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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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INTRODUCTION

The AMERIEZ program

This project was part of the interdisciplinary Antarctic Marine Ecosystem Research at the Ice Edge Zone (AMERIEZ) program. Continuous vertical temperature and salinity profiles were obtained along meridional transects in the southern Scotia Sea near the South Scotia Ridge during austral winter (June-August) of 1988. Argos-tracked, drogued drifting buoys were deployed along a meridional transect at the western edge of the study region. The purpose of these observations was to define the oceanic temperature, salinity, density and current fields associated with the marginal ice zone during a period of accretion at the ice edge and to document the complex mesoscale oceanographic structures associated with the Weddell-Scotia Confluence and the Scotia Front. Particular emphasis was placed on measurements of the upper layer vertical stratification which is considered an important factor in the development of enhanced productivity in the marginal ice zone.

Results will be integrated with chemical and biological information obtained by other elements within the AMERIEZ program. Continuing analyses of their data will provide new information on physical oceanographic processes in the Scotia Sea, the site of energetic mesoscale activity and possible deep winter convection, and will advance our understanding of high biological productivity in the Antarctic MIZ by documenting mid-winter conditions within the context of AMERIEZ, a multi-year program which has previously studied the Weddell-Scotia Sea MIZ in early summer and late autumn.

This report presents the T, S, density and current (as Lagrangian drift) data obtained in their entirety. Since this report is intended as a data report which can serve as a tool for further analysis, extensive discussion is not presented.

Regional Background

Observations during this survey extended from the South Scotia Ridge at the northern boundary of the Weddell Sea several hundred kilometers into the Scotia Sea and zonally from 48° to 34° degrees West (Figures 1-3). Hydrographic conditions in this region are complex, since it encompasses the Weddell-Scotia Confluence between waters flowing northeastward out of the Weddell Sea and those flowing eastward from Drake Passage. The waters at Drake Passage are separated into distinct zones by several fronts with large shear and eastward flow (Sievers and Nowlin,1984). Recent hydrographic surveys during austral summer have shown the boundary region to be characterized by meanders and eddy-like structures (Foster and Middleton,1984). A well-defined temperature/salinity front was documented near the South Scotia Ridge in the vicinity of 50°W, becoming more diffuse to the east of the South Orkney Islands (Foster and Middleton,ibid.). Gordon et al.(1977) termed the frontal zones on the northern and southern edges of the Weddell-Scotia Confluence along 50°W as the Scotia Front and Weddell Front, respectively.

The Antarctic zones in the Weddell and Scotia Seas are characterized by well-developed T-minima above 200 m and weak thermohaline stratification below 200 m. The Weddell-Scotia Confluence zone is characterized by relatively saline surface water and weak vertical stratification. Patterson and Sievers (1980) in a descriptive review of historical hydrographic station data in the region to the east of the Antarctic Peninsula (55°W to 20°W) proposed that the relatively weak summer vertical stratification of Weddell-Scotia Confluence waters was due to winter vertical mixing processes within the oceanic lateral boundary layer. These turbulent mixing processes were proposed as a mechanism to homogenize the water column and incorporate cold, fresh meltwater from the pack ice into the water column.

The Field Program

Chronology and conditions

The 1988 field program was carried out in two phases. The first phase, Leg 1, took place in early winter (9 June to 5 July) before the ice had reached its maximum northward extent. Activities were focussed primarily within the marginal ice zone but extended southward into multi-year pack ice to allow extensive chemical, biological and physical studies of the pack ice ecosystem. CTD casts were made within the pack ice and on two rapid transects (less than 72 hours required for completion) along 40° and 48°W longitude. These transects extended from 100 km into the pack ice to several hundred kilometers northward into open water (Figure 2). Nominal station spacing along the transects was 15 km. Two PRL satellite-tracked automatic data acquisition platforms (ADAP) were deployed on multi-year ice floes to measure pack ice drift during the survey period.

The second phase of the survey, Leg 2, emphasized water column measurements in and north of the Scotia Sea marginal ice zone between 18 July to 13 August. Transects along 35^o, 40^o, 44^o and 48^oW longitude were occupied successively from east-to-west (Figure 3). Six Tristar satellite-tracked buoys were deployed on 18 July, at the outset of the leg, in the northwesternmost part of the study region. These buoys were drogued to track near-surface water movement and were positioned several times a day (typically about 10) by the satellite-borne ARGOS location system.

At the start of the survey the ice edge was oriented zonally approximately along $60^o30'$ S latitude in this area, and the southern portion of the survey region lay under multi-year pack ice. By the completion of the survey the ice edge had advanced nearly to 58^o S in the survey region. This ice edge advance in the period encompassing the two phases of the survey is evident comparing the locations of the ice edges denoted on Figures 2 and 3. The ice edge advanced and retreated between cold Weddell water and warmer Scotia Sea water along each of the four transects. An upper layer thermal front coincided with the deeper Scotia front in the northern portions of all the transects. A localized freezing event occurred along the 35^oW transect when an open lead caused by divergence in the pack ice was closed by ice formation. A melt-water lens along the 48^oW transect was associated with deteriorating multi-year floes. More localized ice edge-associated features were also observed.

Routine meteorological measurements were made by ship personnel; however, meteorological data are not available for the entire survey due to equipment problems, e.g., the ship anemometer froze during the latter half of Leg 2. Air temperatures during Leg 1 ranged from -18^oC within the pack ice to $+2^oC$ at the northern limits of the survey region. Winds were generally light during Leg 1, ranging from calm to up to 15 m/s. Winds were calm to light with some snow flurries during the southward penetration of the ice pack along 40^o W in the early portion of Leg 1. The passage of a strong cyclone was observed on the morning of 20 June during the east-to-west transit between the 40^oW transect and the 48^oW transect. Winds were gusting to

30 m/s and seas were in excess of 10 meters.

Weather was more severe during Leg 2 as storms frequently passed through the survey area. Winds in excess of 15-20 m/s were experienced every 3-6 days. Westerly winds up to 25 m/s were observed on 5 August near the southern end of the 44°W transect.

Instrumentation

The observations were carried out from the UNOLS research vessel Polar Duke. Temperature and salinity (as conductivity) measurements were obtained using a Seabird SBE 9/11 CTD (conductivity/temperature/depth) profiling system coupled to a Compaq 286/20 microcomputer. Sampling rate was 12 Hz for all casts. The lowering rate for the underwater unit was held between 0.5 m/s (in the more highly structured upper 200 m) and 1.0 m/s (in the more uniform deeper water), yielding approximately 12-24 observations/meter. Data and header files were stored on 20 Mb Bernoulli cartridges. Real-time plots of temperature, salinity and density (as sigma-t) were displayed during each cast to monitor water column characteristics and to check for instrument problems. Fifty-five CTD casts were completed on leg 1 and 88 casts on leg 2. Geographical locations of the casts are displayed in Figures 2 and 3 , and a listing of exact coordinates,times and maximum depths of all casts are provided in Appendix I.

On Leg 1 electronic interference from the underwater pump for the CTD conductivity sensor limited the useable data to the uppermost 200-300 m for stations 1-34. For the remainder of Leg 1 the underwater pump was disconnected, and acceptable data were obtained for stations 34-55. This problem was corrected on Leg 2 by replacing a power supply component in the deck unit and a power cable leading to the underwater pump. This problem notwithstanding, the majority of the CTD casts extended to at least 500 meters and over half extended to 1500 meters or to within 100 meters of the bottom when the water depth was less than 1500 meters.

The CTD was integrated into a General Oceanics rosette water sampling system equipped with ten 10-liter sample bottles. Water samples for chemical and biological analyses were obtained, in support of other components of the AMERIEZ program, on all transect casts and most non-transect casts at depths from the surface down to 500 m and, occasionally, to 1500 m .

The performance of the conductivity sensor was checked regularly (every third or fourth CTD cast) during the field program. Water samples for salinity determination were obtained from rosette sample bottles and the analyses were performed on a Plessey laboratory salinometer. No attempt was made to check the performance of the temperature sensor of the CTD because adequate reversing thermometers were not available. The CTD sensors were calibrated prior to and following the survey at the Northwest Regional Calibration Center in Bellevue, Washington, and the results showed virtually no change in the temperature, conductivity and pressure calibrations. The final data are accurate to within 0.01°C in temperature and 0.01 o/oo in salinity.

The ship's precision depth recorder was not operating during the survey. Bathymetry used in this report was obtained from Admiralty Chart 3200 (corrected to 1986).

The T and S Observations

Overview

This report presents the CTD data as transects which show the vertical distribution of T, S and density (as sigma-t) and as maps of T, S and sigma-t at 50 meters depth during both legs of the survey. The distributions of temperature at 400 meters (the approximate warm-core depth of the Scotia Sea water) and depth of and temperature at the 27.6 sigma-t surface are presented for leg 2. The 27.6 sigma-t surface was located in the core of the main pycnocline beneath the upper mixed layer and was continuous across nearly the entire study region.

T, S and density (as sigma-t) are shown along meridional and zonal transects. Meridional sections are oriented with the observer looking westward, so that the left-hand edge of the section is the southern end of the transect. Zonal sections are oriented with the observer looking north, and the left-hand edge of the section is the western end of the transect. For Leg 1 the sections along 40°W (stas. 10-21) and along the east-west transect (stas. 23-30) are restricted to the upper 200 meters due to malfunction of the CTD below this depth.

The horizontal distributions presented in this report do not represent truly synoptic data due to the large distances (as large as 250 km) and time intervals (up to two weeks) between the occupations of the meridional transects. The distributions at 50 meters represent upper mixed layer conditions during the survey.

LEG 1 observations: 9 June-5 July 1988

First 40W Transect: 16-18 June (Figure 4)

During this transect (occupied in approx. 48 hours) the upper 80-100 m of the water column was well-mixed in both T and S. In the southern portion of the transect, beneath the pack ice, this layer was near the freezing point ($T < -1.8^oC$). Toward the north it was warmer. The cold, relatively low salinity mixed layer was separated throughout the transect from the warmer, more saline deeper water by a strong pycnocline between depths of 100 and 150 meters characterized by strong vertical gradients in temperature and salinity. The waters beneath the pycnocline showed T and S structures associated with the Scotia Front.

The strongest observed upper layer horizontal gradients were associated with what appeared to be a meltwater lens north of the ice edge. This lens was manifested as a shallow layer of low S water($S < 34.1$ o/oo) approx. 50 km wide. At the northern end of the transect a weak upper layer thermal front was nearly coincident with the deeper front which was associated with the higher T ($T > 1.0^o$ C) in the Scotia Sea water .

First East-West Transect:20-25 June (Figure 5)

This transect was not occupied in the rapid mode of the meridional transects, and station spacing was rather coarse(52 to 100 km) relative to the closer spacing in the meridional transects. Relatively homogeneous conditions were observed in the upper layers along the ice edge. The 90-100 m deep upper mixed layer was characterized by low salinity ($S < 34.1$ o/oo) and temperatures less than -1.5^oC. The mixed layer shoaled to approximately 50 m at station 23 on the eastern end of the transect.

First 48W Transect: 2-5 July(Figures 6-8)

Station spacing along this transect was 15 km for stations 37-50 and 30 km thereafter. Total time required for completion of the transect was approximately 72 hours.

The upper mixed layer ranged in depth from 90-130 m in the southern half of the transect to about 25 m at the northern end. The mixed layer was near the freezing point ($< -1.8^o$ C) in the southern portion, with the coldest temperatures (-1.85^o C) beneath the ice cover. The upper layer affected by these near-freezing temperatures extended about 75 km seaward of the nominal ice edge, as reflected in the depth of the -1.8^oC isotherm (Figure 6). Shallow, isolated low salinity lenses ($S < 34.0$ o/oo) were found north of the ice edge and were probably due to meltwater. There was a significant horizontal gradient in upper layer temperature in the northern portion of the transect. This region was associated with low salinity ($S < 34.0$ o/oo) water in the upper 100 m, with salinities decreasing to less than 33.9 o/oo at the northern end of the transect.

The main pycnocline was 100-200 m deep along most of the transect, and separated the cold, relatively low salinity upper mixed layer from the warmer, more saline deep water. The vertical structure of properties beneath the main pycnocline was complicated by strong T and S gradients between the waters of the Weddell-Scotia Confluence and the Scotia Sea Warm Deep Water (or Circumpolar Deep Water). Patterson and Sievers (1980) identified the northern boundary of the WSC as the southern terminus of the deep 1.5^oC isotherm in the Scotia Sea. Using this criterion, the northern boundary of the WSC along this transect was coincident with the location (station 51) of an upper layer thermal front . The T maximum north of this front was centered at 400 m, and the complex T and S structures south of the T maximum suggest turbulent mixing across the front.

T and S at 50 m: 9 June- 5 July(Figures 9 and 10)

The upper layer in the southern portion of the area was dominated by near freezing temperatures ($T < -1.75^o$C) associated with the ice cover. Temperatures increased northward to values greater than -0.5^oC. The strongest T gradient was located in the northwestern portion of the area and was associated with the southern boundary of the Scotia Sea water, the Scotia Front.

The horizontal salinity distribution shows a weak northwest-to-southeast gradient between the lower S Scotia Sea water ($S < 34.0$ o/oo) and higher salinities ($S > 34.1$ o/oo) associated with the Weddell-Scotia Confluence. The highest salinities observed ($S > 34.2$ o/oo) were located beneath the pack ice at the southern end of the 40°W transect.

T/S diagram: 2-5 July 1988 (Figure 11)

The T/ S curves for stations 37, 39 and 55 are presented as representative of water masses on the first 48°W transect. The lack of deep T/S data for the first 40°W transect precluded their inclusion in the T/S diagram.

Station 55 at the northern end of the 48°W transect is representative of the Antarctic zone of the Scotia Sea, north of the Scotia Front (Gordon et al., 1977). Surface water south of the Polar Front is termed the Antarctic Surface Water and is characterized by relatively low temperatures and salinities and a subsurface temperature minimum which is most pronounced in the austral spring and summer (Sievers and Nowlin,1984). Separated from the surface water by a strong halocline, the Warm Deep Water or Upper Circumpolar Deep Water is identified by a broad deep temperature maximum (generally greater than 2°C) with salinities between 34.6-34.65 o/oo centered at about 500 m. There is an indication of interleaving of water masses along isopycnal surfaces within the T maximum at station 55. Temperature and salinity decrease monotonically below the deep T maximum.

Stations 37 and 39 were occupied at the edge of the relatively narrow passage (sill depth 2000 m) between the Powell Basin of the Weddell Sea and the Scotia Sea (Figure 2). The water masses are derived from those flowing out of the northern Weddell Sea. Surface waters were at or near the freezing point. Below the halocline the Warm Deep Water, characterized by temperatures just above 0°C and a narrow salinity range (S near 34.65 o/oo), was centered near 700 m.

LEG 2 observations: 18 July-13 August 1988

35W Transect : 22-24 July (Figures 12-14)

This easternmost transect was the first transect occupied during Leg 2. The upper layer was vertically well-mixed to a depth of approx. 140 m. Temperatures were at or near the freezing point in the ice-covered southern portion and increased to the north. The ice edge was diffuse, with several large bands of ice at the north edge. A narrow (20 km wide), low S lens ($S < 34.1$ o/oo) was associated with these bands and a weak upper layer thermal front coincided with the low salinity lens.

A warm-core ($T > 1.5^o$ C) feature centered at 350 m underlay the low salinity surface lens . This warm core marked the southern boundary of the Scotia Sea water, and the isolated boluses of water with $T > 0.5^oC$ at 300-400 m south of the deep front suggest active mixing across this front. The deep water (250-1500 m) below the main pycnocline in the southern portion of the transect was vertically relatively uniform in temperature ($0.0^o < T < 0.5^oC$) and salinity ($34.60 < S < 34.68$ o/oo), compared with elsewhere in the transect. This vertical homogeneity typifies Weddell-Scotia Confluence water (Patterson and Sievers,1980) .

The south to north slope of the 27.8 isopycnal indicates a general eastward baroclinic flow. Steepened slope associated with the front just north of the ice edge suggests intensified eastward flow associated with the front.

Second 40W Transect: 26-28 July (Figures 15-17)

The upper mixed layer along this transect ranged in depth from 90 to 140 meters. A strong upper layer thermal front was centered about 25 km north of the ice edge. This was the most intense surface T front (approx. $1.5^oC/30$ km) observed among all the meridional transects. Mixed layer temperatures exceeded 0^oC north of the front. The upper layer front coincided with the deep front between Weddell-Scotia Confluence waters and the southern edge of the Scotia Sea deep temperature maximum ($T > 2.0^oC$) centered at 400 m, i.e., the Scotia Front. North of these fronts the deep T maximum extended from 250 to approx. 800 meters. The convoluted structure of the 0.5^oC isotherm south of the deep front suggests active mixing between warm deep water and the colder water farther south.

The steep slopes of the 27.5-27.8 isopycnal surfaces across the frontal region suggest significant eastward baroclinic flow. These slopes were the steepest observed at this front during the survey.

44W Transect: 31 July-2 August(Figures 18-20)

During occupation of this transect the ice edge had migrated to the southernmost location at which it was observed during Leg 2. The upper mixed layer, ranging from 90-140 m in depth, was relatively homogeneous laterally with $-1.8^{o} < T < -1.2^{o}$C and salinities of 34.0-34.1 o/oo, except for a weak upper layer T and S front which was observed about 50 km north of the ice edge. This upper layer front was coincident with the deeper front associated with the Scotia Sea deep temperature maximum ($T > 1.5^{o}$C) centered at about 350m. Strong westerly winds (> 20 m/s) were encountered at the southern end of the transect and may have forced the ice southward . The -1.8^{o}C isotherm, associated with the presence of ice in the upper layer, extended about 40 km north of the ice edge consistent with recent southward wind-forcing of the ice. The northern half of the transect below about 200 m was occupied by Scotia Sea Warm Deep Water (UCDW).

As for all the other vertical density sections, the Scotia Front marking the southern extent of Scotia Sea water, was accompanied by a sharp deepening of the 27.8 isopycnal.

Second East-west transect:8-9 August (Figures 21-23)

This transect crossed a strong upper layer thermal front between 46° and 47°W, where the temperature gradient was about 2.0°C/40 km between stations 125 and 126. This thermal front overlay a deep warm-core ($T > 2.0^{o}$C) feature centered at 450 m. Downwarping of the isopycnal surfaces associated with this warm-core feature suggests a warm-core eddy or meander ,i.e., anticyclonic circulation around the warm-core. Presence of an eddy was substantiated by drifter results (see below). The upper mixed layer was deepened (> 150 m) above this warm-core eddy and was characterized by $T > 1.0^{o}$C and $S = 34.05$ o/oo.

Second 48W Transect: 10-11August (Figures 24-26)

This was the westernmost meridional transect and was farthest upstream in the Weddell-Scotia Confluence. Consequently, the most complex T and S structures were observed here. The upper layer at the southern end of the transect was vertically well-mixed in both T and S to depths of 100-130 m. The large lead in the southern portion of the transect was associated with a relatively warm ($T > -0.5^{o}$C), fresh ($S < 33.9$ o/oo) surface layer which may have been derved from ice meltwater. This apparent "meltwater lens " overlay a warm-core ($T > 2^{o}$C) feature centered at 250 m which may have been related to eddy motion or to a meander of the frontal boundary. The upper layer along the transect showed considerable complexity, with a cold-core feature located at 30-700 m near the center of the transect. The upper 100 m of this feature was well-mixed and near the freezing point.

A weak upper layer thermal front north of the ice edge overlay an apparent mixing zone where warm, saline water from the north interleaved with the colder, less saline waters from the south (between 75 and 300 m).

An extensive warm-core ($T > 2.0^oC$) feature was centered at 400 m in the northern portion of the transect and showed the strongest lateral T gradients observed during Leg 2. These strong gradients reflected the contrast between the cold-core feature and the deep T maximum of the Scotia Sea Warm Deep Water. The track of one of the satellite-tracked drogued buoys (see below) revealed that an anticyclonic (counterclockwise) eddy existed in the vicinity of this active frontal zone during 18 July-4 August, prior to the occupation of this transect.

The south-to-north sloping isopycnals beneath the upper mixed layer indicate an eastward baroclinic flow.

T and S at 50 m: 18 July-13 August(Figures 27 and 28)

Upper layer temperature fronts were present in the northern portions of the 40°W and 48°W transects, reflecting the boundary between the Weddell-Scotia Confluence and the warmer Scotia Sea water. These strong fronts may have been associated with eddies or meanders of the Scotia Sea water in the active mesoscale mixing zone associated with the Weddell-Scotia Confluence.

The T and S distributions reveal, through extension of the -1.75^oC isotherm beyond 59°S, the effects of northward seasonal ice edge advance. The position of the 34.1 isohaline was nearly coincident with that of the -1.75^oC isotherm, reflecting the approximate boundary of the marginal ice zone which was characterized by near-freezing temperatures and relatively high salinities. The apparent ice edge meltwater lens (near 59°S on the 48°W transect) is identified here by the warm ($T > 1.0^oC$), low salinity ($S < 34.0$ o/oo) tongue extending to the east.

T at 400 m: 18 July-13 August (Figure 29)

The deep temperature maximum in the Scotia Sea south of the Polar Front, known as the Warm Deep Water (or Upper Circumpolar Deep Water), is characterized by a core of warm ($T > 2.0^oC$) water extending from 250 to 700m, centered at approximately 400m (Patterson and Sievers,1980). The distribution of temperature at 400 m during Leg 2 suggest that the two warm-core features observed in the northern areas near 48°W and 40°W were derived from this Scotia Sea water mass. Along the 48°W transect the cold-core feature ($T < 0.5^oC$) extended eastward as a tongue and may have been associated with the eastward flow of Weddell-Scotia Confluence water.

T on, and depth of, 27.6 sigma-t surface: 18 July-13 August (Figures 30 and 31)

The 27.6 isopycnal level was centrally situated in and is taken to represent the main pycnocline throughout the survey area. The horizontal distribution of temperature on this surface reveals a predominantly zonal gradient which decreases in magnitude, probably due to the effects of turbulent mixing(Figure 30), from west-to-east. At the western edge of the survey area an eastward-extending tongue-like feature of water ($T < -0.5^oC$) probably represented Weddell-Scotia Confluence water. Temperatures greater than 1.5°C along the northern portions of the 48°W and 40°W transects suggest segments of the Scotia Front or eddies/meanders of the warmer Scotia Sea water.

The consistent south-to-north deepening of the 27.6 isopycnal reflects the distribution of mass associated with eastward baroclinic flow (Figure 31). The strong depth variations in the northern portions of the 48°W and 40°W transects suggest increased baroclinic flow associated with eddies or meanders.

T/S diagrams: Figures 32 and 33

Temperature vs. salinity plots are presented for the 35°W transect (stations 58, 66 and 71)and the 40°W transect(station 75) in Figure 32 and for the 48°W transect (stations 128, 139 and 142) in Figure 33. These stations effectively bracket the entire survey area and provide T/S envelopes for the range of water masses observed.

The T/S curve for station 128 illustrates typical characteristics for the Antarctic zone south of the Polar Front in the Scotia Sea. The upper 100-200 m in this zone are characterized by low temperatures and relatively low salinities due to dilution by ice melting and an excess of precipitation over evaporation. This surface water mass was termed the Antarctic Surface Water by Sievers and Nowlin(1984). Temperature increases with depth below the surface water, and a relatively strong halocline is typically present to depths of about 250 m. The Upper Circumpolar Deep Water (UCDW) is identified by the broad temperature maximum near 2.0°C, beneath the halocline, and is centered at about 500 m on the 48°W transect. The broad nature of the temperature maximum of the UCDW, (i.e. the relatively great S range encompassed by the maximum) is further illustrated at station 75 at the northern end of the 40°W transect where salinities at the T max range from 34.4-34.6 o/oo. Temperature and salinity decrease monotonically with depth below the temperature maximum.

The progression of the T/S curves from stations 128 to 142 illustrates the transition southward across the Scotia Front into the Weddell-Scotia Confluence. The surface water at station 142 was near freezing, and the upper layer salinities were higher than north of the front, probably due to vertical mixing between the surface waters and deeper layers. There was an indication of interleaving of water masses along isopycnal surfaces at the level of the deep T maximum (near 0.5°C) centered at about 450 m.

The range in T/S properties north and south of the front (stas. 71 and 58) on the 35°W transect is much less than on the 48°W transect, suggesting mixing in the eastward flow (Figure 32). There is some suggestion of active interleaving along density surfaces near the deep T maximum at stations 66 and 71.

Circulation

Dynamic topographies: 18 July-13 August (Figures 34-36)

The dynamic topographies of the sea surface relative to the 500, 1000 and 1500 db pressure surfaces are presented. We restrict our attention to the

0/1500 db field (Figure 36) which shows the greatest detail. The dynamic topography south of about 59°S is relatively smooth except in the vicinity of 48°W where relatively slow eastward flow is indicated. There is an indication of a weak anticyclonic eddy centered at 59°S. The trend of the dynamic isobaths to the east suggests that the eastward flow accelerates and turns slightly to the northeast in the vicinity of 44°W. Eastward baroclinic flow speeds are greater toward the north in association with the frontal structures described above.

Strong anticyclonic baroclinic flow is indicated in the northern portions of the 48°W and 40°W transects associated with the strong frontal boundaries previously mentioned. These features may be interpreted as eddy motion or as meandering of the frontal boundary. Nowlin et al.(1977) showed that the Antarctic Circumpolar Current at Drake Passage is laterally structured from surface to great depth consisting of several high velocity cores (fronts) separating water mass zones in which the flow is slower. The observed regions of strong gradient are consistent with the conclusions of Nowlin et al.(1977).

