50 m) isolines. The inshore part of this section crosses Middle Albatross Bank, although the depths there are not shoal enough to have marked mixing effects on the property distributions or their vertical gradients. Section B (Fig. 14) also shows the Alaskan Stream offshore but with less relief, presumably because the seaward edge was not reached. The inshore portion of this section runs along the trough between Portlock and North Albatross Banks, except for station 208.1, which was located atop a small shoal. The deepest isolines appear to dome over this ridge; the properties inshore were similar to those at the two northern sections and may reflect westward advection by the flow off the Kenai Peninsula. Section C (Fig. 15) crosses Portlock Bank and indicates that vertical gradients of temperature and salinity are very small at stations 201 and 202, presumably because of local mixing over the bank. Properties in the deeper part of the depression inshore were similar to those offshore. The most striking difference between this and previous sections was the very low surface salinity (<31.0 g kg^{-1}) at stations 192-197. Low surface salinity was also present on the inshore part of section D (Fig. 16) due to freshwater addition farther east. This section also showed virtually no effects of mixing over the continental shelf because of its relatively deep topography.

3. OBSERVATIONS (13 OCTOBER-5 NOVEMBER 1977)

Figure 17 shows the location of CTD casts taken off the Kenai Peninsula-Kodiak Island area aboard the NOAA ship DISCOVERER. Although some changes in hydrographic structure (see Section 4.1) were observed during October and November, we believe that the general distribution of properties was not altered seriously, and therefore we have treated this survey as synoptic.

3.1 Circulation

The 0/500-dB dynamic topography paralleled the shelf edge along the continental slope, as in September (Fig. 18). There are indications, however, that the most intense part of the flow was farther inshore in some locations than it had been in September. One line of CTD casts extended far enough offshore to allow computation of Alaskan Stream transport. Between stations 231 and 235, a value of 9.4 x 10^6 m^3 s^{-1}, based on the deepest common reference level between stations, was computed; when the geopotential anomalies were adjusted to 1500 dB by the method of Jacobsen and Jensen (Fomin, 1964), however, the value computed was 11.4 x 10^6 m^3 s^{-1}. Thus the adjusted transport was close to the value for September (11.9 x 10^6 m^3 s^{-1}).

The 0/100-dB topography (Fig. 19) also indicated a flow regime much like that in September. There was southwestward baroclinic flow along the continental slope and shelf and westward flow off the Kenai Peninsula. Seaward

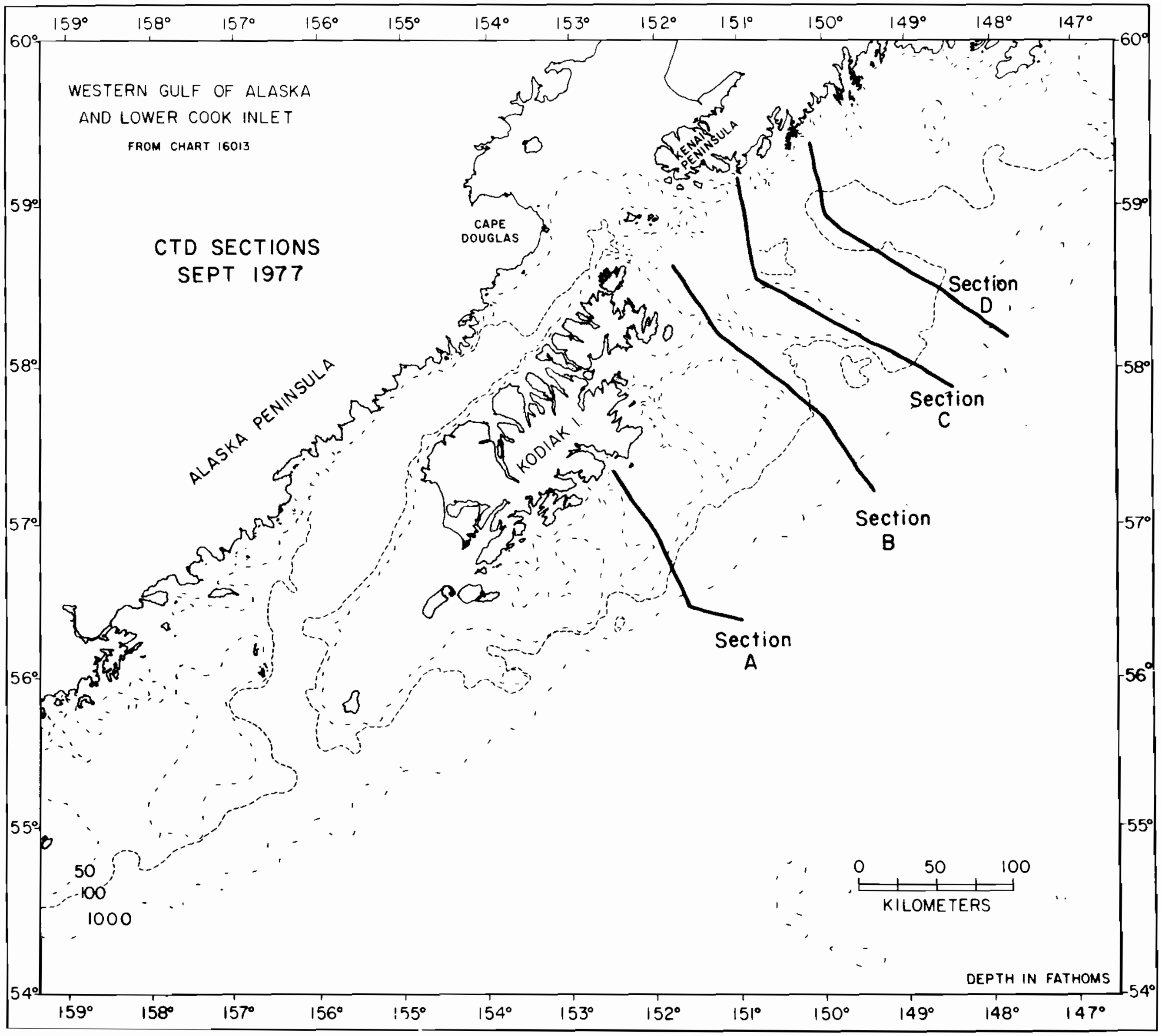

Figure 12. Location of CTD sections A through D for September 1977.

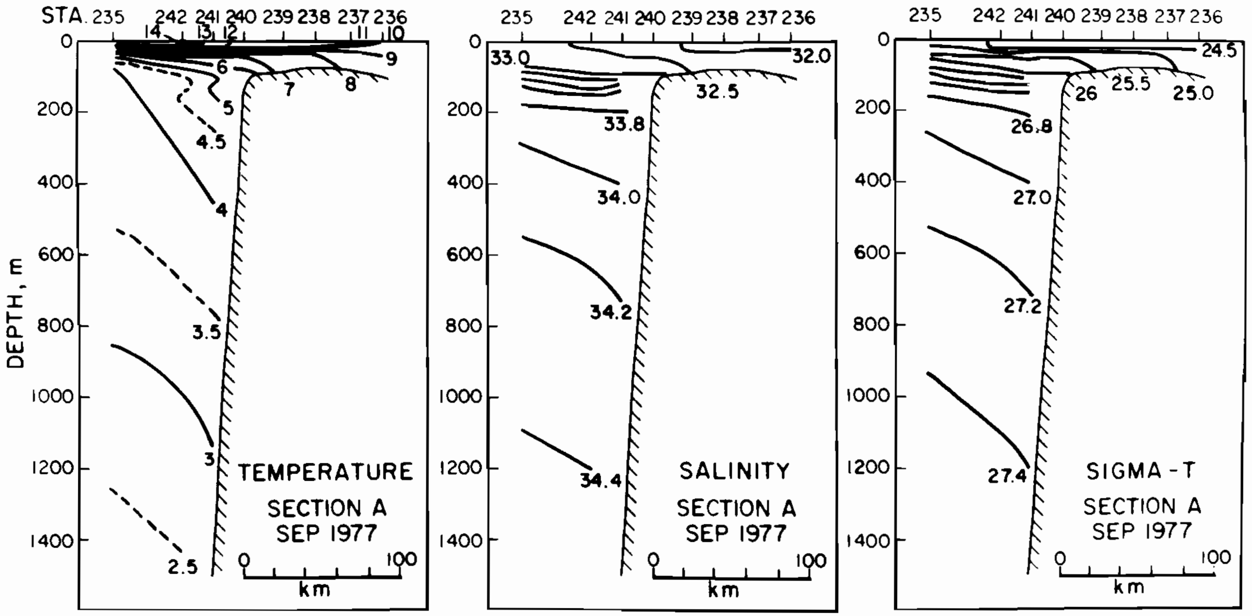

Figure 13. Vertical sections of temperature (°C), salinity (g kg^{-1}), and sigma-t for Section A, 6-7 September 1977.

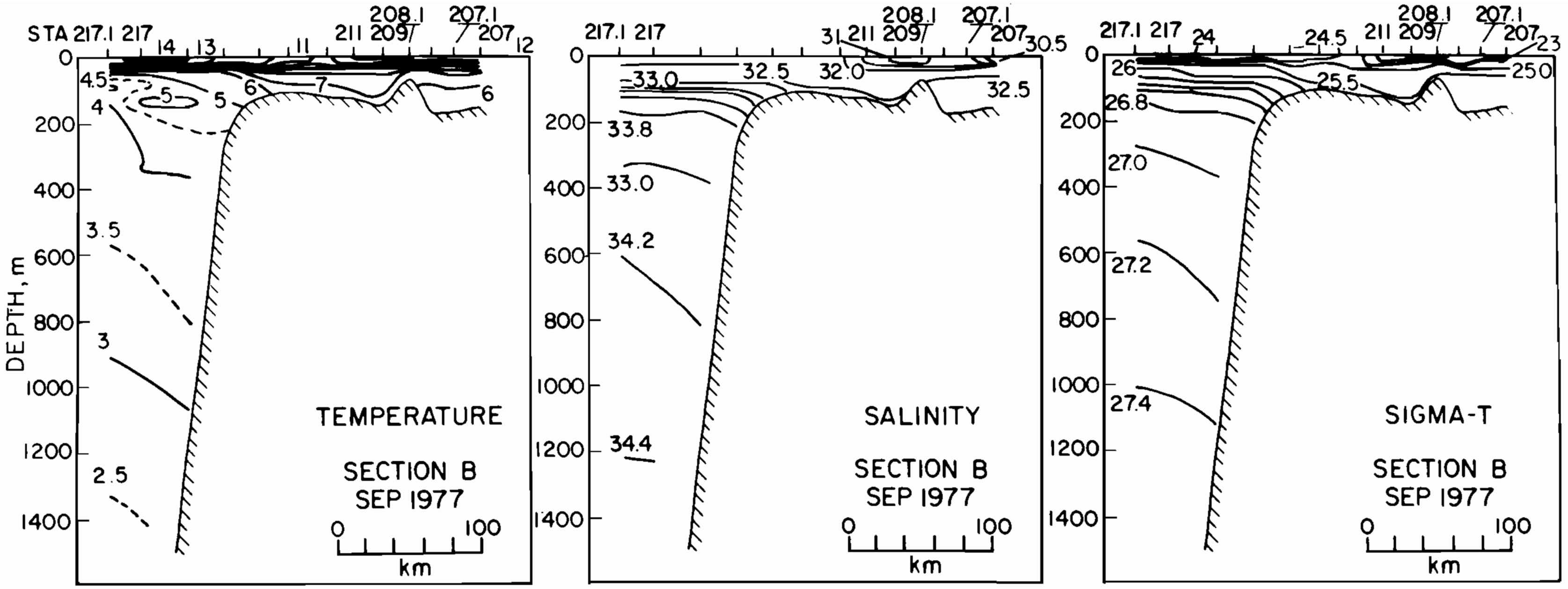

Figure 14. Vertical sections of temperature (°C), salinity (g kg^{-1}), and sigma-t for Section B, 8-9 September 1977.

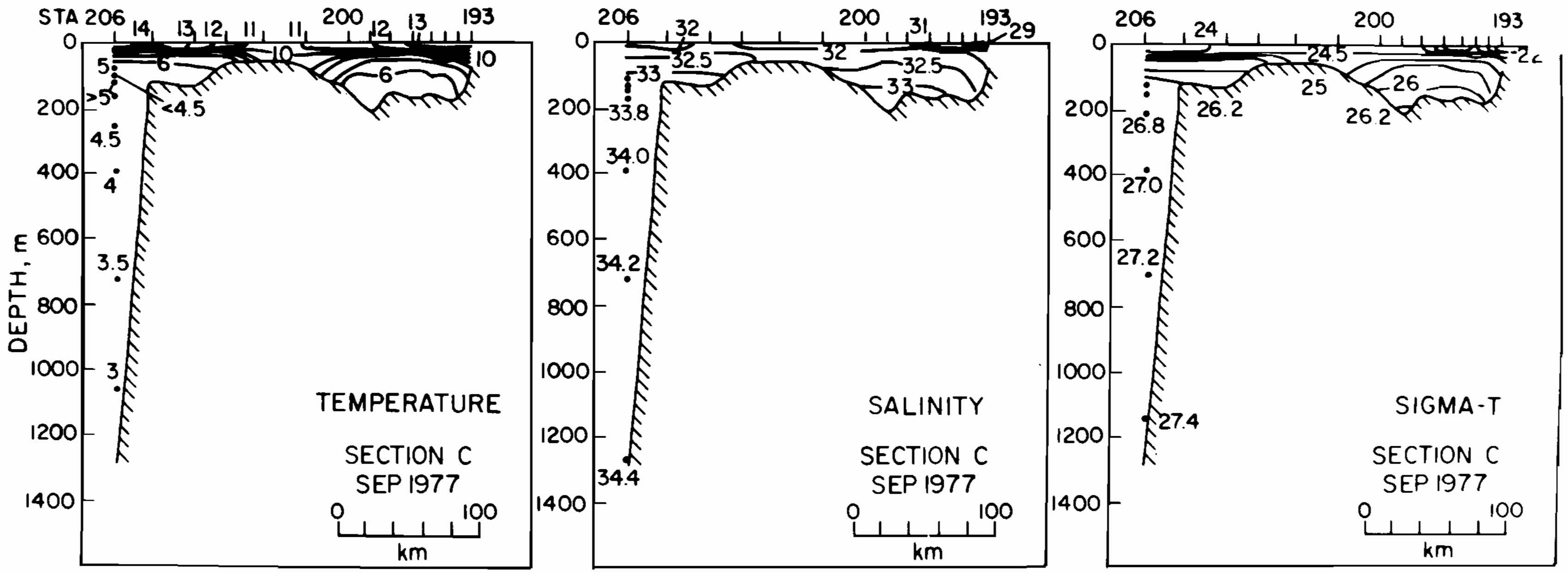

Figure 15. Vertical sections of temperature (°C), salinity (g kg^{-1}), and sigma-t for Section C, 9-10 September 1977.

