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Salinity and Temperature Data Comparisons for 1980-1987 Cruises off the Coasts of Washington, Oregon and California

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by

David S. Savage

Resource Assessment and Conservation Engineering Division
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE, BIN C 15700, Building 4
Seattle, Washington 98115

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INTRODUCTION

In 1980 the NWAFC (Northwest and Alaska Fisheries Center, now referred to as the Alaska Fisheries Science Center) and TINRO (Soviet Pacific Research Institute of Fisheries and Oceanography) began joint ichthyoplankton surveys from the Straits of Juan de Fuca to Northern California (48°N-40°N and offshore to 129°W). The purpose of these cruises was to determine seasonal and spatial distribution of ichthyoplankton in the area. Cruises were scheduled to sample all seasons of the year (Figs. 1a and 1b). Hydrographic casts were made in addition to plankton tows at most stations in order to understand seasonal and interannual variations in physical gradients and how these variations affect ichthyoplankton abundance and distribution. The number of hydrographic stations occupied varied from cruise to cruise, depending on the amount of time available for ichthyoplankton sampling. The collection of hydrographic data was ancillary to main objective of ichthyoplankton sampling. A grid of stations from 3 to 200 miles from shore was normally occupied. The parameters discussed in the following report include temperatures and salinities at both the surface and the 200 meter horizon. Some of the the NWAFC-TINRO hydrographic data was used previously to describe oceanographic conditions following the 1982 El Niño event (Reed, 1984).

Cruise 1TK80, the first cooperative U.S.-U.S.S.R. ichthyoplankton cruise off of the U.S. west coast was conducted aboard the RV Tikhookeanski from April 20th to May 15th, 1980 (Figs. 1a and 1b). A total of 96 hydrographic stations was occupied (Fig. 4). Michael Stepanenko was Chief Scientist. J. Dunn, E. Dunning, and B. Brinton served as American scientists aboard the vessel.

Cruise 1PO80, the second cooperative survey off the U.S. west coast was conducted aboard the RV Poseydon from August 1st-20th, 1980 (Figs. 1a and 1b). A total of 102 hydrographic stations was occupied (Fig. 9). Yu. K. Demidenko was Chief Scientist. Susan Simon and Ralph Honeycutt served as U.S. scientists.

Cruise 1PO81, the third cooperative U.S. west coast survey, took place from May 9th to June 2nd, 1981 (Figs. 1a and 1b), aboard the RV Poseydon . A total of 97 hydrographic stations was occupied (Fig. 7). Igor Zhuteyev was Chief Scientist. Elizabeth Dunning and Susan Simon served as American scientists.

Cruise 1DA81, the fourth cooperative west coast survey, occurred from October 24th through November 19th (Figs. 1a and 1b) aboard the RV Mys Dalniy. A total of 132 hydrographic stations was occupied (Fig. 10). Yu. K. Demidenko was Chief

Scientist. American scientists were Jay Clark and Steve Moulton.

Cruise 1PO82, the fifth cooperative cruise, was conducted from May 3rd to June 1st, 1982 (Figs. 1a and 1b), aboard the RV Poseydon. A total of 127 hydrographic stations was occupied (Fig. 8). The Chief Scientist was A. Artemov. Richard Bates, Jay Clark, and Elizabeth Dunning were the U.S. scientists.

Cruise 1EQ83, the sixth cooperative NWAFC-TINRO cruise, took place aboard the RV Equator from April 23rd through May 15th, 1983 (Figs. 1a and 1b). 1EQ83 occurred during an El Niño year and provided an important contrast in hydrographic data to other years. A total of 98 hydrographic stations was occupied (Fig. 5). The Chief Scientist was M. Stepanenko. Richard Bates, Scott Leopold, and R. Francis were the U.S. scientists.

Cruise 1MF83, the seventh cooperative ichthyoplankton cruise, was conducted aboard the RV Miller Freeman from November 11th to December 2nd, 1983 (Figs. 1a and 1b). Cruise 1MF83 was specifically designed to sample biological and environmental conditions during an El Niño year. A total of 46 CTD (Conductivity, Temperature, Depth) stations was occupied on 1MF83 (Fig. 11). The Chief Scientist was Jay Clark, who was assisted by Richard Bates and Laurel McEwen.

Cruise 1PO84, the eighth cooperative NWAFC-TINRO cruise, occurred from March 11th through April 4th, 1984 (Figs. 1a and 1b) aboard the RV Poseydon. A total of 95 hydrographic stations was sampled (Fig. 3). The Chief Scientist was Y. Pashenko. American scientists were Coreene Stewart and Elliott Menoshe.

Cruise 1BA85, the ninth cooperative U.S.-U.S.S.R cruise, took place aboard the RV Mys Babyshkina from April 19th to May 11th, 1985 (Figs. 1a and 1b). A total of 123 hydrographic stations was occupied (Fig. 6). The Chief Scientist was M. Stepanenko. Arthur Kendall, George Kautsky, and Kurt Brownell were U.S. scientists aboard the vessel.

Cruise 1MF87, the tenth cooperative ichthyoplankton cruise off of the U.S. west coast, was conducted aboard the RV Miller Freeman from January 7th-31st (Figs. 1a and 1b). A total of 65 CTD stations was occupied (Fig. 12). The Chief Scientist was Jay Clark, who was assisted by Richard Bates and Don Fisk.

METHODS AND MATERIALS

Grids of up to 132 hydrographic stations were laid out off of the coasts of Washington, Oregon, and northern California and extended from 3 nautical miles (5.6 km) to 200 nautical miles (370 km) from shore (Figures 3-12). Stations were more closely spaced nearshore than offshore. On the Soviet vessels, hydrographic casts were made with Nansen bottles and reversible thermometers. Standard depths were 0, 10, 20, 30, 50, 75, 100, 150, 200, 250, 300, 400, 500, and 600 m, as water depth permitted. Temperature, salinity, oxygen, phosphate, and silicate determinations were made aboard ship with these samples. On the American vessel (i.e. the Miller Freeman), hydrographic observations were made at depths of 0, 10, 20, 30, 40, 50, 75, 100, 150, 200, 250, 300, 400, 500, 600, 700, 800, 900, and 1,000 m, as water depth permitted, with a Plessey/Grundy Model 6040 CTD Underwater Unit with a rosette of Niskin bottles and reversing thermometers. On 1MF83, the 600 m to 1,000 m depths were sampled on one transect only. Selected salinities were measured aboard the Miller Freeman with a Guildline Model 8400 Laboratory Salinometer for calibration.

RESULTS

Observations of salinities and temperatures at the surface and the 200 m horizon are discussed in the following section. Salinity and temperature contours are compared for cruises which occurred during the same season, but in different years. Salinity and temperature contours for individual cruises are then compared with long-term means previously published by the Naval Oceanographic Office (Robinson, 1976). Temperatures and salinities from three arbitrarily chosen regions in the 1980-1987 survey area are then compared.

Surface Salinity Observations

The station grids for surface salinity measurements were very similar on the spring cruises 1TK80, 1EQ83, and 1BA85. These three cruises spanned a period of time between April 19th and May 15th with nearly complete overlap. Cruise 1EQ83 had lower surface salinities between 46°00'N and 48°00'N and 124°00'W and 125°00'W (Figs. 17 and 18) than did cruises 1TK80 and 1BA85 (Figs. 15,16,19 and 20), probably due to larger than normal amounts precipitation (Diaz and Kiladis, 1983) and freshwater runoff during the El Niño year of 1983. Cruise 1BA85 had low salinities also in this region, but the gradient was not nearly as steep. There was a low salinity reading of 28.4 gm/kg in this region during 1BA85 (Fig. 20) and a low reading of 26.5 gm/kg in this region during 1EQ83 (Fig. 18). A low reading of 26.5 gm/kg was obtained near the mouth of the Columbia River during 1BA85 (Fig. 20). During 1EQ83, the same area had a surface salinity of 29.5 gm/kg (Fig. 18), so freshwater influx from the Columbia River was probably greater during 1BA85. Cruise 1TK80 had higher surface salinities near the coast than either 1EQ83 or 1BA85, although 1TK80 had a lower surface salinity near the mouth of the Columbia than 1EQ83 (28.7 gm/kg vs. 29.5 gm/kg in Figs. 16 and 18). The 32.5 gm/kg line of equal salinity did not penetrate as far south on cruise 1TK80 as it did on 1EQ83 and 1BA85 (Fig. 93), demonstrating that offshore surface salinities were higher during 1TK80.

Cruise 1PO84, which occurred earlier in the spring (March 11th-April 4th) than the above three cruises, had higher surface salinities near the mouths of the Columbia River and Willapa Bay than the above three cruises, but considerably lower surface salinities near the Quinalt River (26.2 gm/kg in Figs. 2 and 14). The 32.5 gm/kg line of equal salinity extended farther offshore on 1PO84 than the above mentioned cruises, showing 1PO84 had lower offshore surface salinities (Fig. 93).

Cruises 1PO81 and 1PO82, which occurred for the most part in May (Figs. 1a and 1b), both showed the effects of spring runoff. Surface salinities were lower during 1PO81 than 1PO82. The Quinalt River area of Washington gave the lowest surface salinity reading of cruise 1PO81 (25.5 gm/kg in Fig. 22) compared to 27.9 gm/kg during 1PO82 (Fig. 24). The area offshore from Willapa Bay also had lower surface salinity during 1PO81 (27.7 gm/kg) compared with 29.4 gm/kg during 1PO82 (Figs. 22 and 24). Surface salinities were also high in the southern portion of the survey area during 1PO82 (>33.5 gm/kg nearshore with a high reading of 33.9 gm/kg in Figs. 23 and 24). On 1PO81 salinities greater than 33.0 gm/kg did not extend nearly as far north as in 1PO82 (40°20'N on 1PO81 compared with 43°20'N for 1PO82). The salinity gradient was gradual during 1PO82, levelling off at 125°30'W in the east-to-west direction. During 1PO81, the inshore-to-offshore gradient was steep, but reached a plateau at 125°30'W.

Cruise 1PO80, which took place on August 1st-20th (Figs. 1a and 1b), had a very small surface salinity gradient, probably due in part to lesser amounts of freshwater runoff during late summer in the Columbia River, Willapa Bay (Fig. 2), and other areas (Glenne and Adams 1971). Nearshore stations south of 44°30'N had surface salinities greater than 33.0 gm/kg; evidence that upwelling was still taking place in these coastal areas (Fig. 25). Higher surface salinities as a result of upwelling seemed especially evident between 40°00'N and 42°00'N. Surface temperatures were correspondingly low in these areas (less than 11.0°C compared with greater than 15.0°C offshore). Most of the surface salinities seen were between 32.0 gm/kg and 33.0 gm/kg. The surface salinity contours during the late summer of 1980 were much more widely-spaced and uneventful when compared with those of the spring of 1980 (Figs. 25 and 15).

There was a 9 day overlap on cruises 1DA81 and 1MF83. The dates of overlap were November 11th-19th. 1MF83 began 2 weeks later than 1DA81. There was a large amount of runoff on 1MF83, probably due to heavier than normal winter rains in the area as a result of El Niño. Less runoff was apparent during the same period on 1DA81. A reading of 29.0 gm/kg was seen near Gray's Harbor on 1DA81, but the rest of the surface salinity data for the cruise was nearly homogeneous and above 32.0 gm/kg. Coastal surface salinities north of the Columbia River were very low during 1MF83. There was a very low reading of 24.6 GM/KG just west of Willapa Bay. Low salinities also were recorded off of Gray's Harbor and the Quinalt River. Offshore surface salinities were for the most part homogeneous and equal to or slightly greater than 32.0 gm/kg during both cruises.

Cruise 1MF87 was a late winter (January 7th-31st) cruise which overlapped with none of the other cruises. There were three areas where surface salinities were low due to freshwater influx. There was a station off of Willapa Bay with a 29.8 gm/kg surface salinity, a station off of the Quinalt River with a surface salinity of 29.3 gm/kg, and a nearshore station at 48°00'N with a reading of 29.7 gm/kg. Outflow from coastal rivers in Washington, Oregon, and California normally peaks in January due to heavy precipitation, mostly rain, in the Coast Range. Both the Columbia and the Klamath are bimodal river systems, meaning that they have heightened periods of flow in both the winter and the spring. The Columbia is different from the other major river systems in that it's peak flow occurs during June and it is the only river system that appreciably modifies Pacific Ocean coastal waters off of the U.S. west coast (Glenne and Adams, 1971).

Comparisons of Observed Surface Salinities with Long-Term Means

The surface salinity chart presented in Figure 93 is based on all-data means, rather than true annual means, from the 1969 National Oceanographic Data Center hydrocast tapes (Robinson 1976). The hydrocast tapes include all data collected by the center prior to, and including 1969. The plot in Figure 93 is not a seasonal average but is an overall average of all surface salinities recorded for given regions.

Cruise 1PO84 (March 11th- April 4th) was similar to the plot of average salinities. The surface salinity dropped below 29.0 gm/kg between 45°40'N and 47°10'N on the average salinity plot. There was an area of reduced salinity between 45°30'N and 48°00'N on 1PO84. A low reading of 26.5 gm/kg was measured at 47°25'N. Lowered salinities and steep gradients on both plots are due to the freshwater influence of the Columbia River plume. On 1PO84, the 32.0 gm/kg was shifted about 2° north of the 32.0 gm/kg contour on the average salinity plot (Fig. 94). The 32.5 gm/kg contour on 1PO84 covered more area than on the plot of averages. It began at 41°10'N and ended near 47°00'N on 1PO84, in contrast to the average salinity plot, where it began at 42°00'N and ended at 44°00'N.

On 1TK80 (April 20th-May 15th) the surface salinities were considerably higher than average. The salinity gradient near the mouth of the Columbia River was not as steep on 1TK80 as on the plot of average salinities. The 32.5 gm/kg contour on 1TK80 was shifted nearly 1° farther north than on the plot of average salinities (Fig. 95).

1EQ83 (April 23rd-May 15th), also a spring cruise, more closely approximated the average salinity plot. The 32.0 gm/kg contour began at 43°45'N on both 1EQ83 and on the average salinity plot and spread northwest and offshore from there on both (Fig. 96). 1EQ83 had a steeper salinity gradient near the mouth of the Columbia River than did the average salinity plot, due to increased outflow of freshwater from the river during El Niño (Diaz and Kiladis, 1983). The 32.5 gm/kg contour covered a larger area on 1EQ83 than during average years. The 32.5 gm/kg on the plot of average salinities spanned the area from 42°00'N to 44°00'N, but was seen from 40°00'N to 47°00'N during 1EQ83, indicating that surface salinities were lower than average on 1EQ83.

Of all the spring cruises, 1BA85 (April 19th-May 11th) most closely resembled the average surface salinity chart. The 29.0 gm/kg contour on 1BA85 extended from 45°30'N to 46°30'N across the mouth of the Columbia (Fig. 97). On the average surface salinity plot, the 29.0 gm/kg contour extended from 45°30'N to just north of 47°00'N across the mouth of the Columbia. The 32.0 gm/kg contour began near 43°30'N on both plots and extended to the north beyond the survey area. The 32.5 gm/kg contour began near 42°30'N on both plots and extended to the northwest and out of the survey area.

On cruise 1PO81 (May 9th-June 2nd), surface salinities were lower than on the average surface salinity plot. The 32.0 gm/kg contour, for example, began at 41°15'N and extended northward to 48°00'N on the 1PO81 plot, whereas it began at 43°45'N and extended to the northern boundary of the survey area on the average surface salinity plot (Fig. 98).

Cruise 1PO82 (May 3rd-June 1st) was unusual when compared with the average surface salinity plot in that the 32.0 gm/kg and 32.5 gm/kg contours were south relative to the plot of averages, yet the 33.0 gm/kg contour was north relative to the plot of overall averages. The contours discussed below spread north and offshore from the point of origin. The 32.0 gm/kg contour began at 42°30'N on 1PO82, whereas it began at 43°45'N on the plot of averages (Fig. 99). The 32.5 gm/kg contour began at 41°35'N on the 1PO82 plot, whereas it began at 42°00'N on the plot of average salinities.

Surface salinity contours on 1PO80 (August 1st-20th) were displaced farther north, i.e. the salinities were higher, than on the plot of average surface salinities. This is a normal condition for late summer due to evaporation and diminished freshwater influx. The 33.5 gm/kg contour, for example, extended north to 42°00'N on 1PO80 and went to only 39°25'N on the average salinity plot (Fig. 100). The 33.0 gm/kg contour extended north from the southern border of the survey area to 44°30'N on 1PO80, whereas it extended to only 39°50'N on the plot of average surface salinities. Surface salinities on 1PO80 were not appreciably lower near the Columbia River as in other months, indicating that freshwater outflow from the river was at a minimum in August 1980.

Cruise 1DA81 (October 24th-November 19th) had a nearly homogeneous surface with regard to salinity. The only salinity gradient found was near the Columbia River, which covered a small range of salinities from 30.0 gm/kg to 32.0 gm/kg. The salinity gradient was steeper in both the north-south and east-west directions on the average salinity plot than on the 1DA81 plot. Salinities were lower in the southern half of the survey area and higher in the northern half of the survey area on 1DA81 than on the plot of averages.

Cruise 1MF83 (November 11th-December 2nd) had strong surface salinity gradients near the coast in several areas, yet had little salinity variation offshore. The average surface salinity plot shows only one strong gradient near the coast at the mouth of the Columbia River. 1MF83 had strong gradients near the coast, centered at three different latitudes: 47°40'N, 46°30'N, and 44°00'N. The plot of surface salinity averages had a steady gradient of increase in salinity in both the onshore-offshore and north-south directions.

Cruise 1MF87 (January 7th-31st) had one region of low salinity northeast of the Columbia River and had a gradual gradient of increasing surface salinities from north to south. The southern half of the survey area on 1MF87 resembled the average surface salinity plot. Values south of 45°00'N on both plots were within 0.2 gm/kg of each other in any given area. North of 45°00'N, salinities were higher on 1MF87 than on the average surface salinity plot, probably due to less-than-average outflow from the Columbia River.

Salinities Observed at 200 m

The 200 m salinity data is homogeneous when compared with surface salinity data. The spring cruises 1TK80, 1EQ83, and 1BA85 had minor differences, but the data deviated little from 33.9 gm/kg. During 1EQ83, the 200 m salinities were unusually high between latitudes 46°30'N and 47°00'N. Readings to 34.2 gm/kg in this area can be attributed to El Niño. The 200 m salinities in this same area during 1TK80 and 1BA85 ranged between 33.8 and 33.9 gm/kg. The stations closest to the coast had slightly higher salinities than those offshore during all three of the cruises. Nearshore stations usually had readings close to 34.0 gm/kg. The 200 m salinities in the southern half of the survey area were higher for nearshore stations than in the northern half of the grid on all three cruises. This corresponds to greater coastal upwelling activity in the southern half of the grid. On cruise 1EQ83, the two or three nearshore stations on the five transects south of 43°00'N measured 34.0 gm/kg at the 200 m horizon. These relatively high salinities provide evidence for upwelling in the region. During 1TK80, the first two shoreward stations on most lines south of 46°00'N had high salinities of 34.0 gm/kg, showing that there was upwelling in this region also. An unusually low 200 m salinity of 33.2 gm/kg was obtained at 40°00'N, 127°00'W. This was an isolated, uncharacteristic reading, and was possibly recorded in error. Salinity readings at the 200 m horizon shoreward and to the south of 44°00'N provide evidence for coastal upwelling. High salinity values of 34.0 gm/kg were found in this region. The offshore stations for all three of the spring cruises ranged between 33.8 and 33.9 gm/kg.