Drogued drift buoy results: Figures(37-39)

Six Tristar shallow-drogued, Argos-tracked buoys were released near 58°S, 48°W on 18 July before the start of the water column measurements . Only three of the six buoys survived long enough to provide useable records. These buoys were typically positioned about 10 times daily. Drift tracks 2 and 3 reveal the buoys moved in an eastward direction at speeds of about 40 cm/s on the first day, then turned north and slowed considerably before exiting the survey area (Figures 37 and 38). Drift track 4 shows that one buoy was entrained in an anticyclonic (counterclockwise) eddy just west of the 48th meridian during the period 18-31 July, then exited the survey area to the north (Figure 39). Maximum daily drift speeds within the eddy were on the order of 40 cm/s. This eddy coincided with the region of strong anticyclonic baroclinic flow which was associated with the Scotia Front in the northwestern corner of the survey area (see Figure 36) and substantiates that the baroclinic feature was in fact associated with a mesoscale eddy .

Ice drift buoy results: (Figures 40 and 41)

During Leg 1 two Argos-tracked ADAPs were deployed on two large (greater than 100 m in diameter) multi-year ice floes to track the pack-ice drift during the survey period. These platforms were positioned about 10 times daily. The first was deployed at 61°17′ S, 42°16′W on 13 June; the second at 61°04′S, 48°49.6′W on 28 June. The deployment locations are indicated by a star on the drift tracks (Figs. 40-41).

The first ADAP was deployed on a floe southeast of the South Orkney Islands on 13 June. The irregular track showed that the ice floe remained over the South Scotia Ridge during the short life of the platform (Figure 40). It moved slowly northward at speeds of about 5-10 cm/s until 25 June and then southwestward until the signal was lost on 30 June.

The track of the second ADAP, released on 28 June southwest of the South Orkney Islands, revealed a slow northeast drift of the pack ice into shallow water just west of the South Orkneys, by 20 July. Between 20 July and 5 August the ice floe underwent several eddy-like motions in a relatively small area over the South Scotia Ridge. Between 5-10 August it moved northward and then relatively rapidly eastward . The average eastward drift speed during 10-15 August was about 30 cm/s. Since wind observations were not available, it is not possible to separate wind drift from current effect.

During the period 15 August to about 1 September the track of the platform meandered northward. (This nearly S-shaped meander is suggestive of a similar meander farther north near 45°W noted by Mackintosh(1946) in the position of the Polar Front.) The remainder of the track shows eastward to northeastward movement at 20-30 cm/s. There is a weak indication of anticyclonic eddy or meander motion in the track beween 5-20 September. The general north by northeast drift track in the area north of the South Scotia Ridge is consistent with the surface geostrophic flow shown in Figure 35.

Discussion and Summary

The two phases of the 1988 AMERIEZ field program were separated in both time and space. The stations occupied during Leg 1 extended over the South Scotia Ridge, reaching much further south than those of Leg 2 and the observed T/S properties, water masses, reflect a stronger influence of the Antarctic zone waters of the northern Weddell Sea. The ice edge during this leg was located to the south of 60°S and the boundary between the Weddell-Scotia Confluence waters and the Scotia Sea waters, the Scotia Front, was located 150-200 km north of the ice edge during this leg. There was some evidence of active mixing of Warm Deep Water across the front below 200 m on the 48°W transect.

During Leg 2 the ice edge had advanced northward to between 58° and 58°30'S and on three of the four meridional transects was associated with presence of the Warm Deep Water(or Upper Circumpolar Deep Water) at depths below 200 m. Strong upper layer thermal fronts were observed near the ice edges on the 48° and 40°W transects and the deep T and S structure beneath these fronts suggested active mixing. The topography of the 27.6 isopycnal surface indicates intensified baroclinic flow at these frontal boundaries and may reflect eddies or meanders of the Scotia Front. The T/S diagrams for the northernmost stations on the 48°W and 35°W transects indicate that mixing or interleaving along isopycnal surfaces is prevalent at the core of the UCDW.

The circulation information deduced indirectly from T and S properties was supported by drifter measurements. The study region was characterized by eastward baroclinic currents and an observed eastward ice drift with speeds at times exceeding 20 cm/s. The highest observed current speeds were superposed upon the eastward flow and were associated with the westernmost anticyclonic eddy, where drogue drift speeds were of the order 40 cm/s. This current regime can be expected to limit the residence time of water in the region both by the eastward flow and also by a small but consistent northward or off-ice component evidenced in the baroclinic flow field and by larger northward components, which were possibly largely wind-driven, in the drogued buoy and ice drifter trajectories.

The ice edge was very dynamic during the study period and underwent considerable meridional migration within the survey area (Figure 3). There was not a consistent meltwater lens or layer in the vicinity of the ice edge on all the transects, however, such a feature was found on the 35°W and second 48°W transects. The upper layer was vertically well-mixed throughout the survey area and was near the freezing point in the southern portion. Beneath a well-mixed upper layer 100-130 m deep and a relatively uniform pycnocline between 150 and 200 m, complex T and S frontal structures, which are related to water mass frontal boundaries and eddies, were observed in the deeper water.

The major results can be summarized as follows:

1. The winter 1988 survey intersected several segments of the Weddell and Scotia Fronts, as evidenced by the strong lateral temperature and salinity gradients and concentrated eastward baroclinic currents which were encountered on the northern portions of the meridional transects. These segments appeared to be associated with the southern edges of at least one anticyclonic mesoscale eddy and a second feature which may have been either a second anticyclonic eddy or a meander in the eastward-flowing current. Temperatures greater than 0°C were associated with the upper layer waters north of the front, whereas values below 0°C occurred south of the front. Temperatures increased with depth, so that temperatures at mid-depths were greater than +2°C north of the front and greater than about +0.5°C to the south.

2. Lateral and vertical gradients in temperature and salinity generally decreased from west to east in the study region, consistent with an origin for the strong frontal structure to the west at the region of confluence between the outflowing water from the Weddell Sea and the east-flowing Scotia Sea variety of Circumpolar Deep Water from Drake Passage. The gradients decreased through turbulent mixing during eastward passage of water through the study area.

3. The principal regional water masses, separated by the Scotia Front, were the Weddell-Scotia Confluence water in the southern part of the study area and the Antarctic Surface Water (AASW) and Scotia Sea UCDW in the northern part. Weddell-Scotia Confluence water was vertically more well-mixed than Scotia Sea water, and had temperatures of about 0.0 – 0.5° C and salinities of about 34.0-34.6 o/oo. Scotia Sea water was warmer, and the upper layer AASW was less saline. A temperature maximum was centered at 300-400 m where temperatures greater than 1.5°C were associated with the UCDW.

4. Baroclinic surface circulation relative to the 1500 db pressure level was eastward in the entire study area. High-speed current cores were associated with the Scotia Front. There were two well-defined anticyclonic features embedded in the high-speed frontal current: the westernmost of these was shown by a drogued drifter track to be a mesoscale eddy, whereas the second feature to the east may have been the southern portion of either an eddy or a meander. These features both had warm deep cores and large depressions of

the isopycnal surfaces. Maximum surface speeds associated with the western eddy were shown by the drogue track to exceed 40 cm/s.

5. Localized frontal structures were observed in association with the ice edge at some locations. In a few cases, meltwater lenses having salinities significantly below ambient levels were also situated at the ice edges. These features were not universal, however, and in many cases no temperature or salinity features were associated with the ice edges. This probably reflects wind-forcing of the ice edge to different locations over sufficiently short time scales that the water column did not have time to interact with the ice, i.e., to cause melting or redistribution via frontal currents.

6. Irrespective of the presence of the major front, the upper mixed layer extended to depths of 80-140 m. The greatest mixed layer thicknesses were observed in the ice-covered southern portions of the study area, where temperatures were at or near the freezing point and salinities were 34.1-34.4 o/oo.

7. The upper mixed layer was underlain everywhere by a layer between 100 and 200 m having strong increases of temperature, salinity and density with depth. This gradient region or pycnocline showed superimposed mesoscale depth variations which were suggestive of internal waves, eddies or meanders.

8. Ice motion during the experiment and for at least one month following completion of the survey was irregular but generally northward to eastward, as demonstrated by the track of a satellite-tracked ADAP locator deployed on a large ice floe.

References

Foster, T.D. and J.H. Middleton. 1984: The oceanographic structure of the western Scotia Sea I. Physical oceanography. *Deep-Sea Res.*,31: 529-550.

Gordon,A.L., Georgi,D.T., and H.W. Taylor. 1977: Antarctic Polar Front Zone in the western Scotia Sea-Summer 1975. *J. Phys. Oceanogr.*,7:309-328.

Mackintosh,N.A. 1946: The Antarctic Convergence and the distribution of surface temperatures in Antarctic waters.*Discovery Rep.*,36:1-94.

Patterson,S.L. and H.A.Sievers. 1980: The Weddell-Scotia Confluence. *J. Phys. Oceanogr.*,10:1584-1610.

Sievers, H.A. and W.D. Nowlin,Jr. 1984: The stratification and water masses at Drake Passage,*J. Geophys. Res.*,89:10489-10514.

Acknowledgements

This work was supported in part by National Science Foundation Grant DPP-8715979 to SAIC (RDM and JTG) and Grant DPP-8513098(DMH) and by NOAA/NMFS (DMH).

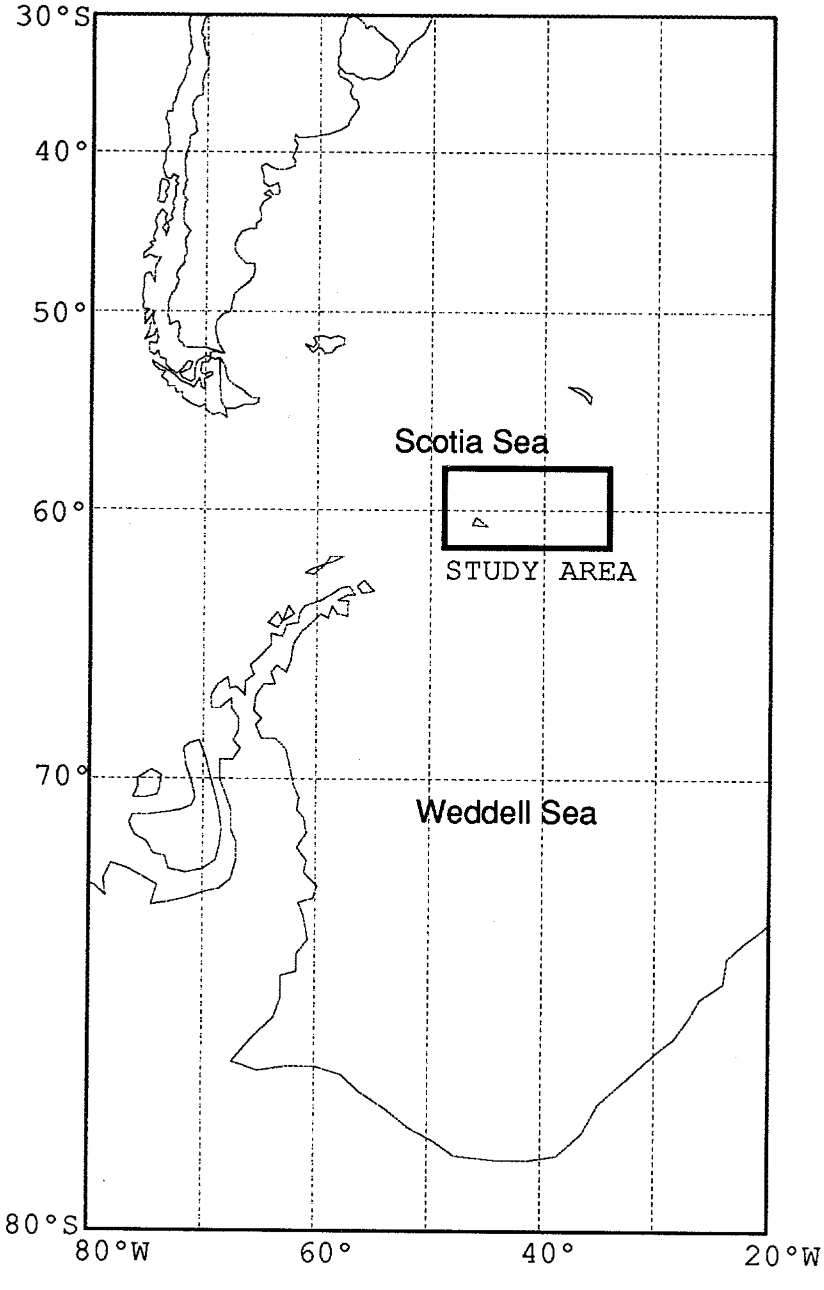

Figure 1. Geographical location of AMERIEZ III survey, June-August 1988

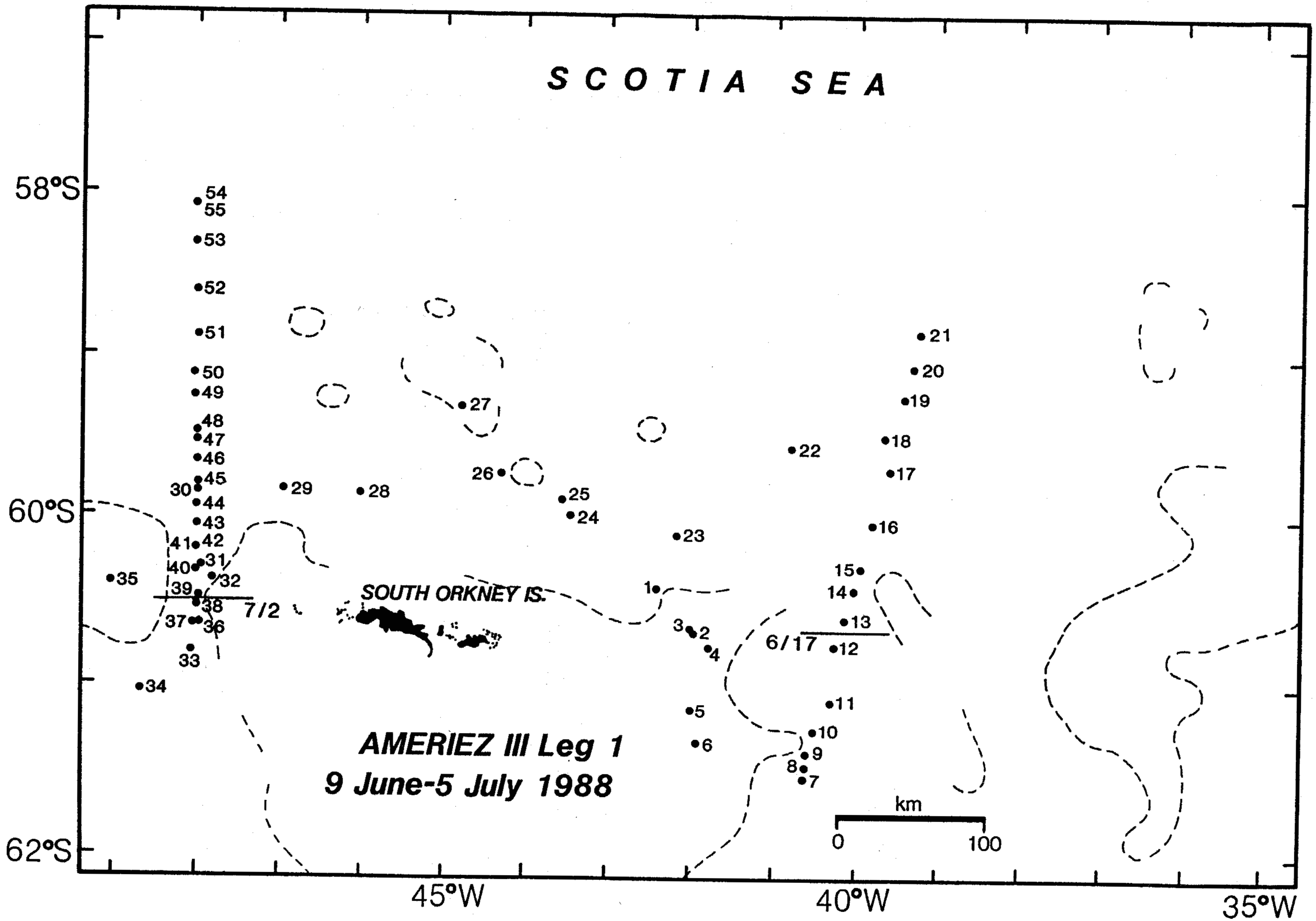

Figure 2. Locations of CTD stations during Leg 1 of AMERIEZ III survey, 9 June - 5 July 1988. Approximate locations of ice edges denoted by horizontal lines and dates along meridional transects.

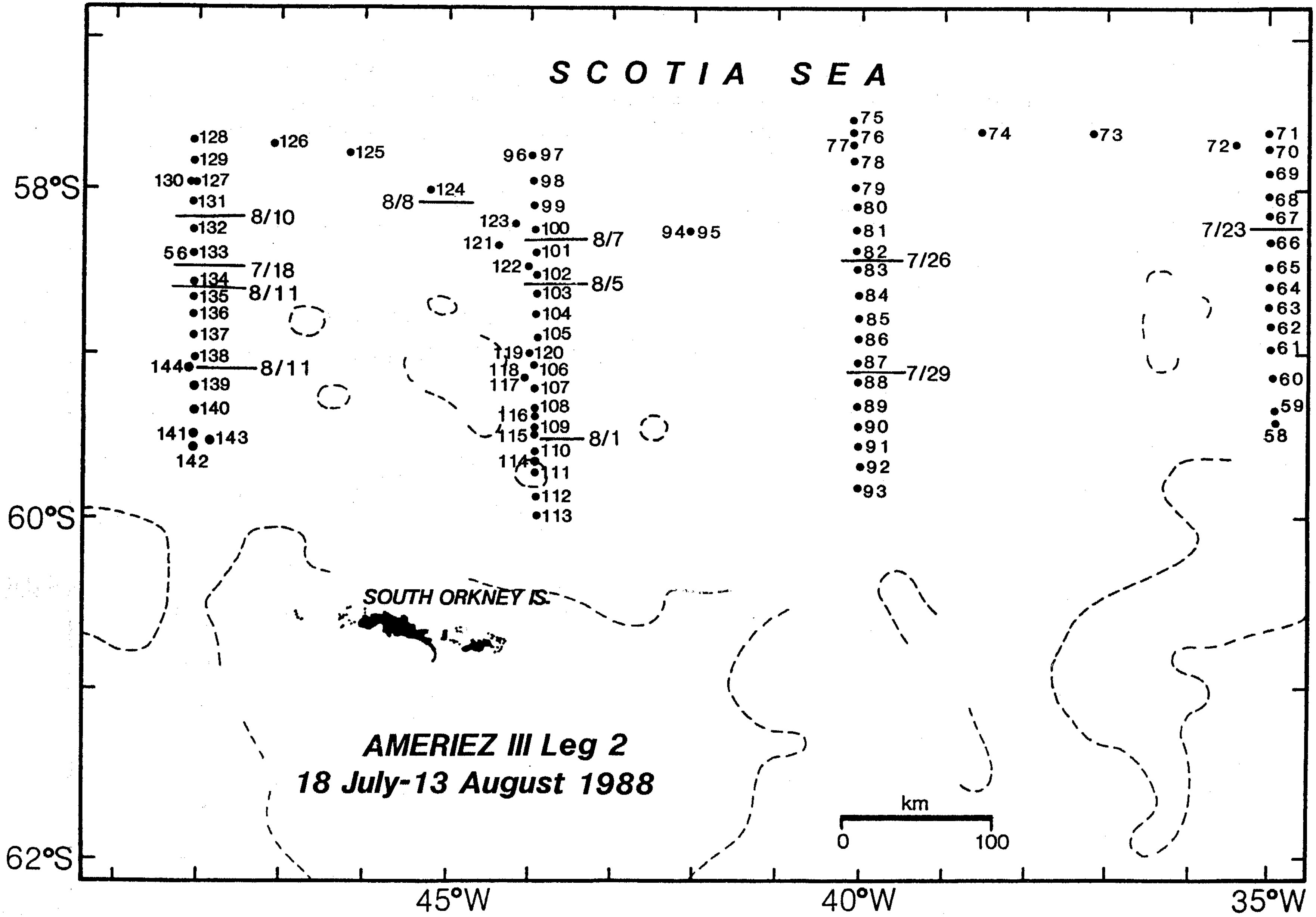

Figure 3. Locations of CTD stations during Leg 2 of AMERIEZ III survey, 18 July - 13 August 1988. Approximate locations of ice edges denoted by horizontal lines and dates along meridional transects.

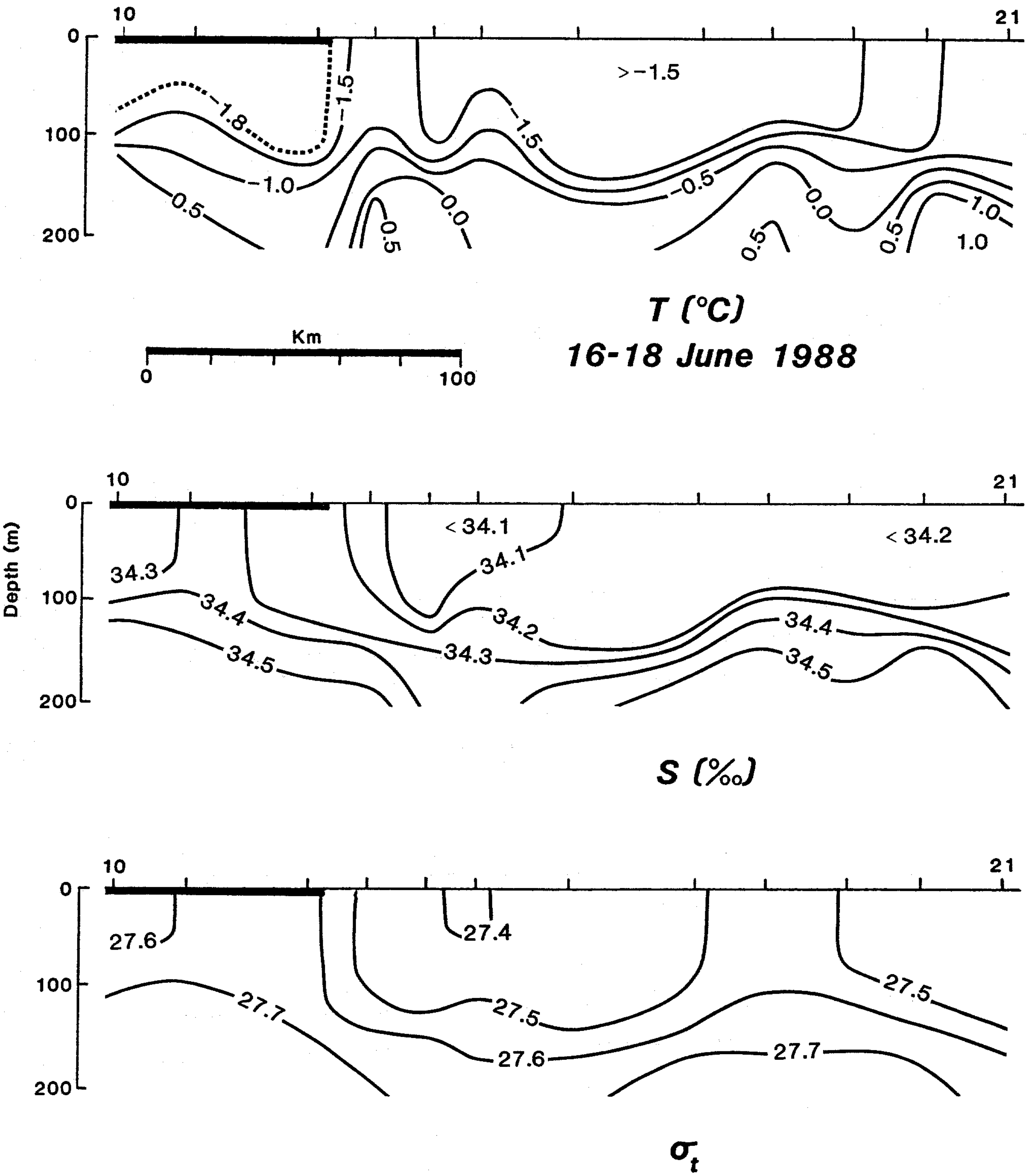

Figure 4. Vertical sections of T, S and sigma-t along first 40°W transect during Leg 1 of AMERIEZ III survey. Contour intervals are 0.5°C, 0.1 o/oo and 0.1 for T, S and sigma-t, respectively. The heavy black lines at the surface denote the approximate extent of pack ice.