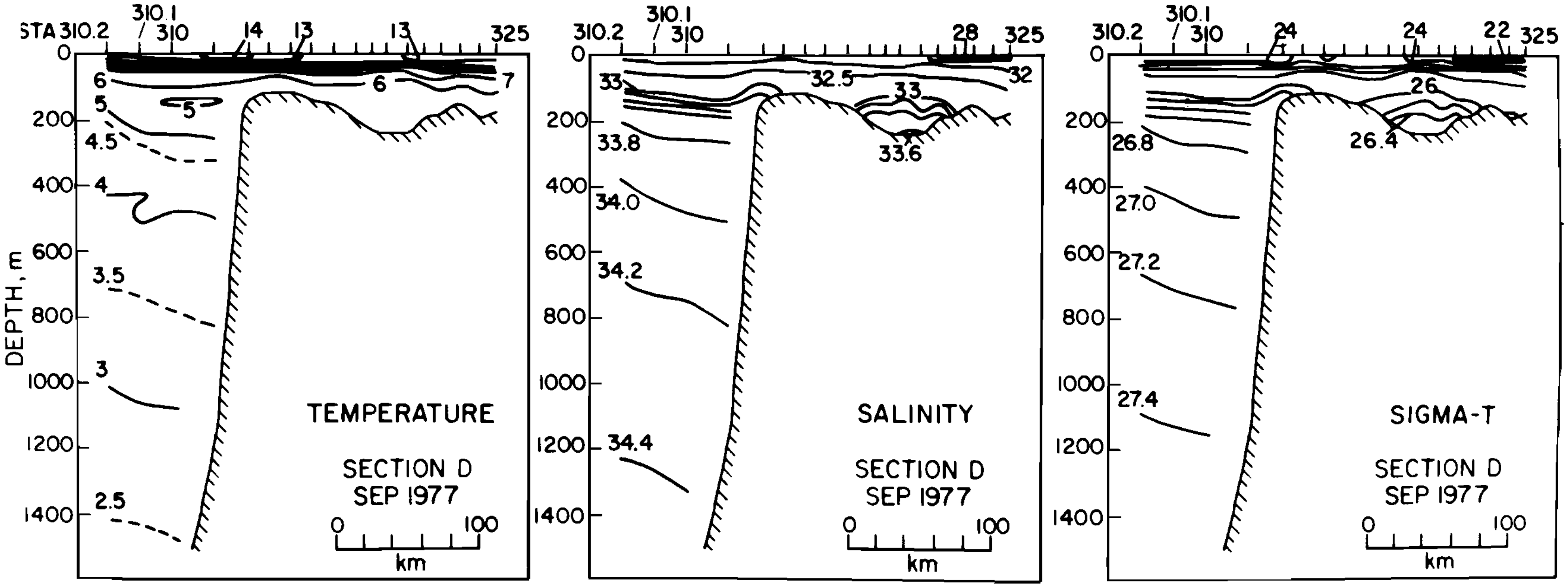

Figure 16. Vertical sections of temperature (°C), salinity (g kg^{-1}), and sigma-t for Section D, 10-11 September 1977.

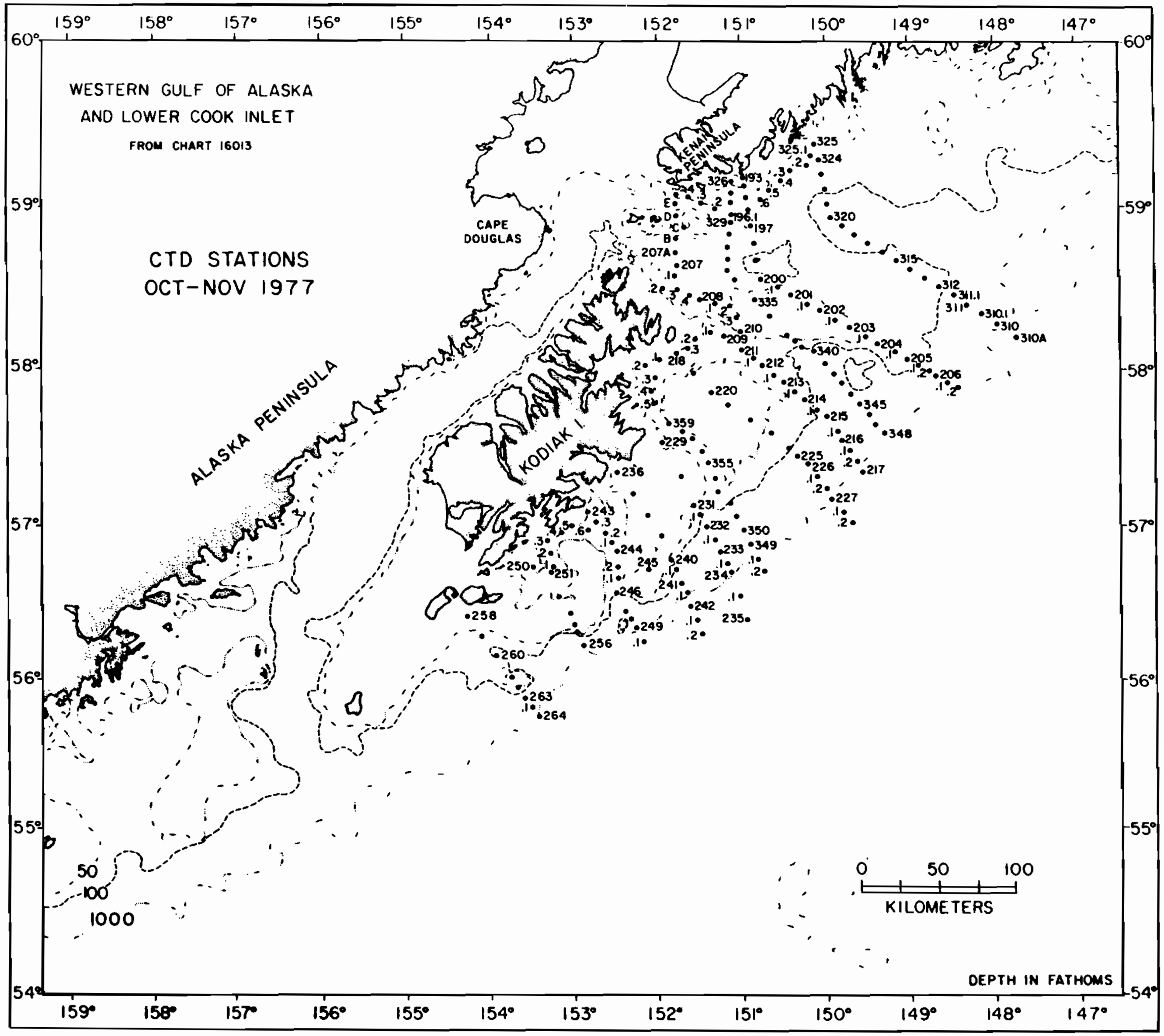

Figure 17. Location of CTD stations occupied during 13 October to 4 November 1977.

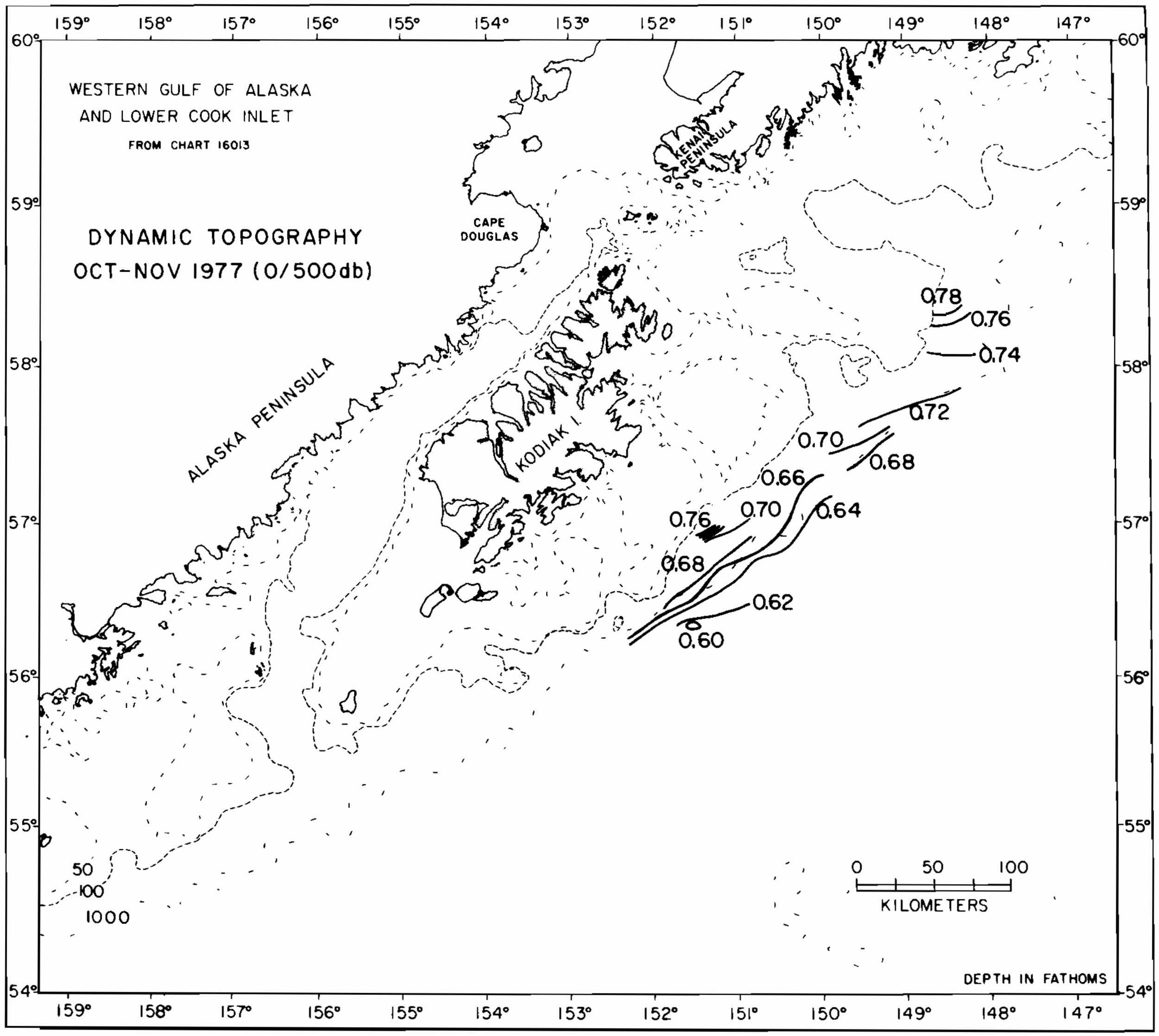

Figure 18. The 0/500-dB geopotential topography for October and November 1977. Contour interval is 0.02 dynamic meters.

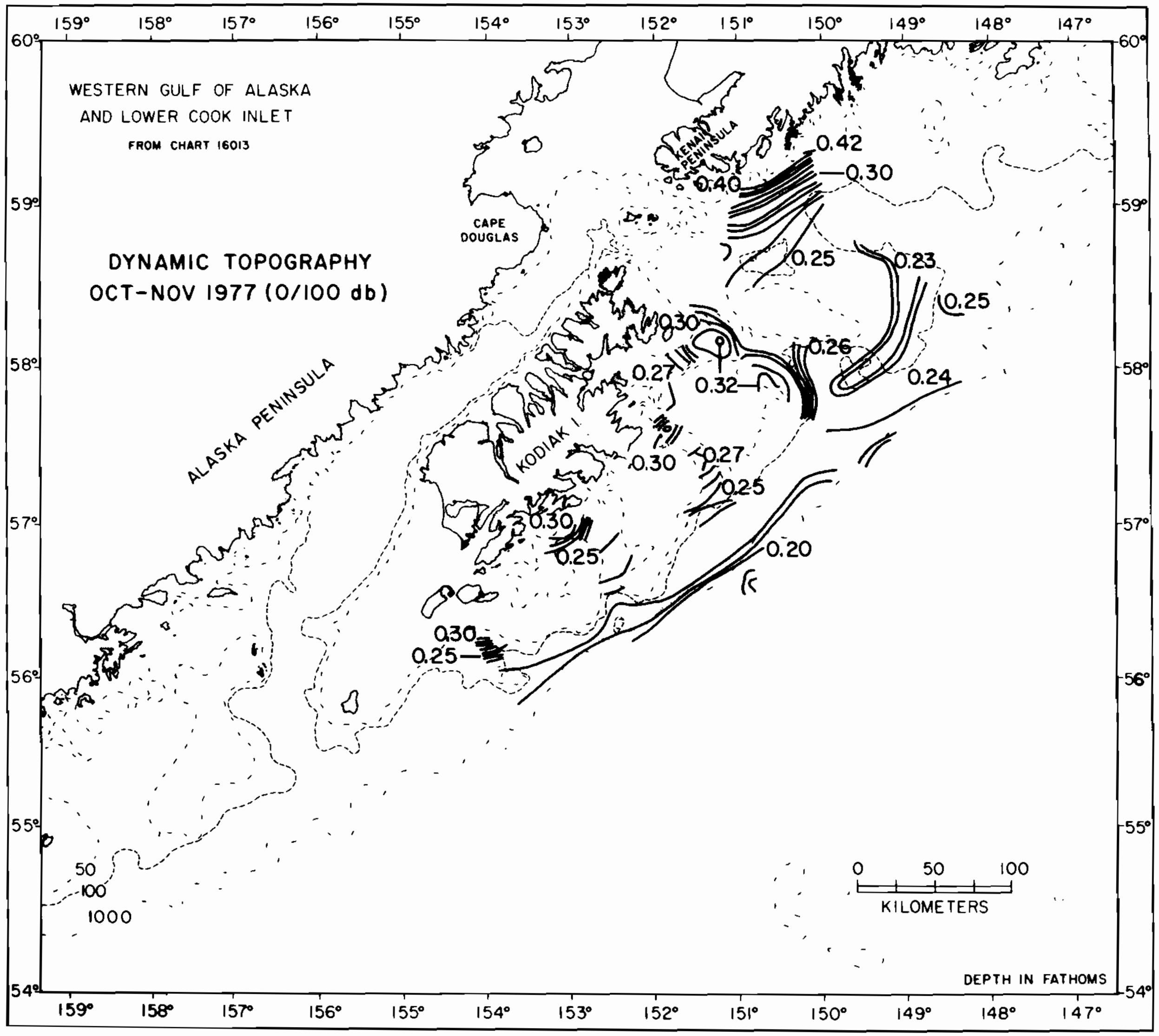

Figure 19. The 0/100-dB geopotential topography for October and November 1977. Contour interval is 0.01 dynamic meters except along the Kenai Peninsula where a 0.02 dynamic meter interval was used.