Cruise 1PO84, which occurred 1 mo before the three above mentioned spring cruises, also had signs of upwelling in coastal stations south of 43°00'N, although not as strong as those on the later spring cruises. Readings of greater than 33.9 gm/kg were found in the southern coastal areas. Unusually low 200 m salinities of 33.4 gm/kg and 33.6 gm/kg were seen at 43°30'N, 128°50'W and 44°05'N, 128°30'W respectively. The remaining stations ranged from 33.8 gm/kg to 34.0 gm/kg.

Cruises 1PO81 and 1PO82 show a higher degree of coastal upwelling, because they occurred later (early May to early June) than other spring cruises. On cruise 1PO81, 200 m salinities to 34.1 gm/kg were seen at coastal stations south of 42°30'N. Readings of 34.0 gm/kg were recorded at coastal stations throughout most of the survey area on 1PO82. Two low readings of 33.3 gm/kg and 33.6 gm/kg at 44°40'N, 127°35'W and 42°45'N, 128°45'W respectively were found at 200 m during 1PO81.

During 1PO80 (August 1980), there was intense coastal upwelling between 41°30'N and 43°00'N, as demonstrated by high salinities to 34.1 gm/kg nearshore. Influence of the Columbia River was still evident late in the summer from a reading of 33.6 gm/kg obtained to the southwest of the river mouth. The Columbia River plume, which spreads warm, low density fresh water offshore and to the southwest during the summer months, stifles upwelling activity, explaining the relatively low salinities (Glenne and Adams, 1971). There was also a low 200 m salinity reading of 33.4 gm/kg at 42°30'N, 126°20'W.

During the fall and winter cruises, 1MF83 and 1DA81 in November, and 1MF87 in January, a different set of 200 m salinity trends was apparent. During 1DA81, coastal station salinities were lower than those seen in the spring during 1PO81, due to reduced upwelling activity caused by a shift of prevailing winds to the south and southeast. This trend of lower salinities (33.4-33.6 gm/kg) was especially noticeable south of 45°00'N. Upwelling activity has historically been minimal near 45°00'N due to the Columbia River plume (Sysoev, 1969). On cruise 1MF83, which occurred during the El Niño year, salinity values at the 200 m horizon were nearly homogeneous. The values seen were between 33.8 and 33.9 gm/kg as shown on the relatively level contour plot. These readings were abnormally high for this time of year, especially near the coast where lower readings (33.6 gm/kg) would normally be expected due to a lack of upwelling activity and runoff from winter rains on the mainland. These salinity anomalies were a product of the El Niño phenomenon. During 1DA81, a low salinity reading of 32.9 gm/kg was recorded at 39°20'N, 128°50'W. This datum is inconsistent with other readings in the area, so it is probably an error. Salinities to the south of 45°00'N were lower than normal on 1DA81. Readings of 33.4 and 33.5 gm/kg were common, both nearshore and offshore.

On cruise 1MF87, which spanned most of January, salinities were high throughout the survey area and showed no marked variation from nearshore to offshore. Upwelling activity is greatly reduced in the Pacific northwest during the winter months (Daghir 1985), creating a more homogeneous salinity environment on the 200 m horizon. Most readings were 33.9 gm/kg to 34.0 gm/kg. There was a reading of 33.8 GM/KG nearshore at 47°25'N, 124°45'W. This is probably because of the Columbia River plume, which typically spreads to the north and nearshore during the winter months when the predominant winds are south-southeast (Bourke and Glenne 1971). Evidence of the Columbia plume having spread to the north is supported by surface salinity data from 1MF87, which indicated low readings off of Willapa Bay and Gray's Harbor. High readings of 34.2 gm/kg were recorded at three of the stations on the southernmost line of the grid. The high readings to the south mark the maxima of a gradual increasing trend of 200 m salinities from north to south.

Surface Temperature Observations

On the spring cruises 1TK80, 1EQ83, and 1BA85, some interesting differences in surface temperatures were observed. Cruise 1EQ83, which occurred during the spring following the 1982 the El Niño event, had unusually warm surface waters which penetrated far to the north. The 12.0°C isotherm extended all the way north to 47°35'N (Fig. 101). On cruises 1BA85 and 1TK80 the 12.0°C isotherm extended to only 41°30'N and 42°15'N respectively. The 12.0°C isotherm extended 365 n. mi. farther north on 1EQ83 than it did on 1BA85. On 1EQ83 the 12.4°C isotherm spread to 45°35'N with a 12.6°C reading at 47°30'N, which is normally not observed at this time of year (Fig. 102). On 1BA85 and 1TK80 the 12.4°C isotherm extended to 41°00'N and 41°55'N respectively. On all three cruises the surface temperatures increased steadily from north to south. During 1BA85 and 1TK80, the surface temperature gradient was steepest in the southern half of the survey area, whereas it was steepest in the northern half of the survey area during 1EQ83. This indicates that on 1EQ83 warm surface waters penetrated from the south off of California and Mexico to the north off of the Washington coast (Cannon, Reed, and Pullen, 1984). On 1BA85 and 1TK80 surface waters were generally warmer offshore in the south and coldest offshore in the north. There were low surface temperatures of 10.0-10.4°C near the coast south of 43°00'N. This is an indicator of coastal upwelling. Evidence of upwelling was particularly strong between 40°00'N and 41°00'N on both cruises. On 1TK80 there were readings as low as 8.8°C and 9.4°C in this region because warm surface waters were being replaced by colder, deeper water due to prevailing northwest winds, Coriolis forces, and Ekman flow (Narimousa and Maxworthy, 1985). Low readings of 8.0°C and 8.9°C were found in this same region during 1BA85 showing even more active upwelling during this cruise.

Cruise 1PO84, which occurred earlier in the spring (March

11th-April 4th) than the above mentioned spring cruises, showed early signs of upwelling activity. Readings of 9.1°C and 9.6°C were recorded off of the southern coast of the survey area between 39°30'N and 40°30'N, in contrast to readings of 11.8°C to 12.2°C off of the northern coast. During 1PO84 there was a steady but gradual increase in surface temperature from north to south. The isotherms were widely spaced and nearly equidistant from each other. Latitude 42°30'N was a good dividing line for nearshore to offshore trends. North of 42°30'N, where upwelling is not expected this time of year, nearshore surface temperatures were higher than corresponding offshore values. South of 42°30'N, nearshore readings were lower than corresponding offshore temperatures due to minor upwelling. March and April are usually too early in the spring to see vigorous upwelling activity because the prevailing winds are in transition (Daghir, 1985).

On the late spring cruises 1PO81 and 1PO82, there were significant differences in surface temperatures. 1PO81 had generally higher temperatures spanning farther to the north. The spring of 1981 had fewer overcast days than the spring of 1982, which translates to more solar irradiation of surface waters during 1PO81. The 11.6°C isotherm reached latitude 47°30'C during 1PO81 nearshore whereas it only reached 44°10'N during 1PO82 (Fig. 103). There was a greater degree of upwelling during 1PO82 than 1PO81, giving further explanation for the lower surface temperatures on 1PO82. Latitudes 40°00'N to 43°00'N were especially active coastal upwelling areas during 1PO82. A low surface temperature of 8.0°C was recorded nearshore at 42°05'N compared to 11.2°C offshore at the same latitude. On 1PO82 there was a strong temperature gradient near the coast south of 40°30'N. This gradient, which was a result of strong upwelling, dipped to 8.9°C. During cruise 1PO81, the surface temperatures ranged from a high of 15.2°C at 39°25'N, 127°45'W to a low of 8.9°C at 40°00'N, 124°10'W. During cruise 1PO82, the surface temperatures ranged from a high of 12.4°C at 39°25'N, 126°00'W, to a low of 8.0°C at 42°05'N, 124°25'W.

Cruise 1PO80, which took place on August 1st-20th, had a steep nearshore-offshore gradient of surface temperatures throughout the survey area. Temperatures were as much as 7.5°C cooler at the nearshore end of the transects than the offshore end. At latitude 42°30'N, 8.8°C was recorded at the inshore station, while 16.3°C was observed at the offshore station. It is evident from the contrast in coastal and offshore surface temperatures that active upwelling was occurring in most coastal areas between 39°00'N and 48°00'N. The highest surface temperature during 1PO80 was 17.2°C, which was recorded at 44°45'N, 127°50'W. High offshore surface temperatures during August can be attributed to solar irradiation. Nearshore temperatures are lowered by upwelling and increased cloud cover and fog.

Cruises 1DA81 and 1MF83, both fall cruises, had a small overlap of 9 days, so only very general comparisons can be made between the two. 1DA81, which took place from October 24th to November 19th, had an average of 2.0°C warmer surface temperatures than 1MF83, which took place from November 11th to December 2nd. The nearshore-offshore temperature gradient was small during both cruises. This is expected during the fall when little or no upwelling is occurring. On 1DA81 the entire survey area was nearly homogeneous with respect to surface temperature. Temperatures varied from 12.5 to 15.3°C. On 1MF83 it was evident that the surface of the northern half of the grid was cooling at a faster rate than the southern half of the grid. Cruise 1MF83 was expected to have warmer surface temperatures than the same period in previous years because of the warming trend of El Niño. Unfortunately, the data base from which this discussion was derived is not broad enough to provide direct comparisons to 1MF83.

Cruise 1MF87, a winter cruise, had uniformly low surface temperatures. The temperatures ranged from 8.9°C at the northernmost line of stations to 11.8°C at the southernmost line. Temperatures were an average of 1.0°C colder nearshore than offshore, probably due to intense mixing of shelf waters and freshwater runoff from winter rains (Bourke and Glenne 1971).

The El Niño cruises, 1EQ83 and 1MF83, had higher surface temperatures than other cruises during the same seasons in different years. This was more evident from our data base with 1EQ83 than with 1MF83, as the hydrographic data base for 1MF83 is small.

Comparisons of Observed Temperatures with Long-Term Means

The following description compares surface temperatures collected on 1980-1987 cooperative ichthyoplankton cruises with those collected by the Naval Oceanographic Office and calculated to monthly average sea surface temperatures. The data collected by the Navy was taken from a wide range of sources, including bathythermograph data from 1942 to 1969, hydrocast data from the National Oceanographic Data Center collected up to 1969, means extrapolated from published charts, and unpublished tabulations of means. This data was published in computer-generated contour plots (Robinson, 1976) similar to those produced for this report.

The sea temperature in the surface layer shows seasonal variations, particularly in the middle latitudes off the U.S. West Coast. The layer between the surface and a depth of 25 to 200 m is usually at much the same temperature as the surface water because of mixing due to wind waves. For this reason it is referred to as the upper mixed layer. In the winter, the surface temperature is low, waves are large, and the upper mixed layer is deep and may extend to the main thermocline. In the summer, the surface temperature rises, the water becomes more stable, and a seasonal "thermocline" often develops in the upper zone (Pickard and Emery, 1984).

In the eastern North Pacific at Ocean Weather Station "P" (Papa), located at 50°-00'N, 145°-00'W, the temperature gradually increases at the surface from March to August due to the absorption of solar energy. A mixed layer from the surface down to 30 m is always evident. After August, there is a net loss of heat energy from the sea while continued wind mixing erodes away the seasonal thermocline until the isothermal condition of March is approached again (Pickard and Emery, 1984).

Cruise 1PO84, which took place March 4th- April 4th, had considerably warmer sea surface temperatures than the March mean SSTs (sea surface temperatures) collected by the Naval Oceanographic Office. The 10.0°C contour on 1PO84 extended to 47°00'N (Fig. 104). The March mean 10.0°C SST contour extended to only 42°00'N. The 10.5°C contour extended as far north as 40°00'N on the March mean SST plot, whereas it extended farther north to 44°30'N on 1PO84.

Cruises 1TK80, 1EQ83, and 1BA85 occurred from late April to mid May. Sea surface temperature contours from 1BA85 closely resemble Robinson's (1976) April mean SST contours. The 1TK80

SST contours most closely resemble Robinson's (1976) May mean SST contours. The contours from 1EQ83 are shifted much farther north than on either the April or the May mean SST plots due to the El Niño/southern oscillation event.

The 10.5°C contour on 1TK80 began near 44°20'N and continued to the coast at 48°00'N (Fig. 105). The 10.5°C contour on the May mean SST plot began near 45°00'N and continued to the northern boundary of the survey area. Both contours are very similar in appearance. The 13.0°C contour on 1TK80 ranged from 39°00'N to 40°00'N and on the May mean SST plot it ranged from 39°00'N to 40°30'N. The 13.0°C contours were similar in appearance. May 1980 sea surface temperatures generally compared well with the May mean SST plot.

1BA85 (April 19th-May 11th) had colder than average surface temperatures when compared with the May mean SST plot, but was similar to the April mean SST plot (Fig. 106). The 9.5°C contour on the April mean SST plot ranged from 44°00'N to 46°30'N. On 1BA85, the 9.5°C contour ranged from 45°20'N to 47°45'N. The northernmost extension of the 9.5°C contour on both plots was nearshore. The 10.0°C and 10.5°C contours on 1BA85 were fairly level. On the April mean SST plot, the 10.0°C and 10.5°C contours had spikes pointing to the south near the coast.

1EQ83 (April 23rd-May 15th) was an unusual cruise with regard to surface temperature when compared with Robinson's

(1976) May mean SSTs. The temperature anomalies, which were a result of the El Niño/southern oscillation event, are best demonstrated by the 12.5°C contour (Fig. 107). During 1EQ83, the 12.5°C contour penetrated as far north as 45°35'N, whereas on the May mean SST plot it only reached 40°30'N.

The sea surface temperatures on cruise 1PO81 (May 9th-June 2nd) and 1PO82 (May 3rd-June 1st) resemble the Naval Oceanographic Office's May mean SST plot. 1PO81 SSTs were slightly higher than average and 1PO82 SSTs were slightly lower than average. On 1PO81, the 13.0°C contour had a spike which extended north and nearshore to 44°00'N, whereas on the May mean SST plot it reached only 39°45'N in the survey area (Fig. 108). 1PO82, in contrast to 1PO81, had no 13.0°C contour. The 12.0°C contour on 1PO82 consisted of isolated values at 40°00'N and 43°30', whereas the same contour on the May mean SST plot extended to 41°30'N in the survey area.

Cruise 1PO80 (August 1st-20th) resembled the August mean SST plot in that there was a steep temperature gradient near the coast which levelled out offshore (Fig. 65). Both plots show a cooling trend nearshore in the southern half of the survey area, which is a result of coastal upwelling. 1PO80 had cooler temperatures nearshore to the south than are seen in the August mean SST plot. 1PO80 probably had more residual coastal upwelling than average for August. For example, on 1PO80, the

14.0°C contour was found as far offshore as 127°30'W with SSTs decreasing rapidly farther inshore. On the August mean SST plot, the 14.0°C contour extended offshore to only 124°40'W with a more gradual drop in temperature toward the coast.

Cruise 1DA81 (October 24th-November 19th) was similar to the October mean SST plot in the northern half of the survey area and similar to the November mean SST plot in the southern half of the survey area. The 13.0°C contour, for example, ranged from 46°30'N to 49°00'N on the October mean SST plot and from 47°40'N to 49°00'N during 1DA81 (Fig. 110). Temperatures did not vary much from north to south on 1DA81, unlike both the October and November mean SST plots, where temperatures increased rapidly to the south and offshore. On 1DA81, surface temperatures had more of an offshore-onshore than north-south gradient, with the coldest temperatures occurring nearshore.

On 1MF83 (November 11th-December 2nd) the SST contours generally had an east-west orientation (Fig. 64). The November mean SST plot contours have a more north-south orientation, making direct comparison with 1MF83 difficult. A general trend seen in comparing 1MF83 with the November mean SST plot is that during 1MF83 the nearshore temperatures were warmer and the offshore temperatures were colder than the November mean SSTs.

On 1MF87 (January 7th-31st) and Robinson's (1976) mean SST plot for January there was a general north-south trend of temperature increase, although the 1MF87 temperatures were warmer than the January mean SSTs. The 10.0°C contour extended north to 47°30'N on 1MF87 and reached only as far north as 45°00'N on the January mean SST plot (Fig. 111).

Temperatures Observed at 200 m

The 200 m temperature data was much less variable and had a smaller gradient than the surface temperature data, as the 200 m horizon is a more stable environment than the surface.
Cruise 1EQ83 showed marked differences in 200 m temperatures from the other spring cruises, 1TK80 and 1BA85. The timing of the three cruises was similar. 1EQ83 had some anomalously high 200 m temperatures, which can be attributed to El Niño (Figs. 77 and 78). A high value of 10.0°C was recorded on the southernmost survey line at 40°00'N, 127°30'W (Fig. 78). Another unusually high 200 m temperature of 9.8°C was seen at 46°30'N, 126°20'W. These two temperatures are an average of 2.0°C to 3.0°C higher than those recorded on the other spring cruises. During 1TK80, the 200 m temperature data ranged between 7.0°C and 8.0°C, with the exception of two steep gradients (Figs. 75 and 76). A low value of 6.4°C was recorded near the coast at 43°50'N, 124°55'W. There was a steeply increasing gradient at 40°45'N, 126°40'W,

where a high reading of 8.6°C was seen. During 1BA85, the 200 m horizon was homogeneous in comparison to 1TK80 and 1EQ83. Most of the 200 m temperature values ranged between 7.0 and 7.8°C (Figs. 79 and 80). There were two slight gradients in the southern half of the survey area. At 40°00'N, 127°30'W there was an increasing gradient which peaked at 8.4°C. On the same latitude at 124°50'W there was a decreasing gradient due to coastal upwelling, which plummeted to 6.5°C. On all three spring cruises, 200 m temperatures near the coast south of 45°00'N were significantly lower than offshore temperatures due to early upwelling.

Cruise 1PO84, the early spring (March 11th-April 4th) cruise, had some interesting features at the 200 m horizon (Fig. 73). There was a region of warm water centered around a reading of 8.76°C at 43°30'N, 128°50'W (Fig. 74). Another area of interest was 40°00'N, 124°30'W, where a low reading of 6.7°C was seen, probably as a result of early, localized upwelling. The rest of the 1PO84 survey had no outstanding features, just a gradually increasing 200 m temperature gradient from north to south.

The late spring cruises, 1PO81 and 1PO82, both had strong upwelling south of 45°00'N. 200 m temperatures during 1PO81 suggest that coastal upwelling activity was occurring to the largest degree between 40°00'N and 44°40'N (Figs. 81 and 82). 200

meter data from 1PO82 revealed a smaller coastal area between 40°40'N and 43°20'N (Figs. 83 and 84). These observations are based on the amount of contrast in 200 m temperatures between nearshore and offshore stations. There were two more obvious gradients on 1PO81. Temperatures climbed more than a degree to 8.5°C at 44°40'N, 126°35'W. There was also a high 200 m reading of 7.8°C at 47°20'N, 126°00'W. On 1PO82 the 200 m temperature data was unremarkably homogeneous, except for two small areas in the southern half of the survey area. There was an increasing gradient to 8.5°C at 42°05'N, 126°00'W. Another high temperature of 8.3°C was found at 40°00'N, 126°30'W. A general trend seen on both 1PO81 and 1PO82 with the 200 m temperature horizon was that north of 45°00'N the temperatures usually decreased in the inshore-to-offshore direction, whereas south of 45°00'N, 200 m temperatures usually increased in the inshore-to-offshore direction.