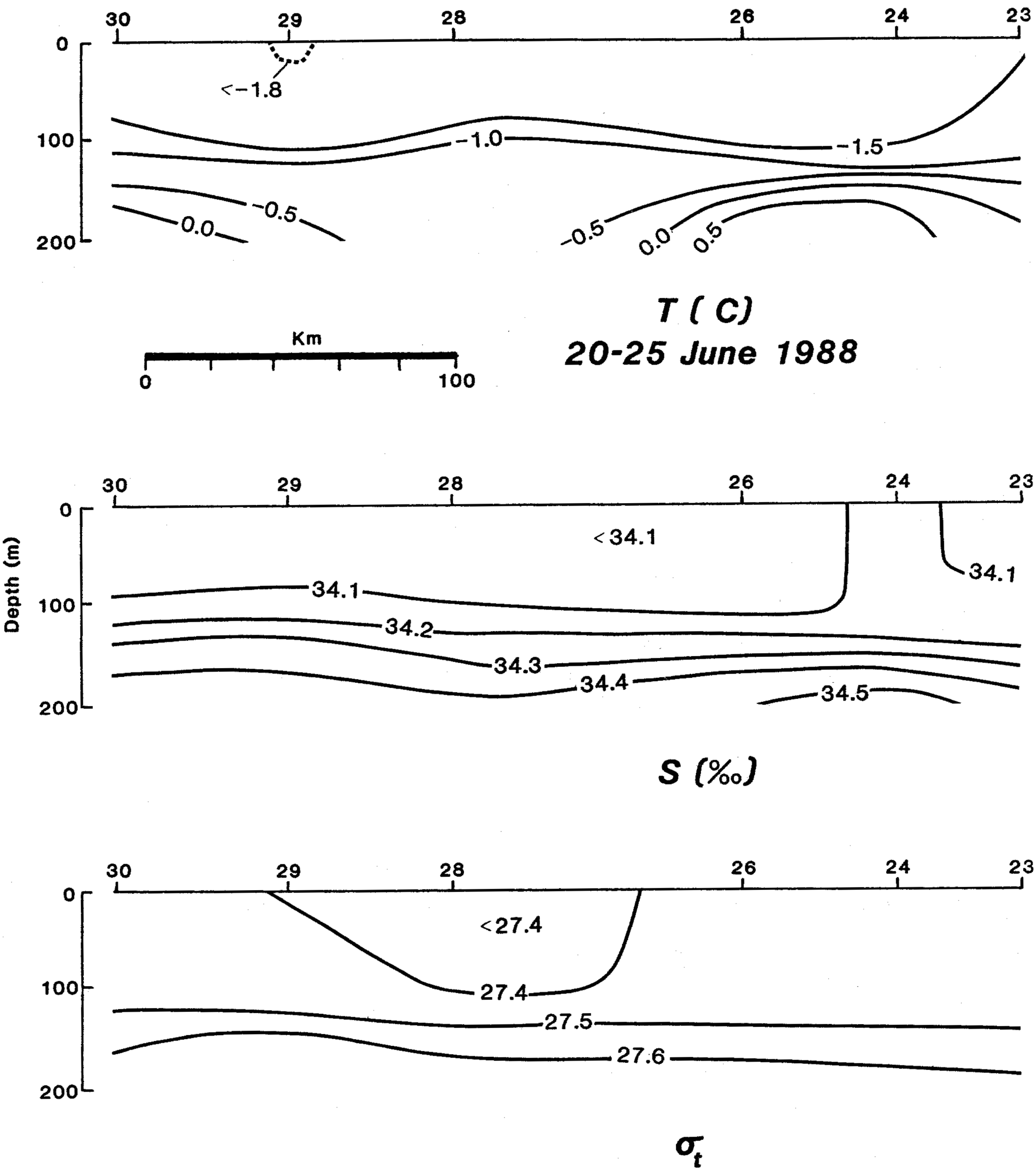

Figure 5. Vertical sections of T, S and sigma-t along east-west transect during Leg 1 of AMERIEZ III survey.Contour intervals are 0.5°C, 0.1 o/oo and 0.1 for T, S and sigma-t, respectively. The heavy black lines at the surface denote the approximate extent of pack ice.

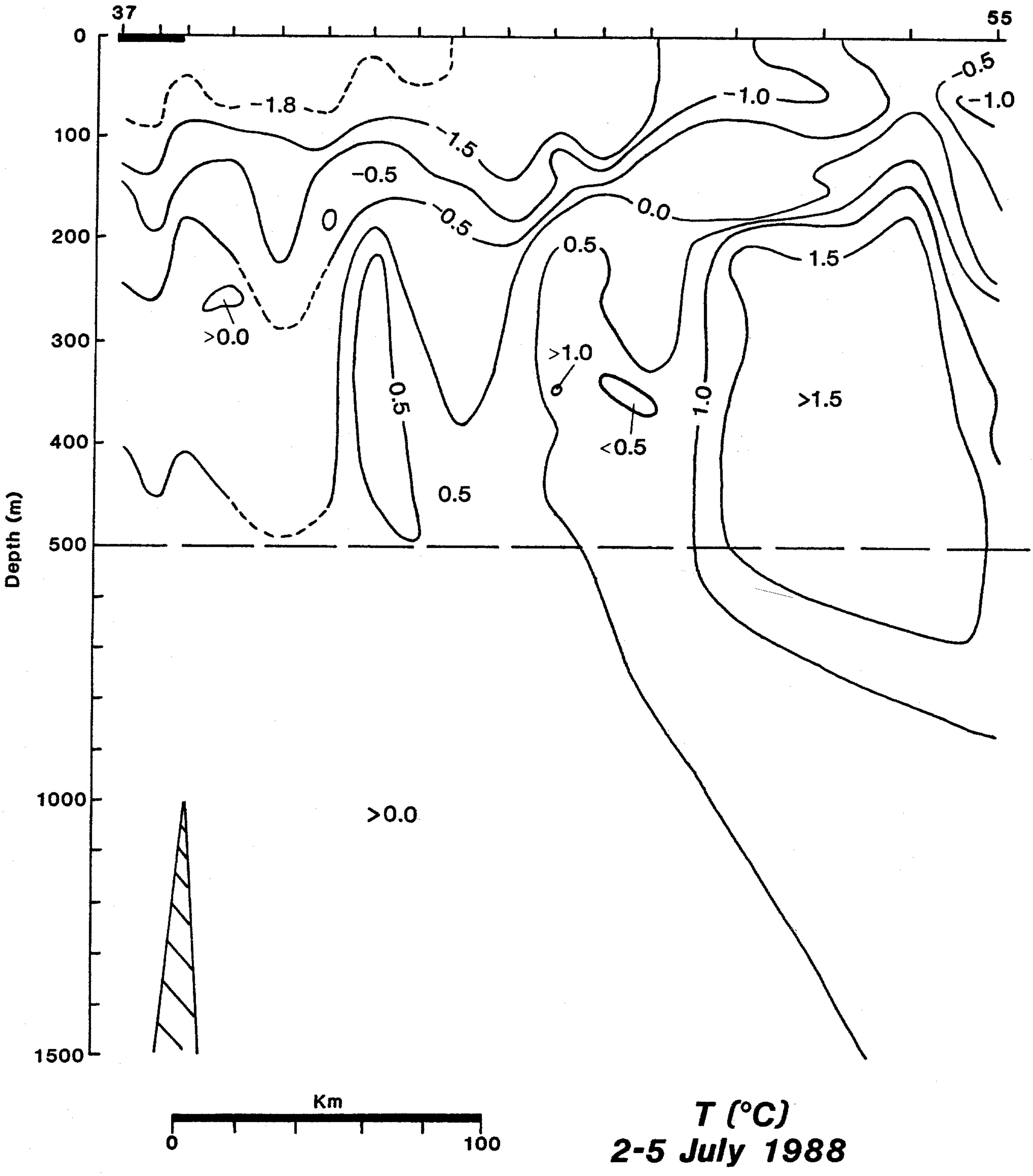

Figure 6. Vertical section of T(°C) along first 48°W transect during Leg 1 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.5°C. The heavy black line at the surface denotes the approximate extent of pack ice.

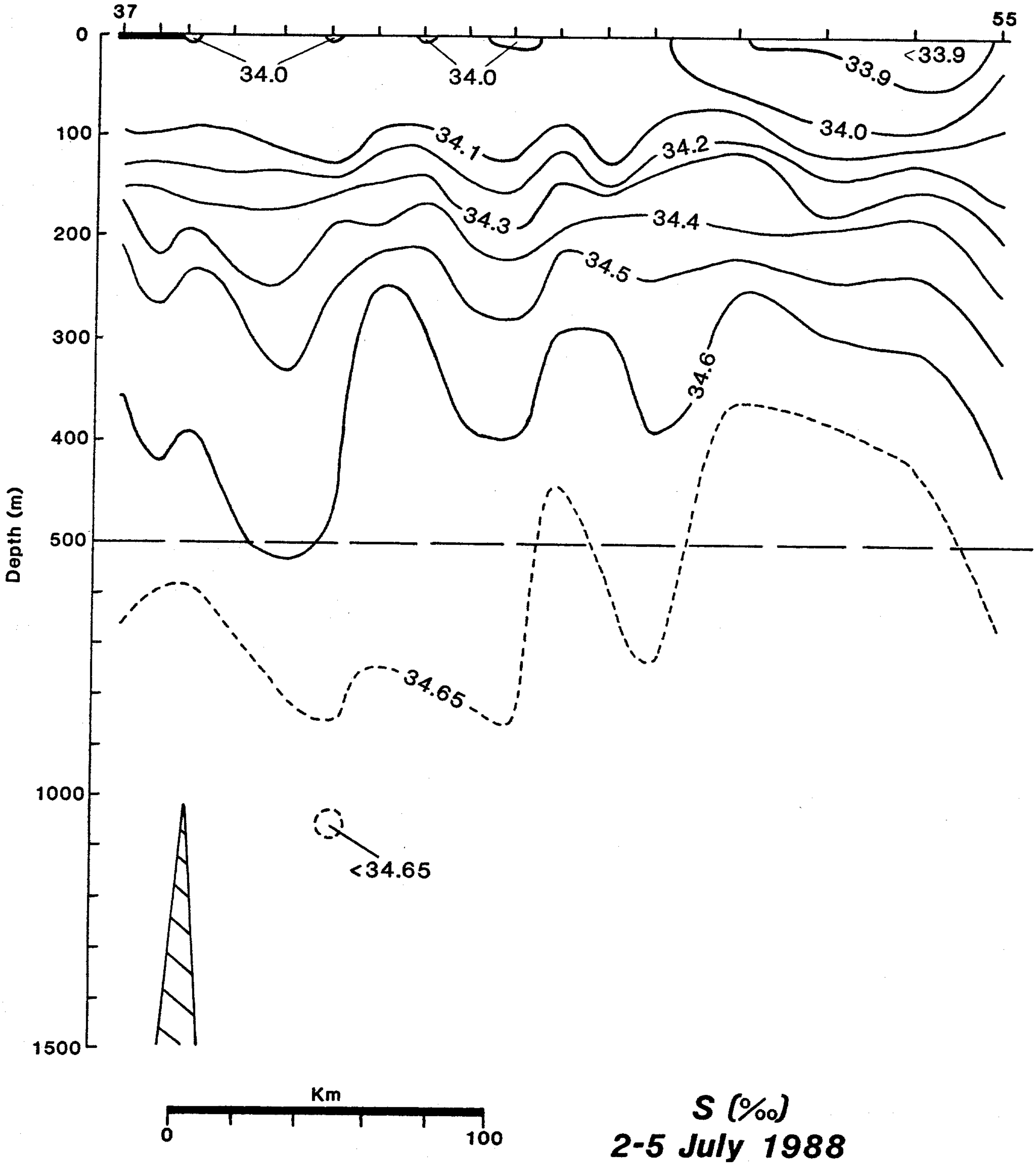

Figure 7. Vertical section of S(o/oo) along first 48°W transect during Leg 1 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.1 o/oo. The heavy black line at the surface denotes the approximate extent of pack ice.

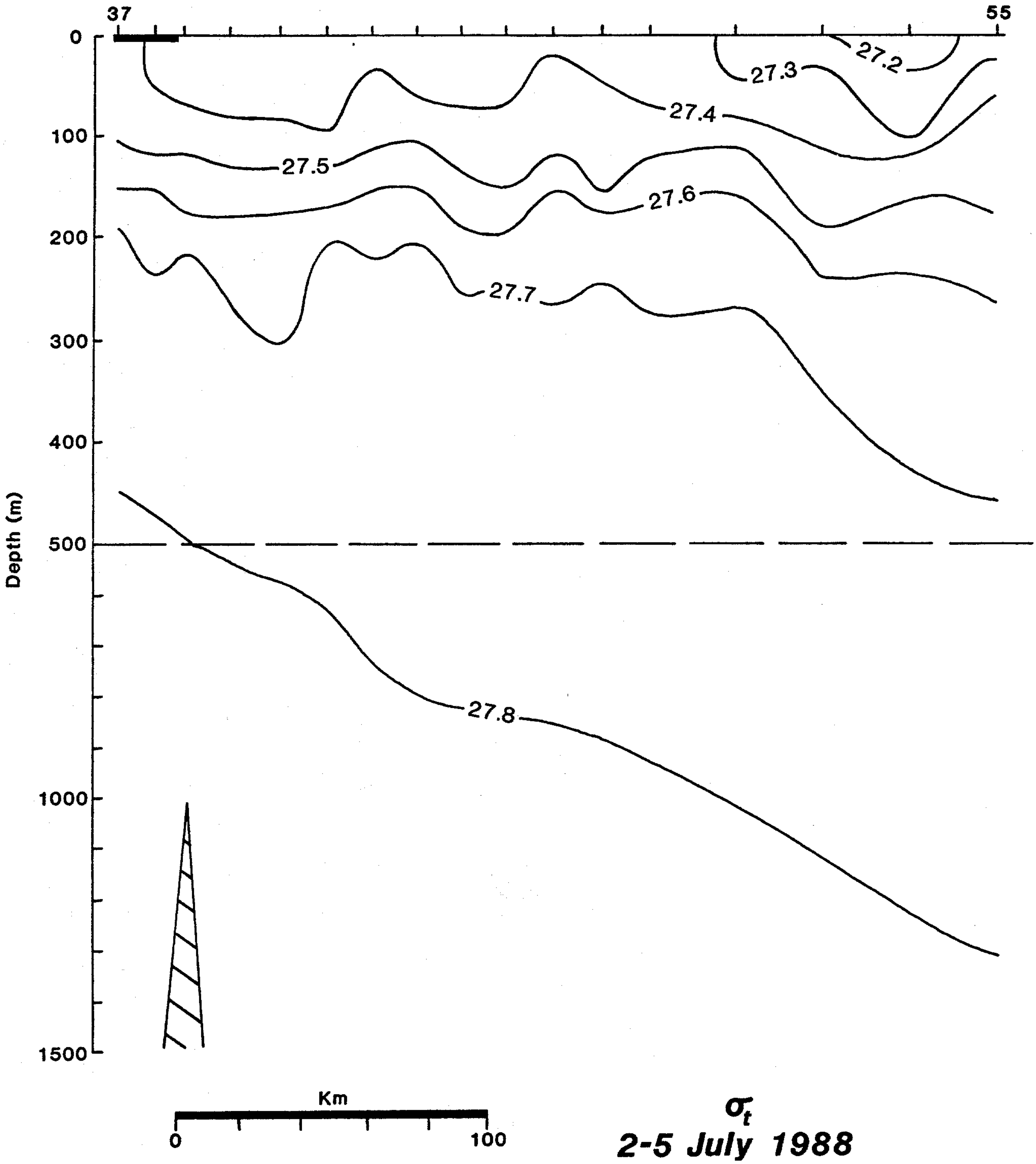

Figure 8. Vertical section of sigma-t along first 48°W transect during Leg 1 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.1 . The heavy black line at the surface denotes the approximate extent of pack ice.

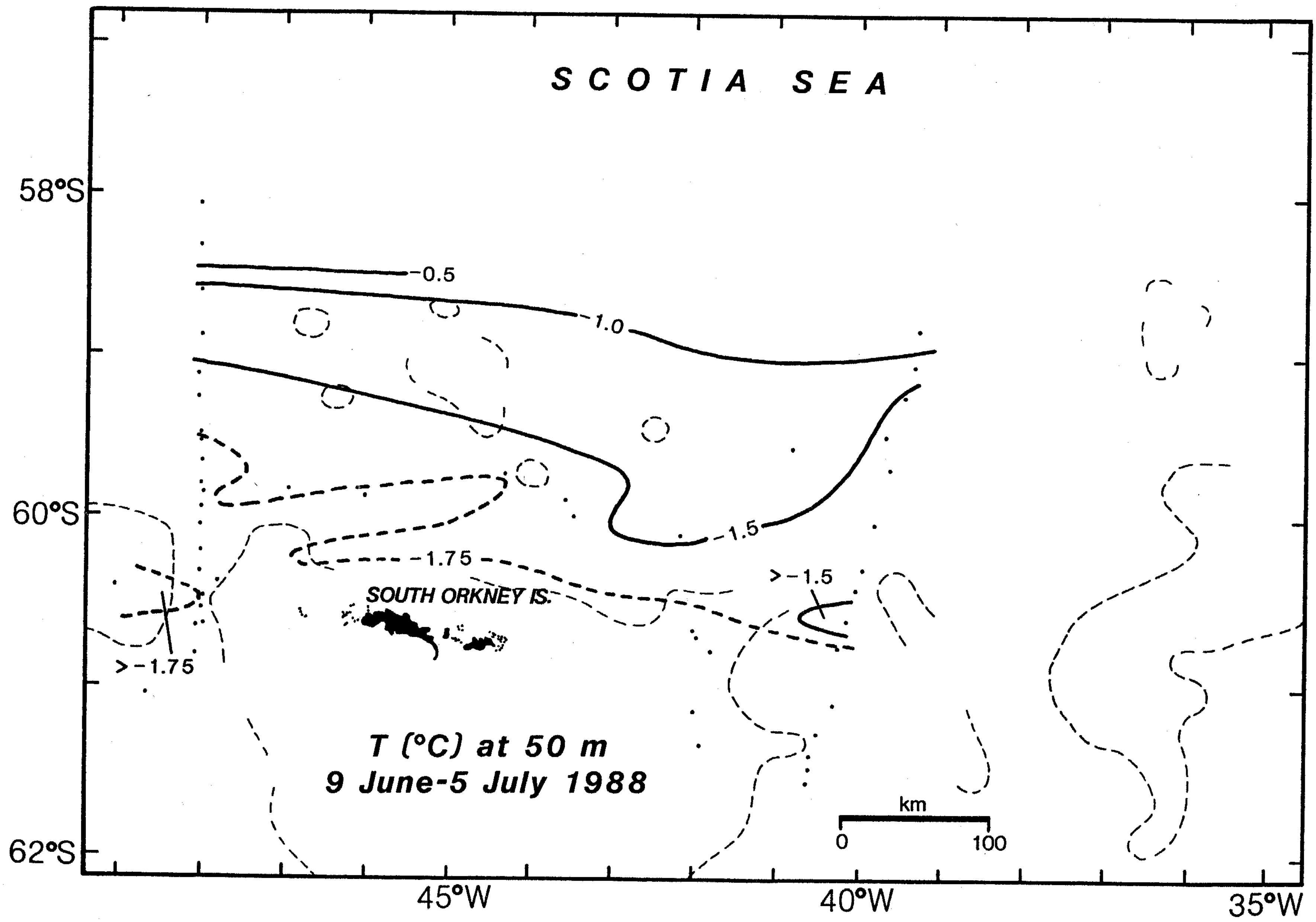

Figure 9. Map of T(°C) at 50 m during Leg 1 of AMERIEZ III Survey. Contour interval is 0.5°C. Dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

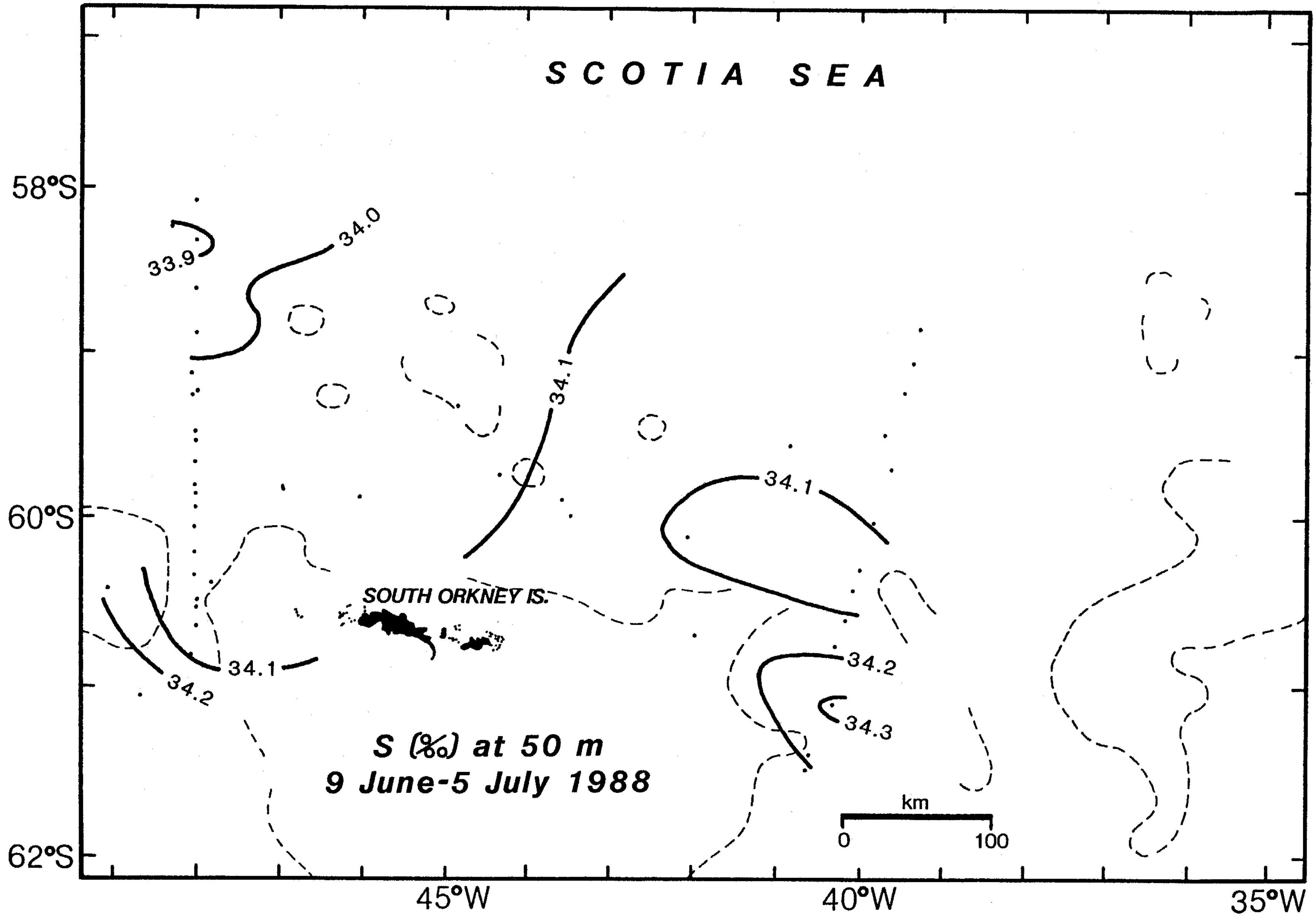

Figure 10. Map of S(o/oo) at 50 m during Leg 1 of AMERIEZ III Survey. Contour interval is 0.1 o/oo. Dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

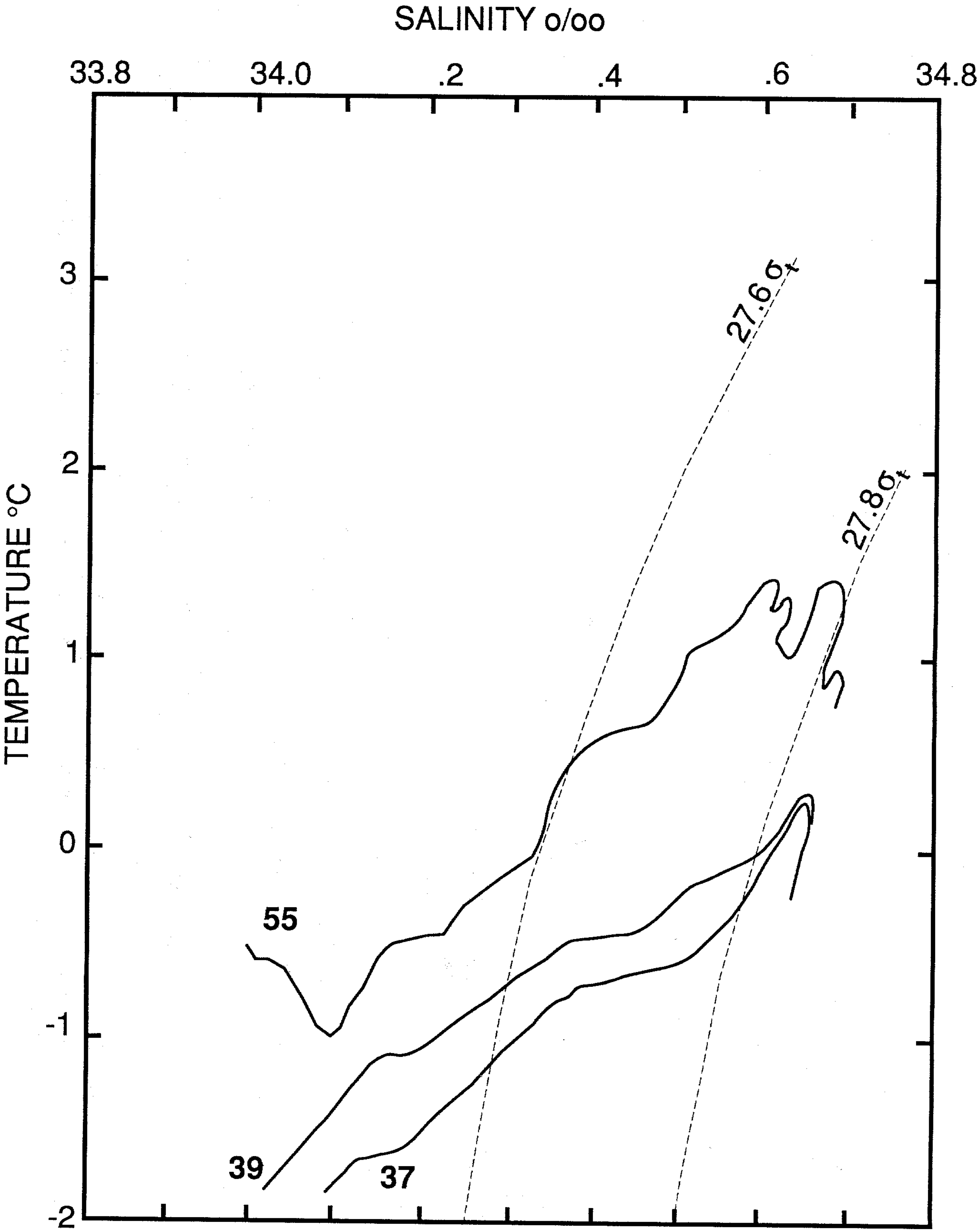

Figure 11. T/S curves for stations 37, 39, and 55 on the first 48°W transect during Leg 1 of AMERIEZ III survey.