flow was indicated between Portlock and North Albatross Banks but did not appear to be appreciably more intense than in September. Using the deepest common depth as a reference surface, the transports between stations 320-325 and 194-198 were both computed to be 1.0 x 10^6 m^3 s^{-1}. Thus the transport of this branch had more than doubled from early September to mid-October. We suspect that this increase may have been influenced by an increase in coastal rainfall (and drainage) in October as postulated by Royer (in preparation). We note, however, that there were no marked changes in surface salinity except for an apparent deepening of the low-salinity surface layer, perhaps as a result of convergence caused by local winds. Winds recorded at NOAA data buoy 46008 (obtained from R. M. Reynolds, PMEL) southwest of the Kenai Peninsula (57°06'N, 151°44'W) revealed two events in October with relatively strong winds from the northeast, the proper direction to produce coastal convergence. During 2-5 October, persistent northeast winds had a mean speed of ∿8 m s^{-1}; on 14-15 October similar winds for a 30-hr period had a mean speed of ∿12 m s^{-1}.

3.2 Hydrography

The warmest surface water occurred near the Kenai Peninsula (Fig. 20), suggesting that the waters have a relatively large component of land origin, since fresh water in this season would be warmer than oceanic water. Water over the banks was generally cool as a result of mixing. Offshore, the water in the northeastern area was warmer than that to the southwest, because observations in the latter area were made 2 to 3 weeks after those in the former region. The lowest-salinity water occurred just offshore from the Kenai Peninsula, suggesting that this flow is strongly influenced by land drainage (Fig. 21). There was a rather uniform salinity increase offshore as in September, but offshore values were approximately 0.5 g kg^{-1} greater than in September. It is unclear whether this difference was caused by local changes or by advection of more saline water into the region.

Patterns of temperature at 50 m were much the same as in September; relatively warm temperatures occurred over banks; cold water was located near the low in geopotential off the Kenai Peninsula; and there was a sharp horizontal gradient offshore associated with rising isotherms in the Alaskan Stream (Fig. 22). The salinity distribution (Fig. 23) was virtually identical to that in September and will not be discussed further. The distrubtion of sigma-t was essentially identical to that of salinity.

The patterns in temperature gradient shown as surface to 50-m differences were generally like those in September, but the gradients were appreciably smaller because surface waters had cooled (Fig. 24). There was a small zone of well-mixed water just off the Kenai Peninsula that was not present in September, however, and the maximum gradient associated with the low in geopotential on the seaward side of the westward coastal flow was less clearly defined than previously. At some sites over the banks, the water was completely mixed. Some of the differences offshore resulted from time differences in the occupation of stations. The distribution of salinity (Fig. 25) and sigma-t (Fig. 26) gradient was near zero because surface salinities were higher than in September.

The four vertical sections presented for September were reoccupied during the October-to-November survey (Fig. 27). Section A did not extend far enough seaward to cross the Alaskan Stream as in September, but the flow is clearly

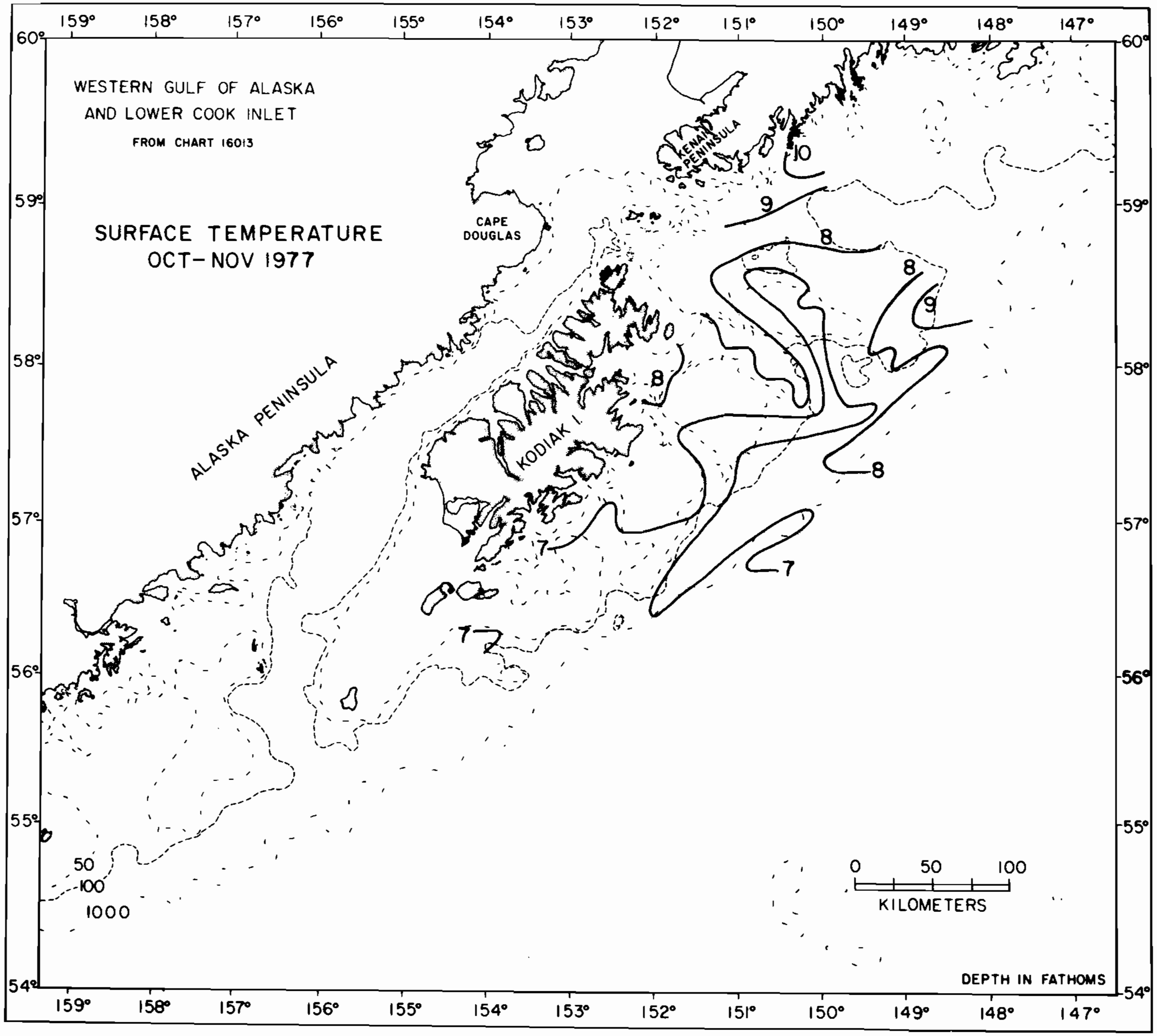

Figure 20. Distribution of surface temperature for October and November 1977. Contour interval is 1.0°C.

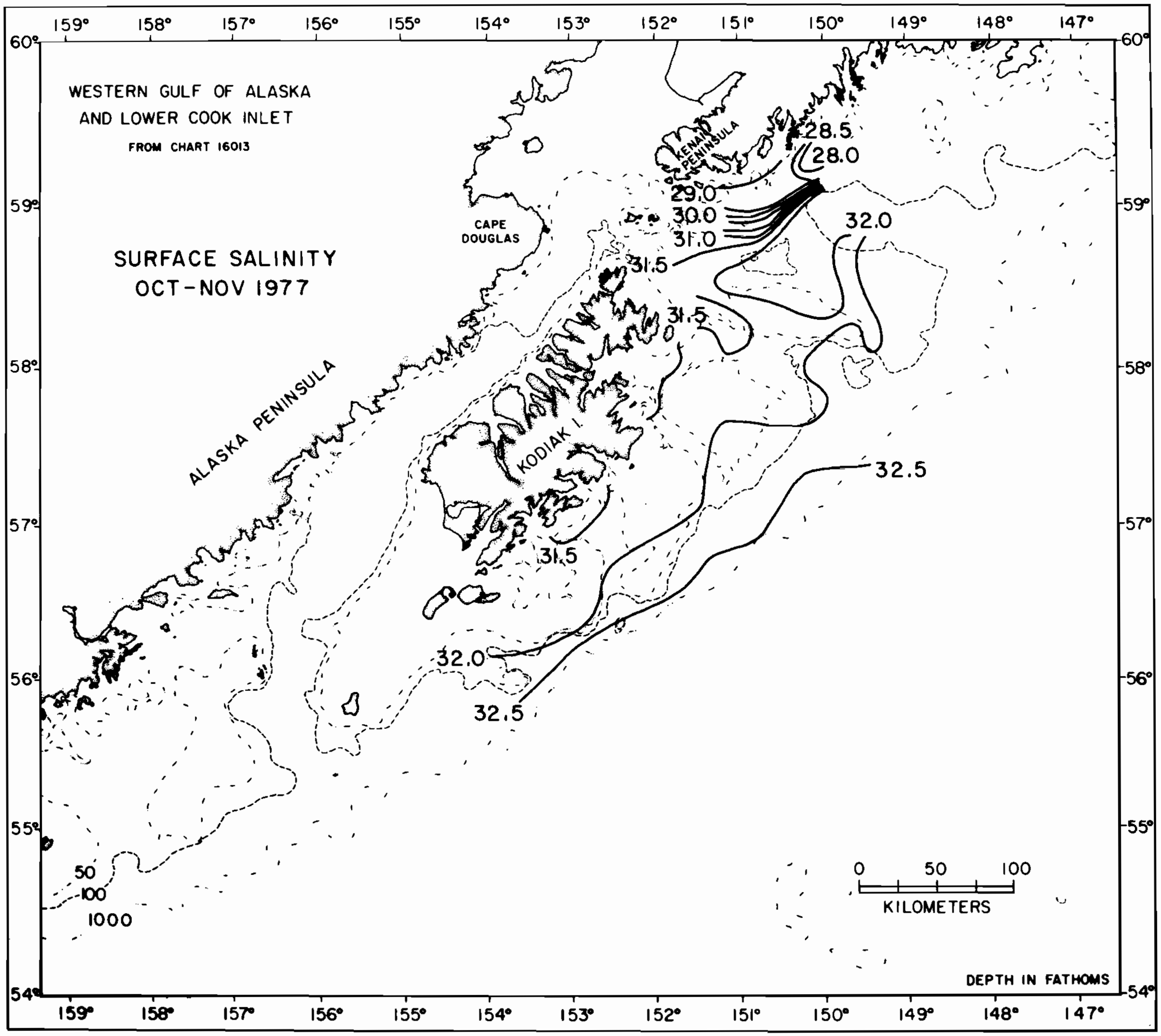

Figure 21. Distribution of surface salinity for October and November 1977. Contour interval is 1°C.

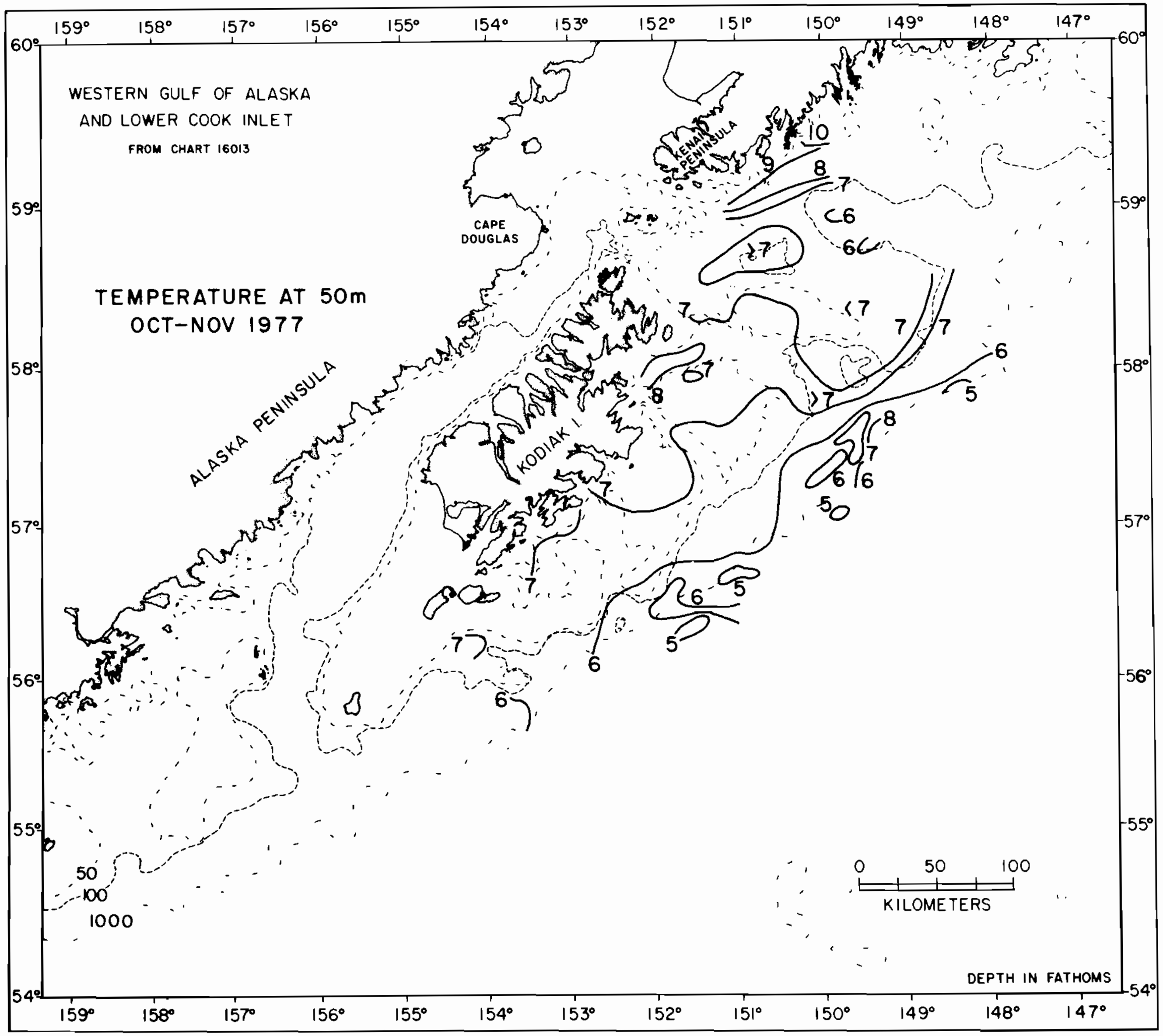

Figure 22. Distribution of temperature at 50 m for October and November 1977. Contour interval is 1°C.