Cruise 1PO80 had relatively few data points at 200 m. The effects of upwelling were still being seen on a limited basis in coastal areas south of 40°00'N on this late summer cruise (Figs. 85 and 86). The 200 m temperatures on 1PO80 differed little from those on 1TK80, which occurred earlier in the year during the spring. Most areas differed by no more than 0.2°C on the two cruises. Both cruises had low temperature readings near the coast in the vicinity of 44°00'N with very similar increasing gradient patterns. The similarities between these two cruises demonstrate that the 200 meter horizon is relatively stable when compared with the surface.

When comparing the winter cruises 1DA81 and 1MF83, it should be noted that there is only a 9 day overlap between the two cruises. Cruise 1MF83 had fewer data points and also occurred shortly after an unusually anomalous El Niño event. Temperatures at 200 m were higher on 1MF83 than on 1DA81, even though 1MF83 started 19 days later in the fall (Figs. 87-90). The 7.6°C isotherm, for example, extended all the way south to 40°00'N on 1DA81, whereas it only extended south to 43°35'N on 1MF83 (Fig. 112). On both cruises, nearshore temperatures were, for the most part, higher than offshore temperatures, probably due to the runoff of winter rains, which were mixed to the 200 m horizon by strong south-southeast winds.

On cruise 1MF87 there was a steep 200 m gradient to the north of the Columbia River. Nearshore temperatures were up to 2.0°C higher than offshore temperatures at the same latitude (Figs. 91 and 92). This is probably due to intense vertical mixing in shelf waters caused by winter storms. Warmer surface waters mix with colder deep waters during the winter, resulting in higher temperatures at the 200 m horizon. The Columbia River plume normally extends to the north and nearshore in the winter (Bourke and Glenne, 1971). A steep gradient of decreasing 200 m temperatures was seen from nearshore to offshore north of the Columbia River, where the plume was expected to reside. The rest of the survey was unremarkable, showing a gentle gradient of 200 m temperature increase from north to south. A low reading of 6.9°C was recorded at 40°40'N, 128°30'W.

Temperature and Salinity Scatter-plots

In order to compare temperatures and salinities over time, three 360 square nautical mile areas were chosen, within which stations were consistently sampled (Fig. 115). The northernmost area, designated Area I, is bounded by latitudes 46°30'N and 47°30'N and longitudes 125°30'W and 127°00'W. The central area, designated Area II, is bounded by latitudes 43°15'N and 44°15'N and longitudes 125°30'W and 127°00'W. The southernmost area, designated Area III, is bounded by latitudes 40°00'N and 41°00'N and longitudes 125°30'W and 127°00'W.

The scatter-plots (Figs. 117-121) of temperature and salinity versus time reflect a per cruise average of the plotted parameters. Temperature and salinity averages at the surface and at 200 m were plotted.

Area I, the northernmost region, had the greatest fluctuation of the three areas in surface temperatures from 1980-1987, yet had the smallest fluctuation in 200 m temperatures.

Area I surface temperatures peaked at a cruise average of 16.43°C during August 1980 (1PO80). The low surface temperature average for Area I was 9.18°C, which was obtained in April 1985 (1BA85). Area I had little observed fluctuation over time in 200 m temperatures. Area III had the largest range of 200 m temperatures. The high reading for Area III at 200 m was 8.35°C, which was the average salinity for the May 1980 cruise (1TK80). The low reading for Area III was 7.10°C, the average from August 1980 (1PO80). Cooler temperatures at 200 m in August were probably a result of the lingering effects of upwelling of colder, deeper water. Area III had the least scatter of the three regions in surface temperatures and Area I had the least scatter in 200 m temperatures.

Area III surface salinities peaked at a cruise average of 33.05 gm/kg during August 1980. The low average surface salinity reading from Area III was 32.20 gm/kg, obtained in November 1981. Average 200 m salinities in Area III ranged from 33.58 gm/kg in November 1981 to 34.07 gm/kg in January 1987. Area I, the northernmost region, had the least scatter of the three regions in surface and 200 m salinities.

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Figure 99.--Surface salinity comparisons (32.0 GM/KG contour) for cruise 1PO81 (May 1981) and all-data means (Robinson 1976).

Figure 100.--Surface salinity comparisons (32.0 GM/KG, 32.5 GM/KG, and 33.0 GM/KG contours) for cruise 1PO82 (May 1982) and all-data means (Robinson 1976).

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Figure 120.--Scatter-plots of salinities at the surface and 200 meters for Area II from 1980-1987.

Figure 121.--Scatter-plots of salinities at the surface and 200 meters for Area III from 1980-1987.

COOPERATIVE U.S.-U.S.S.R CRUISES 1980-1987

CRUISE	SEASON	CRUISE DATES
1PO84 RV Poseydon	Early Spring 1984	March 11th-April 4th
1TK80 RV Tikhookeanski	Spring 1980	April 20th-May 15th
1EQ83 RV Equator	Spring 1983	April 23rd-May 15th
1BA85 RV Mys Babyshkina	Spring 1985	April 19th-May 11th
1PO81 RV Poseydon	Late Spring 1981	May 9th-June 2nd
1PO82 RV Poseydon	Late Spring 1982	May 3rd- June 1st
1PO80 RV Poseydon	Summer 1980	August 1st-20th
1DA81 RV Mys Dalniy	Fall 1981	Oct. 24th-Nov.19th
1MF83 RV Miller Freeman	Late Fall 1983	Nov. 11th-Dec. 2nd
1MF87 RV Miller Freeman	Winter 1987	January 7th-31st

Figure 1a.--Seasonal distribution of cooperative NWAFC-TINRO cruises off Washington, Oregon, and California 1980-1987.

Schedule of NWAFC-TINRO Ichthyoplankton Surveys off Washington, Oregon and California

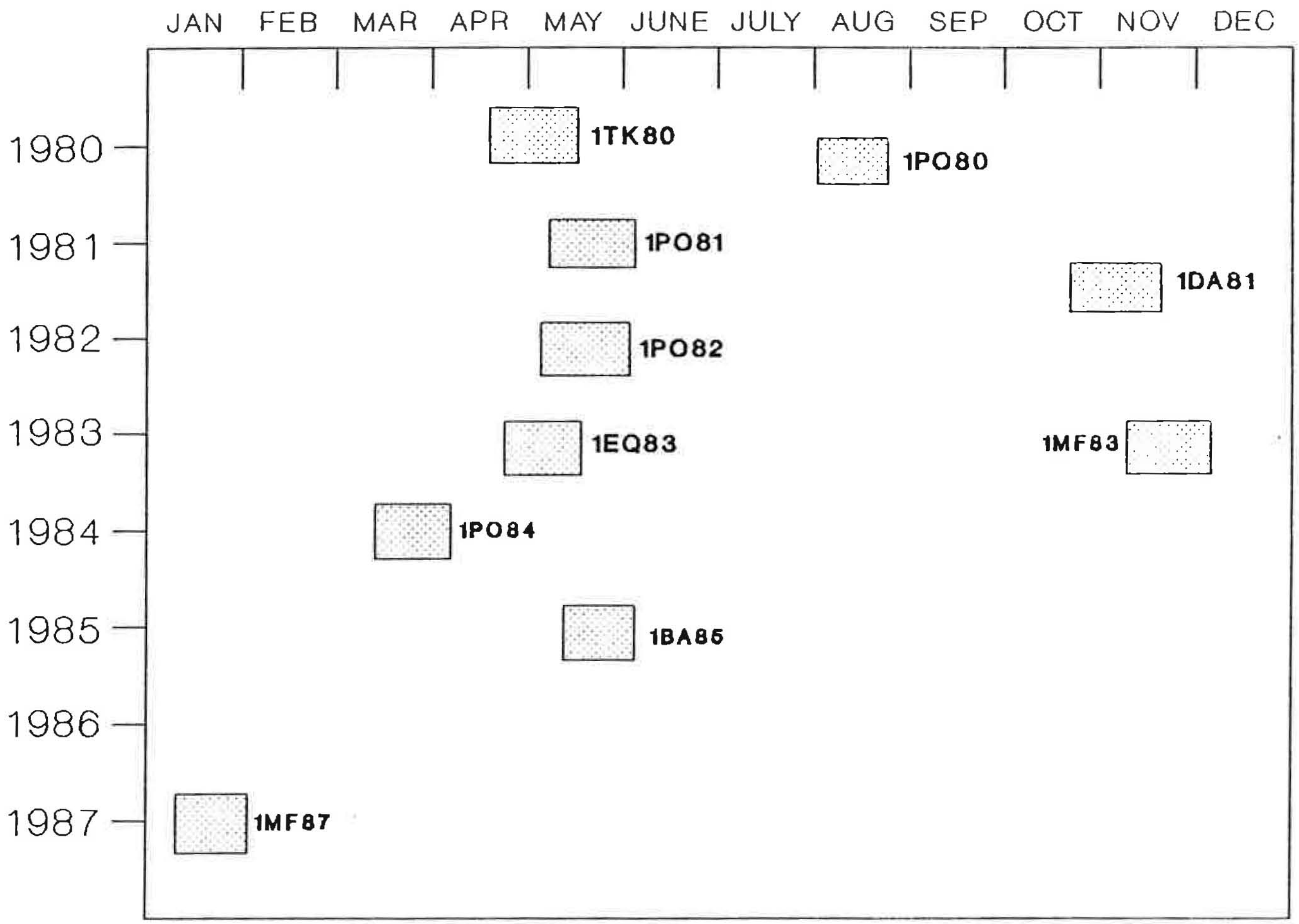

Figure 1b.--Chronology of cooperative NWAFC-TINRO cruises off Washington, Oregon, and California 1980-1987.

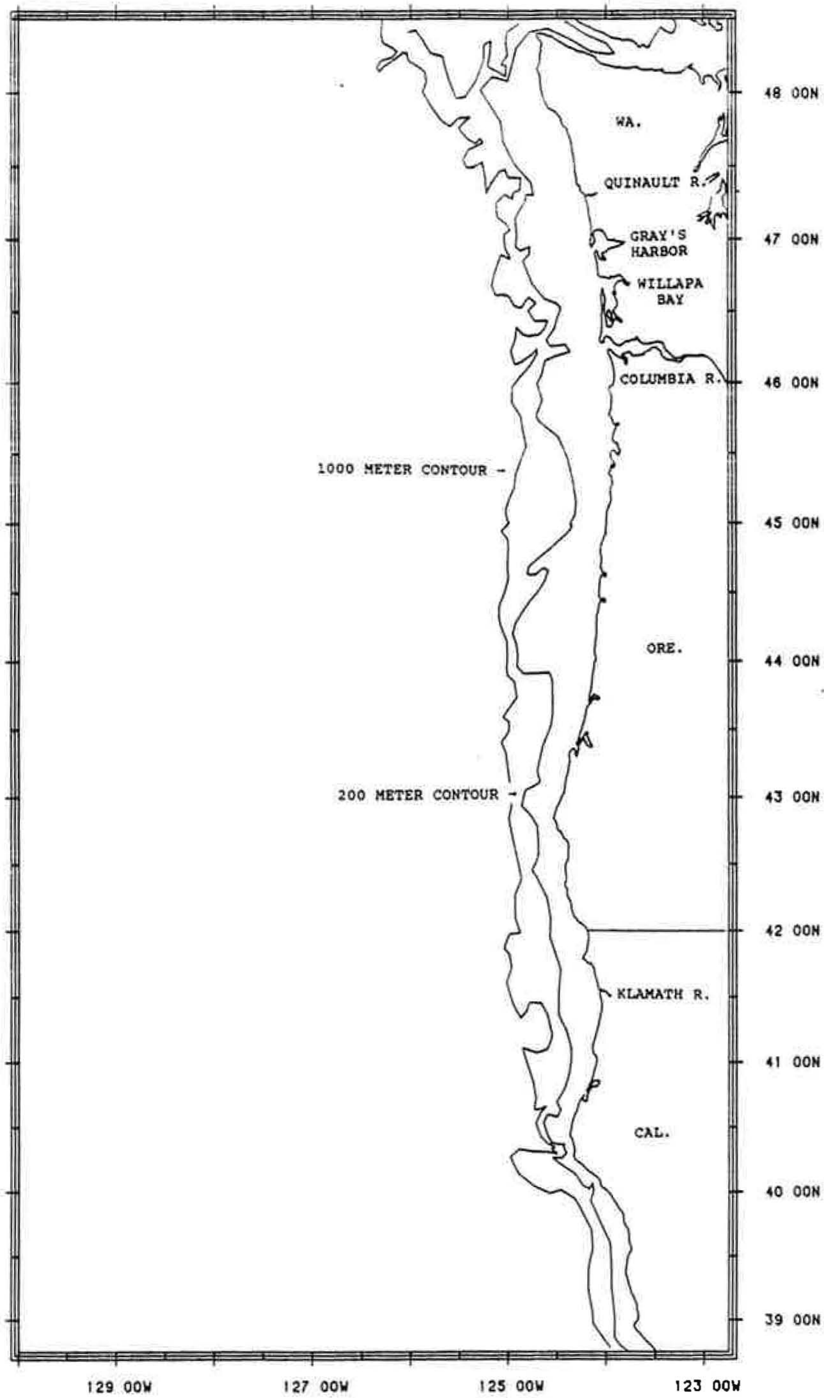

Figure 2.--Outstanding geographic features and 200 meter and 1,000 meter depth contours for NWAFC-TINRO survey area.

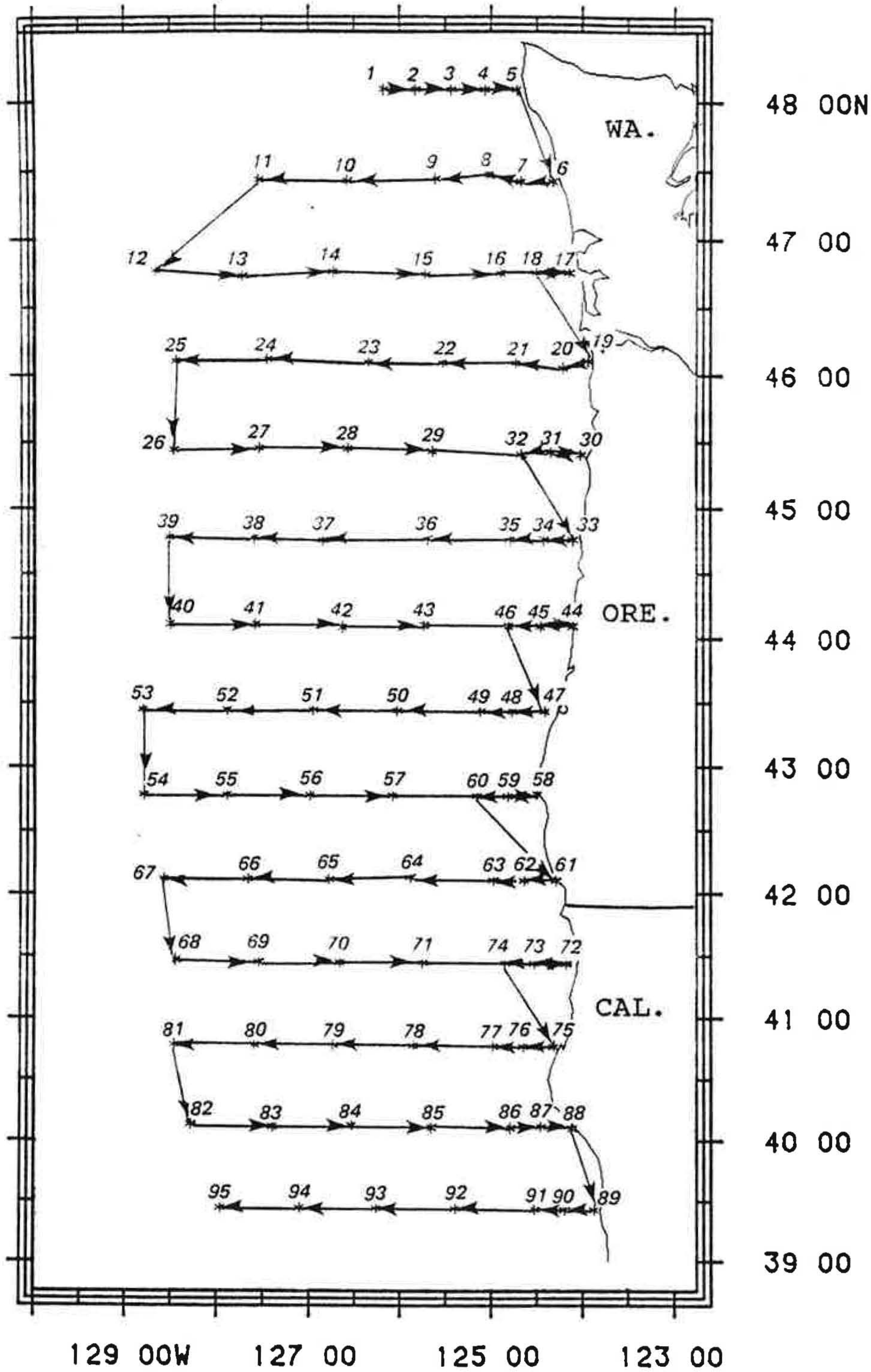

Figure 3.--Station locations and cruise track for cruise 1PO84, March 11th-April 4th, 1984.