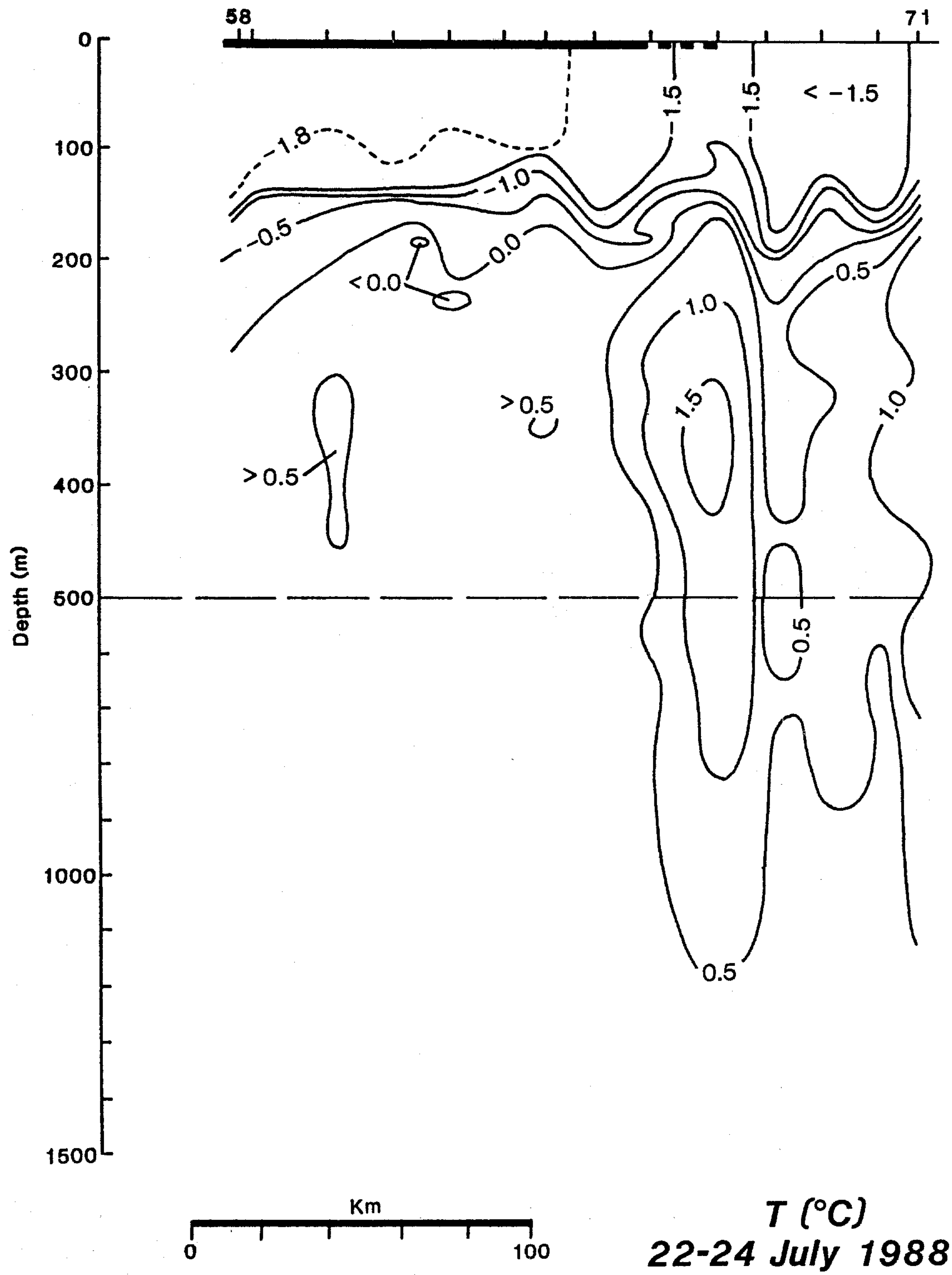

Figure 12. Vertical section of T(°C) along 35°W transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.5°C. The heavy black line at the surface denotes the approximate extent of pack ice.

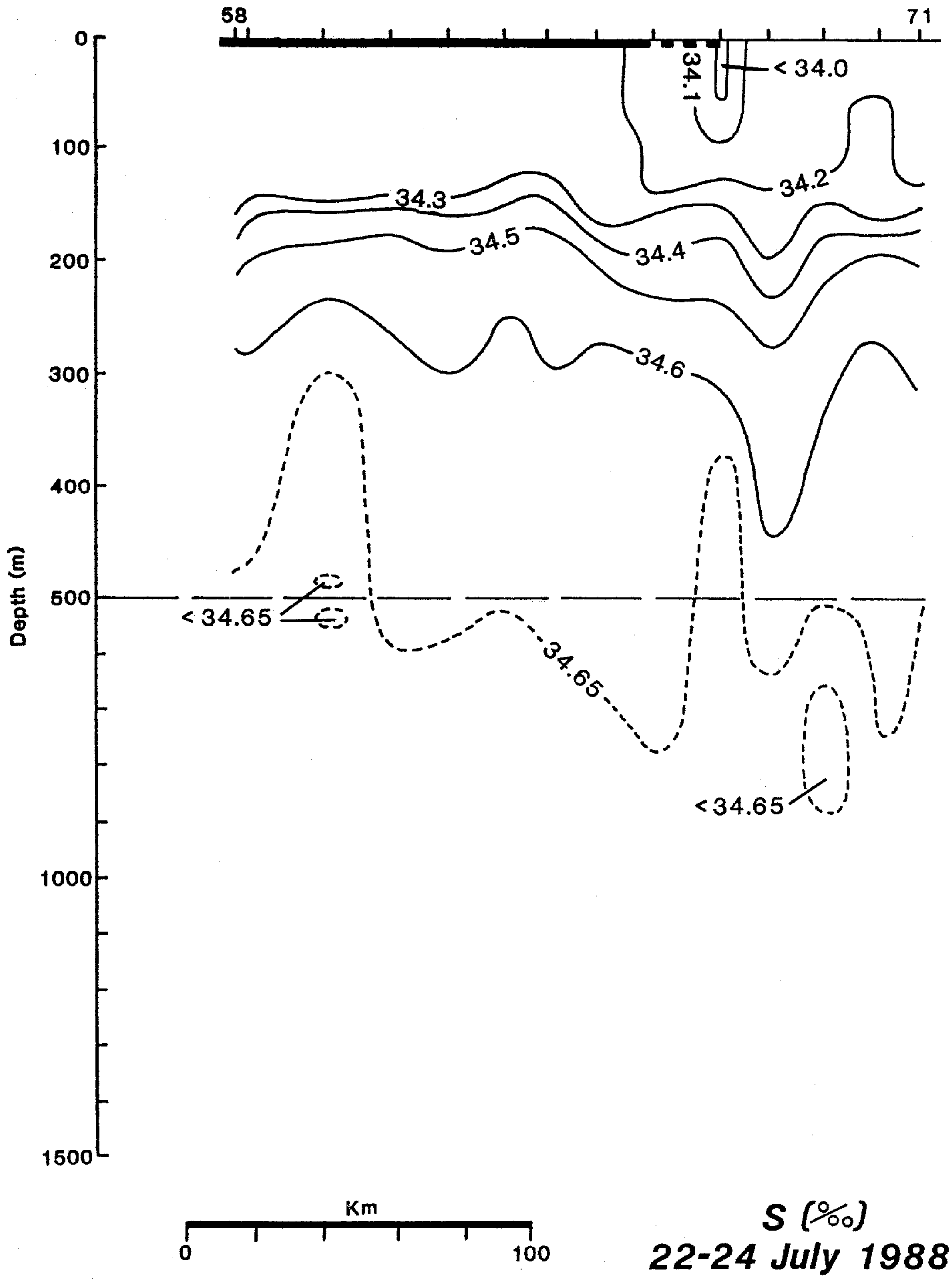

Figure 13. Vertical section of S(o/oo) along 35°W transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.1 o/oo. The heavy black line at the surface denotes the approximate extent of pack ice.

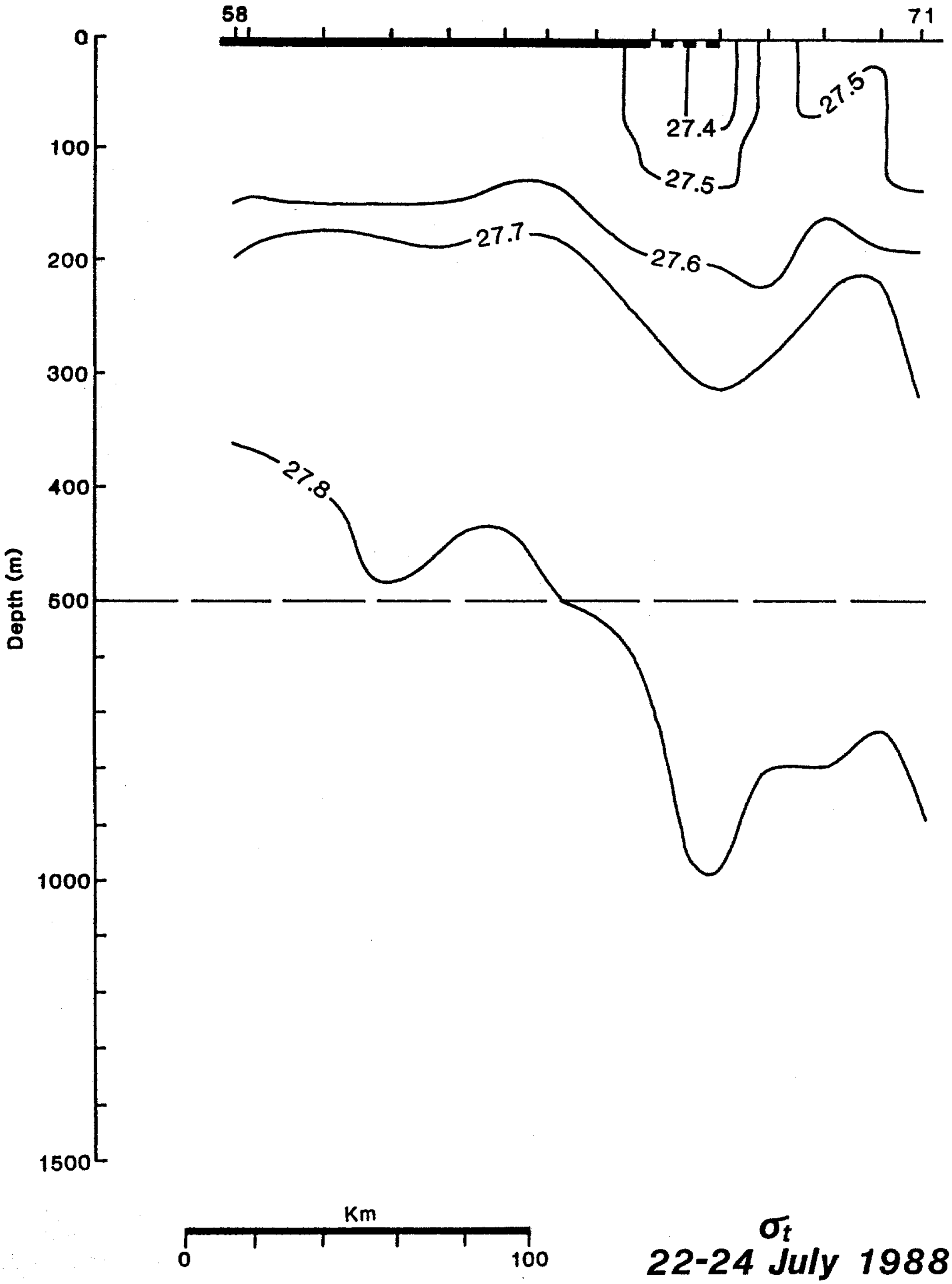

Figure 14. Vertical section of sigma-t along 35°W transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.1. The heavy black line at the surface denotes the approximate extent of pack ice.

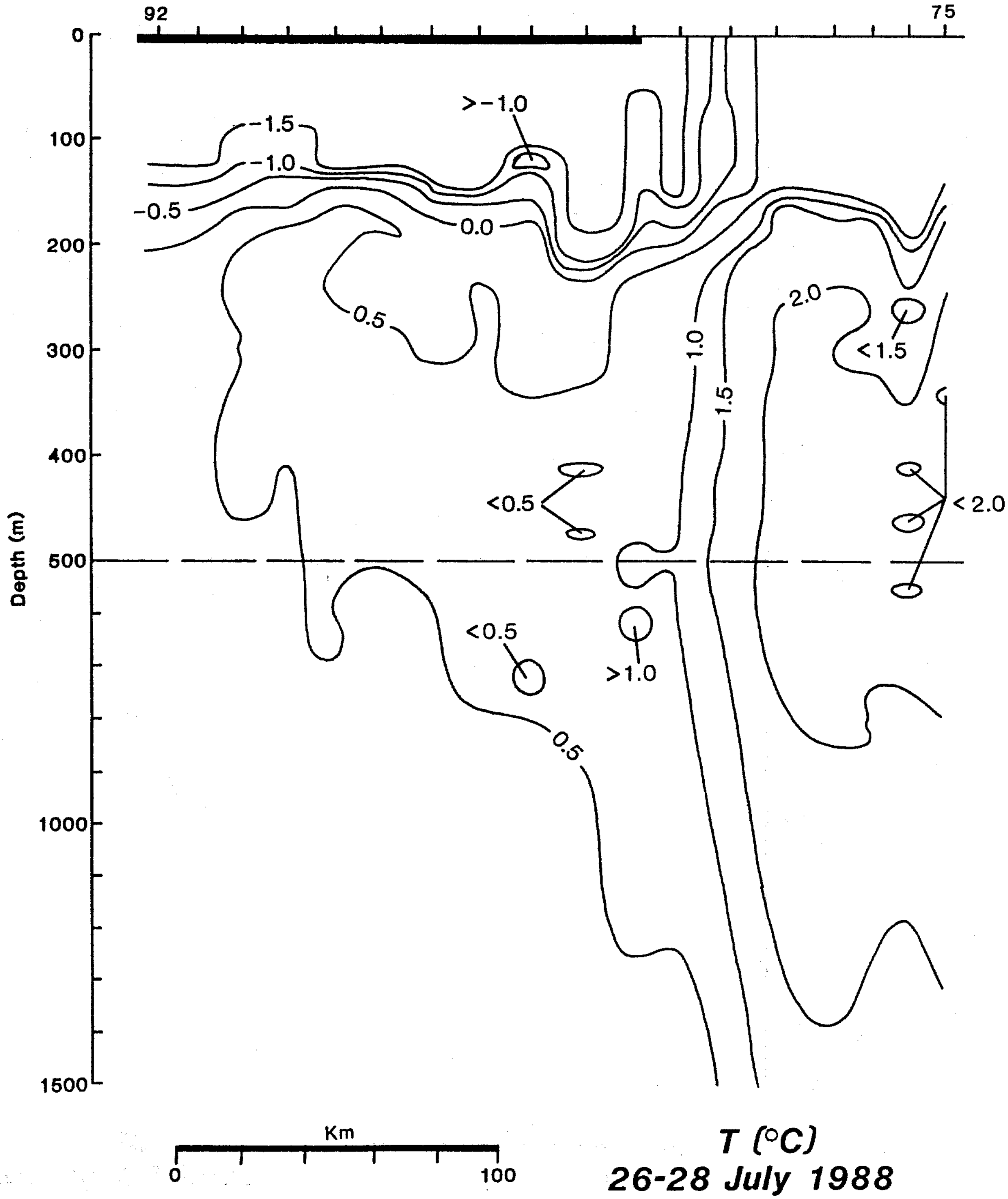

Figure 15. Vertical section of T(°C) along second 40°W transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.5°C. The heavy black line at the surface denotes the approximate extent of pack ice.

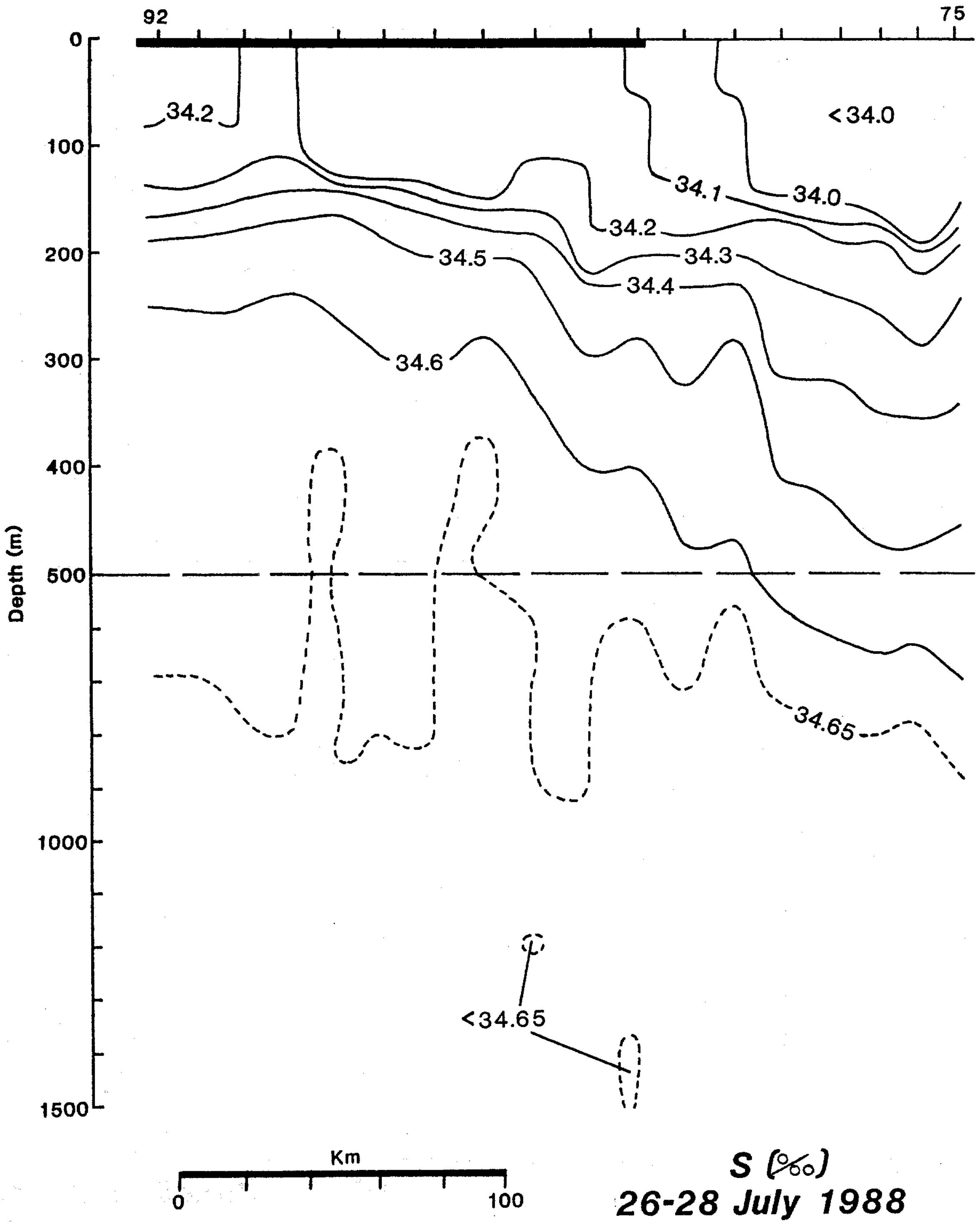

Figure 16. Vertical section of S(o/oo) along second 40°W transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.5°C. The heavy black line at the surface denotes the approximate extent of pack ice.

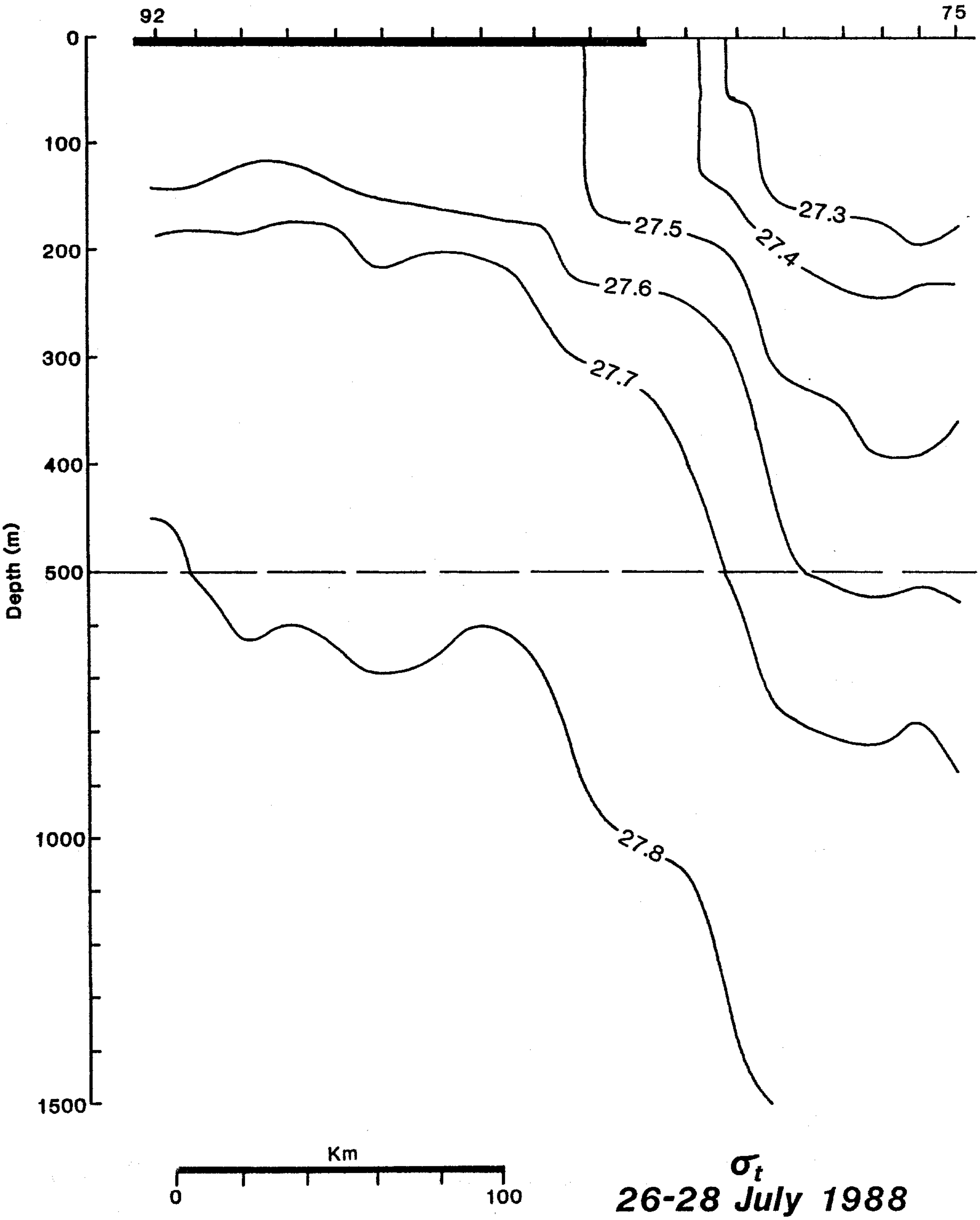

Figure 17. Vertical section of sigma-t along second 40°W transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.1. The heavy black line at the surface denotes the approximate extent of pack ice.