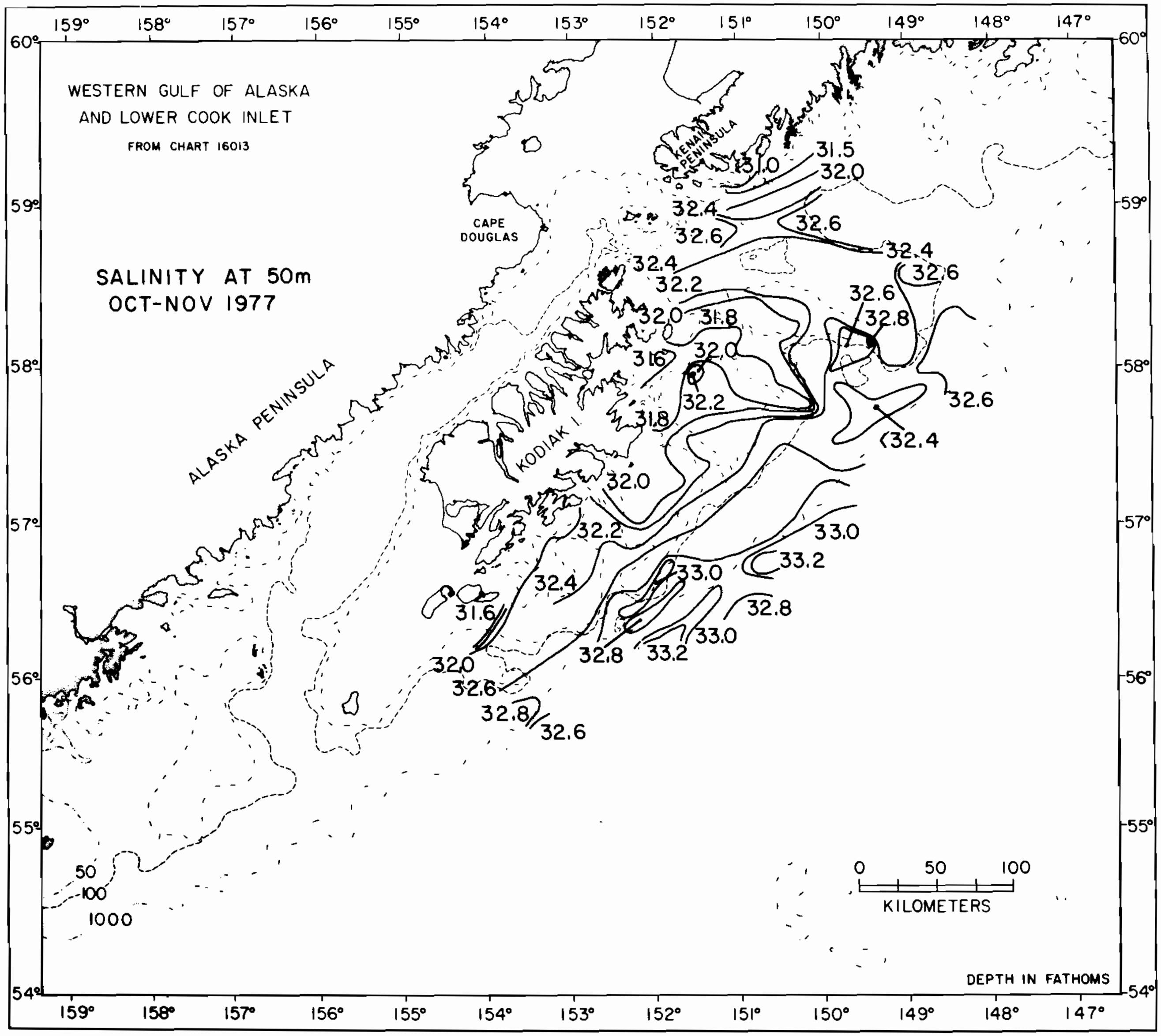

Figure 23. Distribution of salinity at 50 m for October and November 1977. Contour interval is 0.2 g kg^{-1}.

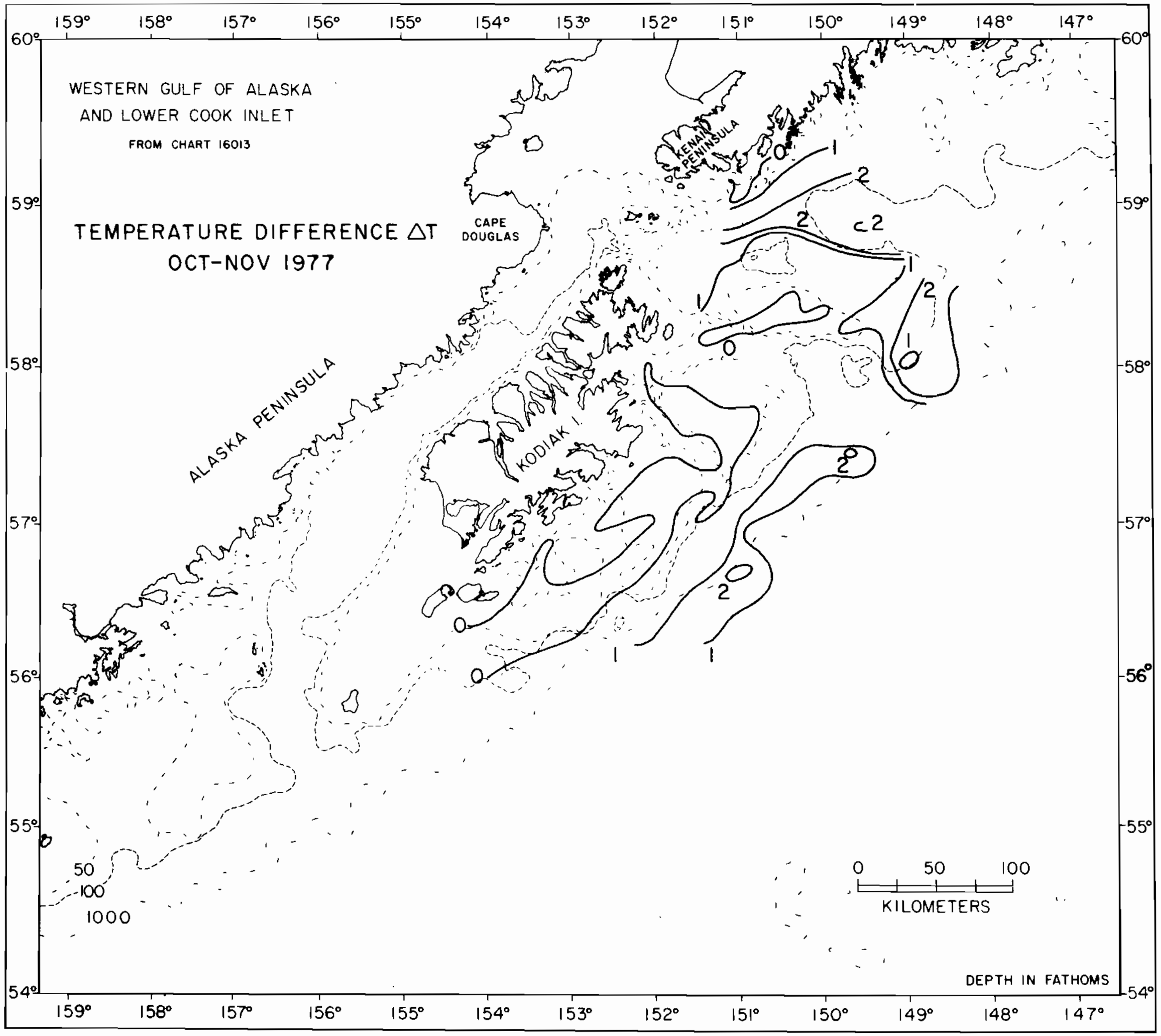

Figure 24. **Temperature difference ΔT between the surface and 50 m for October and November 1977.** Contour interval is 1.0°C.

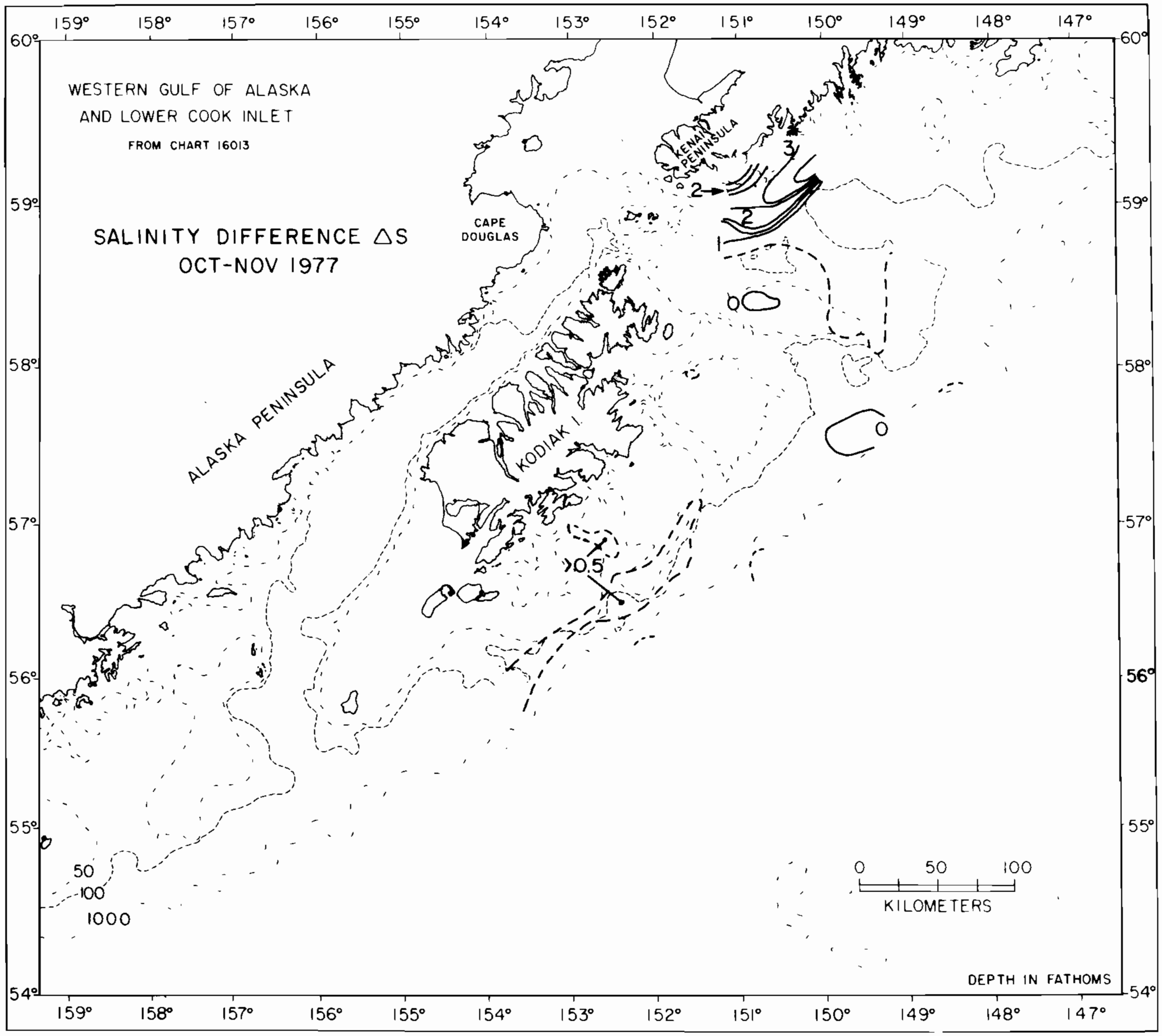

Figure 25. Salinity difference ΔS between 50 m and the surface for October and November 1977. Contour interval is 1.0 g kg^{-1} and the S = 0.5 g kg^{-1} contour (dashed) is presented since vertical structure was weak.