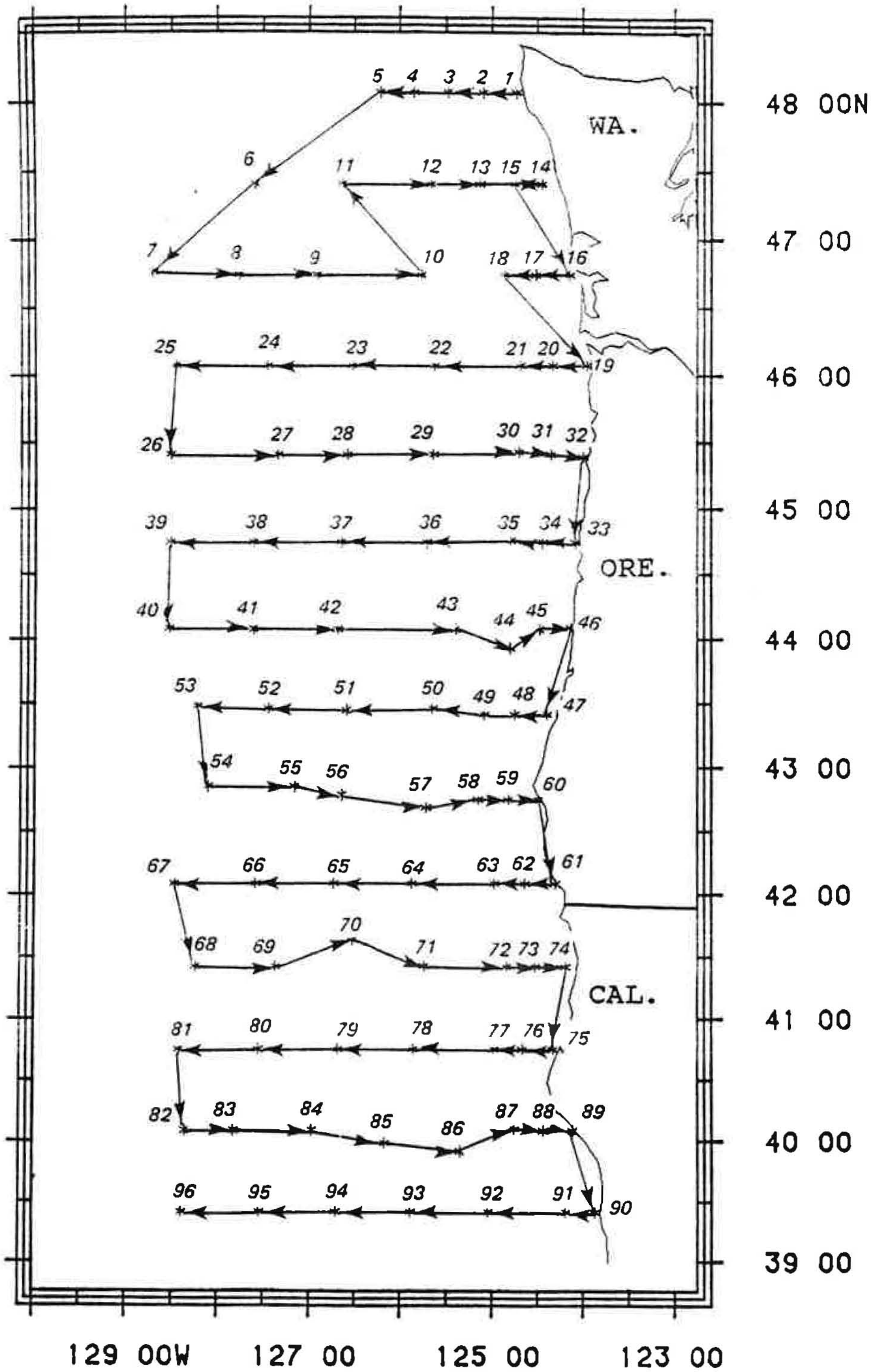

Figure 4.--Station locations and cruise track for cruise 1TK80, April 20th-May 15th, 1980.

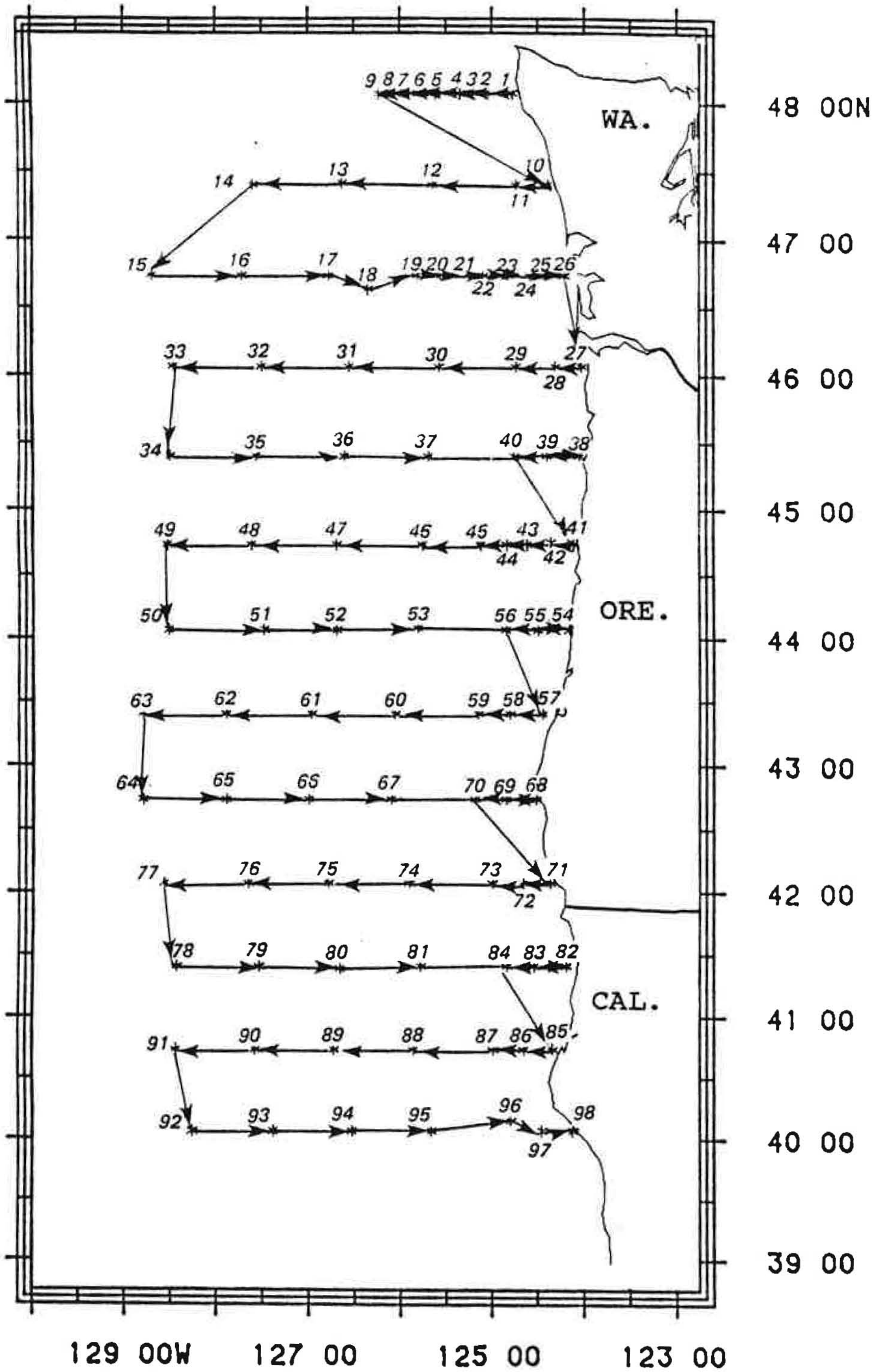

Figure 5.--Station locations and cruise track for cruise 1EQ83, April 23rd-May 15th, 1983.

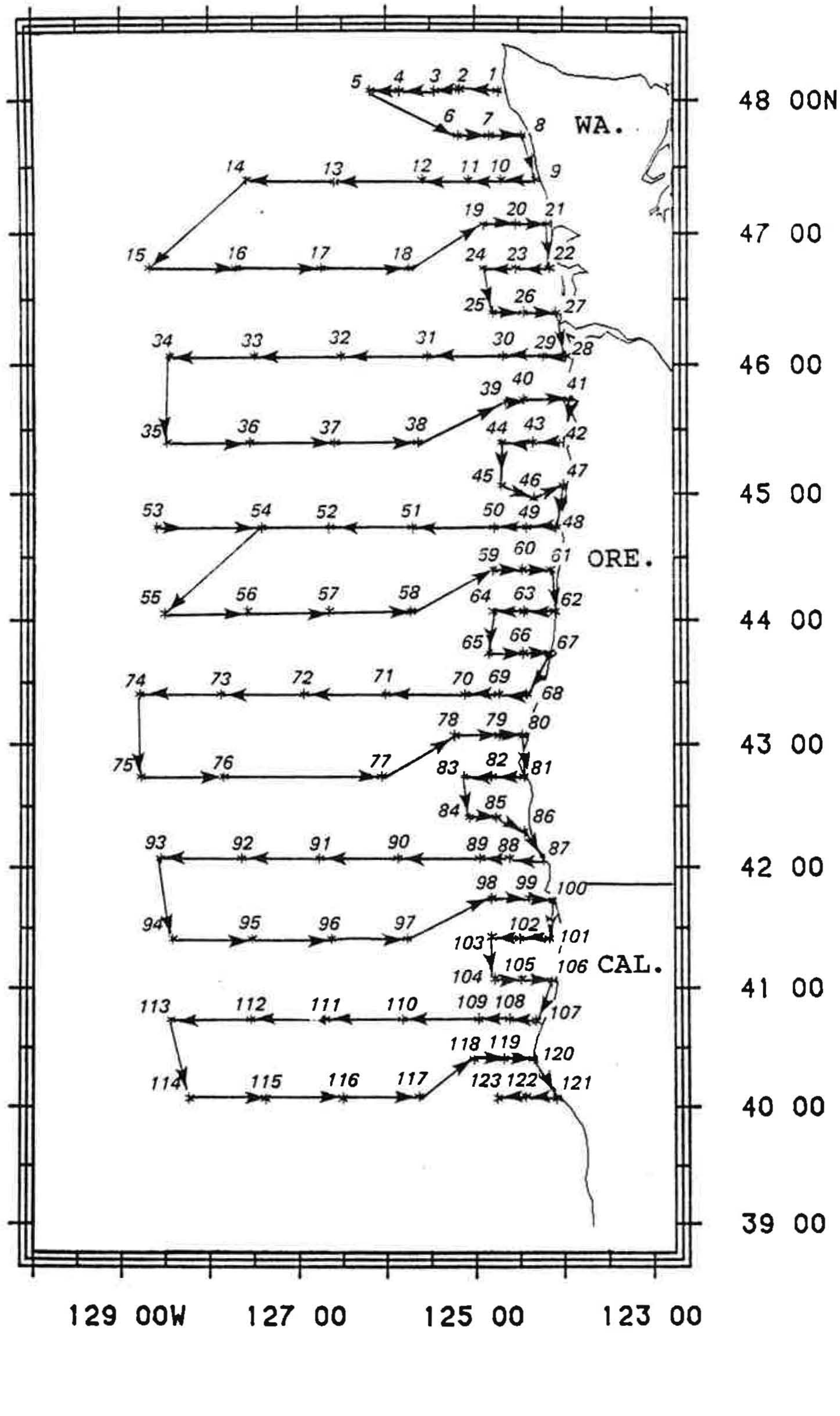

Figure 6.--Station locations and cruise track for cruise 1BA85, April 19th-May 11th, 1985.

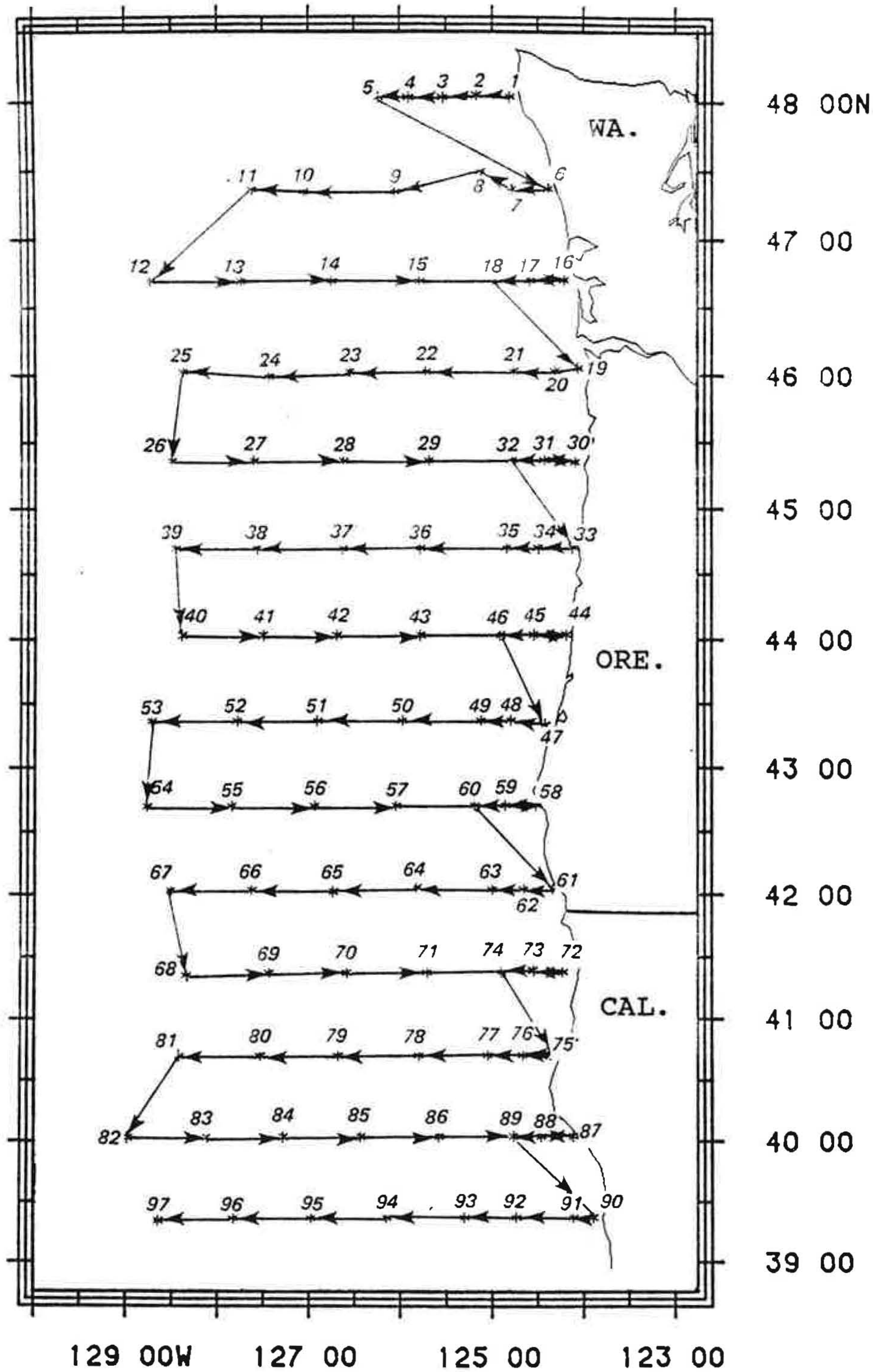

Figure 7.--Station locations and cruise track for cruise 1PO81, May 9th-June 2nd, 1981.

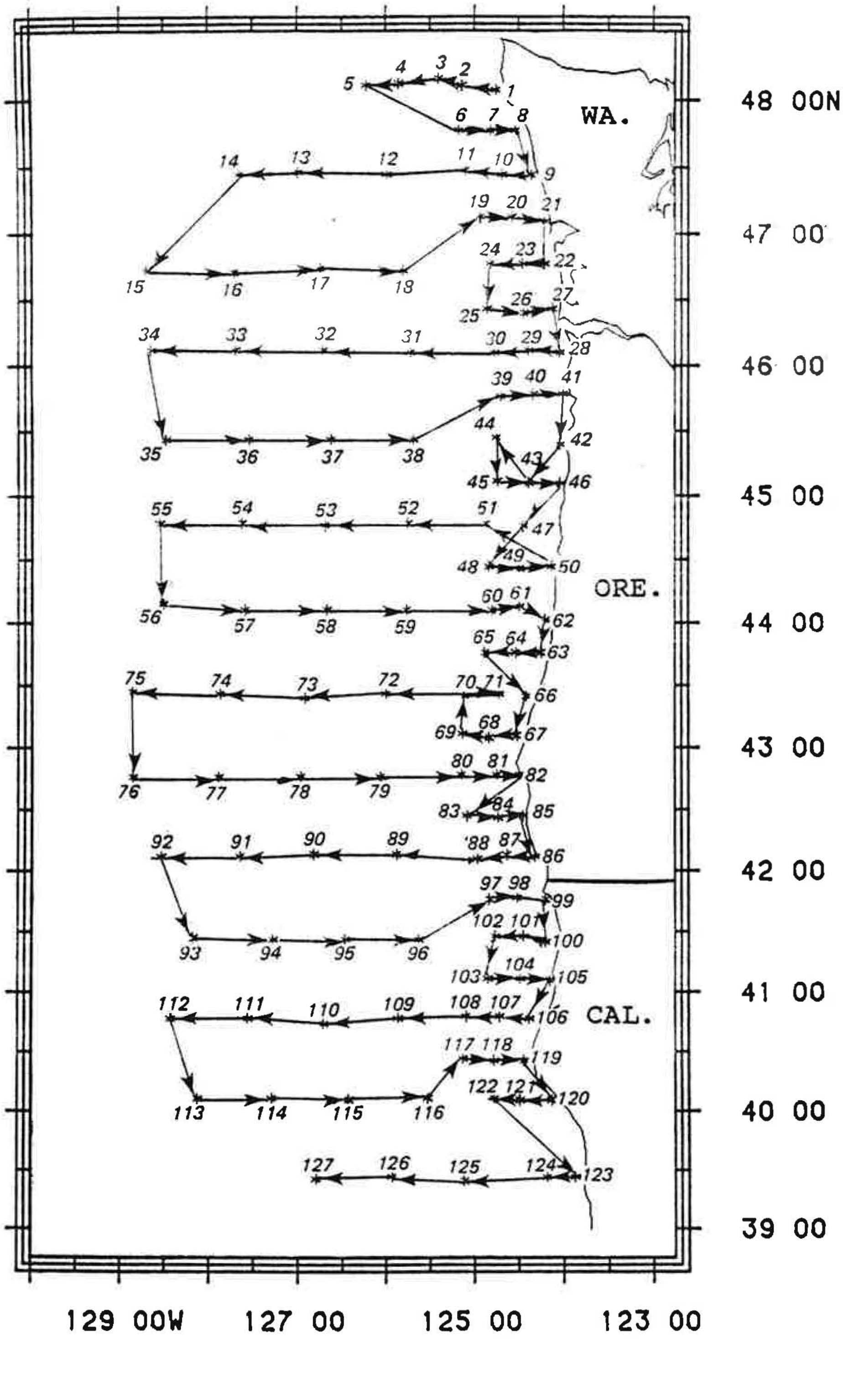

Figure 8.--Station locations and cruise track for cruise 1PO82, May 3rd-June 1st, 1982.