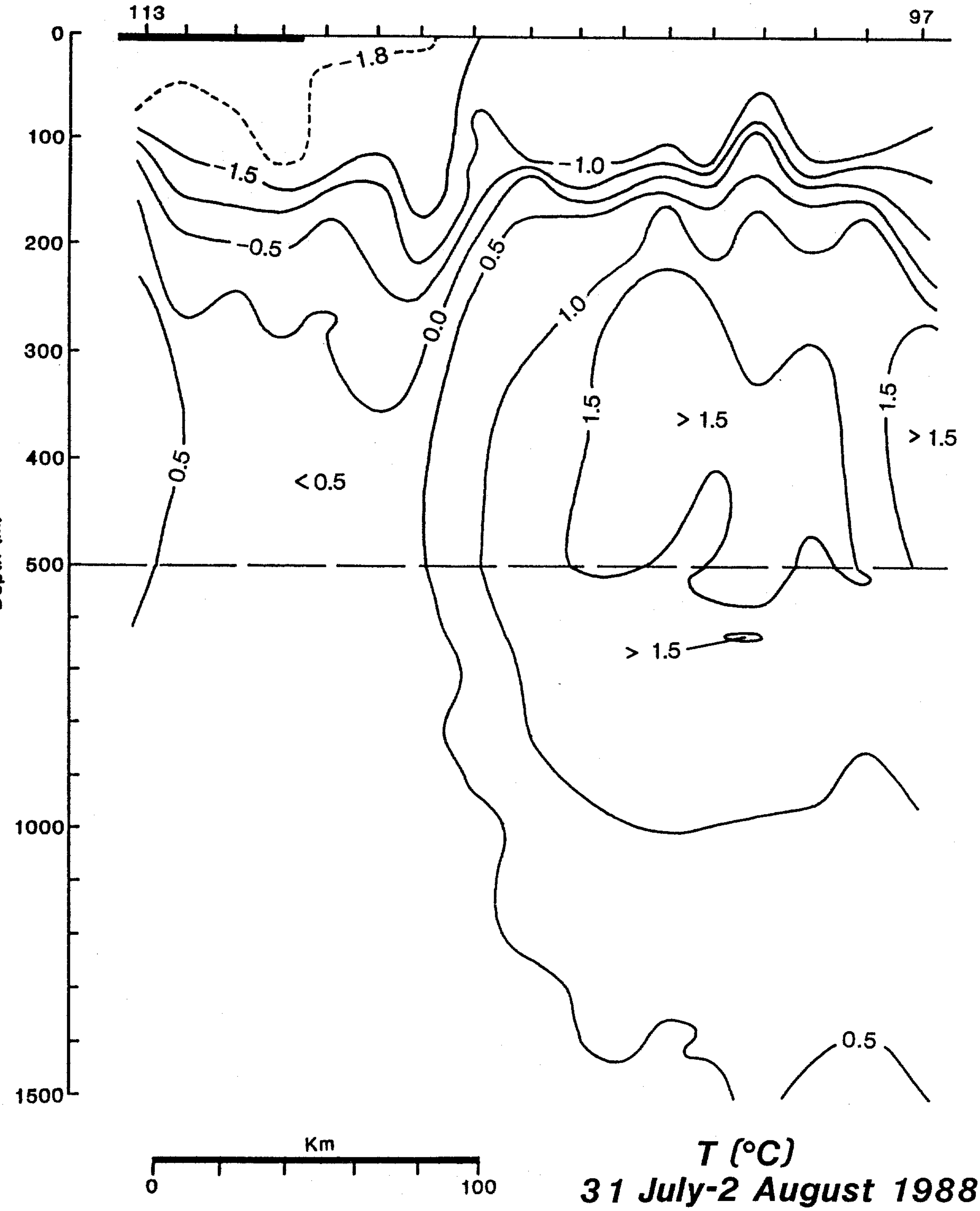

Figure 18. Vertical section of T(°C) along 44°W transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.5°C. The heavy black line at the surface denotes the approximate extent of pack ice.

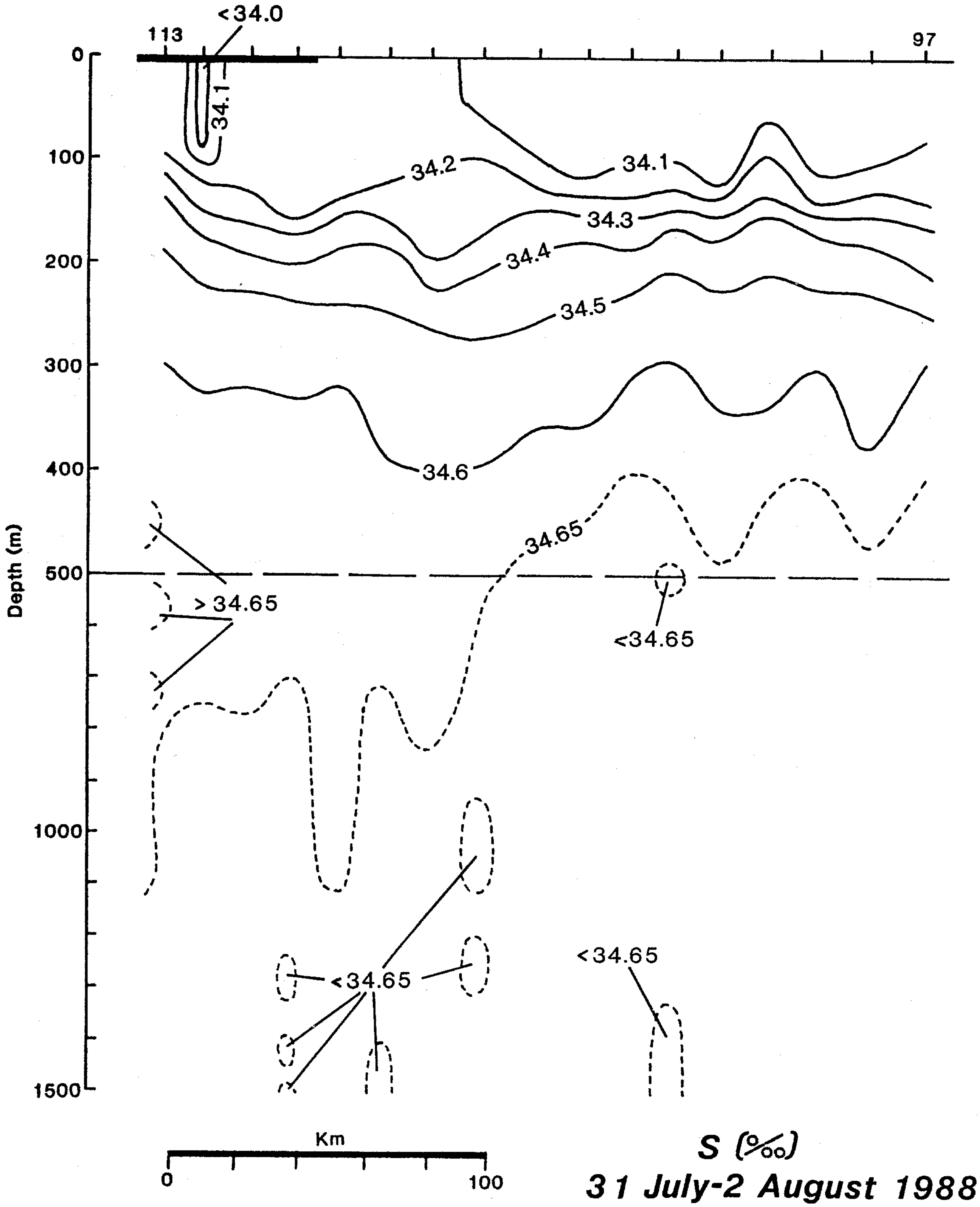

Figure 19. Vertical section of S(°o/oo) along 44°W transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.1 o/oo. The heavy black line at the surface denotes the approximate extent of pack ice.

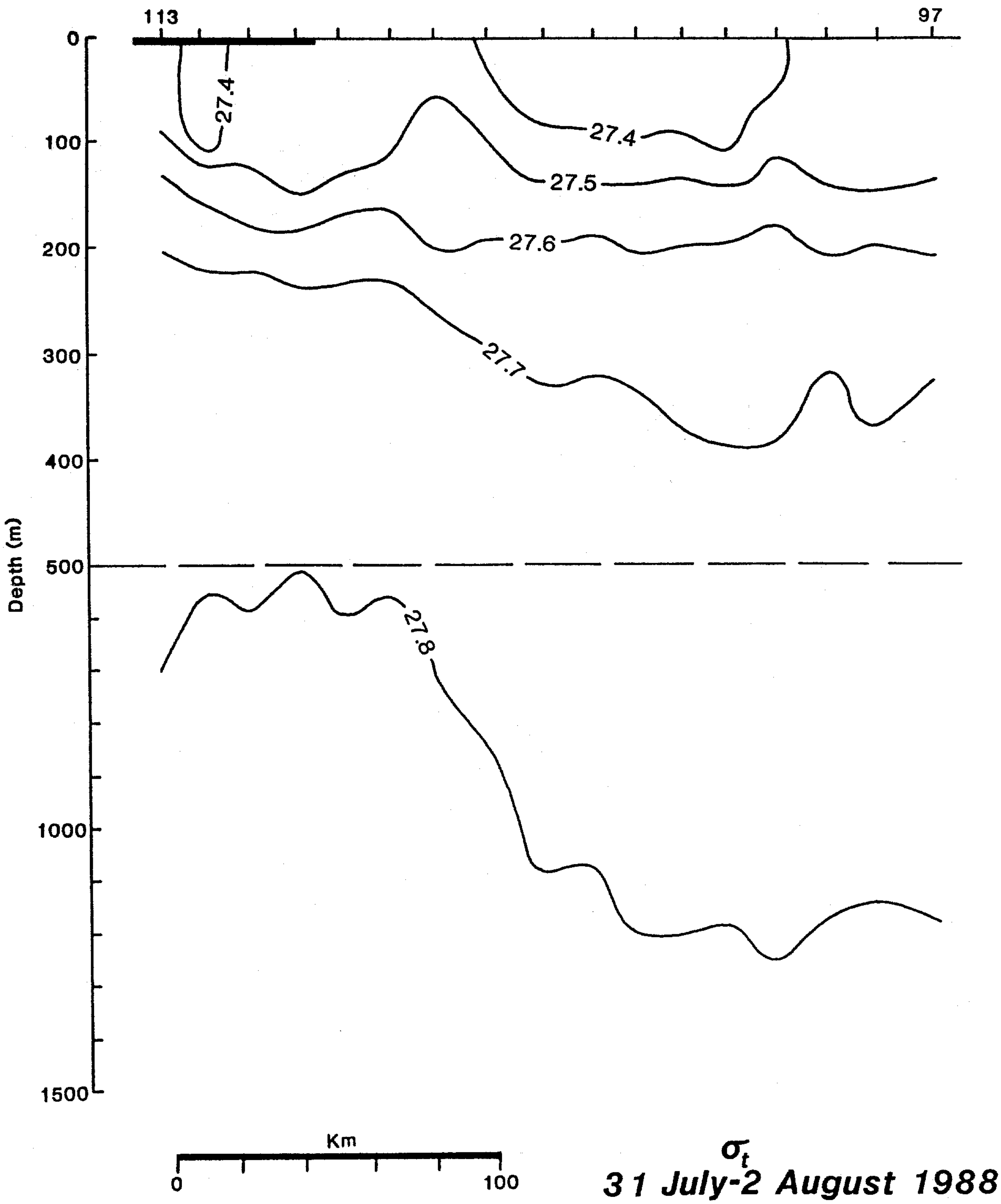

Figure 20. Vertical section of sigma-t along 44°W transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.1. The heavy black line at the surface denotes the approximate extent of pack ice.

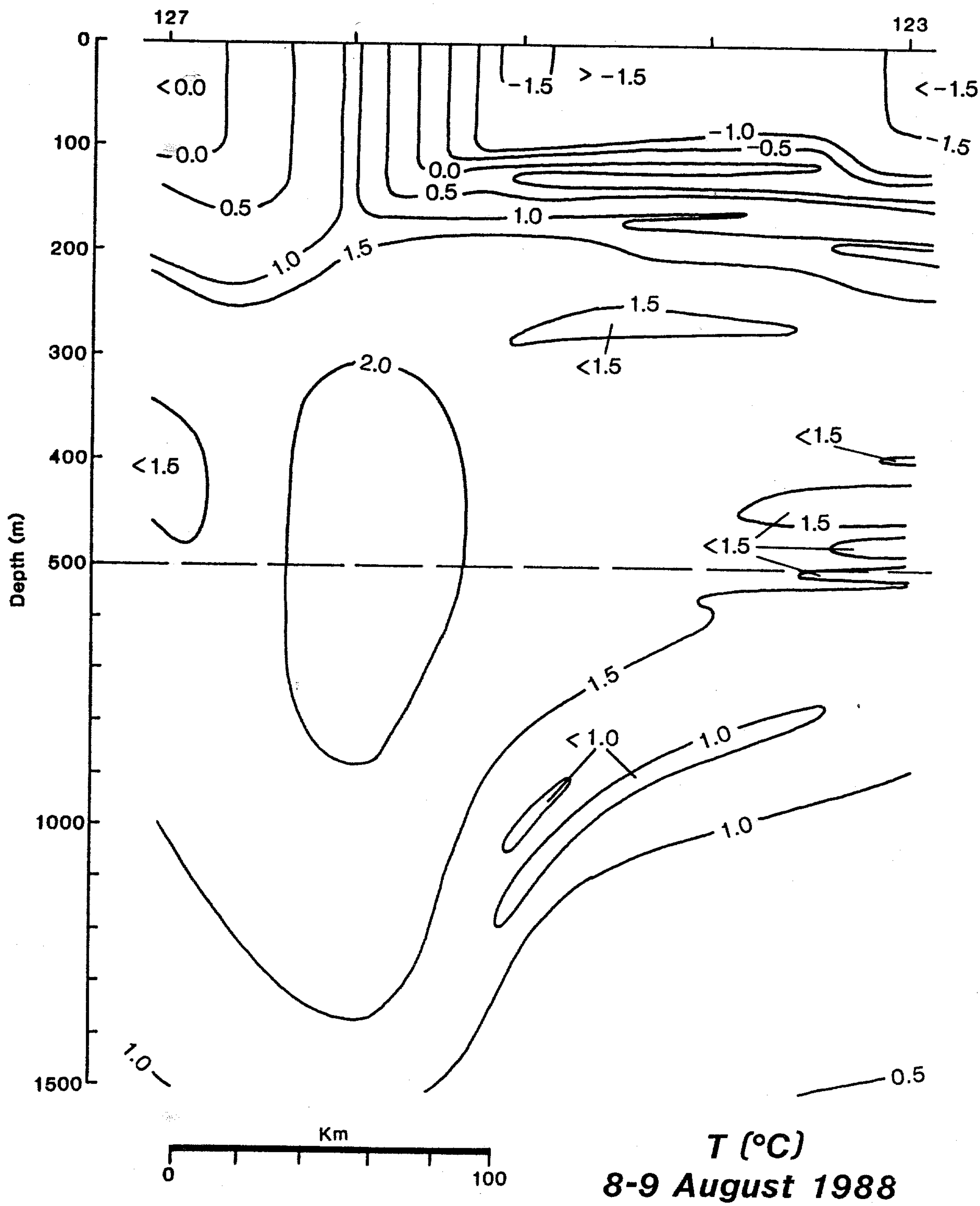

Figure 21. Vertical section of T(°C) along second east-west transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.5°C. The heavy black line at the surface denotes the approximate extent of pack ice.

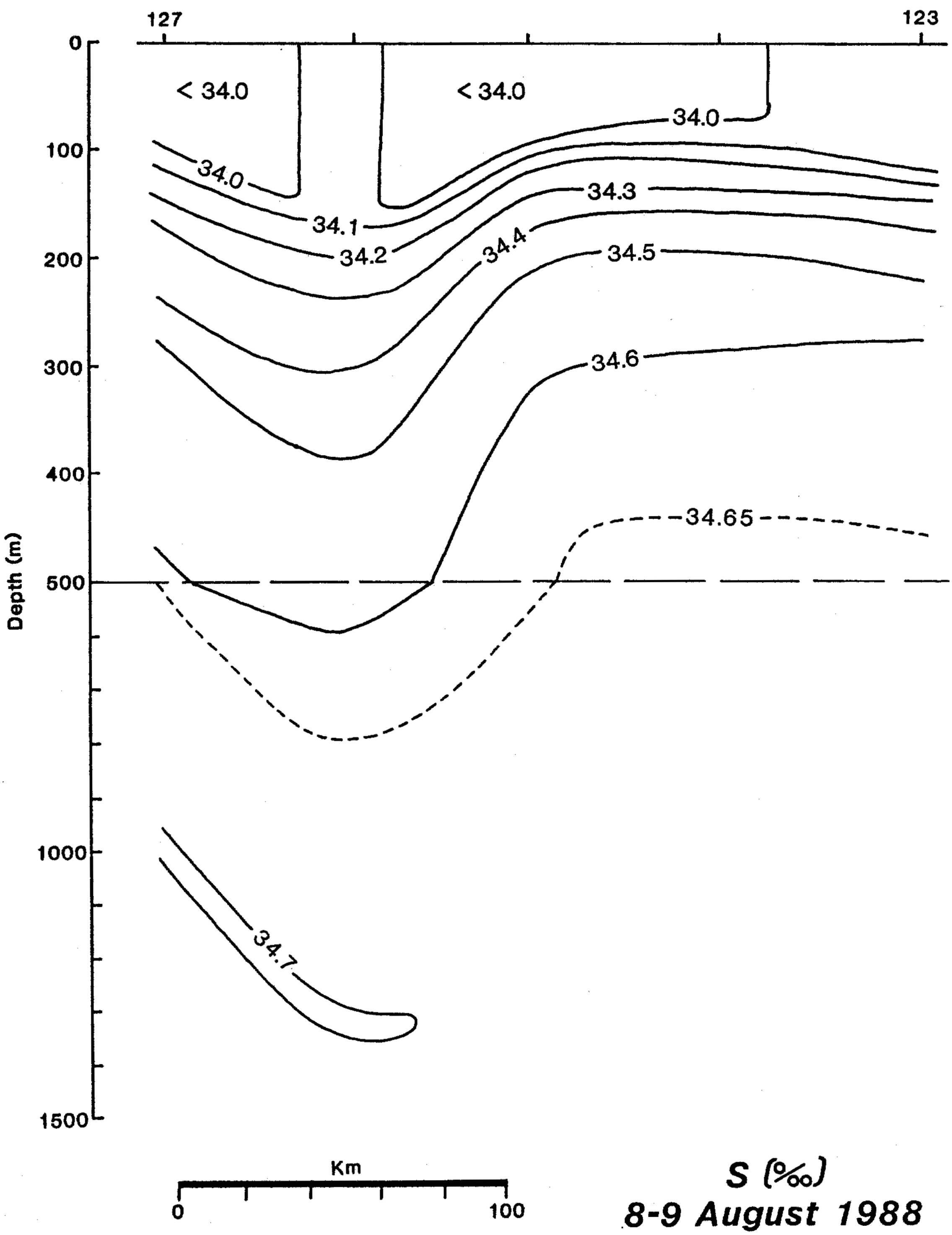

Figure 22. Vertical section of S(o/oo) along second east-west transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.1 o/oo. The heavy black line at the surface denotes the approximate extent of pack ice.

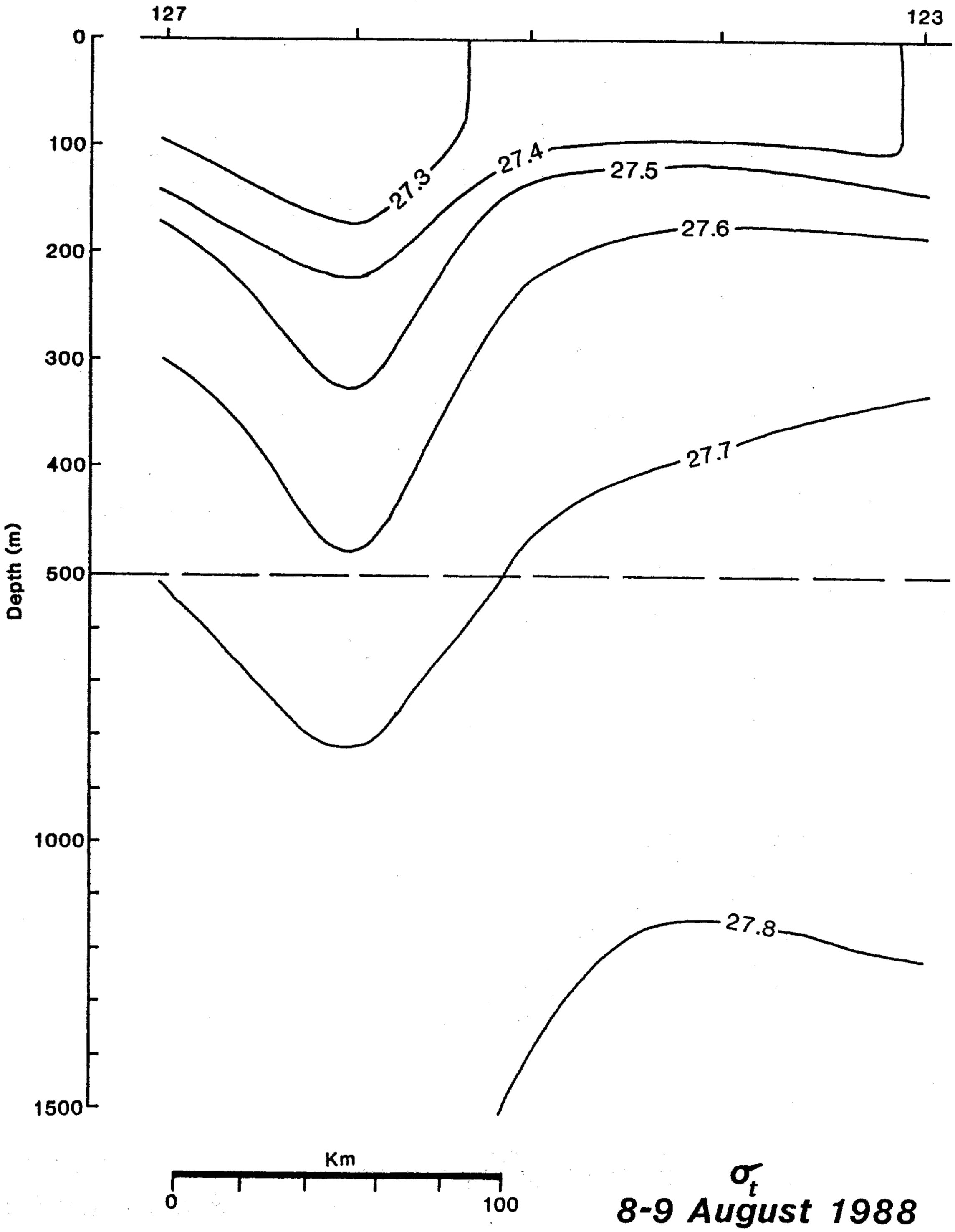

Figure 23. Vertical section of sigma-t along second east-west transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.1. The heavy black line at the surface denotes the approximate extent of pack ice.

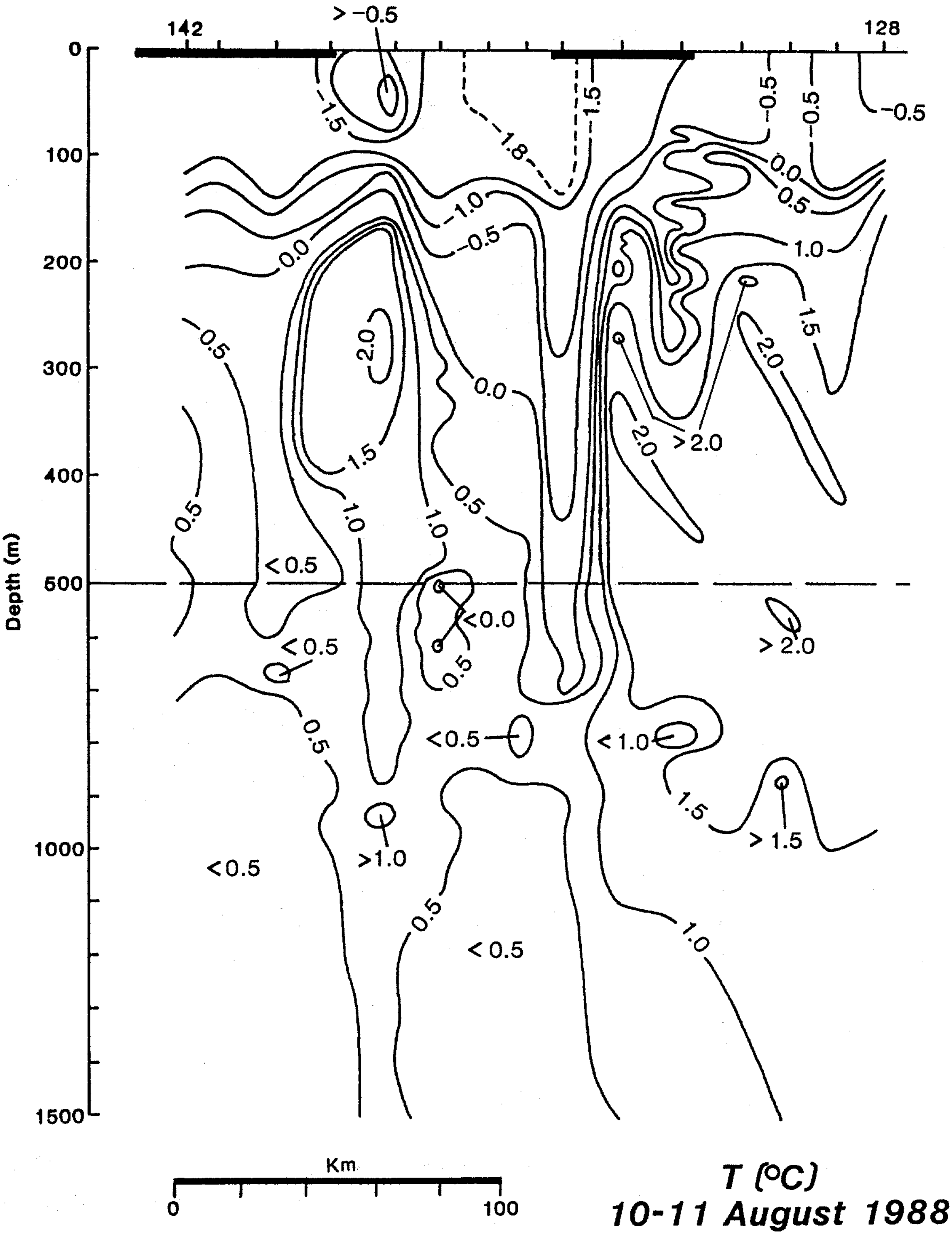

Figure 24. Vertical section of T(°C) along second 48°W transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.5°C. The heavy black line at the surface denotes the approximate extent of pack ice.