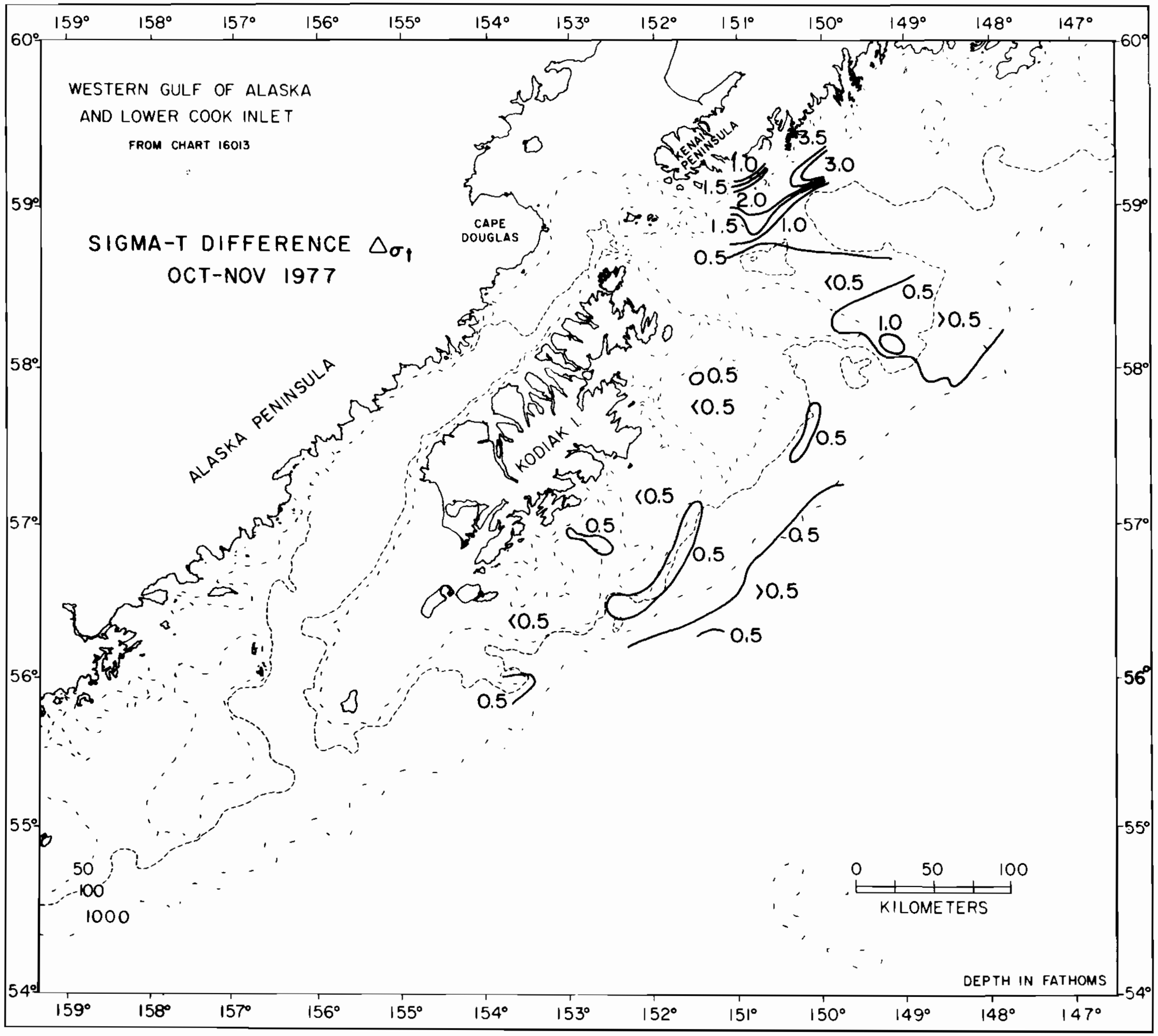

Figure 26. Sigma-t difference $\Delta\sigma_t$ between 50 m and the surface for October and November 1977. Contour interval is 0.5 units.

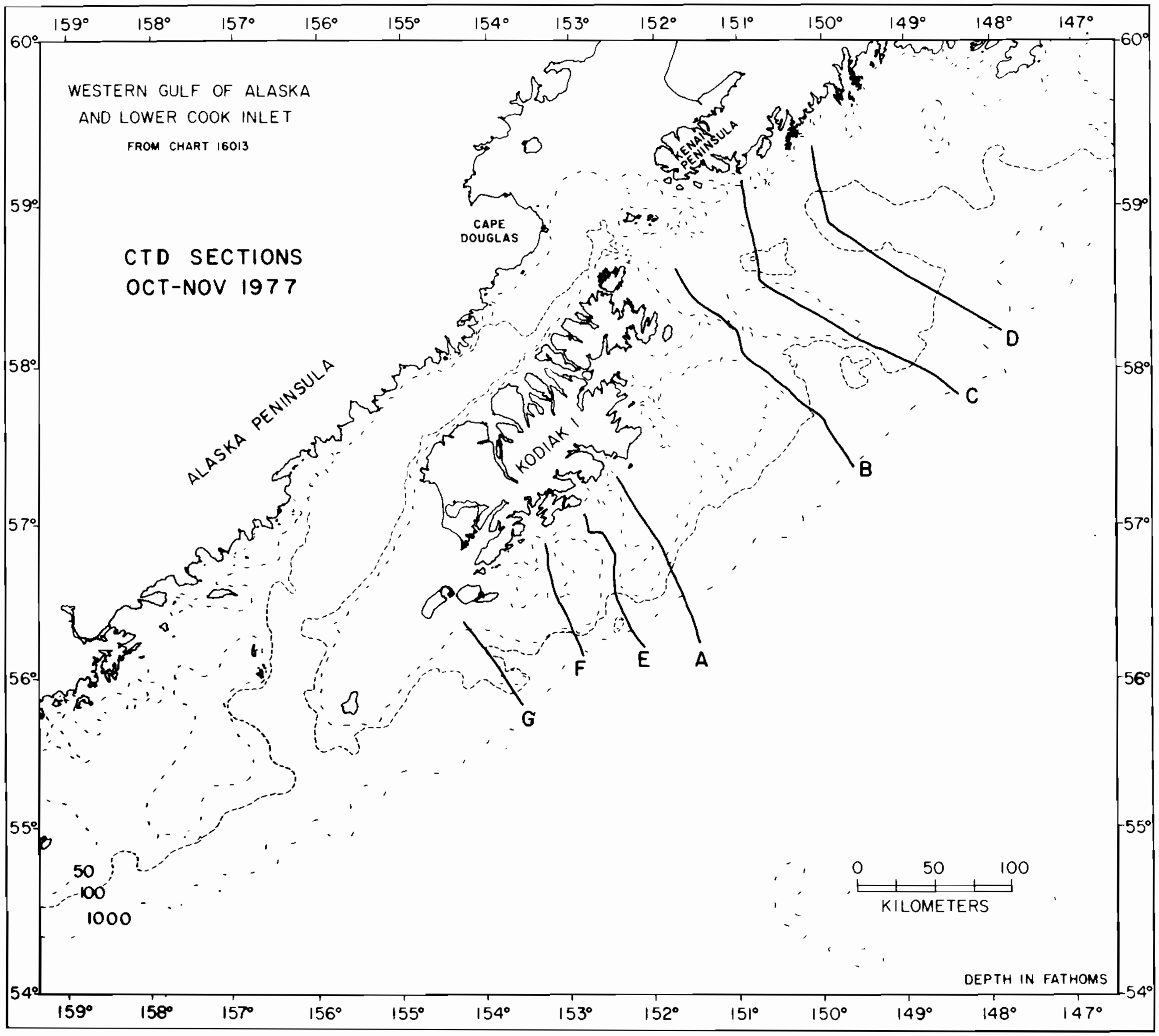

Figure 27. Location of CTD sections A through G for October and November 1977.

shown by the steeply sloping isolines (Fig. 28). The temperature structure over Middle Albatross Bank was more nearly homogeneous in November than in September because of surface cooling. Section B did not extend as far offshore in October as in September, and station 208.1 (atop the small shoal area) was not occupied in October (Fig. 29). The water in the trough between North Albatross and Portlock Banks was not well mixed even though surface salinity was higher and the water had cooled during October. Near the bottom along the Kenai Peninsula, salinities were higher (0.5 g kg^{-1}) in October than in September. In October, the sigma-t section showed steeper slopes near the inshore end than earlier, in agreement with the geopotential topography. Section C crossed Portlock Bank, and the water was essentially homogeneous in all properties over the shoaler parts of this feature (Fig. 30). The most striking change between September and October was that the band of relatively fresh, warm water was confined closer to shore during the latter period and the isolines had much steeper slopes in October, in agreement with the increased baroclinicity and transport during this period. It is interesting to speculate what might have produced this change. Although increased baroclinity could have resulted from processes upstream, the data suggest that the mechanism could be convergence near the Kenai Peninsula caused by strong northeast winds. Section D indicates that colder, more saline water was present in Amatuli Trough during October than in September (Fig. 31). The strong increase in baroclinicity near the Kenai Peninsula is also apparent, as in the previous section.

Three relatively short sections (E, F, and G) were occupied in November. Section E, along Kiliuda Trough, had relatively cool, saline water inshore near the bottom, which suggests effective communication between the outer and inner waters through this depression (Fig. 32). Section F, however, would imply a blockage of the outer waters by South Albatross Bank (Fig. 33). Finally, section G shows conditions much like those on section E (Fig. 34).

4. DISCUSSION

4.1 Temporal Changes in Structure

On 17 October, after occupation of stations 203 and 202.1 over Portlock Bank (see Fig. 35), work was discontinued because of high winds from the north (speeds generally greater than 50 knots). These two stations (203A and 202.1A) were reoccupied 41-42 hr later. The storm obviously produced marked cooling and an increase in salinity of the upper ocean at both sides. Although the cooling rates are plausible as a result of surface heat exchange (about 0.6 cal cm^{-2} min^{-1} was estimated from bulk formulas), the large changes in salinity and almost complete homogeneity of the water suggest that localized upwelling occurred in response to the storm. These data are presented primarily to point out that not all of the changes that occur in this region are seasonal in nature; the upper ocean may change drastically over short time spans, and one must be cautious in the interpretation of temporal variations.

4.2 General Conditions, Fall 1977

It is of interest to attempt to synthesize the general conditions observed during fall 1977. The circulation patterns observed during September and from

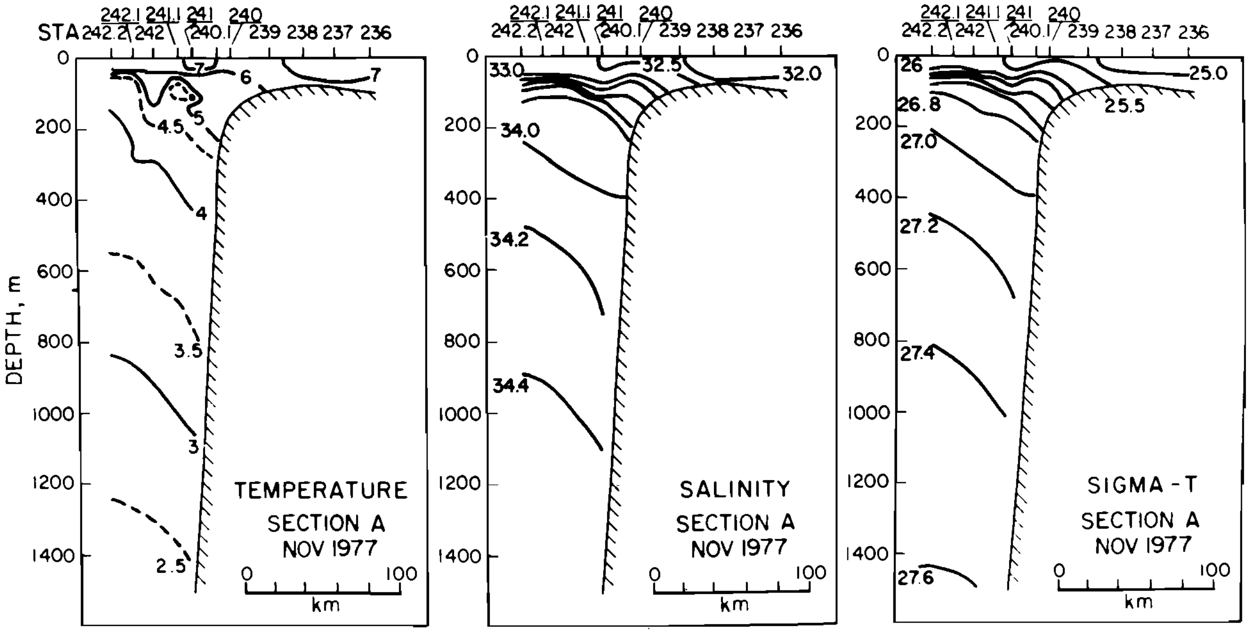

Figure 28. Vertical sections of temperature (°C), salinity (g kg^{-1}), and sigma-t for Section A, 20-21 October 1977.

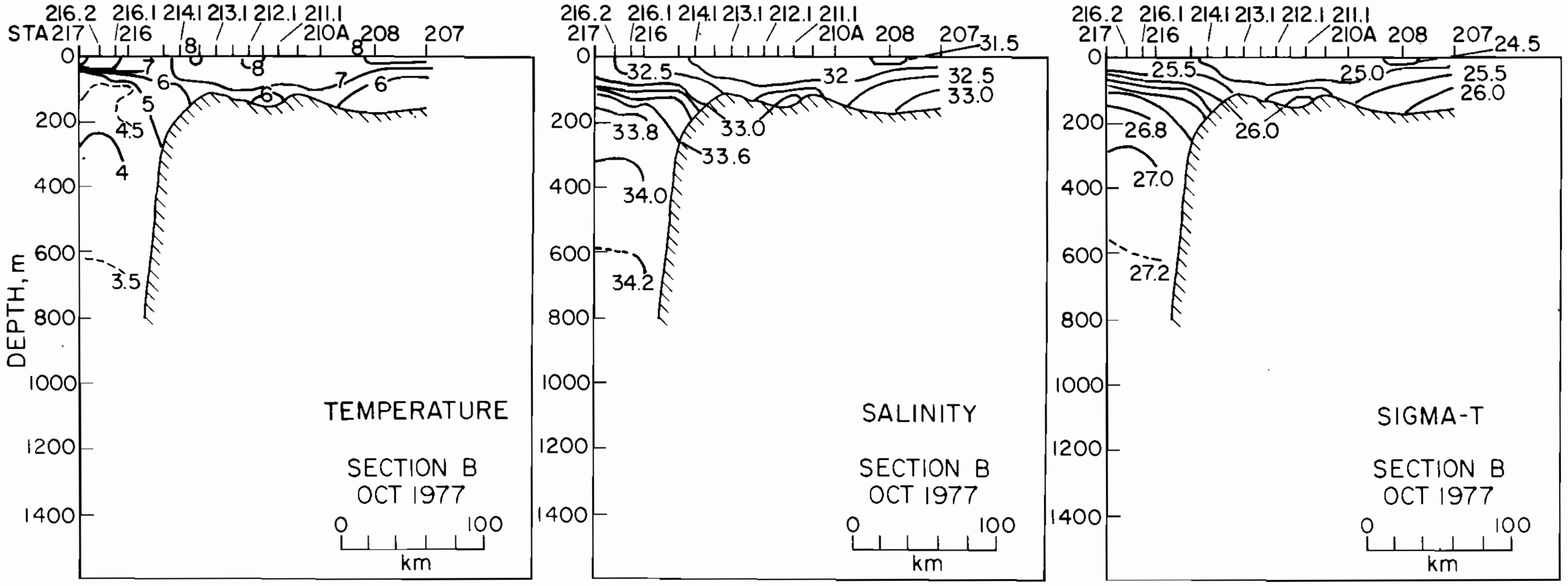

Figure 29. Vertical sections of temperature (°C), salinity (g kg^{-1}), and sigma-t for Section B, 20-21 October 1977.