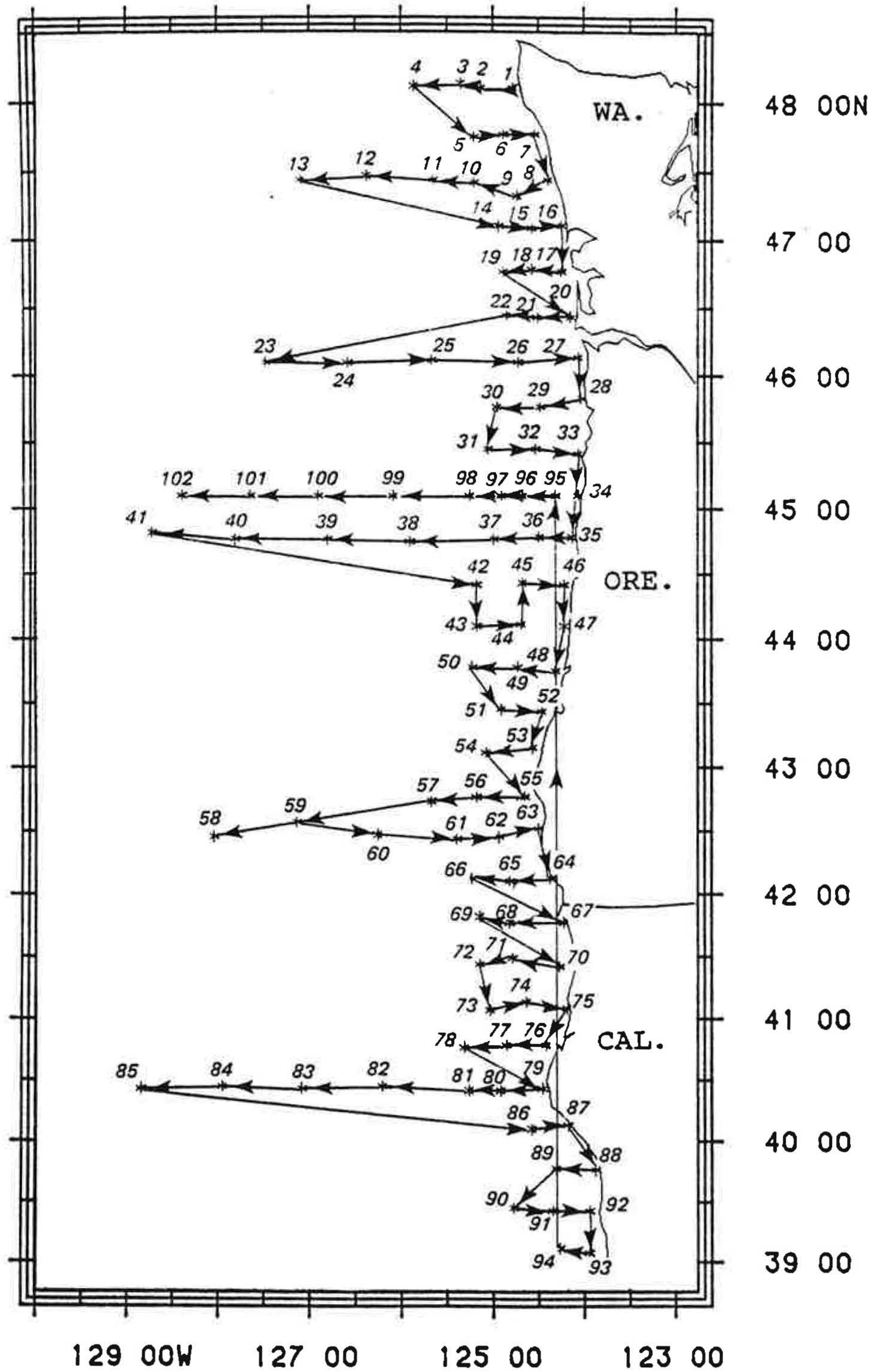

Figure 9.--Station locations and cruise track for cruise 1PO80, August 1st-20th, 1980.

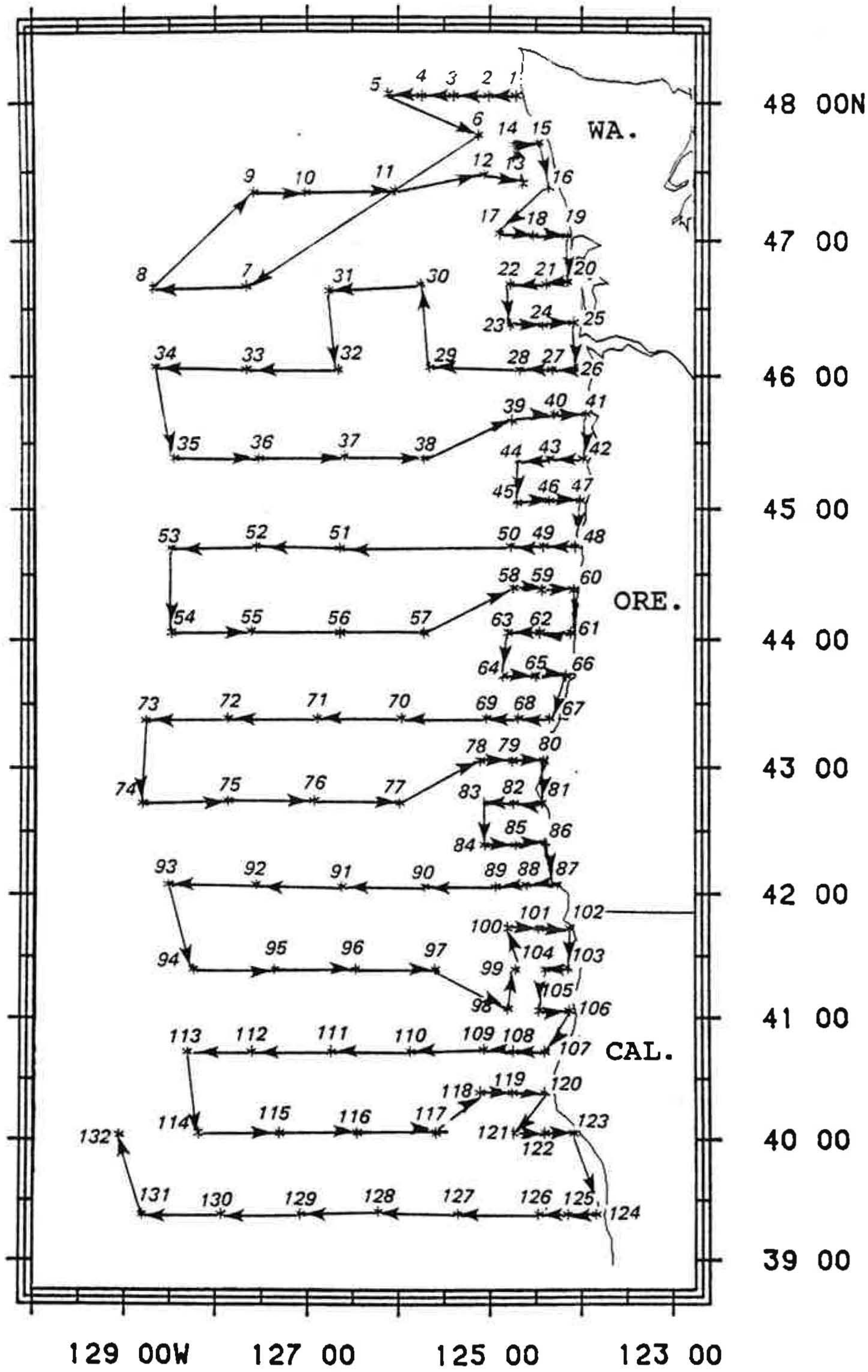

Figure 10.--Station locations and cruise track for cruise 1DA81, October 24th-November 19th, 1981.

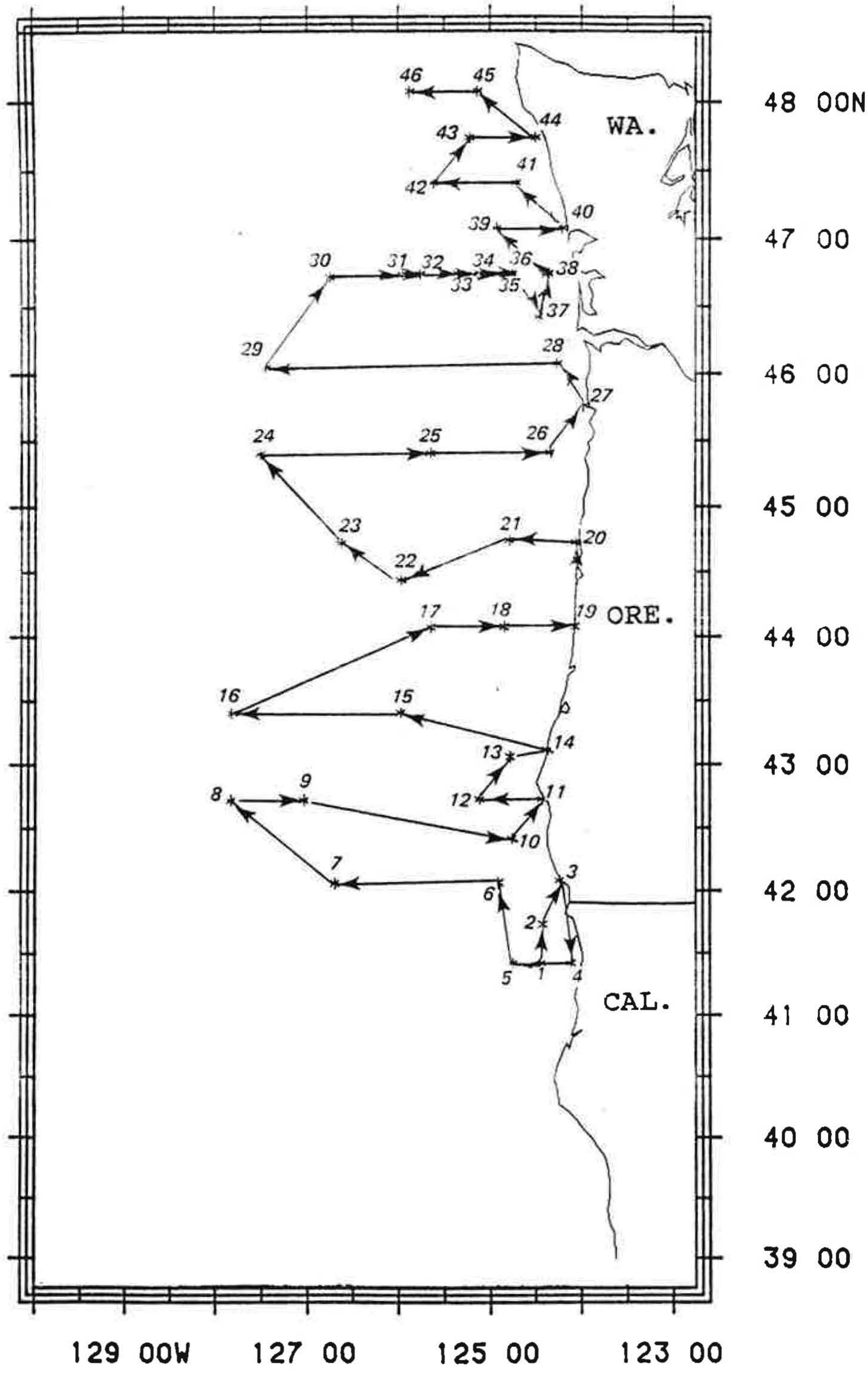

Figure 11.--Station locations and cruise track for cruise 1MF83, November 11th-December 2nd, 1983.

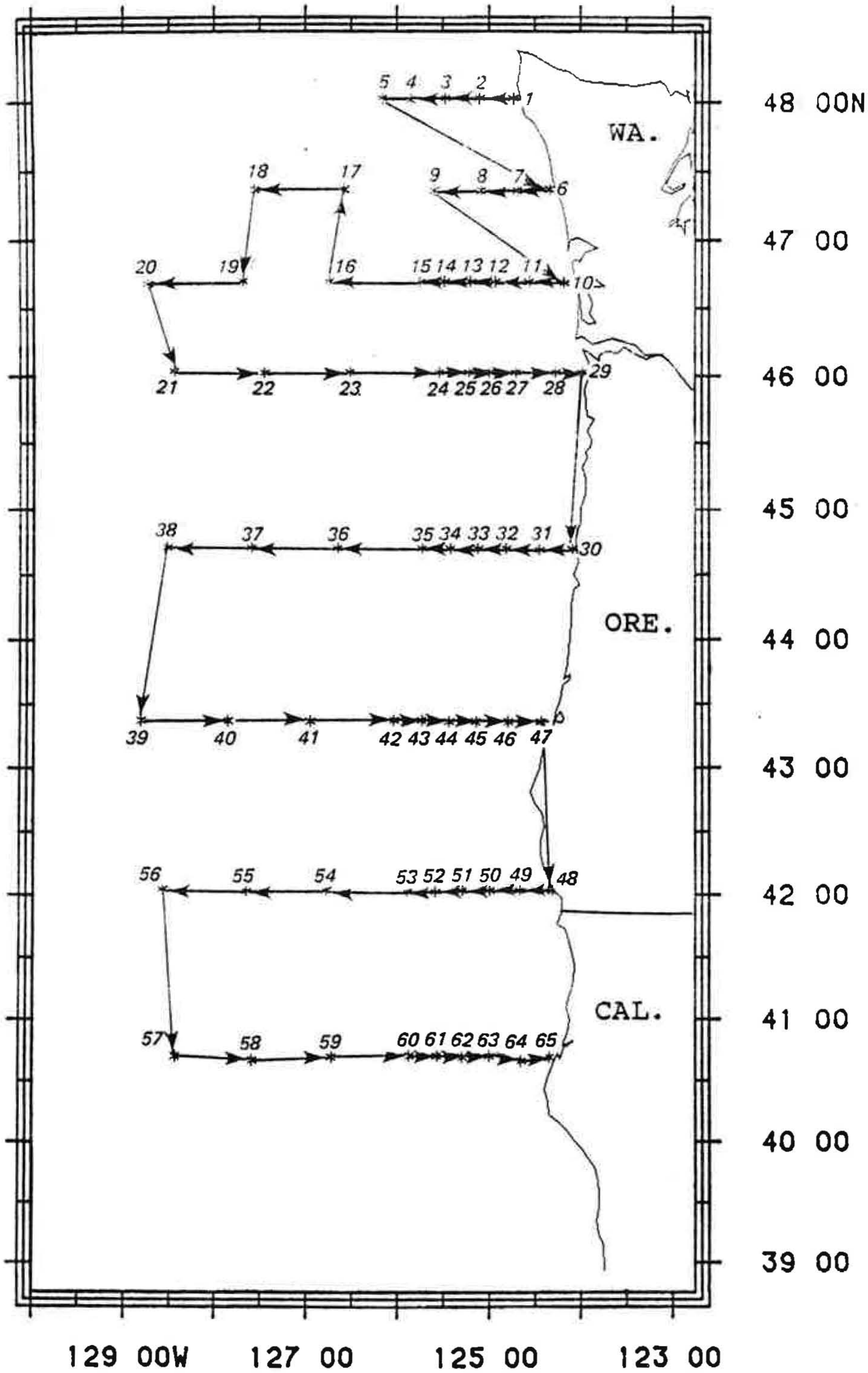

Figure 12.--Station locations and cruise track for cruise 1MF87, January 7th-31st, 1987.

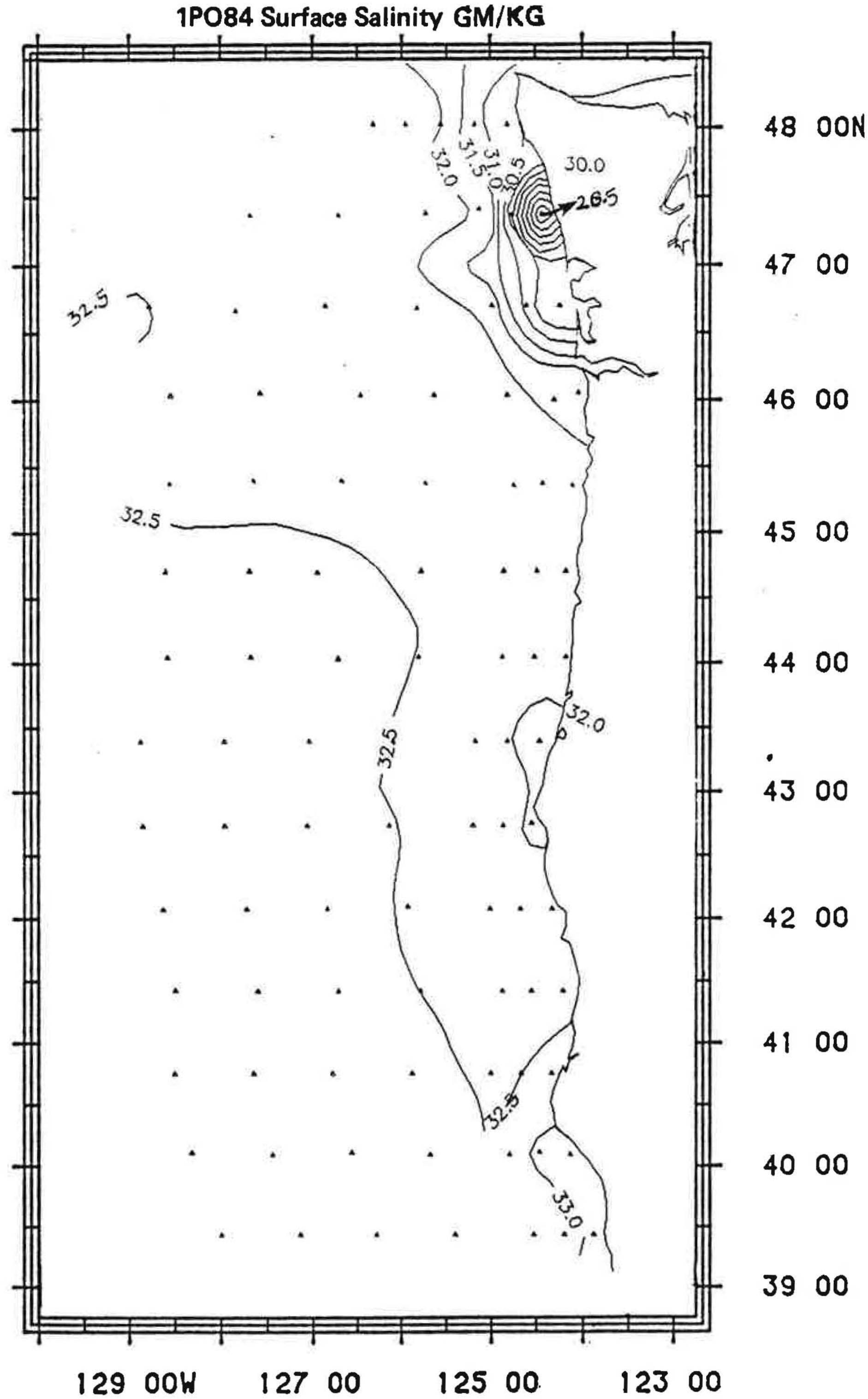

Figure 13.--Surface salinity contours (GM/KG) for cruise 1PO84, March 11th-April 4th, 1984.