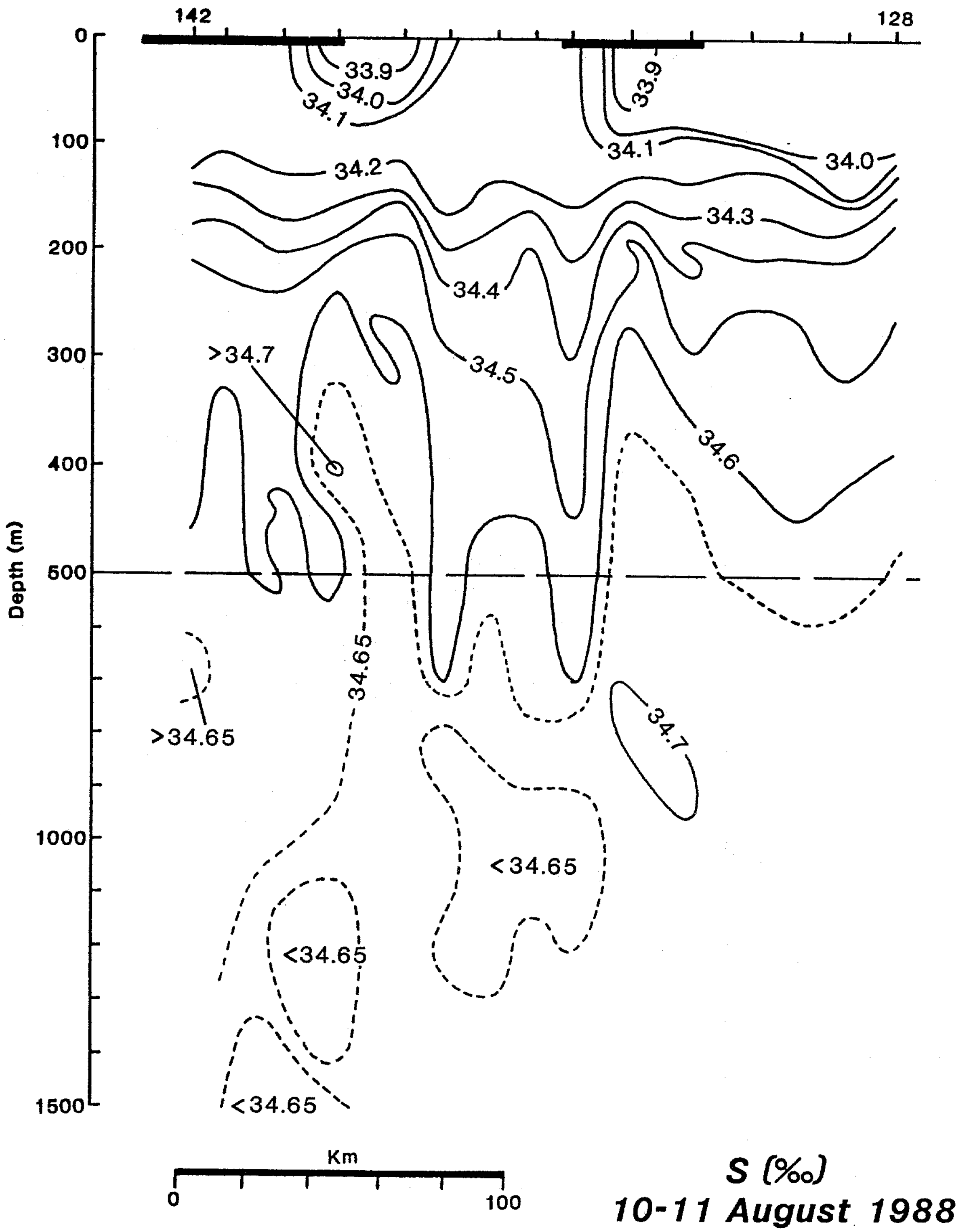

Figure 25. Vertical section of S(o/oo) along second 48°W transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.1 o/oo. The heavy black line at the surface denotes the approximate extent of pack ice.

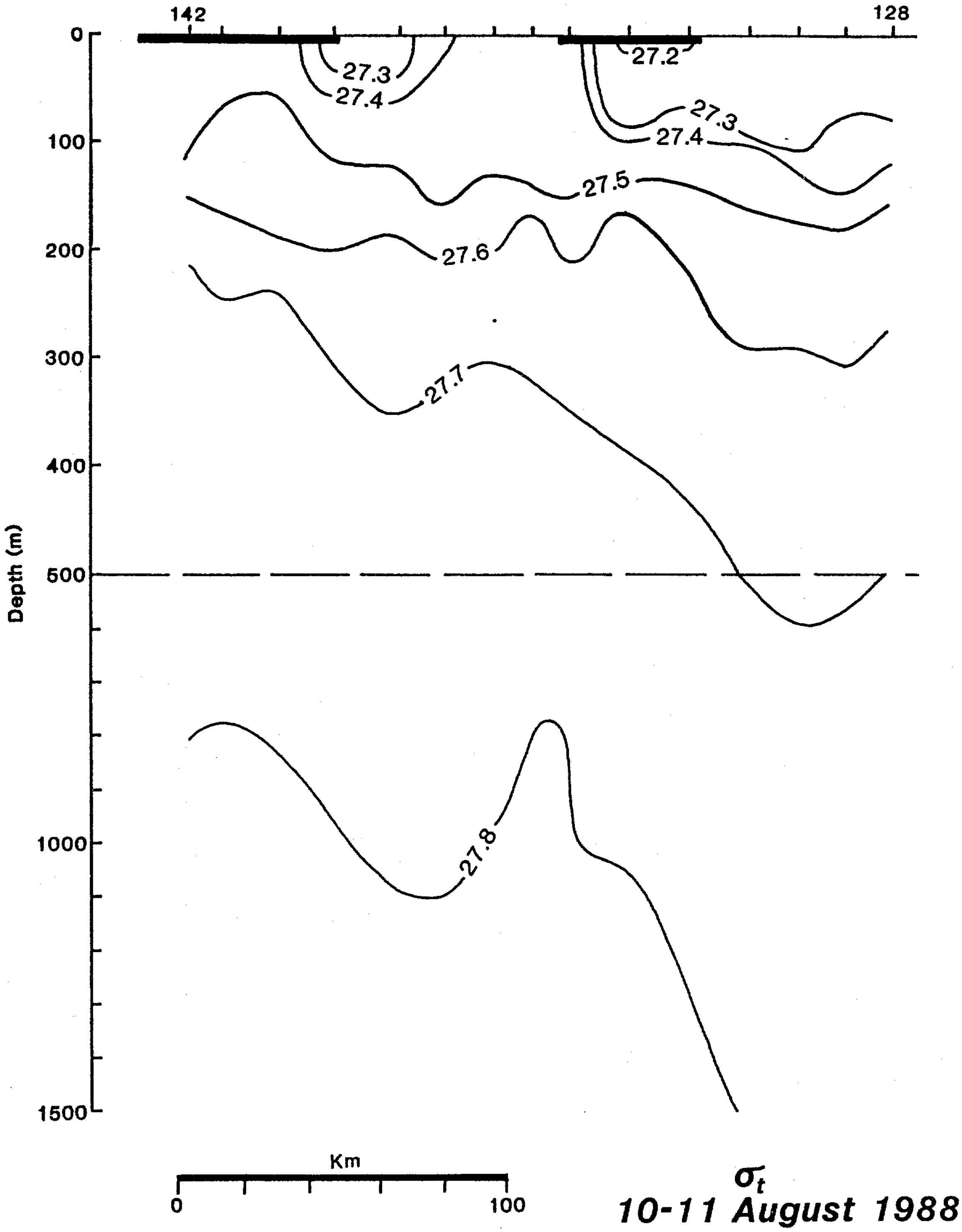

Figure 26. Vertical section of sigma-t along second 48°W transect during Leg 2 of AMERIEZ III survey. Depth scale change at 500 m denotes by horizontal dashed line. Contour interval is 0.1. The heavy black line at the surface denotes the approximate extent of pack ice.

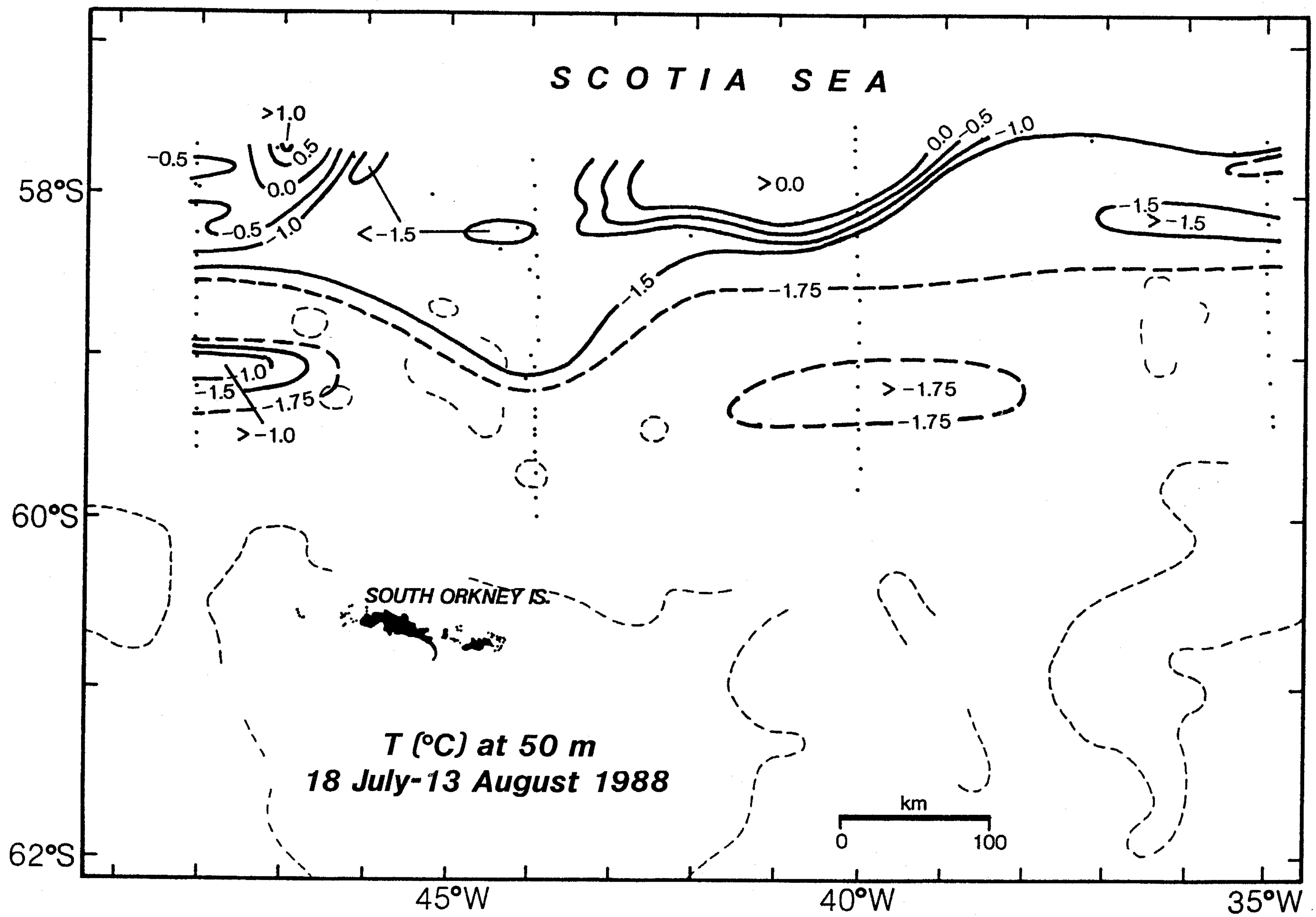

Figure 27. Map of T(°C) at 50 m during Leg 2 of AMERIEZ III survey. Contour interval is 0.5°C. Dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

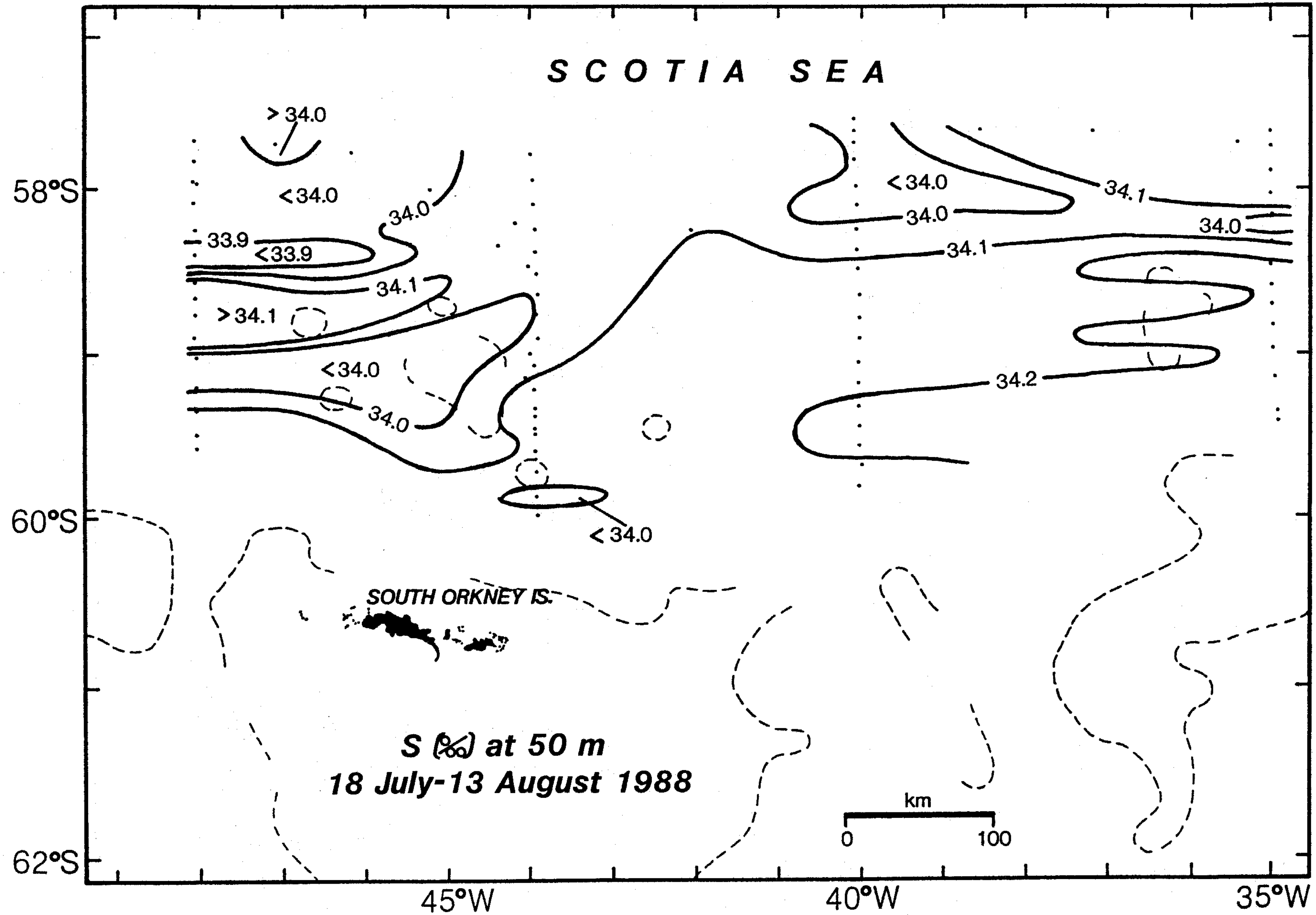

Figure 28. Map of S(o/oo) at 50 m during Leg 2 of AMERIEZ III survey. Contour interval is 0.1 o/oo. Dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

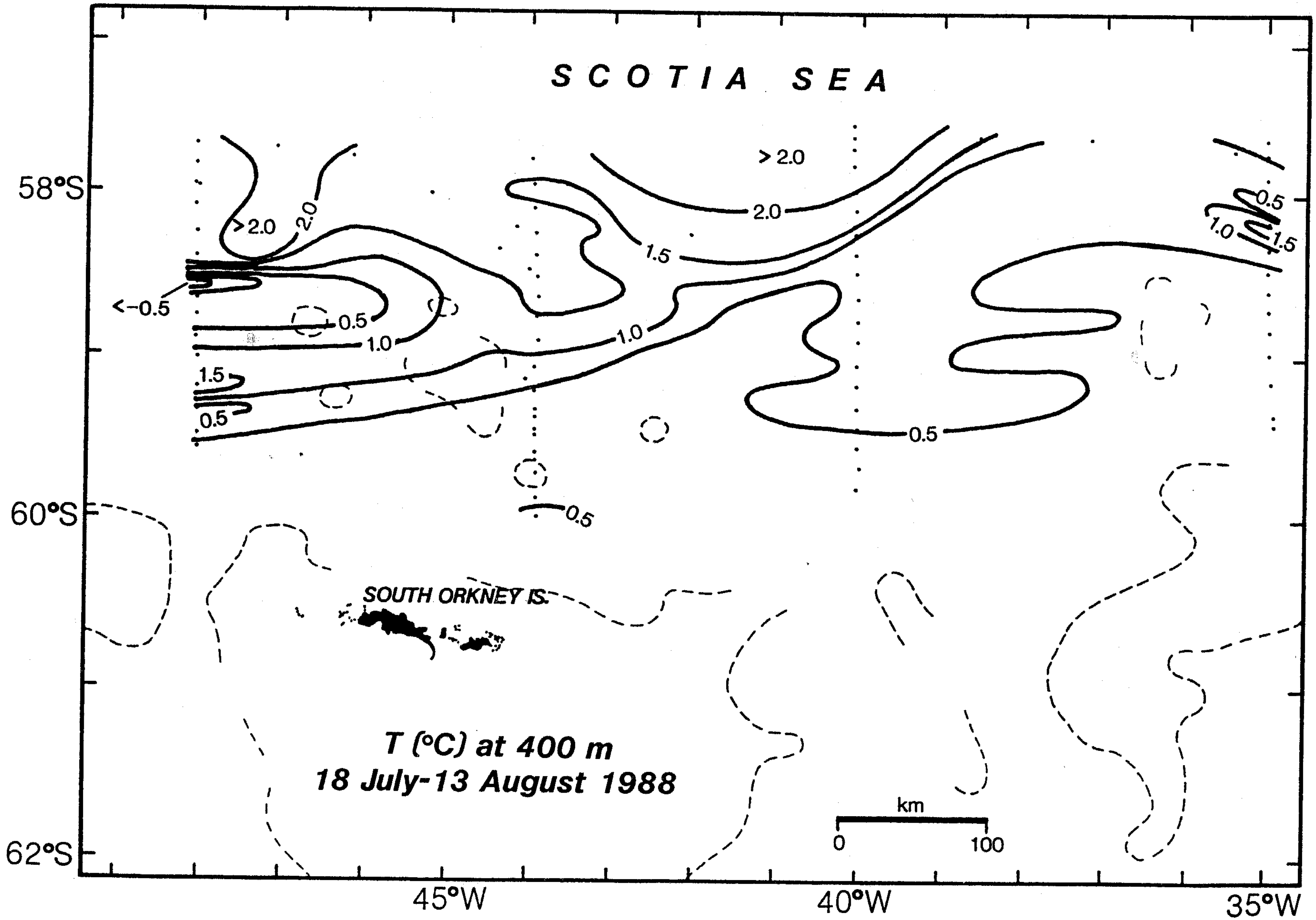

Figure 29. Map of T(°C) at 400 m during Leg 2 of AMERIEZ III survey. Contour interval is 0.5°C. Dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

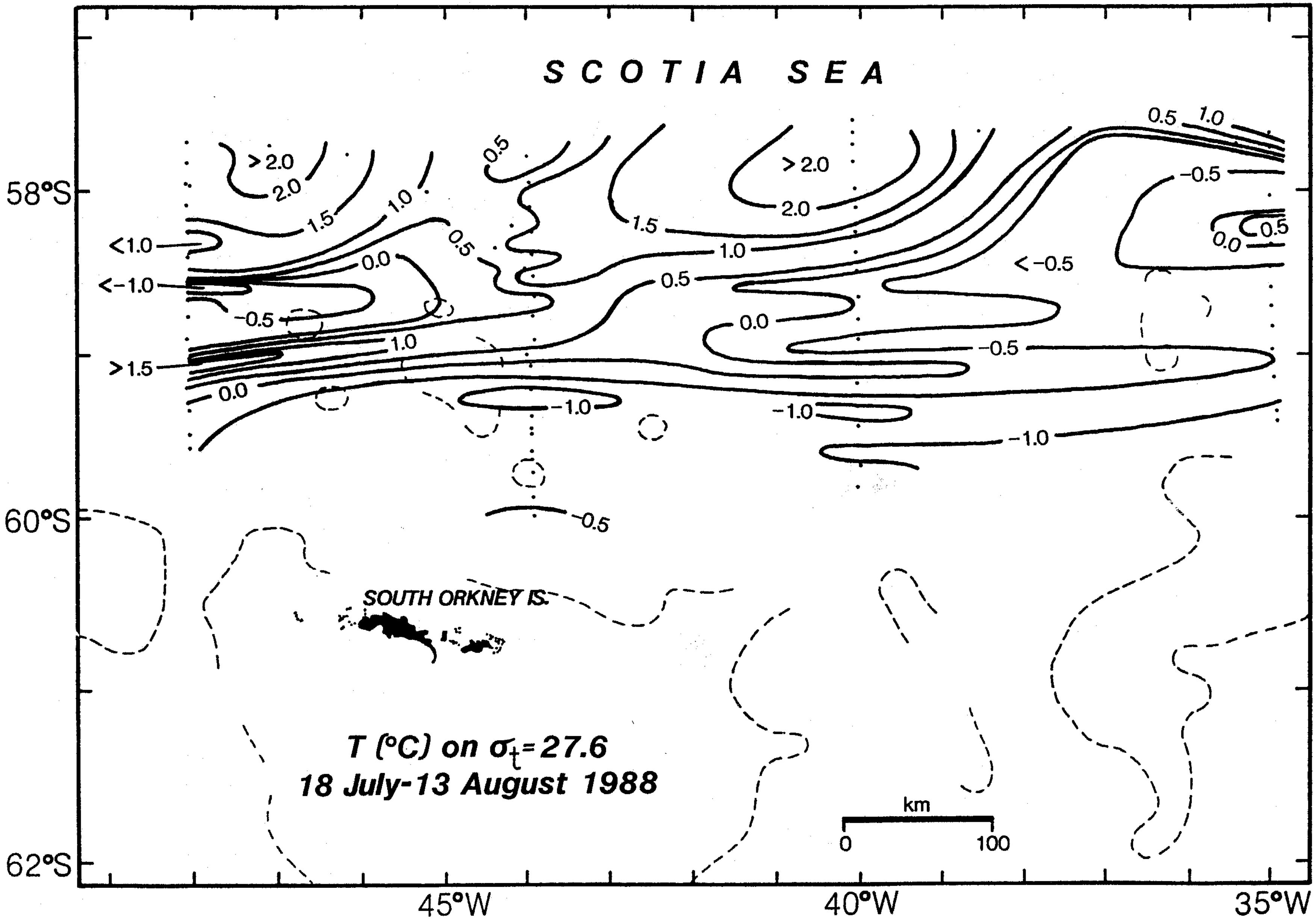

Figure 30. Map of T(°C) on 27.6 sigma-t surface during Leg 2 of AMERIEZ III survey. Contour interval is 0.5°C. Dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