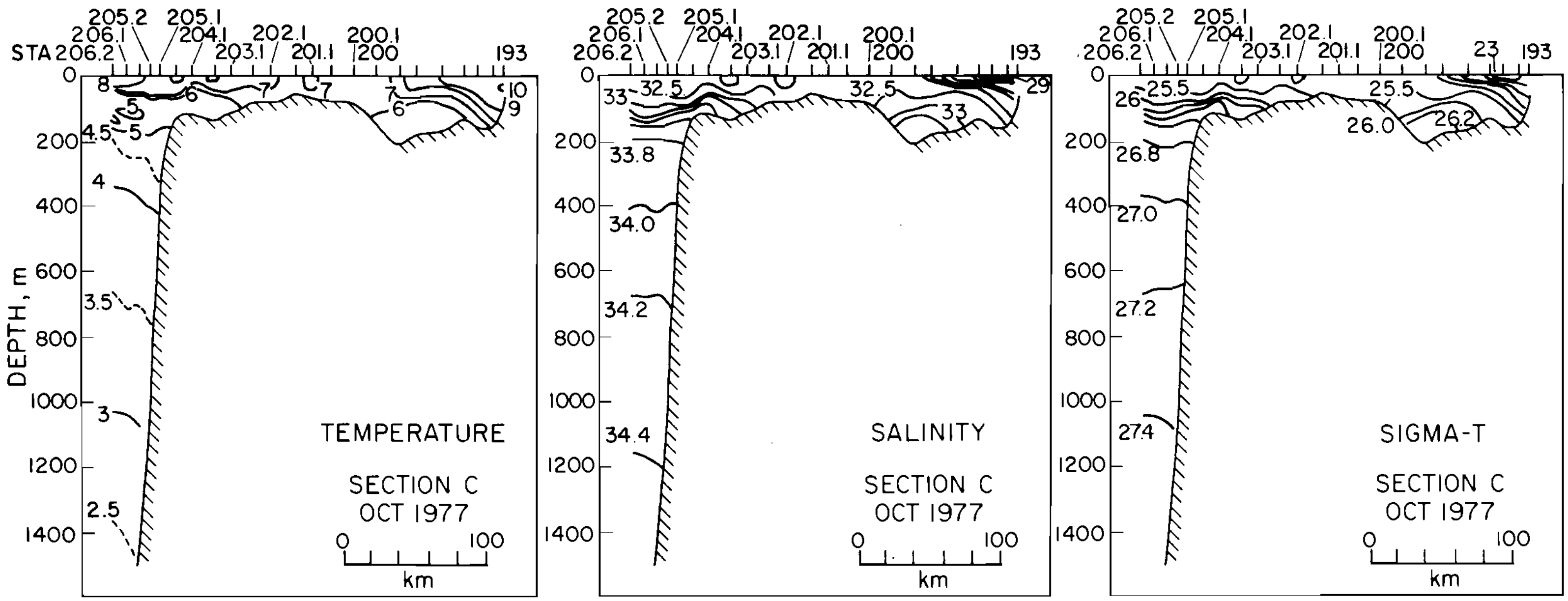

Figure 30. Vertical sections of temperature (°C), salinity (g kg^{-1}), and sigma-t for Section C, 16-19 October 1977.

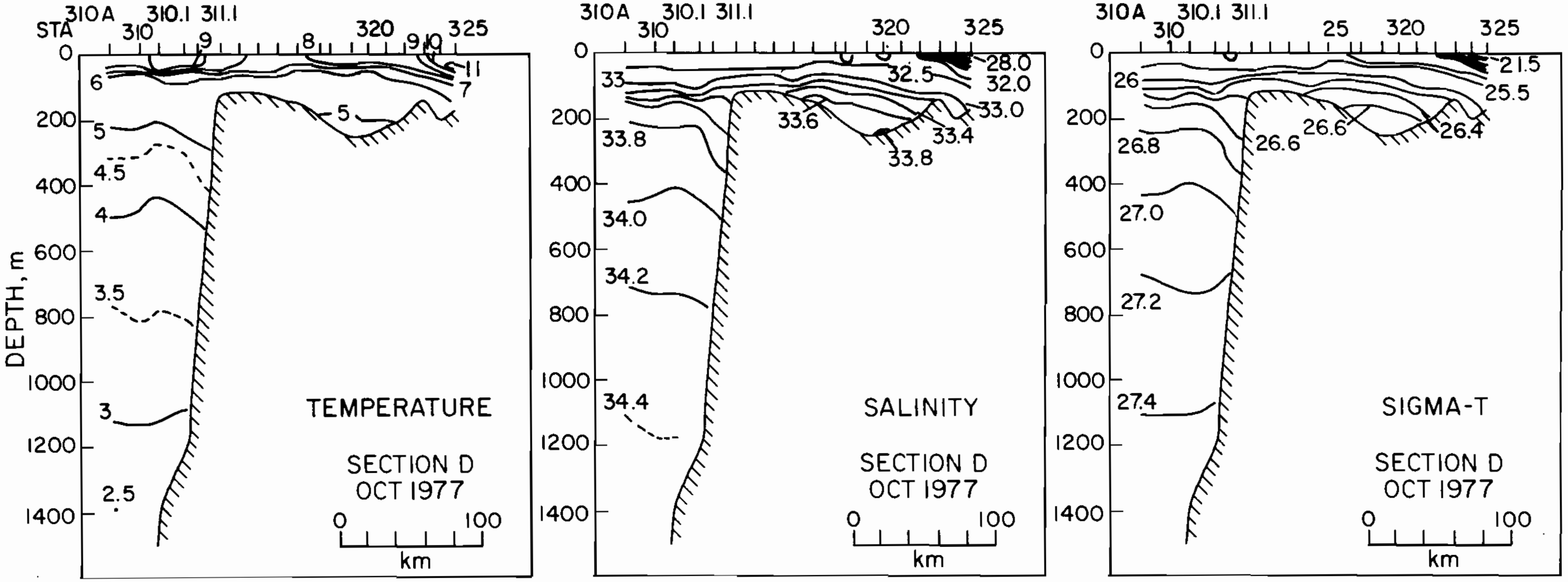

Figure 31. Vertical sections of temperature (°C), salinity (g kg^{-1}), and sigma-t for Section D, 14-16 October 1977.

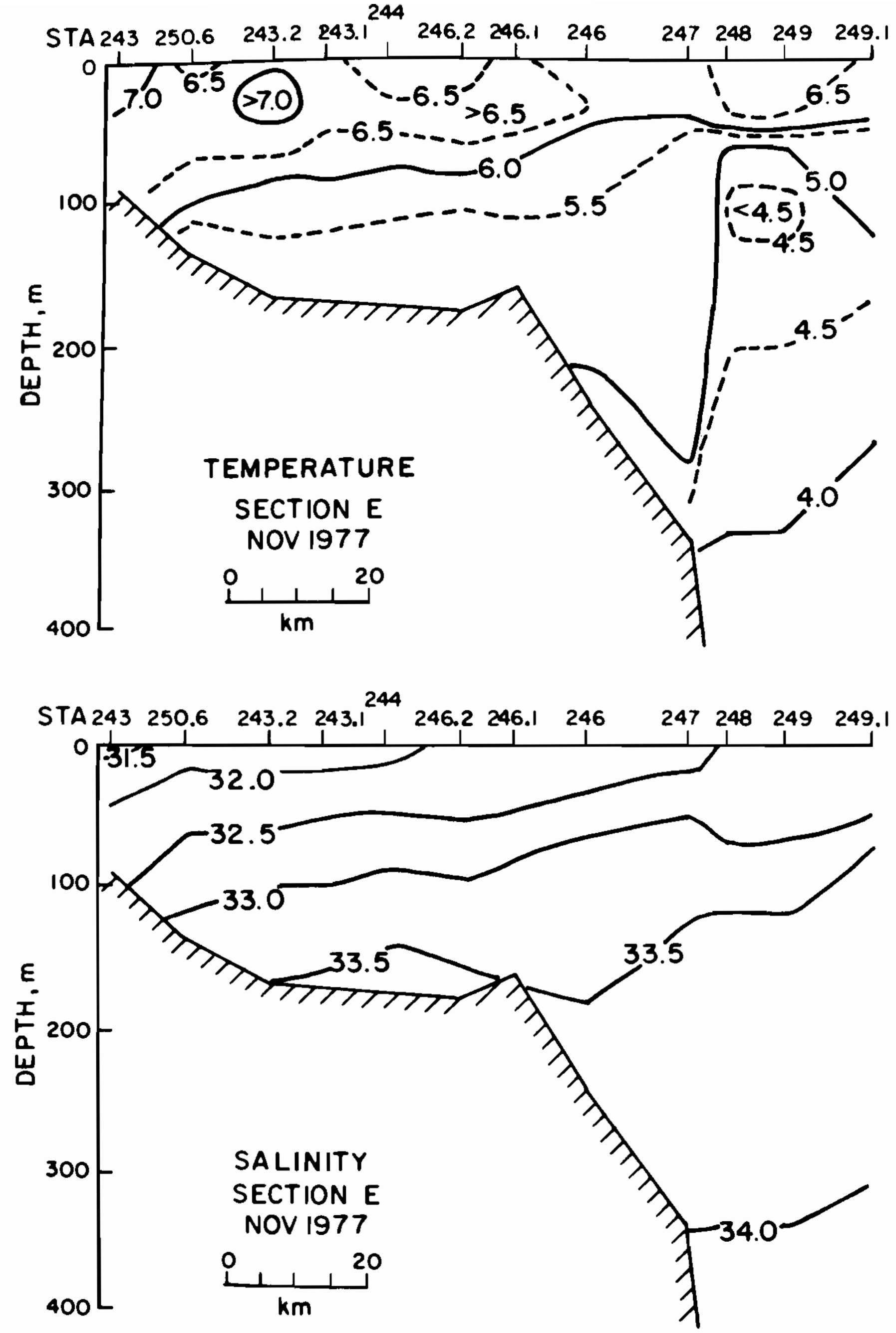

Figure 32. Vertical sections of temperature (°C), salinity (g kg^{-1}), and sigma-t for Section E, 3-4 November 1977.

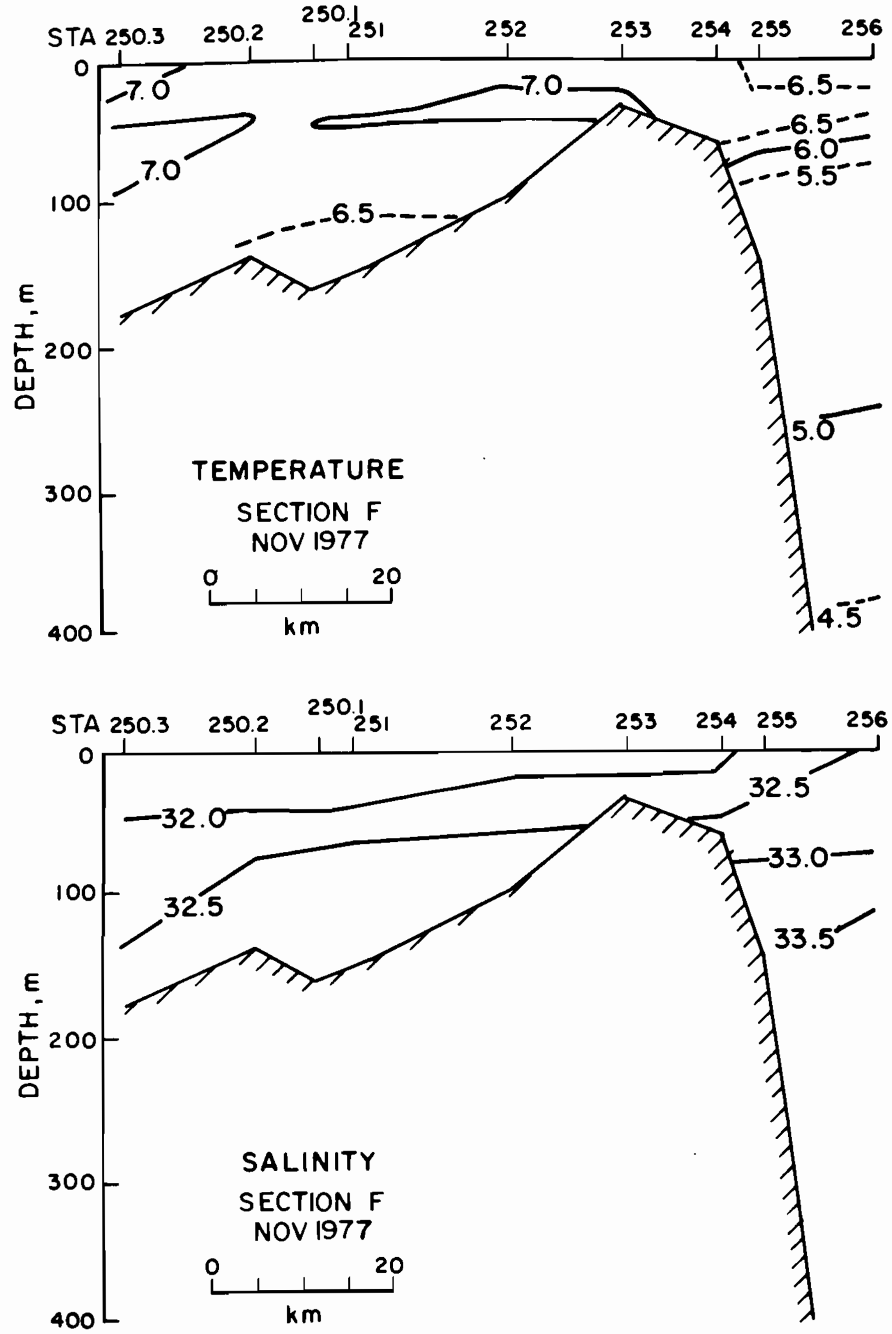

Figure 33. Vertical sections of temperature (°C), salinity (g kg^{-1}), and sigma-t for Section F, 4 November 1977.