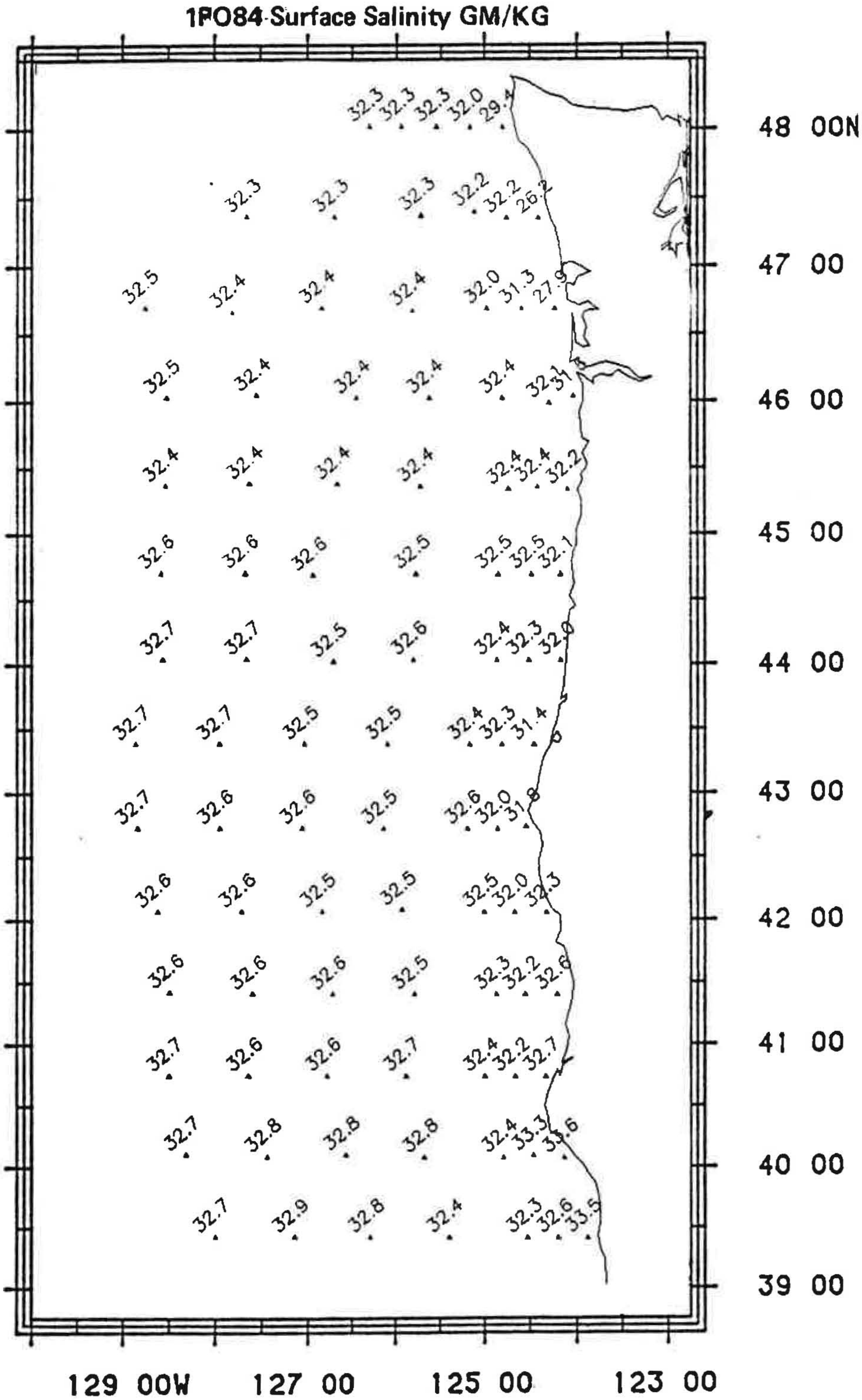

Figure 14.--Surface salinity values (GM/KG) for cruise 1PO84, March 11th-April 4th, 1984.

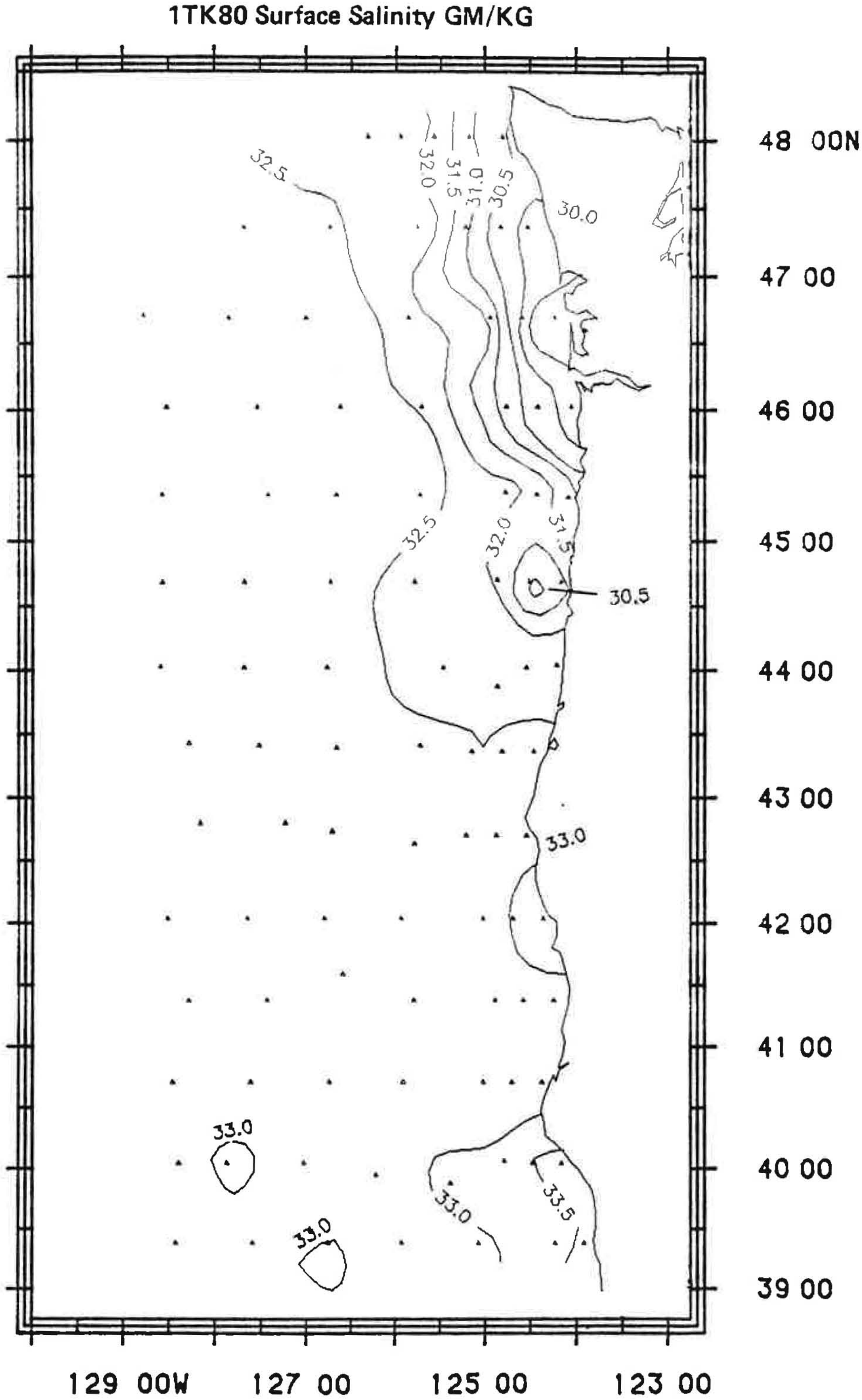

Figure 15.--Surface salinity contours (GM/KG) for cruise 1TK80, April 20th-May 15th, 1980.

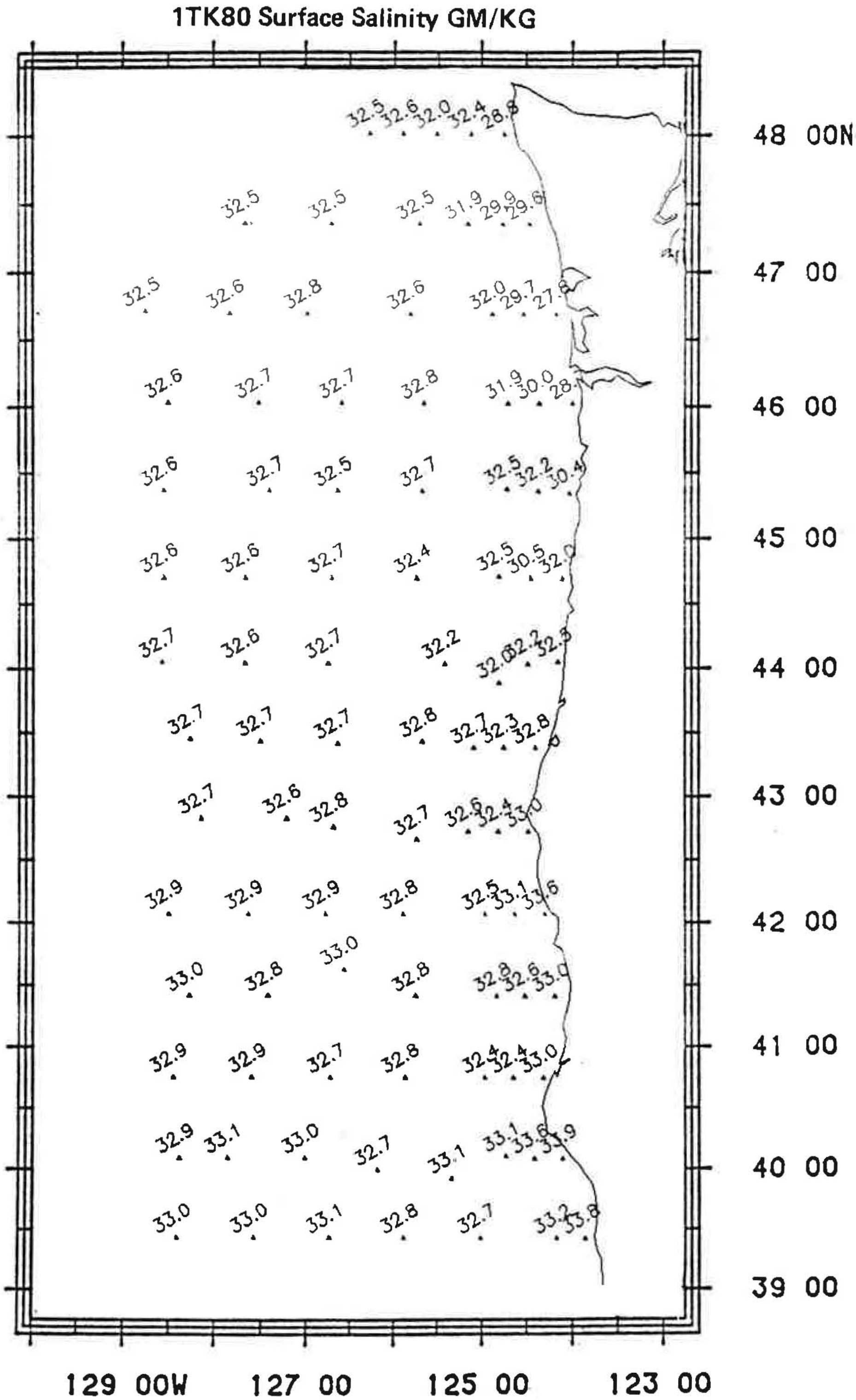

Figure 16.--Surface salinity values (GM/KG) for cruise 1TK80, April 20th-May 15th, 1980.

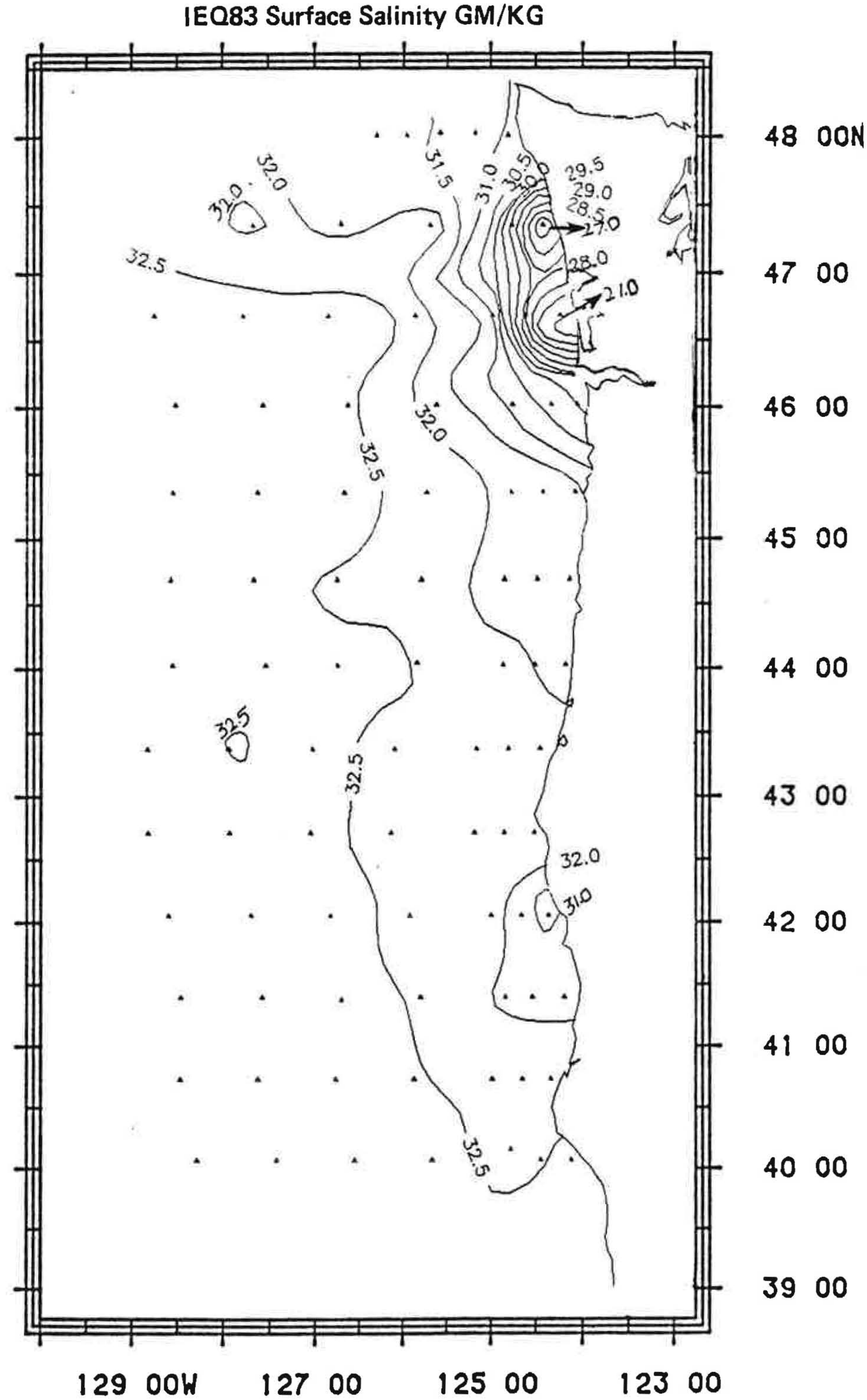

Figure 17.--Surface salinity contours (GM/KG) for cruise 1EQ83, April 23rd-May 15th, 1983.

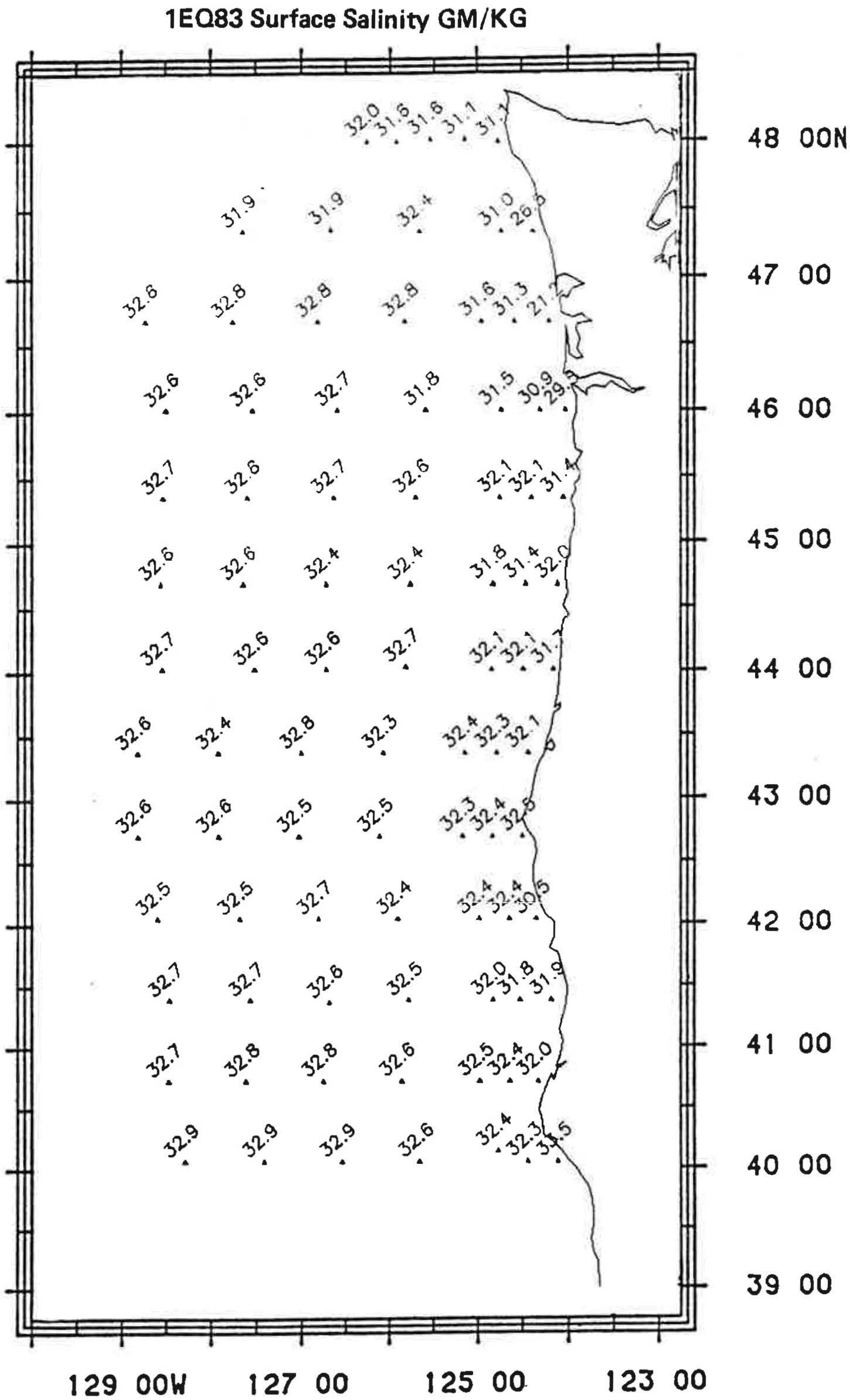

Figure 18.--Surface salinity values (GM/KG) for cruise 1EQ83, April 23rd-May 15th, 1983.