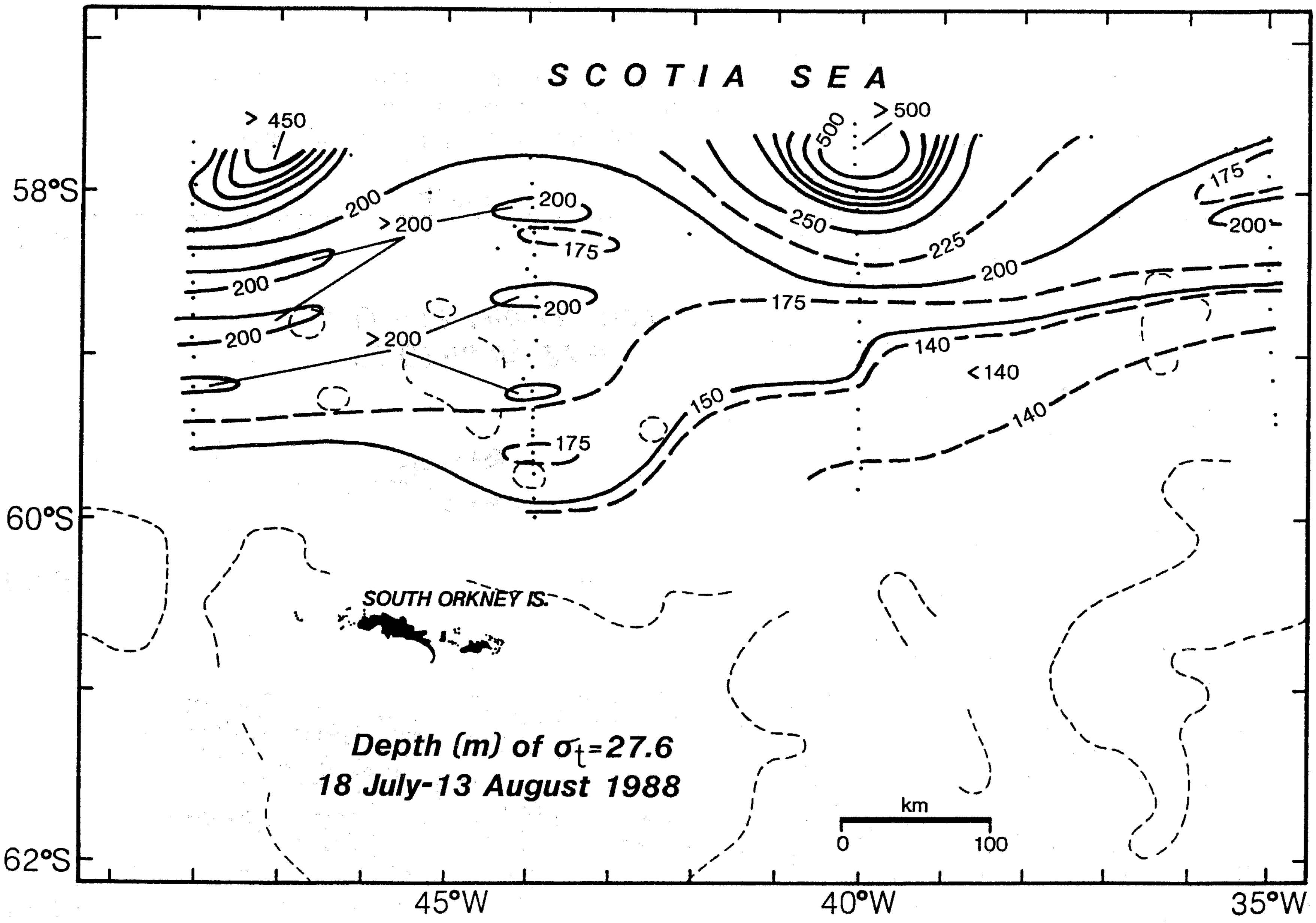

Figure 31. Map of depth of 27.6 sigma-t surface during Leg 2 of AMERIEZ III survey. Contour interval is 50 m with the exception of heavy dashed contours which delineate depth minima. Light dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

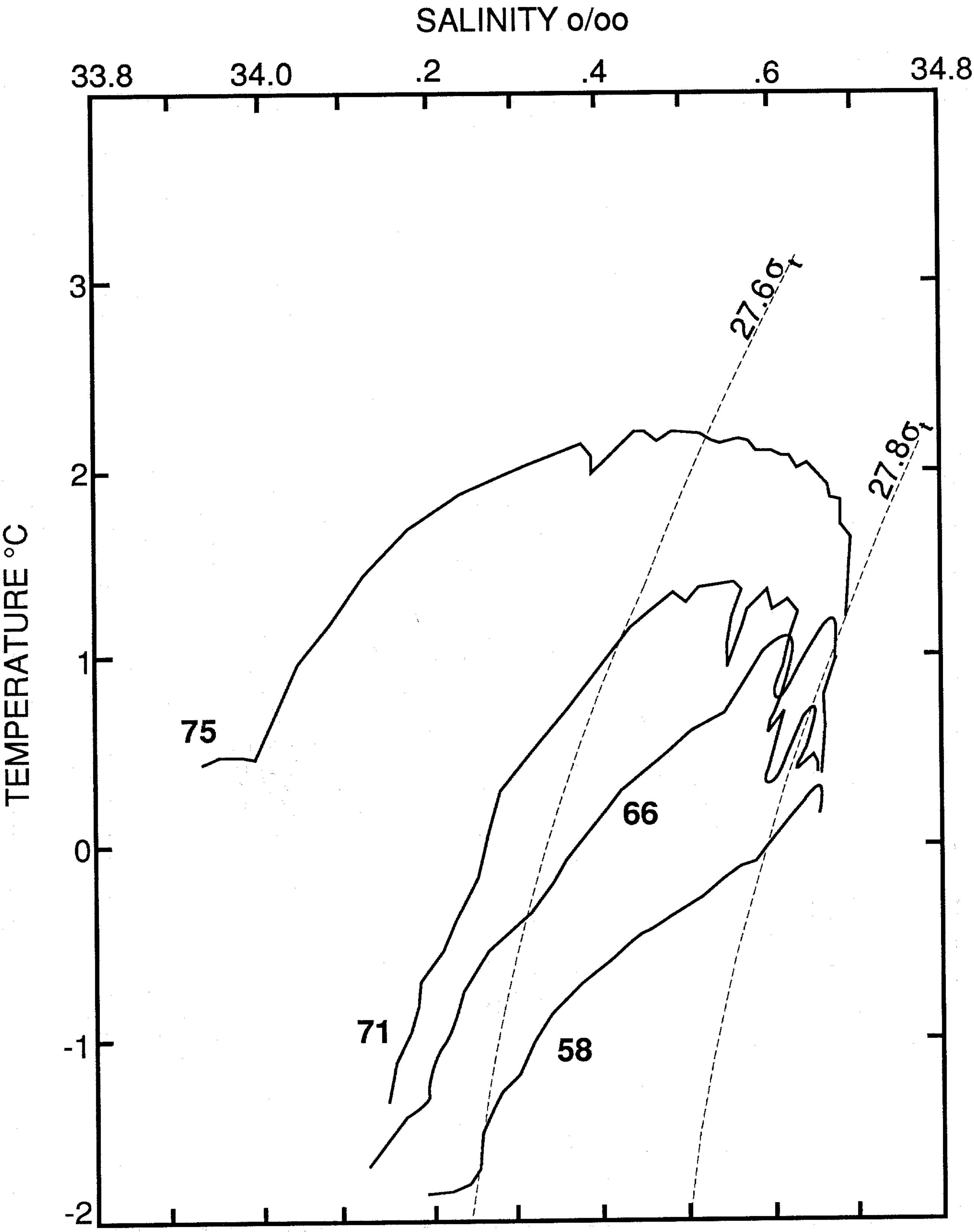

Figure 32. T/S curves from Stations 58, 66 and 71 on 35°W transect and station 75 on 40°W transect , Leg 2 of AMERIEZ III survey.

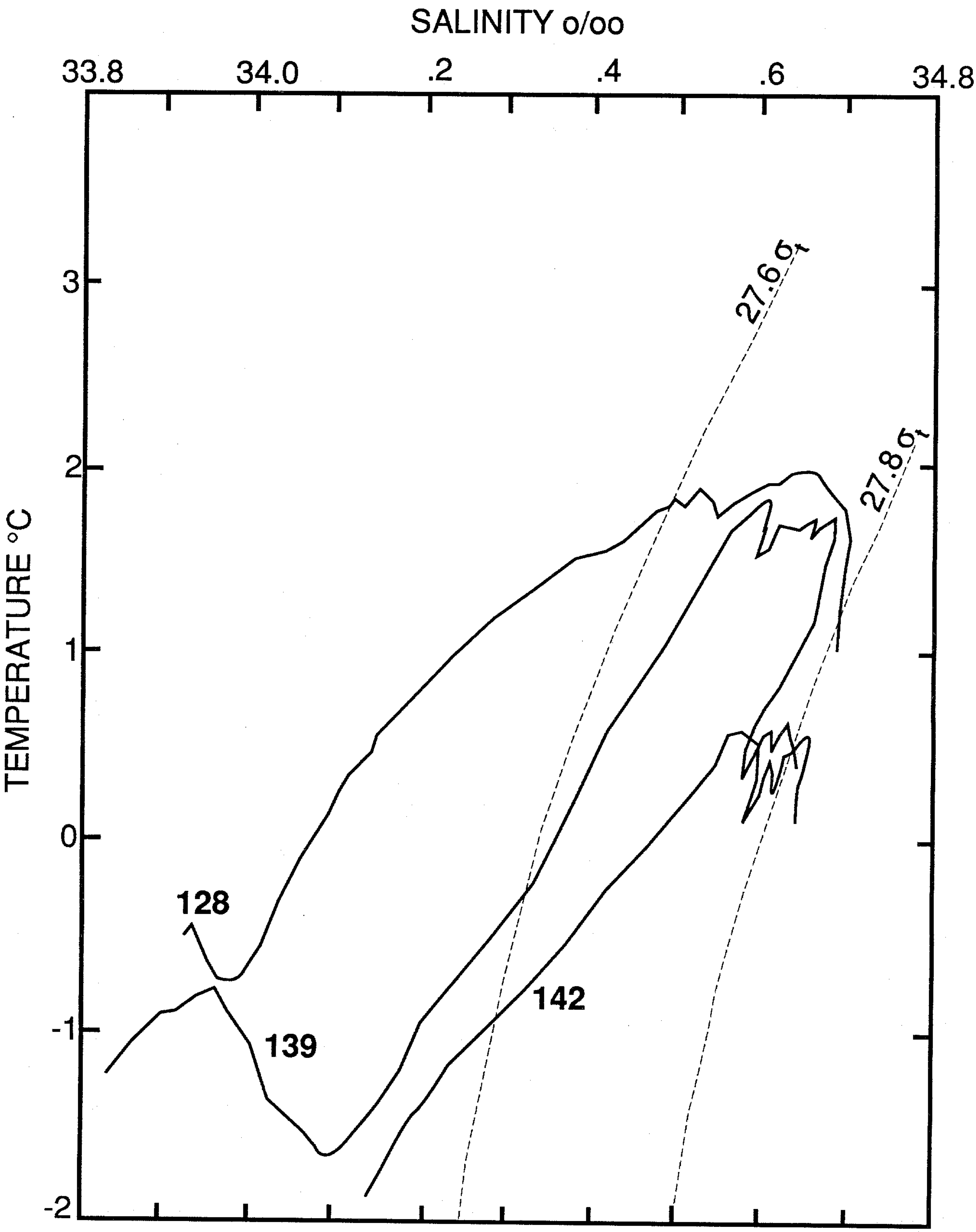

Figure 33. T/S curves from stations 128, 139 and 142 from second 48°W transect , Leg 2 of AMERIEZ III survey

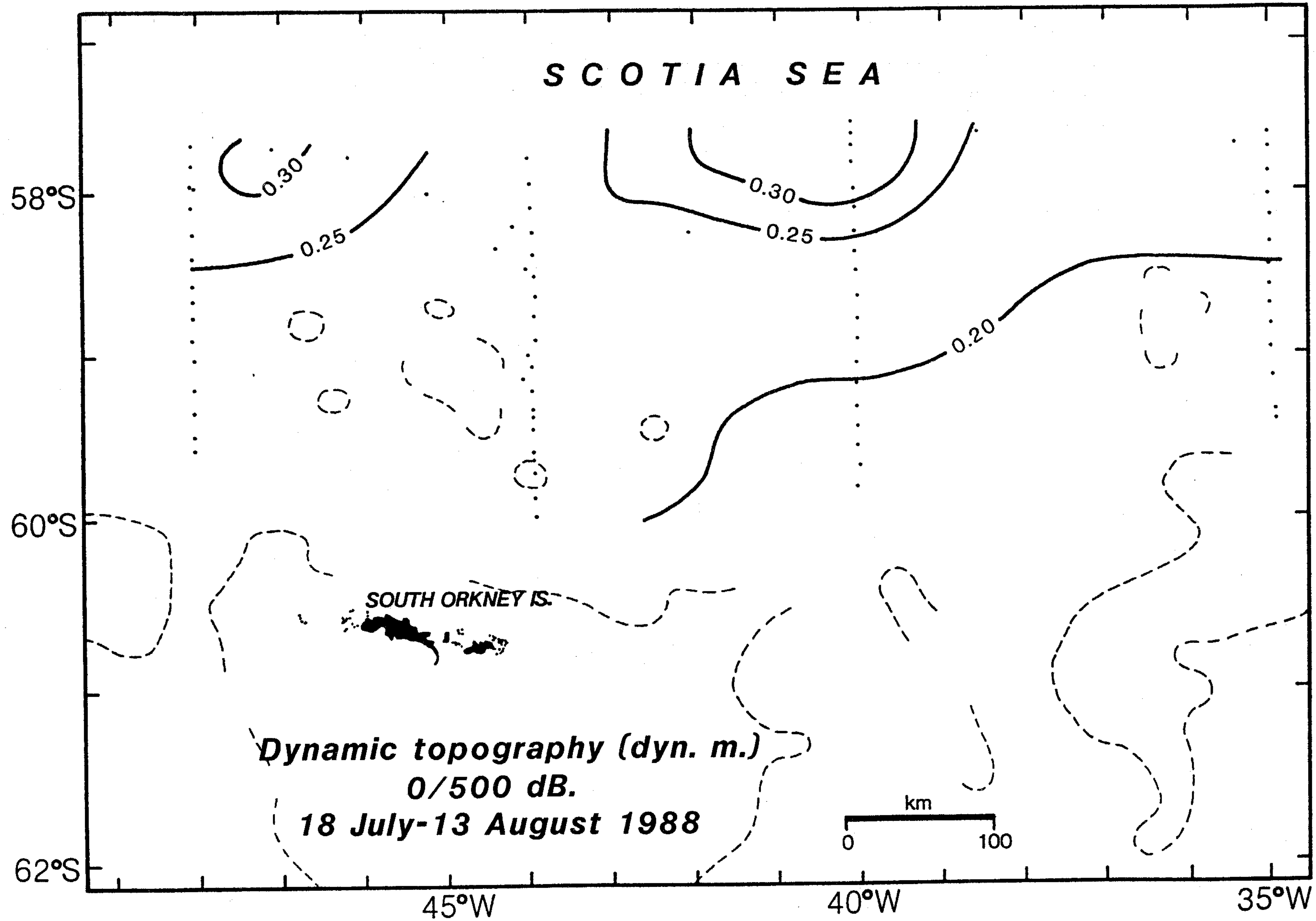

Figure 34. Map of dynamic topography of the sea surface relative to the 500 db pressure level computed from the data of Leg 2 of AMERIEZ III survey. Contour interval is 0.05 dyn. m. Dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

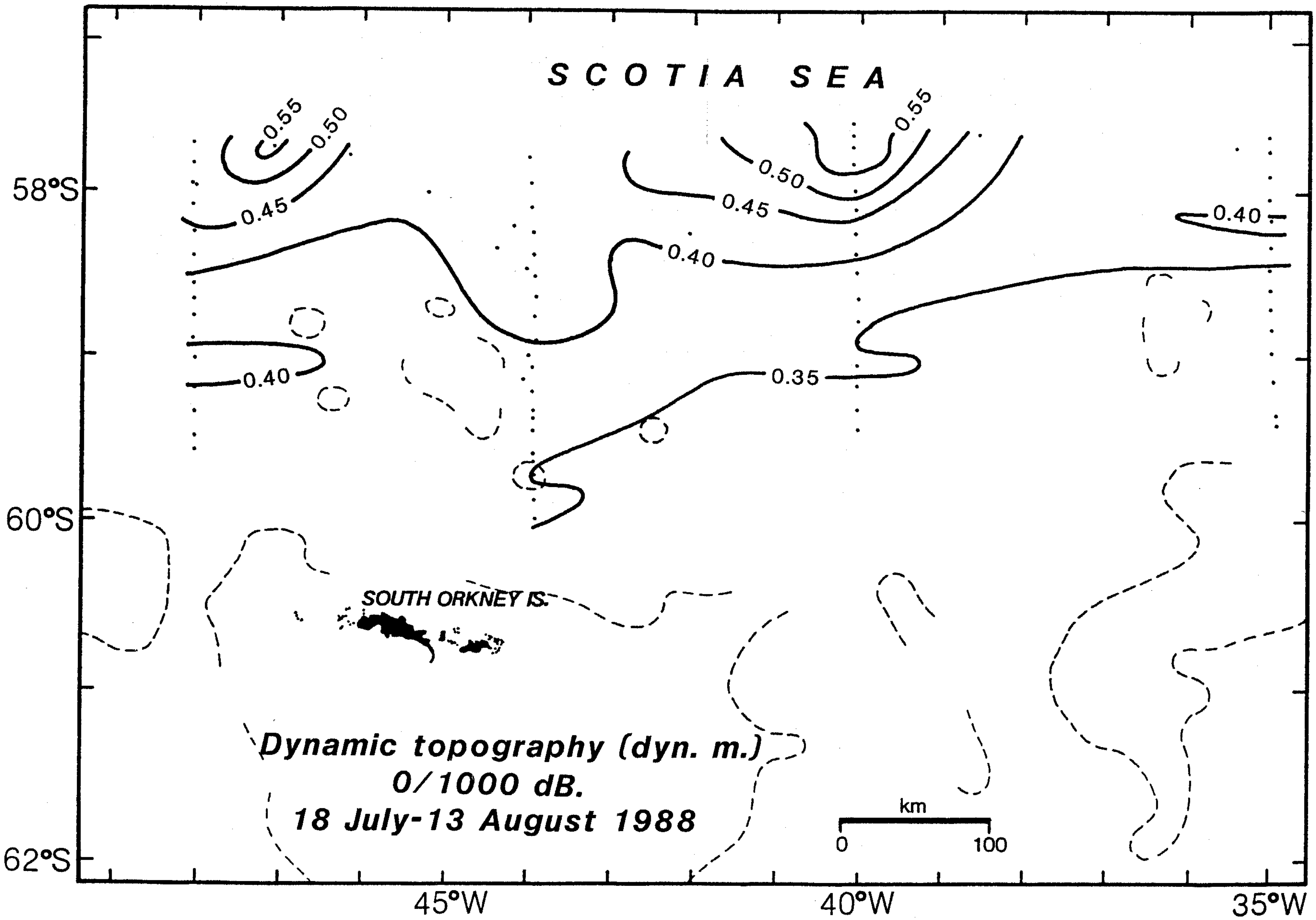

Figure 35. Map of dynamic topography of the sea surface relative to the 1000 db pressure level computed from the data of Leg 2 of AMERIEZ III survey. Contour interval is 0.05 dyn. m. Dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

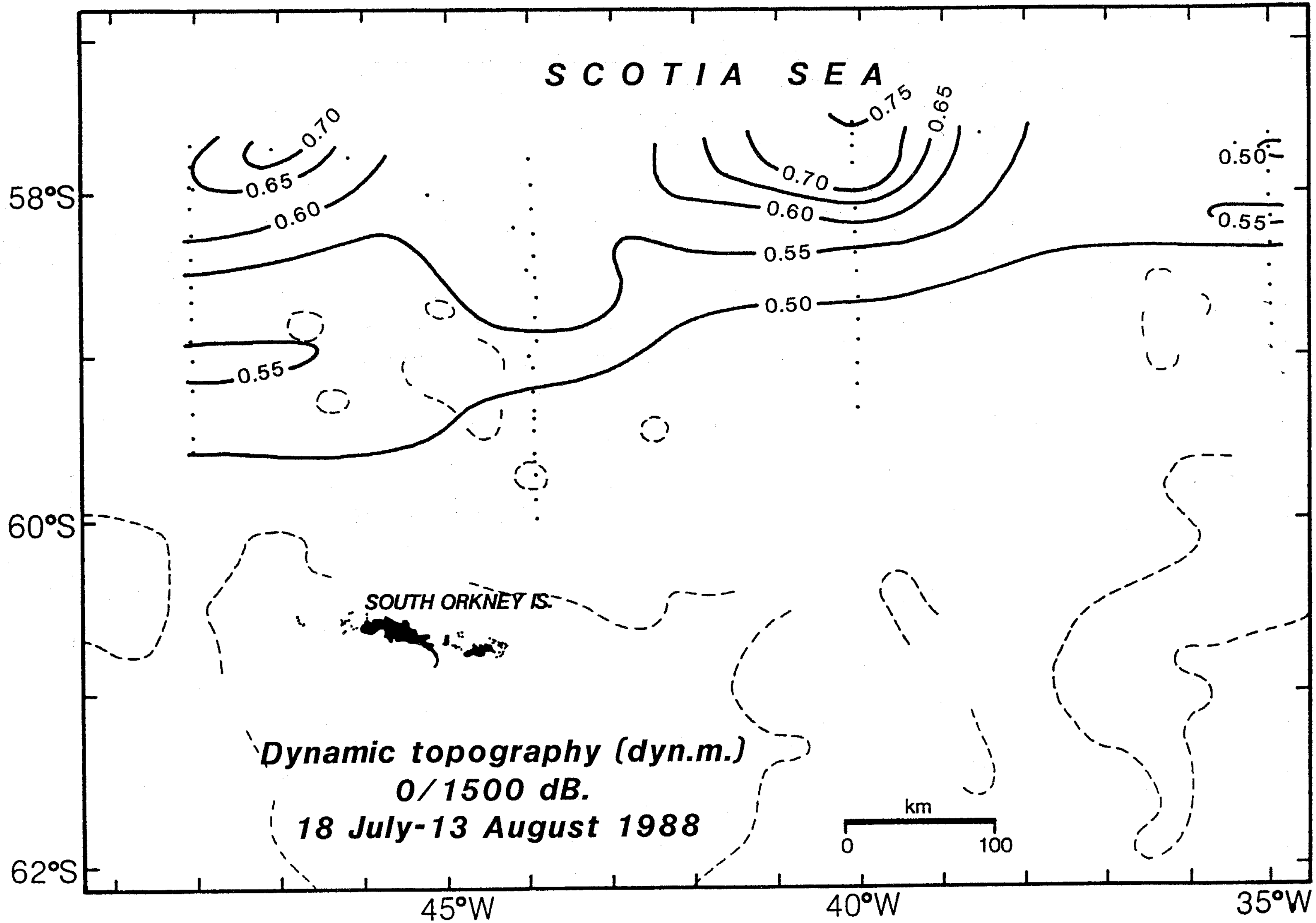

Figure 36. Map of dynamic topography of the sea surface relative to the 1500 db pressure level computed from the data of Leg 2 of AMERIEZ III survey. Contour interval is 0.05 dyn. m. Dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

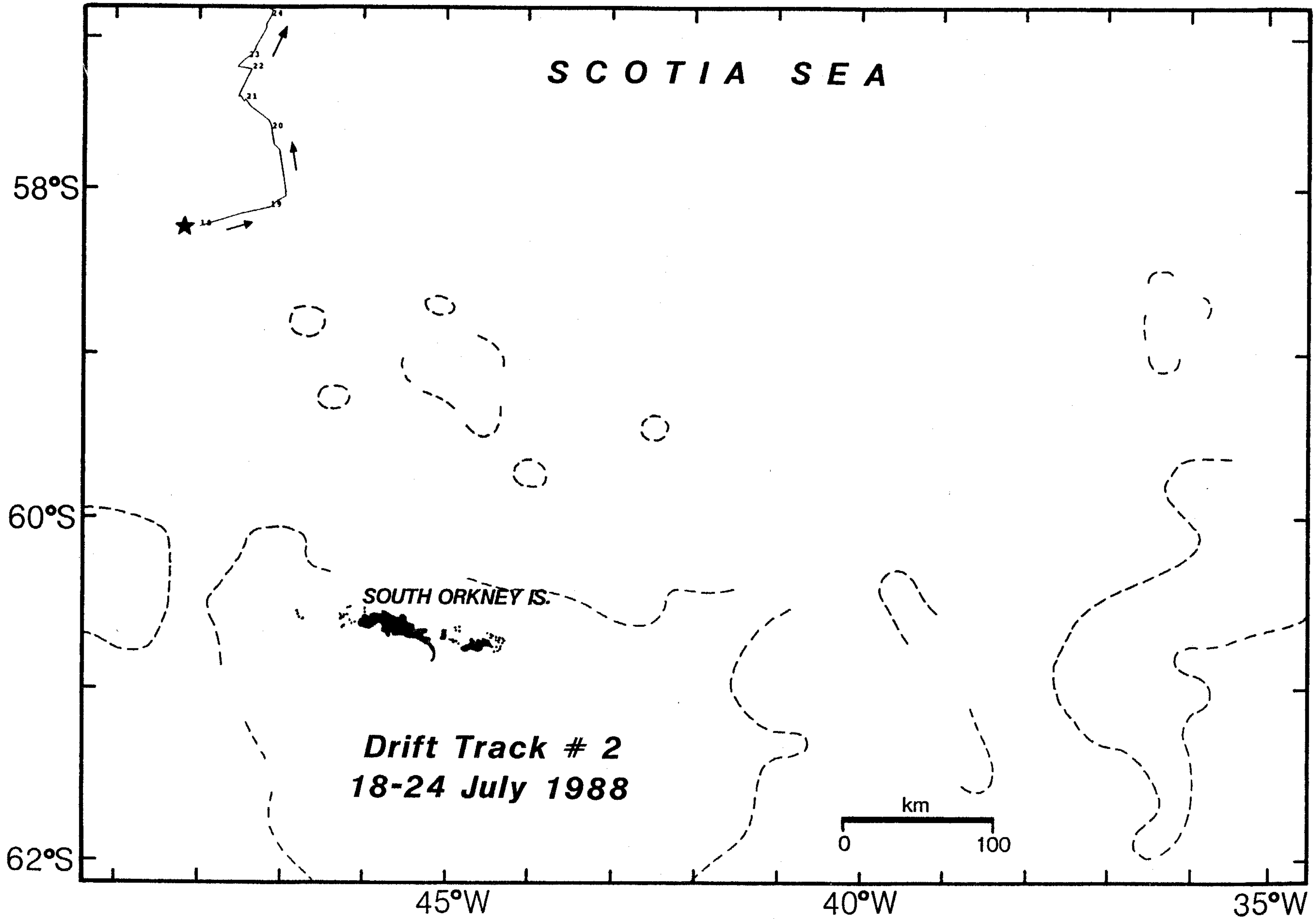

Figure 37. Track of drogued buoy released at point indicated by star. Numerals along track indicate day of the month.Position determined by satellite fixes approximately 10 times daily Dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