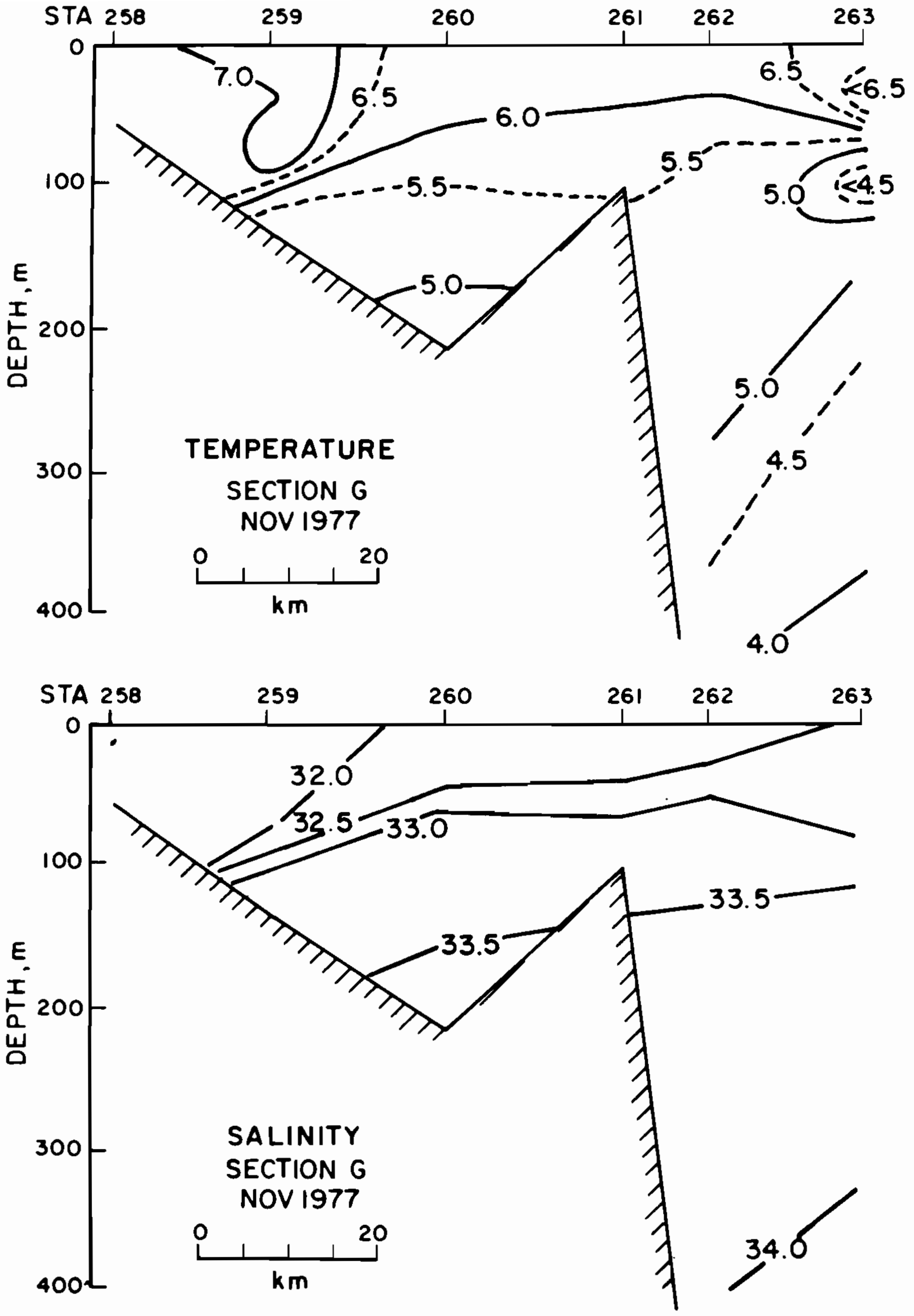

Figure 34. Vertical sections of temperature (°C), salinity (g kg^{-1}), and sigma-t for Section G, 4-5 November, 1977.

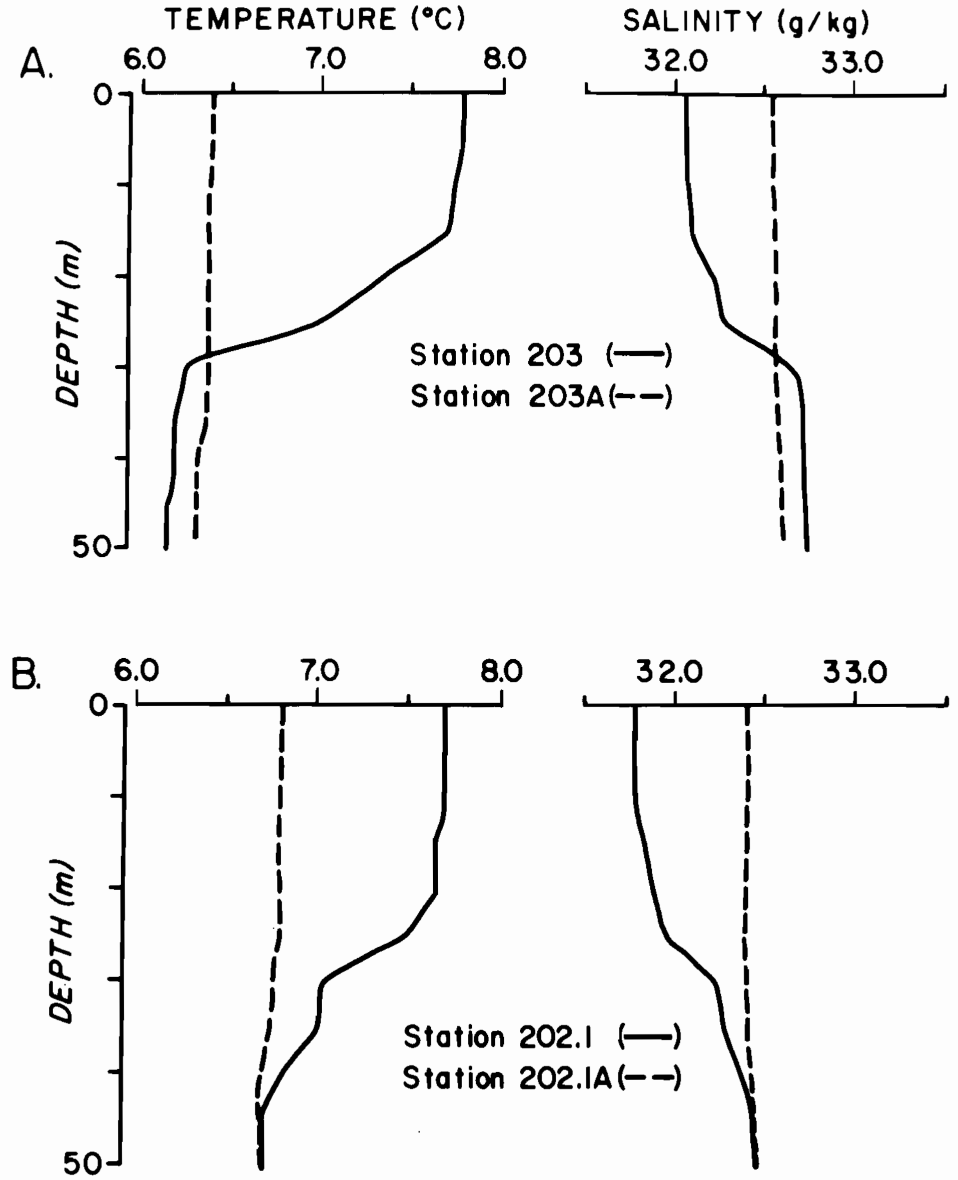

Figure 35. Vertical profiles of temperature and salinity before (solid line) and after (dashed line) a storm over Portlock Bank. See Fig. 17 for CTD station locations.

mid-October to early November were similar. Transport in the Alaskan Stream during both periods was approximately 12 x 10^6 m^3 s^{-1}. Weak southwestward flow extended onto the outer continental shelf, and gyre-like features were present in the troughs off Kodiak Island. The major difference during the two periods was an increase in the westward coastal flow off the Kenai Peninsula from 0.4 x 10^6 m^3 s^{-1} in September to 1.0 x 10^6 m^3 s^{-1} in October. This may have been caused by an increase in fresh water drainage, but there also could have been a mass redistribution by local winds.

Property distributions during the two periods were similar except for changes resulting from surface-exchange processes. As expected, the surface water was markedly cooler during the latter period; this resulted in essentially homogeneous water over some banks, whereas vertical gradients were present in September. During October and November, surface water over the central shelf was somewhat more saline than previously, and in some locations it was also more saline near the bottom. Enhanced evaporation may have been a factor, but advection and redistribution of mass by winds probably contributed also.

4.3 Comparison with Winter Conditions

In comparing certain features of circulation and hydrography presented in this paper with results from a similar study performed by Schumacher *et al.* (1978), which used data from March 1977, we note that the data obtained in early September 1977 were more representative of summer than fall conditions. We can therefore examine data typical of winter, summer, and fall 1977.

Circulation on the continental shelf in winter was similar in some respects during summer and fall. There was evidence of southwestward flow over the outer shelf, and the well-developed westward flow was present off the Kenai Peninsula. In winter, however, the gyre-like features seen in the troughs off Kodiak Island were absent. The transport of the flow off the Kenai Peninsula was 0.4 x 10^6 m^3 s^{-1} as in September, but in March the flow moved west into Shelikof Strait without some portion flowing southwest into the troughs and providing a baroclinic structure resulting in the gyres observed in October.

Surface temperature in March was 2-3°C colder than in October and November. The bottom (or 200 m) temperature pattern (Fig. 36) may be compared with a similar distribution in Schumacher *et al.* (1978). Offshore in the Alaskan Stream, temperatures were similar, but on the shelf they were about 1°C colder in March than in the fall. Surface salinities on the outer shelf were similar in winter and fall, but off the Kenai Peninsula they were almost 3 g kg^{-1} lower in fall than winter as a result of summer-fall freshwater addition along the coast. The fall bottom (or 200 m) salinity distribution (Fig. 37) was much like that in March. The temperature difference between the surface and bottom (or 200 m) is presented in Fig. 38. The gradients were about 2-3°C greater in fall than in winter, and there were no negative values as in March. Salinity gradients were similar in fall (Fig. 39) to those in March on the outer shelf but were much greater near the Kenai Peninsula in October because of low surface salinity.

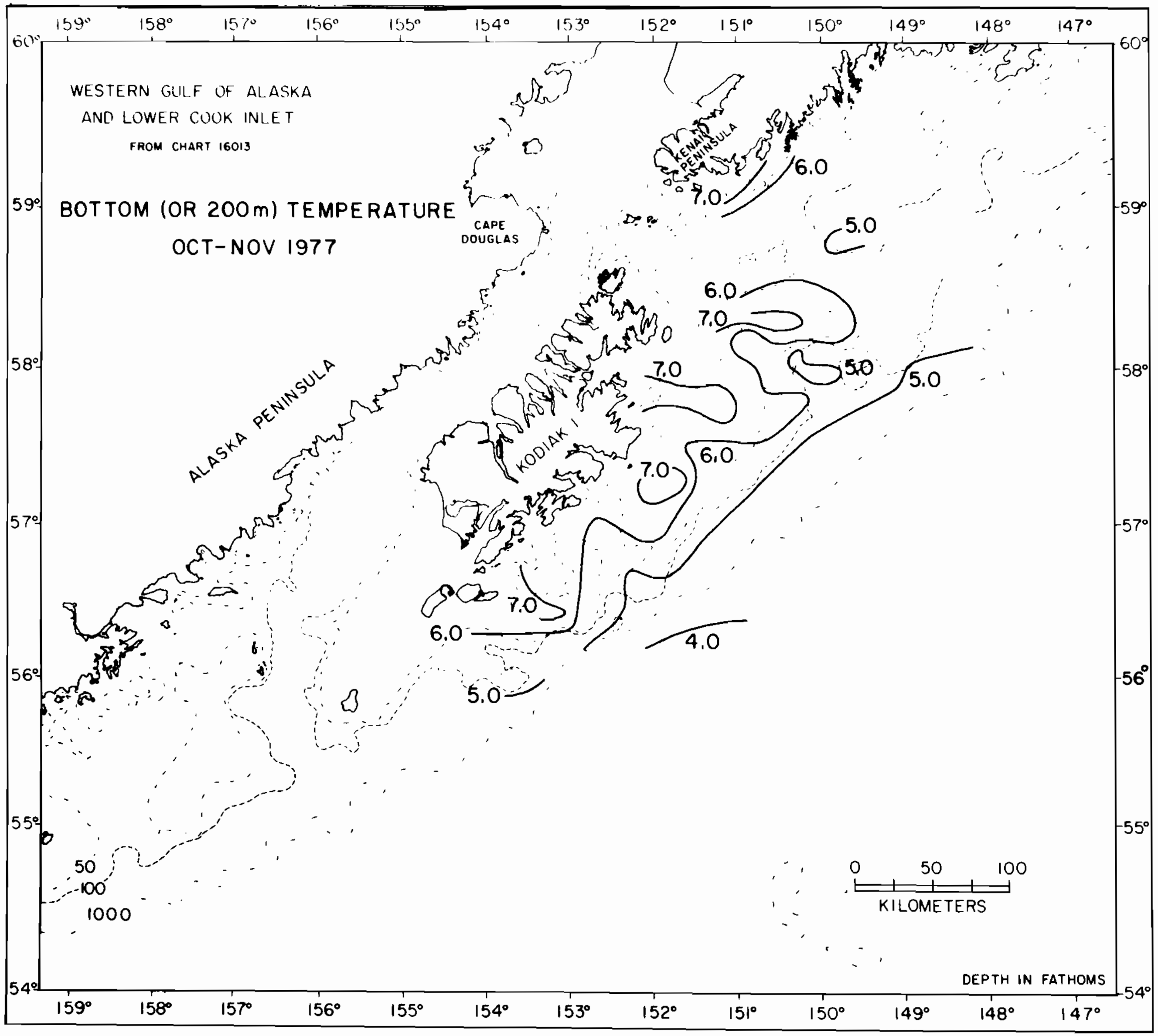

Figure 36. Distribution of bottom (or 200 m) temperature for October and November 1977.