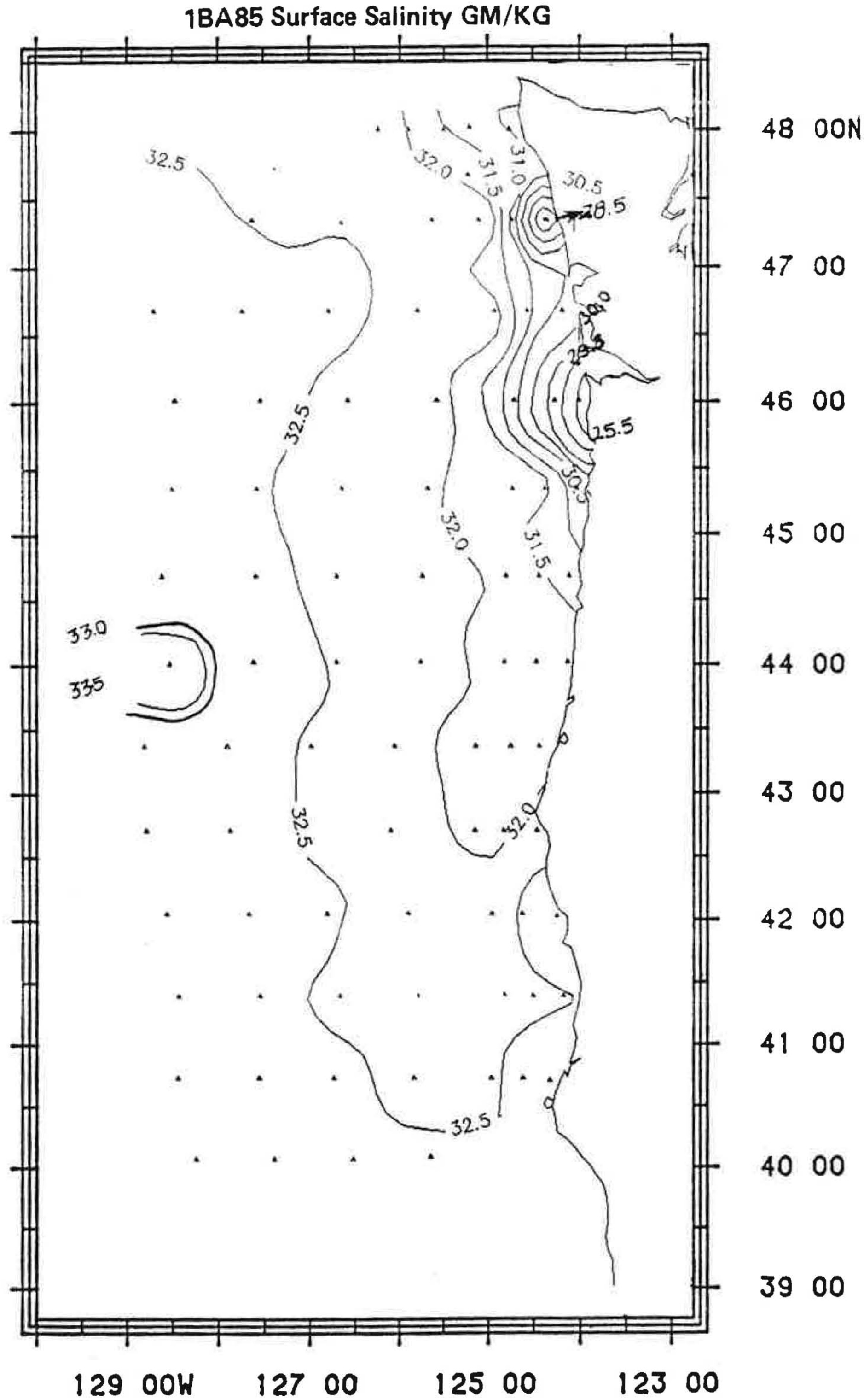

Figure 19.--Surface salinity contours (GM/KG) for cruise 1BA85, April 19th-May 11th, 1985.

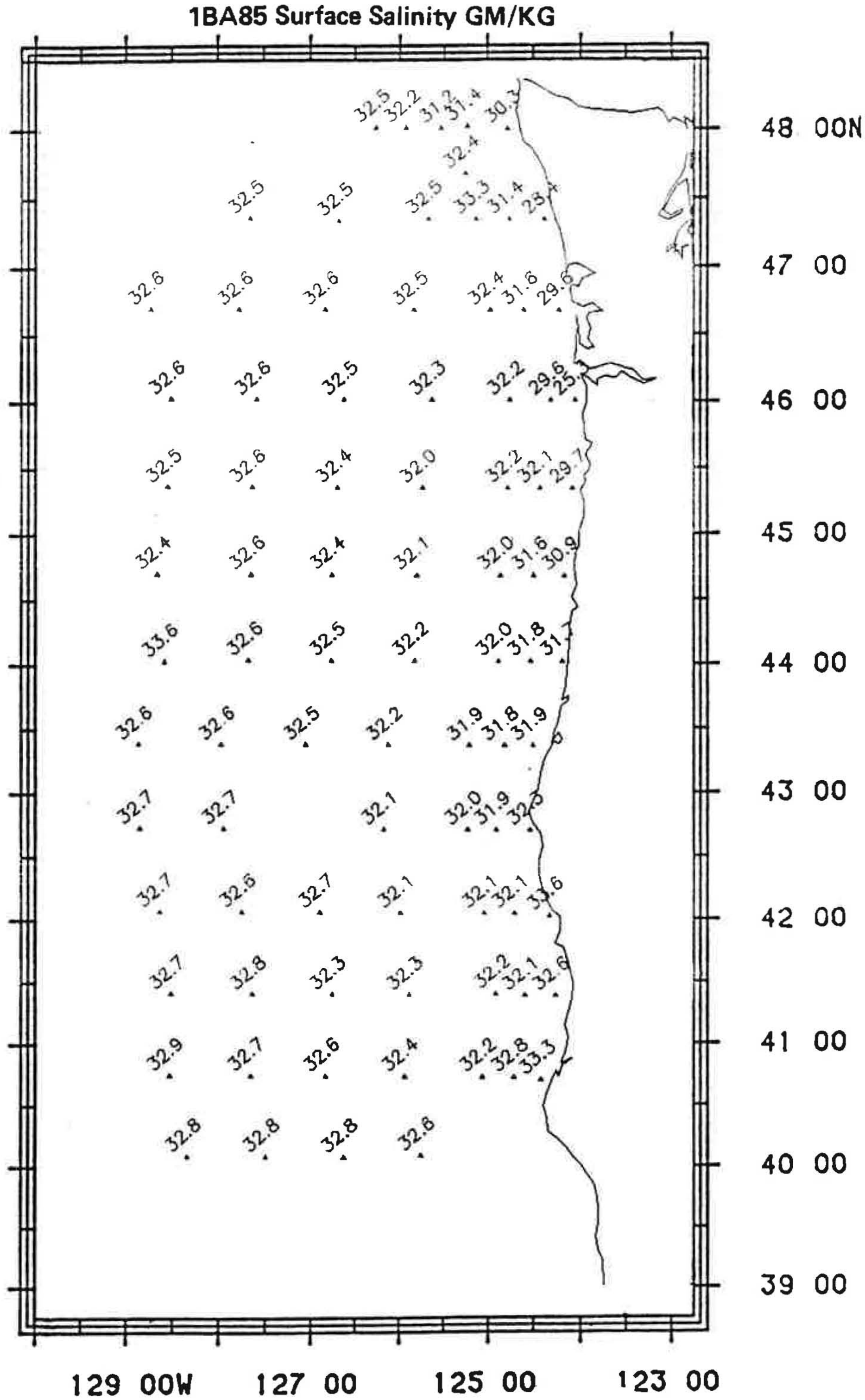

Figure 20.--Surface salinity values (GM/KG) for cruise 1BA85, April 19th-May 11th, 1985.

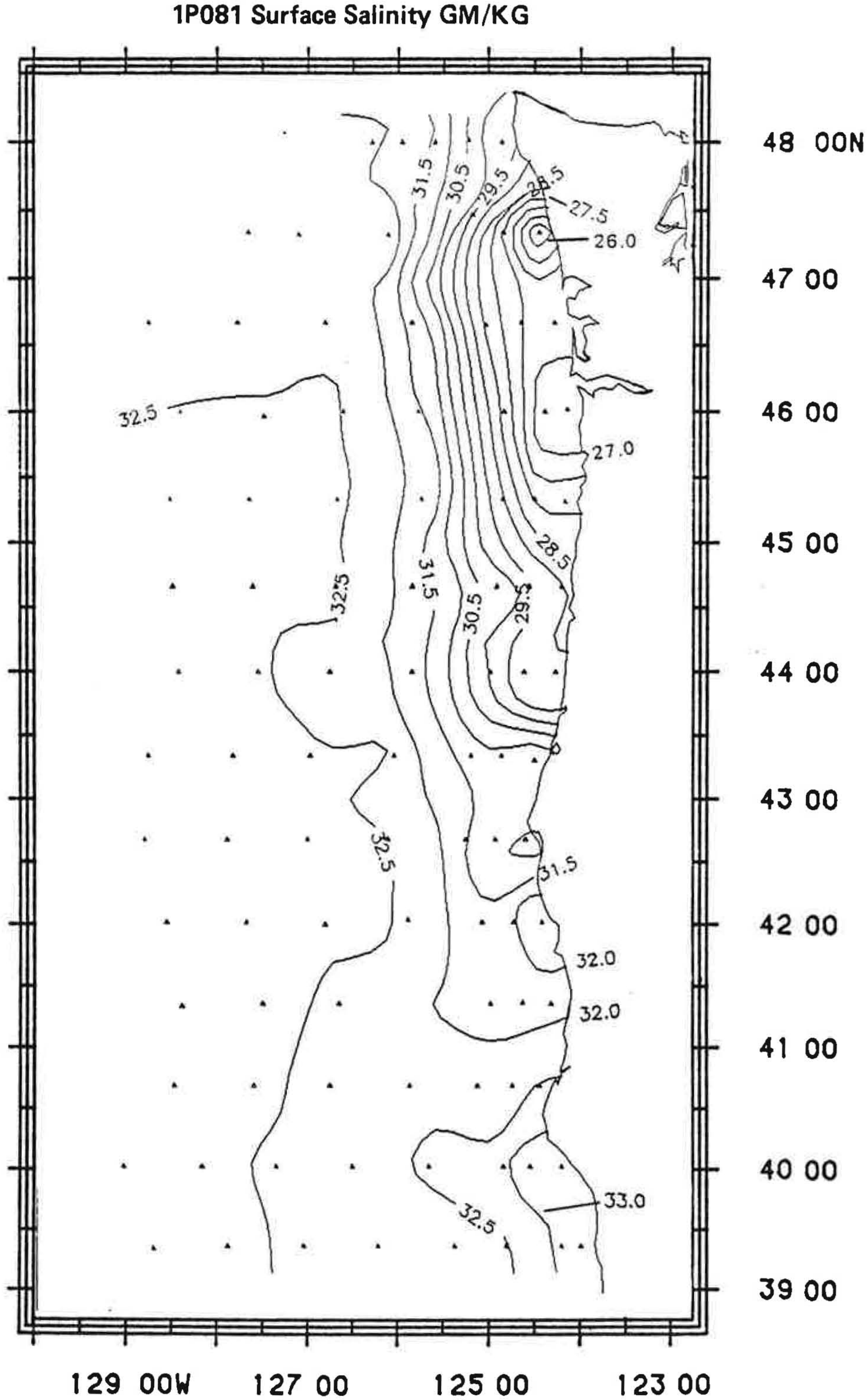

Figure 21.--Surface salinity contours (GM/KG) for cruise 1PO81, May 9th-June 2nd, 1981.

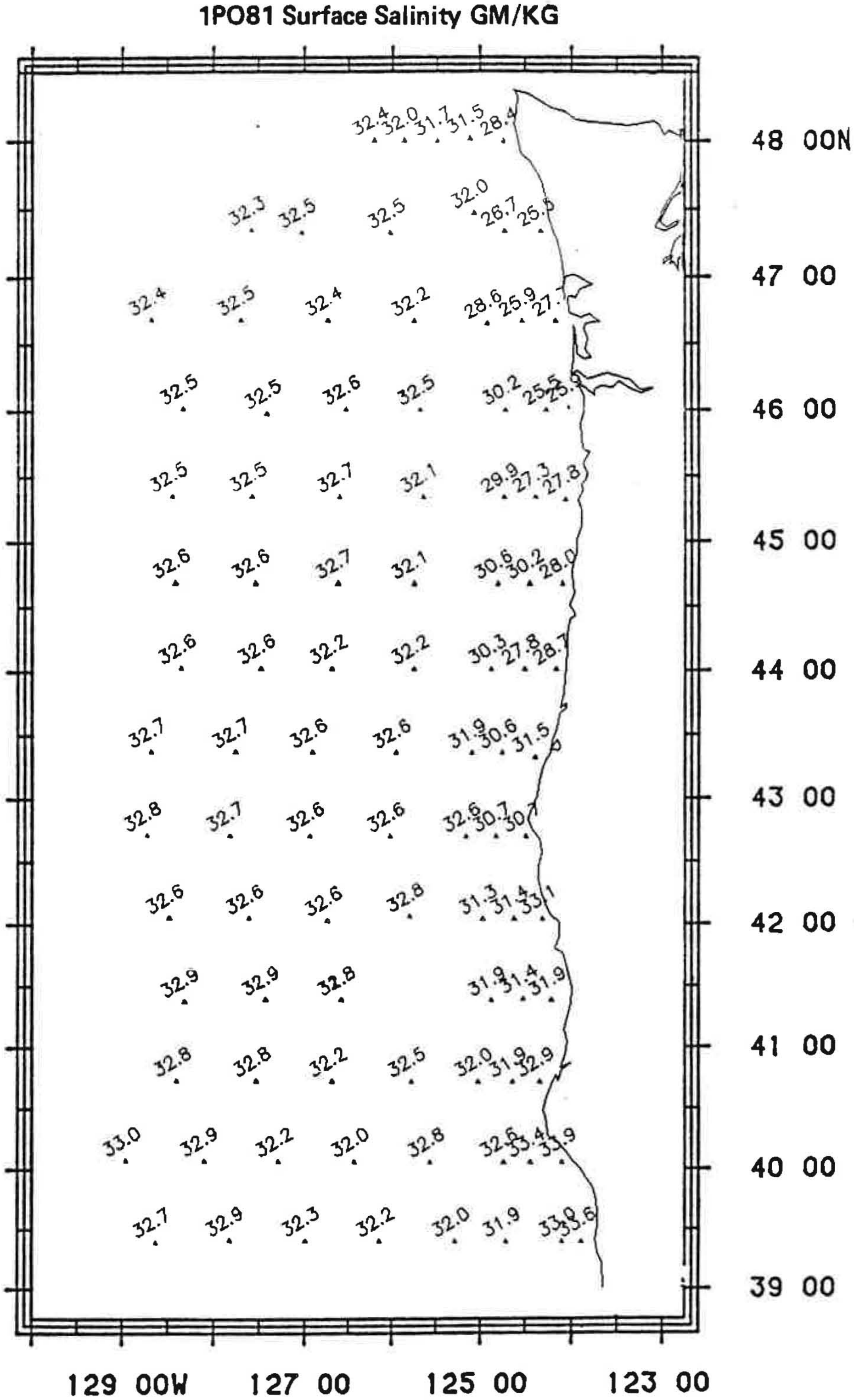

Figure 22.--Surface salinity values (GM/KG) for cruise 1PO81, May 9th-June 2nd, 1981.

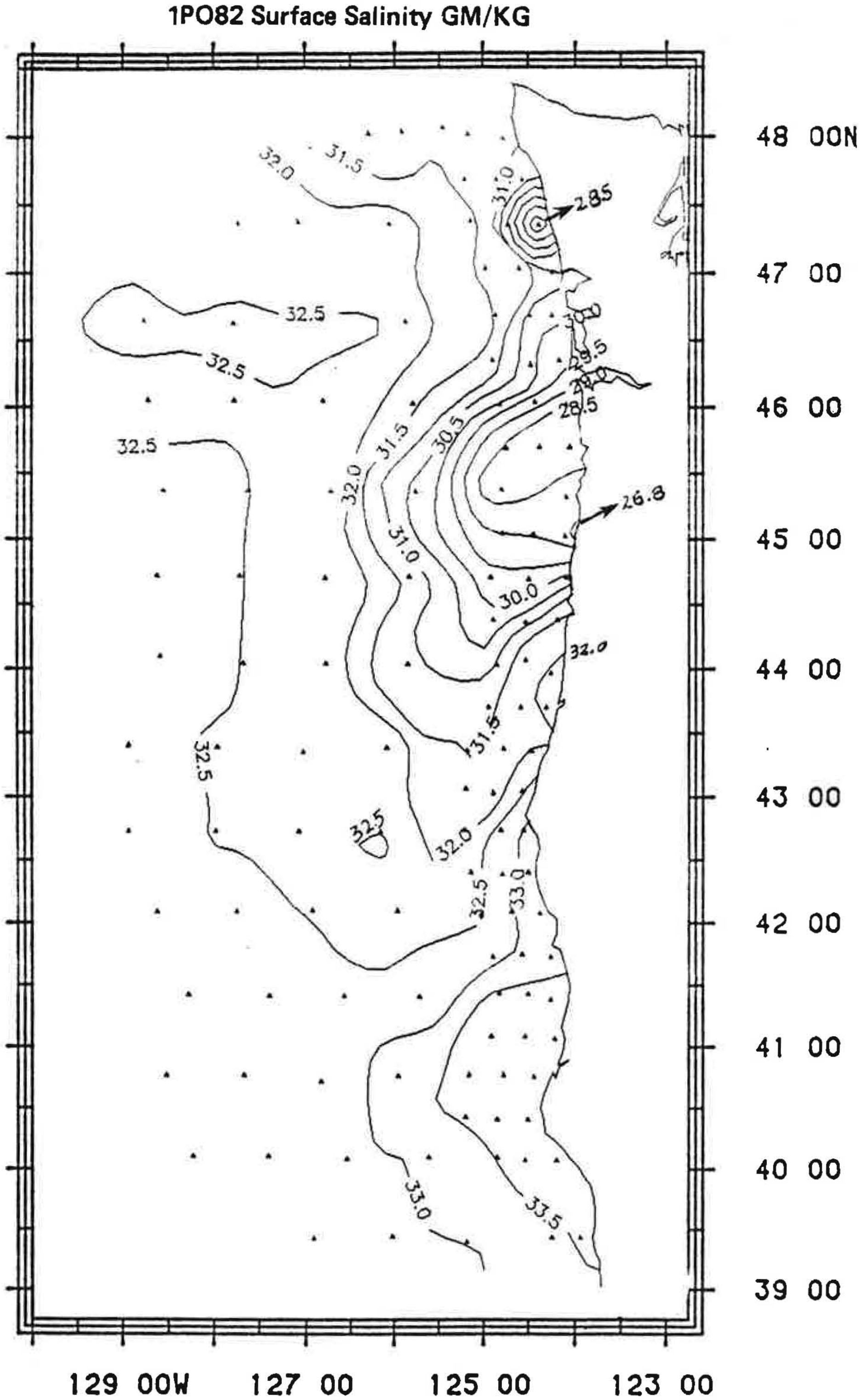

Figure 23.--Surface salinity contours (GM/KG) for cruise 1PO82, May 3rd-June 1st, 1982.