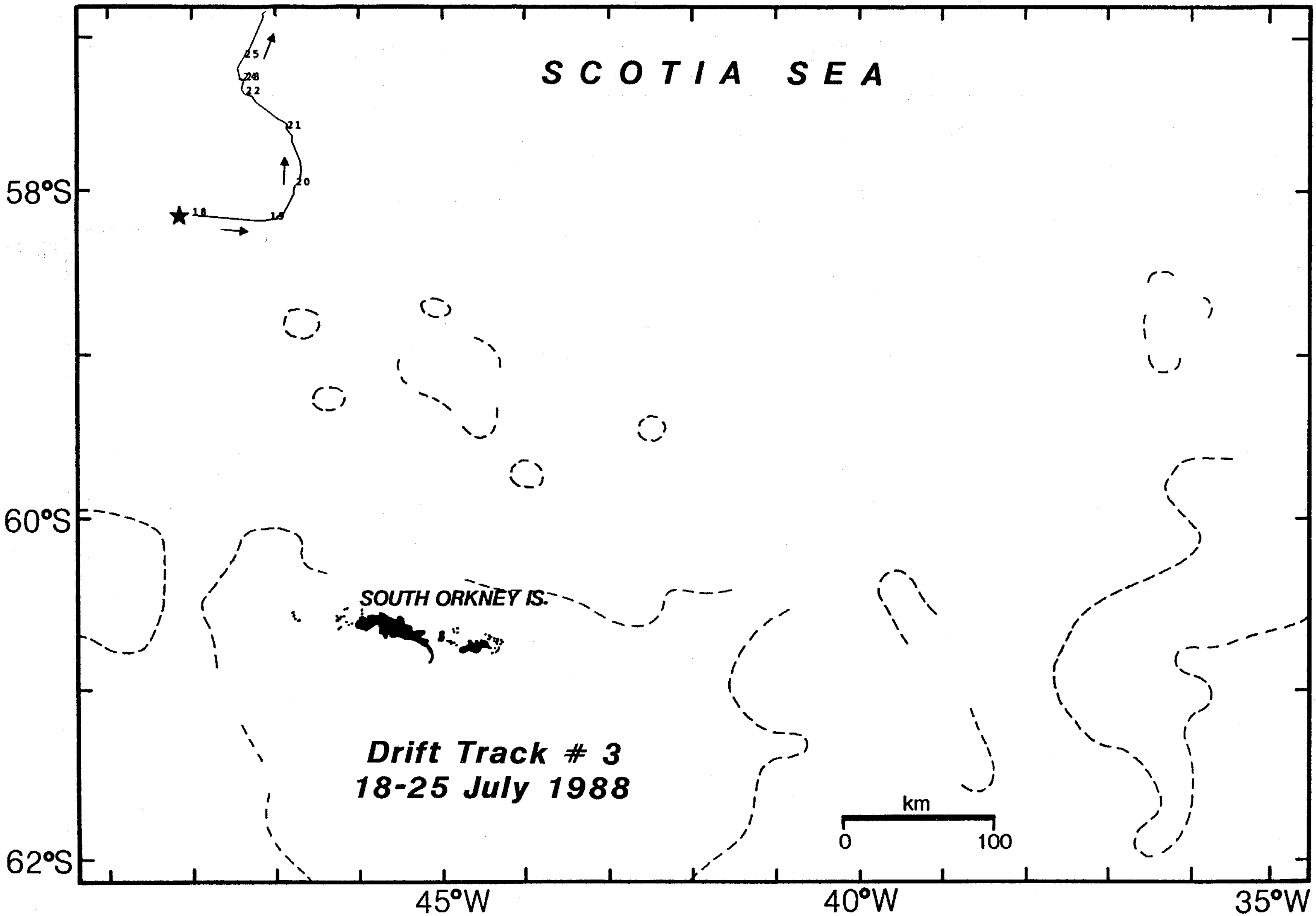

Figure 38. Track of drogued buoy released at point indicated by star. Numerals along track indicate day of the month.Position determined by satellite fixes approximately 10 times daily Dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

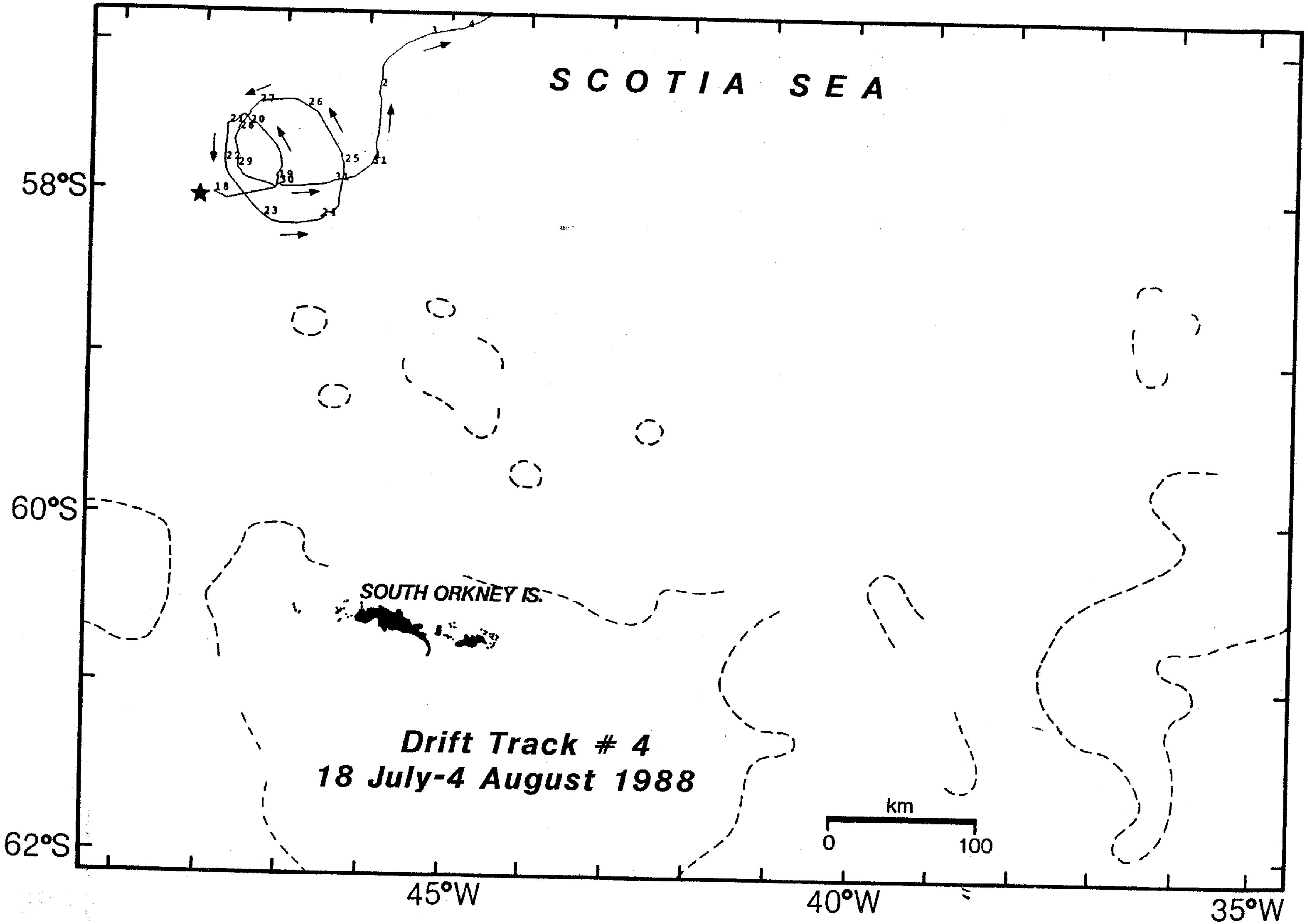

Figure 39. Track of drogued buoy released at point indicated by star. Numerals along track indicate day of the month. Position determined by satellite fixes approximately 10 times daily. Dashed contours represent 1000 fathom isobaths from Admiralty Chart 320 (corrected 1986).

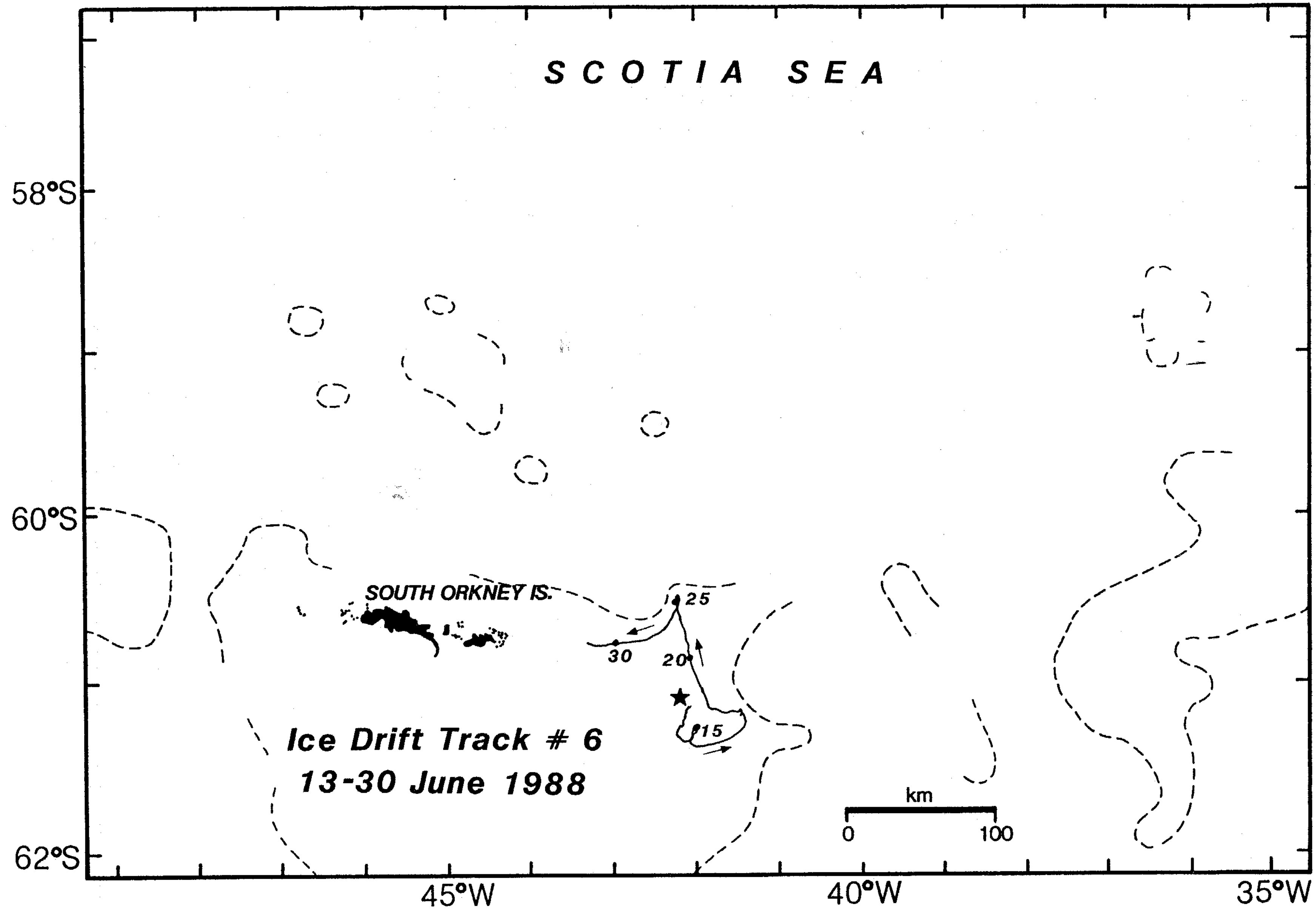

Figure 40. Track of automatic data acquisition platform deployed on ice floe at location indicated by star. Day of the month indicated by numerals along track. Dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

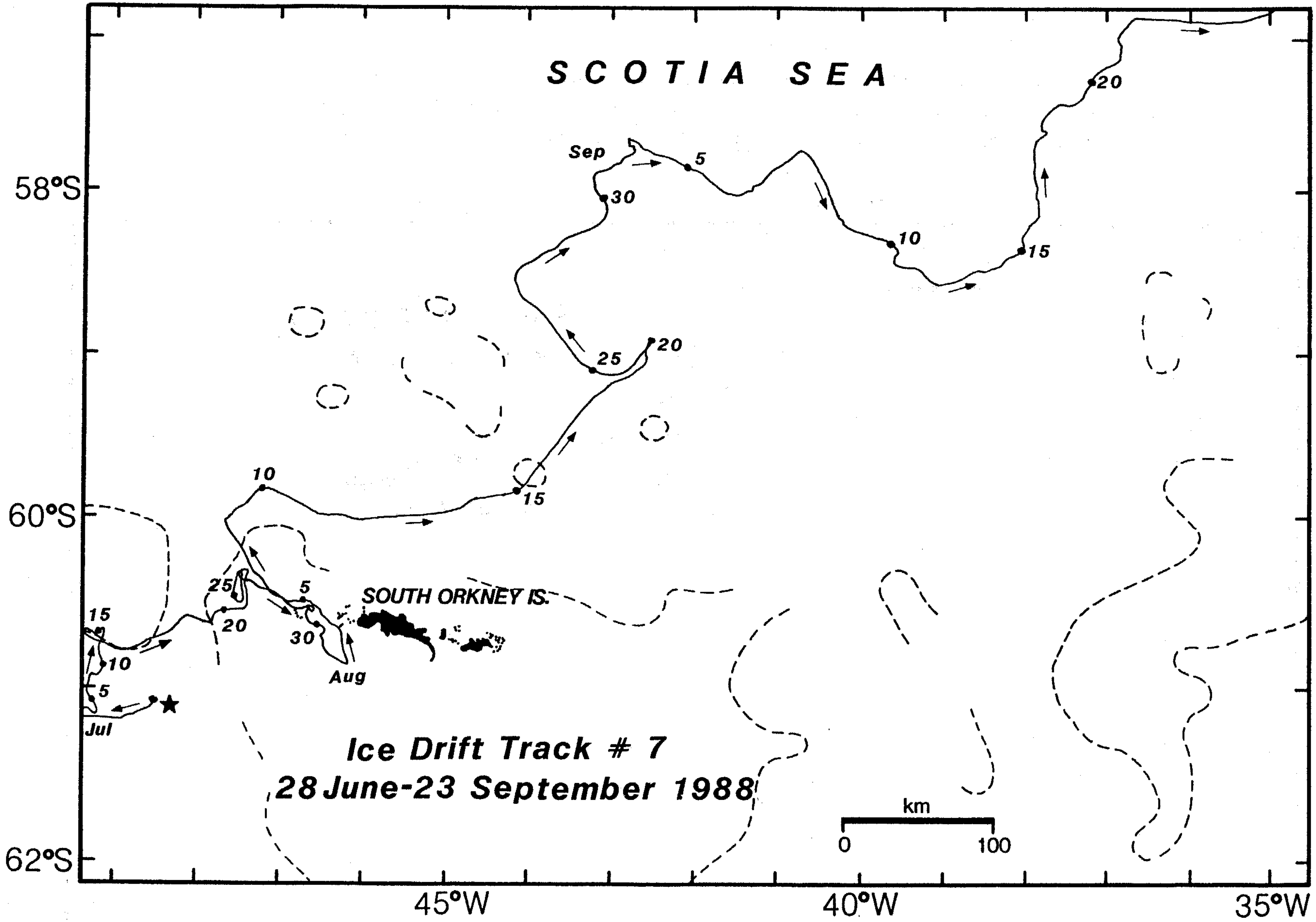

Figure 41. Track of automatic data acquisition platform deployed on ice floe at location indicated by star. Day of the month indicated by numerals along track. Dashed contours represent 1000 fathom isobaths from Admiralty Chart 3200 (corrected 1986).

STA. NO.	DATE	LATITUDE (S)	LONGITUDE (W)	CAST DEPTH (m)
8	6/15/88	61-32.6	40-34.7	515
9	6/16/88	61-25.2	40-34.4	1524
11	6/16/88	61-07.3	40-17.0	432
12	6/16/88	60-45.7	40-13.8	1541
13	6/17/88	60-36.6	40-05.7	528
14	6/17/88	60-27.2	40-00.8	1506
15	6/17/88	60-19.1	39-53.7	528
16	6/17/88	60-02.8	39-45.7	1022
17	6/17/88	59-41.4	39-36.1	526
18	6/17/88	59-29.9	39-37.7	533
19	6/18/88	59-17.3	39-25.1	1534
20	6/18/88	59-05.5	39-16.6	521
21	6/18/88	58-51.8	39-10.7	1515
22	6/19/88	59-33.8	40-44.5	525
23	6/20/88	60-06.8	42-08.9	521
24	6/20/88	59-59.6	43-31.5	505
25	6/21/88	59-54.3	43-34.2	525
26	6/22/88	59-44.8	44-19.3	1508
27	6/23/88	59-19.0	44-48.2	524
28	6/24/88	59-52.3	46-00.4	527
29	6/24/88	59-50.6	46-56.4	526
30	6/25/88	59-51.0	47-57.4	526
32	6/26/88	60-23.2	47-50.3	518
33	6/27/88	60-49.1	48-03.7	515
34	6/28/88	61-04.1	48-43.0	1018
35	7/1/88	60-26.0	49-03.1	502
36	7/1/88	60-39.4	48-00.8	502
37	7/2/88	60-40.1	48-03.8	1505
38	7/2/88	60-33.9	48-00.9	503
39	7/2/88	60-29.0	47-59.9	753
40	7/2/88	60-21.0	47-59.9	504
41	7/2/88	60-12.7	47-59.3	473
42	7/3/88	60-12.6	47-59.8	368
43	7/3/88	60-04.1	47-59.2	1506
44	7/3/88	59-56.1	48-00.3	1510
45	7/3/88	59-48.2	48-00.0	507
46	7/3/88	59-40.1	48-00.1	506
47	7/3/88	59-32.3	48-00.5	1503
48	7/3/88	59-24.2	47-58.9	508

STA. NO.	DATE	LATITUDE (S)	LONGITUDE (W)	CAST DEPTH (m)
49	7/4/88	59-16.1	48-00.0	504
50	7/4/88	59-07.9	47-59.9	1504
51	7/4/88	58-51.9	48-00.2	503
52	7/4/88	58-36.1	47-59.9	503
53	7/4/88	58-20.1	47-59.9	502
54	7/4/88	58-04.2	47-59.8	502
55	7/5/88	58-04.4	47-59.9	1506
56	7/17/88	58-23.17	48-00.7	1503
58	7/20/88	59-25.1	34-56.8	1010
59	7/21/88	59-22.39	34-58.02	1015
60	7/21/88	59-10.3	34-58.8	1014
61	7/21/88	59-00.2	35-00.1	1510
62	7/21/88	58-52.8	34-58.6	1513
63	7/22/88	58-44.9	34-59.6	1512
64	7/22/88	58-36.83	34-59.87	1509
65	7/22/88	58-28.9	35-00.6	1510
66	7/22/88	58-21.6	34-58.8	1510
67	7/22/88	58-13.0	35-00.0	1512
68	7/22/88	58-04.5	35-00.4	1509
69	7/23/88	57-56.5	35-00.2	1505
70	7/23/88	57-48.6	34-59.8	1518
71	7/23/88	57-40.5	34-59.7	1511
72	7/23/88	57-41.7	35-25.0	1510
73	7/24/88	57-40.4	37-10.0	1513
74	7/24/88	57-40.26	38-35.49	1509
75	7/24/88	57-40.3	39-59.9	1503
76	7/25/88	57-35.48	40-05.3	1519
77	7/25/88	57-43.7	39-59.8	1593
78	7/25/88	57-51.8	40-00.0	1504
79	7/25/88	57-59.8	40-00.2	1553
80	7/25/88	58-07.9	40-00.2	1506
81	7/26/88	58-15.9	40-00.1	1505
82	7/26/88	58-24.2	39-59.9	1514
83	7/26/88	58-32.39	39-59.31	1523
84	7/26/88	58-40.3	40-00.0	1513
85	7/26/88	58-48.4	40-00.0	1504
86	7/26/88	58-56.6	40-00.0	1512
87	7/26/88	59-04.7	40-00.1	1512
88	7/26/88	59-11.7	39-59.7	1506
89	7/27/88	59-20.7	40-00.0	1519

STA. NO.	DATE	LATITUDE (S)	LONGITUDE (W)	CAST DEPTH (m)
90	7/27/88	59-28.9	40-00.0	1009
91	7/2/88	59-37.6	40-00.8	905
92	7/27/88	59-46.3	40-03.3	915
93	7/28/88	59-48.8	39-58.6	904
94	7/29/88	58-16.3	41-59.8	1507
95	7/29/88	58-16.1	42-01.0	121
96	7/30/88	57-51.6	43-55.1	1515
97	7/30/88	57-51.8	44-02.9	1507
98	7/30/88	57-59.8	43-55.0	1509
99	7/30/88	58-08.0	43-55.8	1509
100	7/30/88	58-16.1	43-55.3	1509
101	7/31/88	58-24.0	43-55.0	1508
102	7/31/88	58-32.1	43-55.0	1510
103	7/31/88	58-40.2	43-55.1	1509
104	7/31/88	58-48.4	43-54.9	1506
105	7/31/88	58-56.4	43-54.9	1505
106	7/31/88	59-04.5	43-54.9	1506
107	7/31/88	59-13.0	43-54.5	1503
108	7/31/88	59-20.9	43-55.0	1504
109	7/31/88	59-28.9	43-55.6	1503
110	7/31/88	59-37.1	43-55.0	1504
111	8/1/88	59-45.1	43-55.0	1504
112	8/1/88	59-53.2	43-55.0	1510
113	8/1/88	60-01.4	43-55.0	1506
114	8/2/88	59-38.2	43-54.8	501
116	8/3/88	59-23.1	43-58.9	1505
117	8/4/88	59-10.4	44-02.9	1102
118	8/4/88	59-08.0	44-05.5	1101
119	8/4/88	59-03.1	43-54.1	1502
120	8/5/88	58-59.8	44-01.6	1504
121	8/6/88	58-21.8	44-21.7	1002
122	8/6/88	58-29.5	44-00.6	1503
123	8/7/88	58-16.3	44-08.4	1505
124	8/7/88	58-02.3	45-10.6	1504
125	8/8/88	57-47.2	46-07.9	1506
126	8/8/88	57-43.4	47-03.3	1505
127	8/8/88	57-57.5	48-00.2	1504
128	8/9/88	57-42.1	48-00.1	1504
129	8/9/88	57-50.2	48-00.1	1505
130	8/9/88	57-58.2	48-00.1	1505

Appendix I

STA. NO.	DATE	LATITUDE (S)	LONGITUDE (W)	CAST DEPTH (m)
131	8/9/88	58-06.8	48-00.3	1504
132	8/9/88	58-14.3	48-00.0	1503
133	8/9/88	58-24.3	47-55.3	1506
134	8/10/88	58-32.4	48-00.0	1503
135	8/10/88	58-40.5	48-00.0	1503
136	8/10/88	58-48.6	48-00.2	1510
137	8/10/88	58-56.9	48-00.6	1503
138	8/10/88	59-05.1	48-00.1	1509
139	8/10/88	59-12.8	48-00.6	1502
140	8/10/88	59-20.8	48-00.3	1502
141	8/10/88	59-28.7	47-59.0	1505
142	8/11/88	59-33.8	47-59.4	1509
143	8/11/88	59-32.3	47-50.3	150
144	8/12/88	59-05.2	48-01.2	502

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