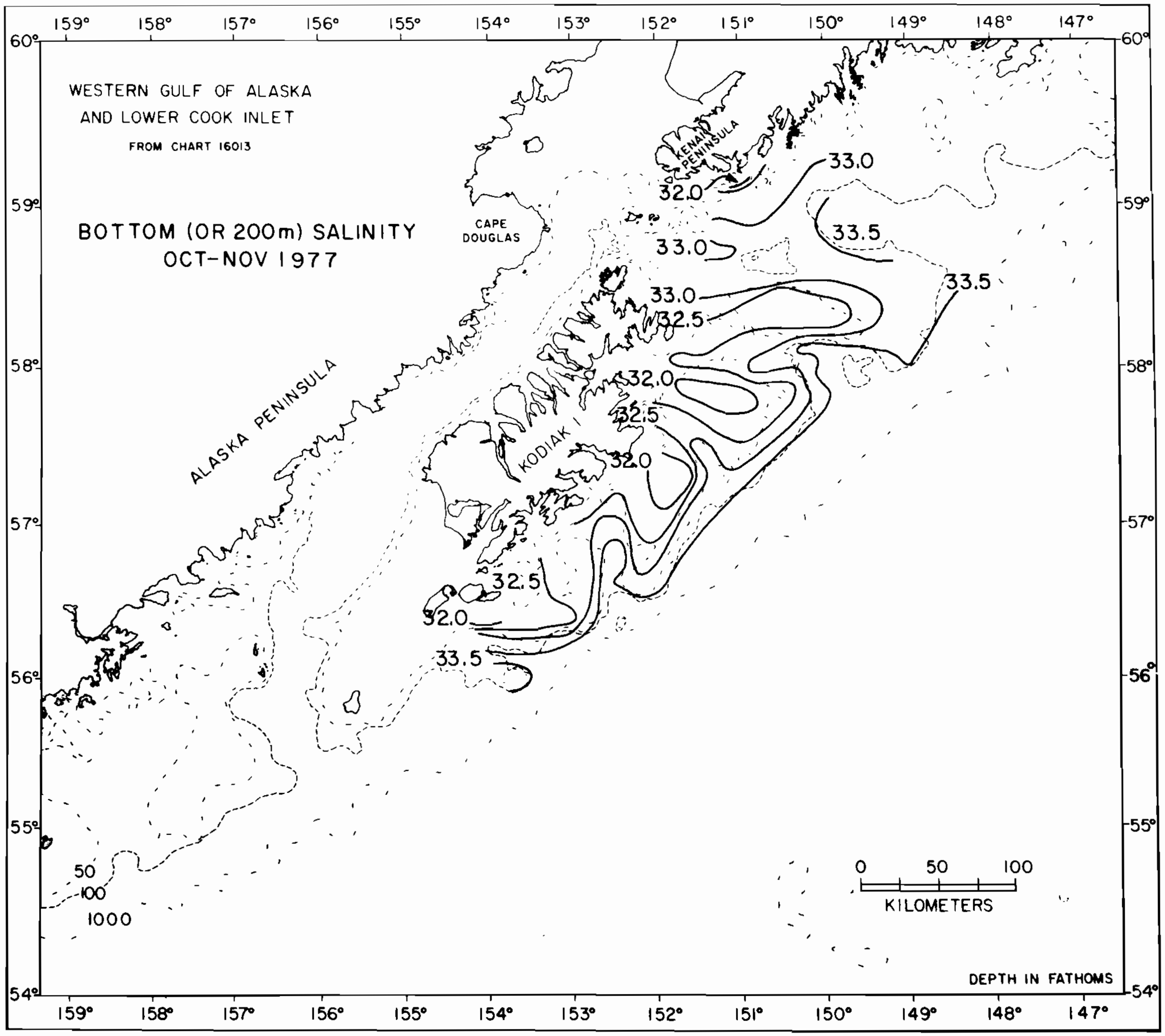

Figure 37. Distribution of bottom (or 200 m) salinity for October and November 1977. Contour interval is 0.5 g kg^{-1}.

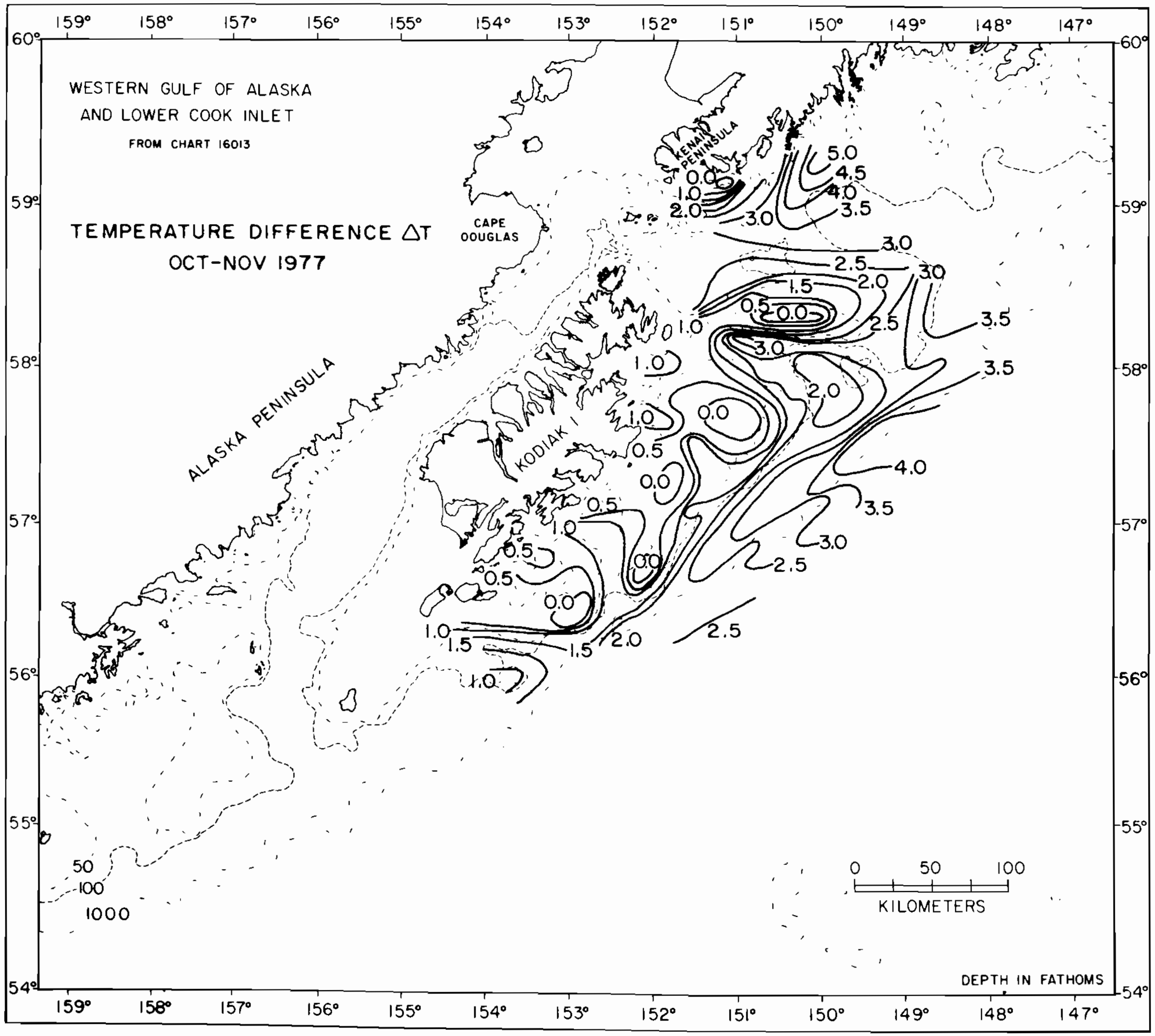

Figure 38. Temperature difference ΔT between the surface and bottom (or 200 m) for October and November 1977. Contour interval is 0.5°C.

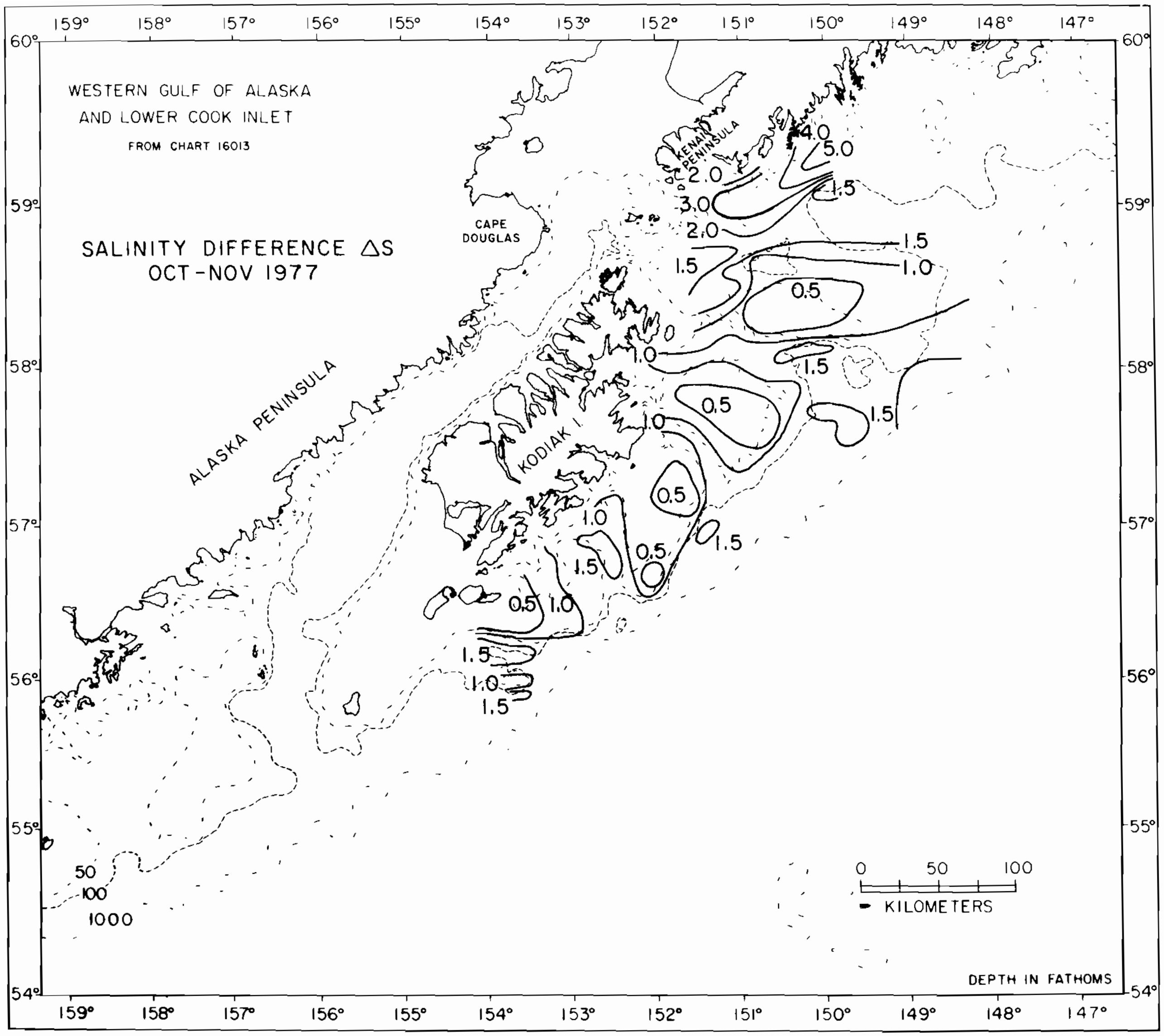

Figure 39. Salinity difference ΔS between the bottom (or 200 m) and the surface for October and November 1977. Contour interval is 0.5 g kg^{-1}.

Data collected during fall, winter, and summer oceanic conditions indicate that two regions of organized flow exist in the vicinity of Kodiak Island; the Alaskan Stream flows southwestward seaward of and parallel to the shelf edge, and westward coastal flow occurs along the Kenai Peninsula. Estimates of baroclinic transport suggest a lack of seasonal variation over the approximately 250-km long portion of the Alaskan Stream encompassed in our studies. There was evidence, however, that the impact of this current upon shelf circulation does vary. During winter, a portion of the Alaskan Stream appeared to have bifurcated near Amatuli Trough and contributed to coastal flow along the Kenai Peninsula (Schumacher *et al.*, 1978). Geopotential contours shown herein suggest that the Alaskan Stream was farther seaward of the shelf break in summer than in fall. Further, we have observed a summer-to-fall increase in the salt content below the halocline in the Amatuli Trough-Portlock Bank region. This change may have resulted from advection of Alaskan Stream water through Amatuli Trough. Flow of more saline Alaskan Stream water, coupled with an inflow of fresh waters along the coast, would have intensified horizontal pressure gradients and could account for the observed increase in transport along the Kenai Peninsula.

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