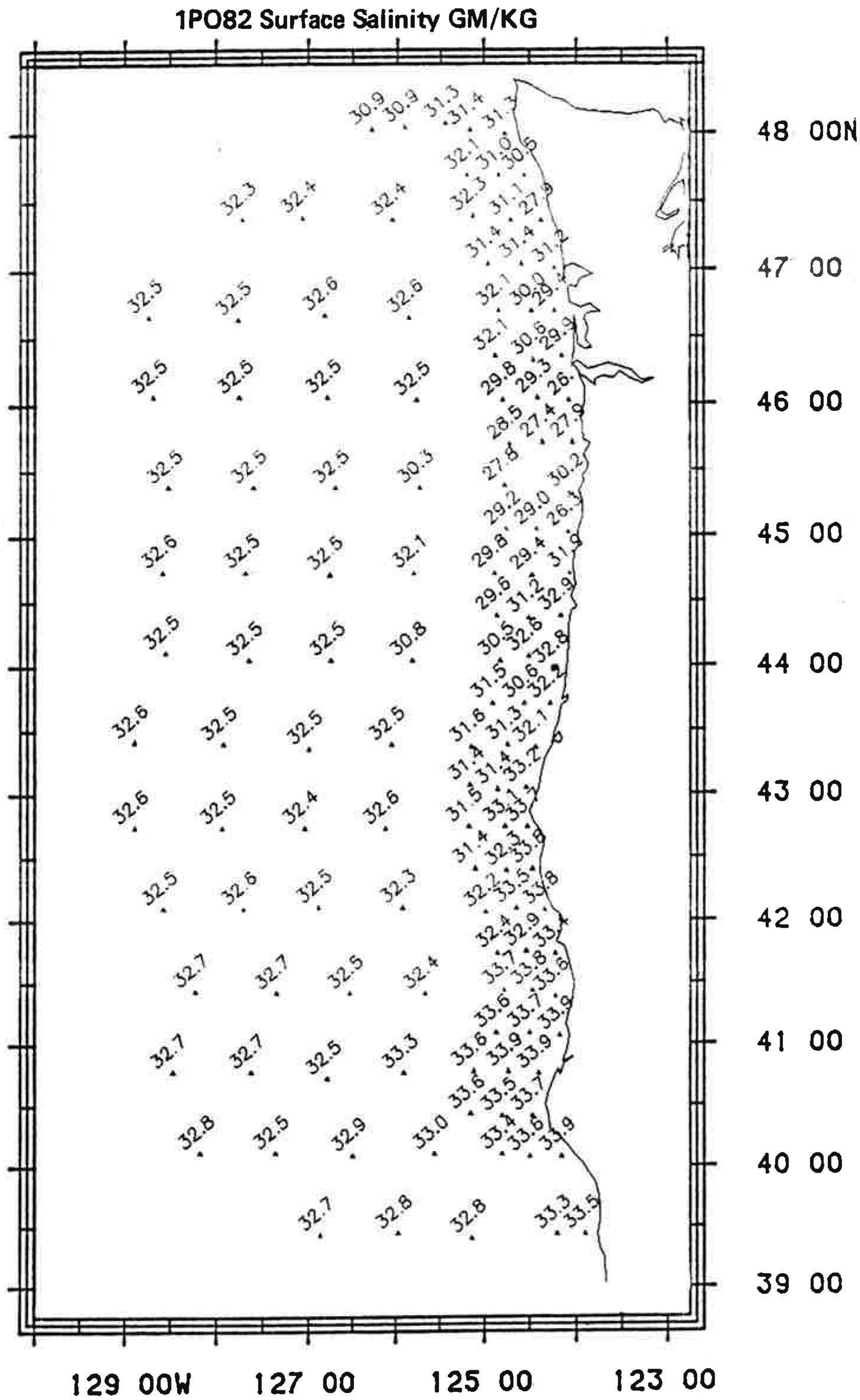

Figure 24.--Surface salinity values (GM/KG) for cruise 1PO82, May 3rd-June 1st, 1982.

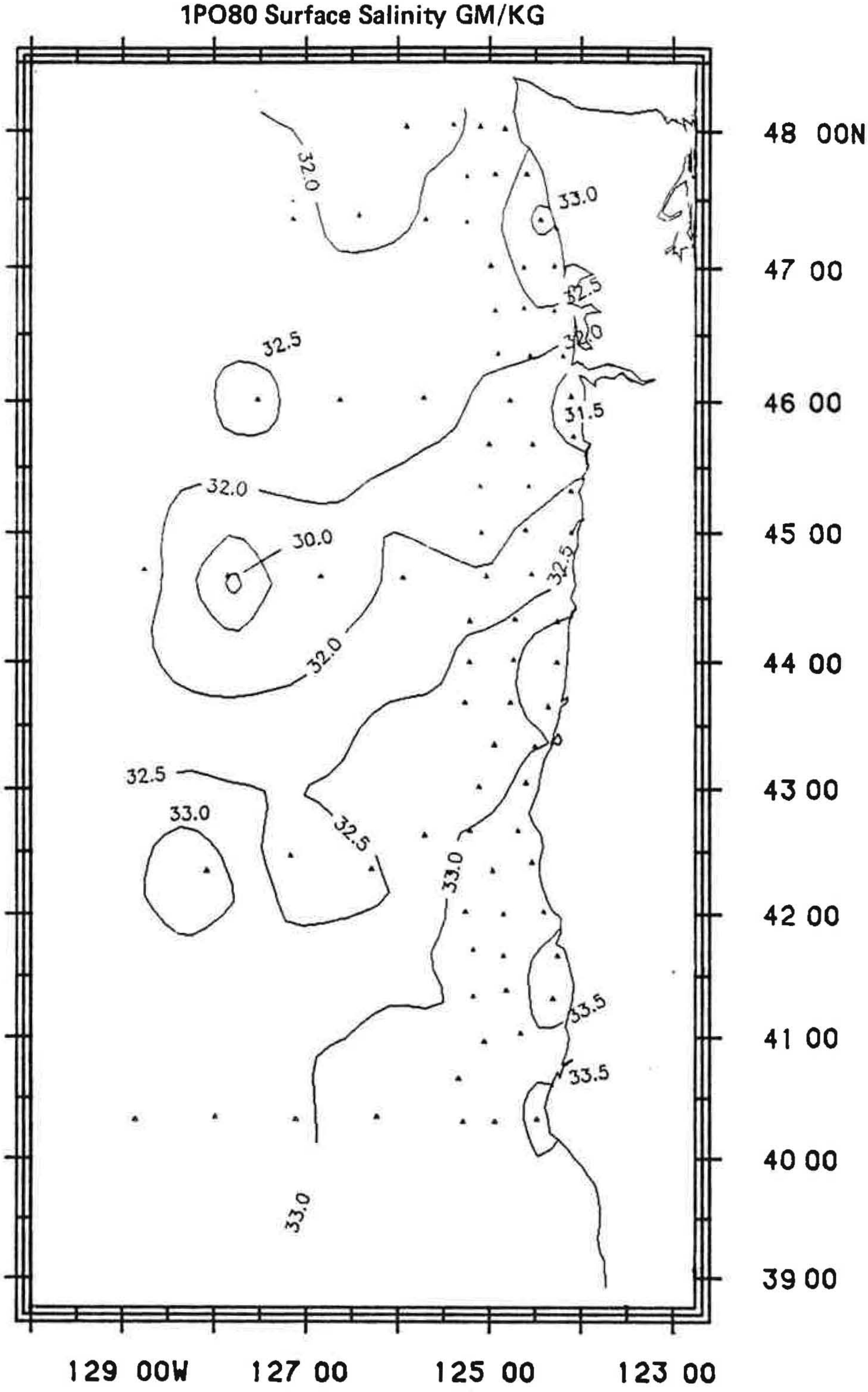

Figure 25.--Surface salinity contours (GM/KG) for cruise 1PO80, August 1st-20th, 1980.

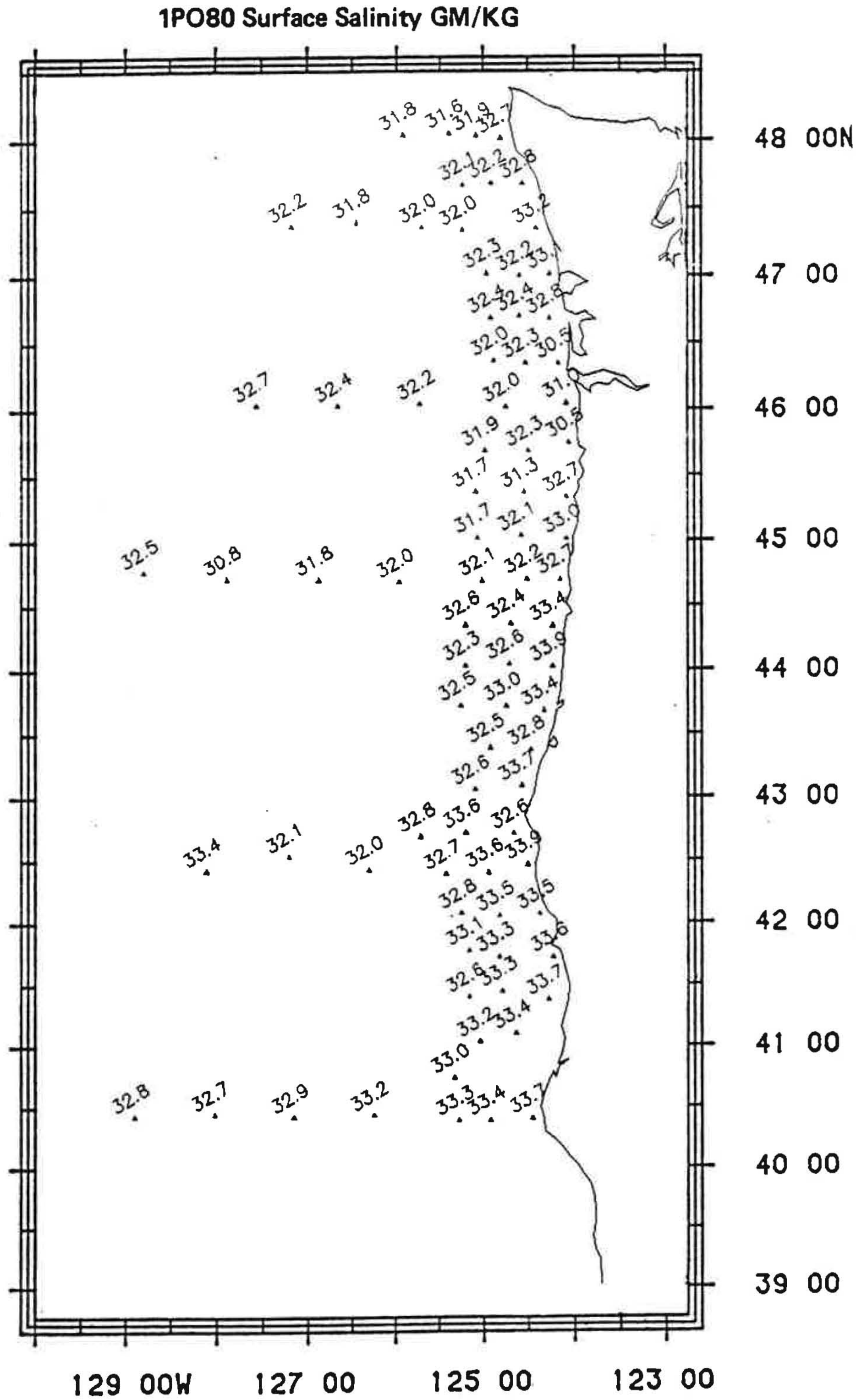

Figure 26.--Surface salinity values (GM/KG) for cruise 1PO80, August 1st-20th, 1980.

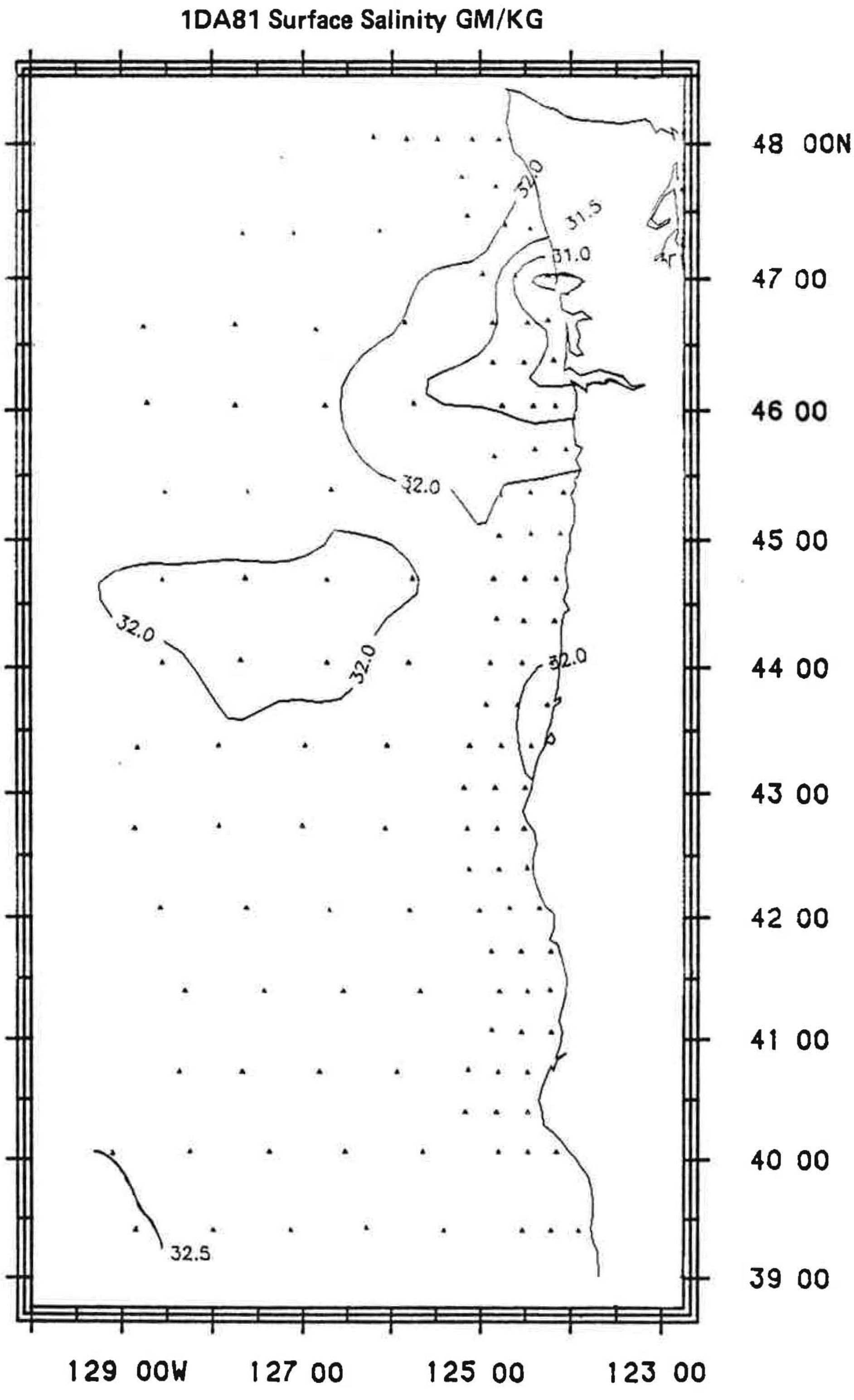

Figure 27.--Surface salinity contours (GM/KG) for cruise 1DA81, October 24th-November 19th, 1981.

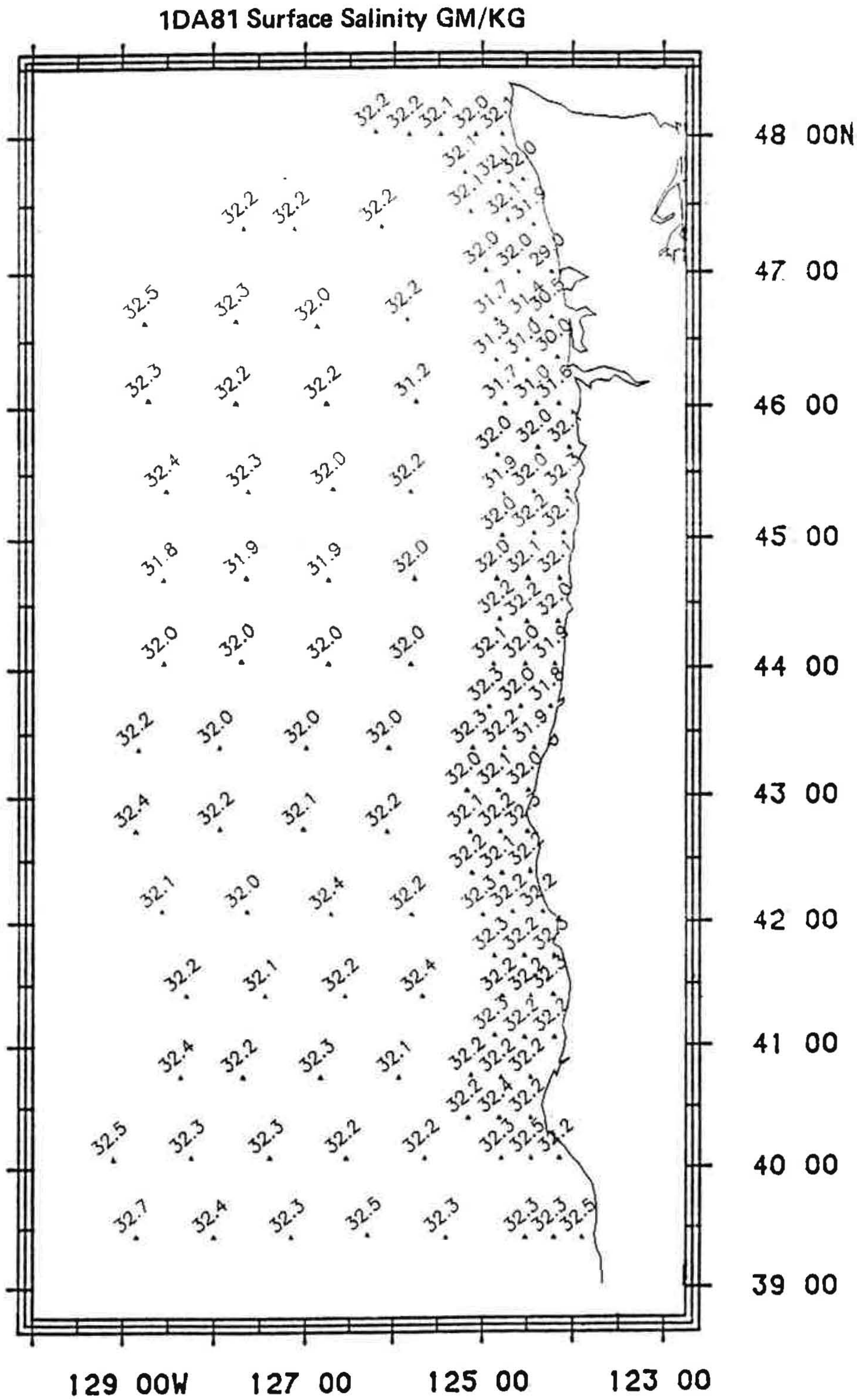

Figure 28.--Surface salinity values (GM/KG) for cruise 1DA81, October 24th-November 19th, 1981.

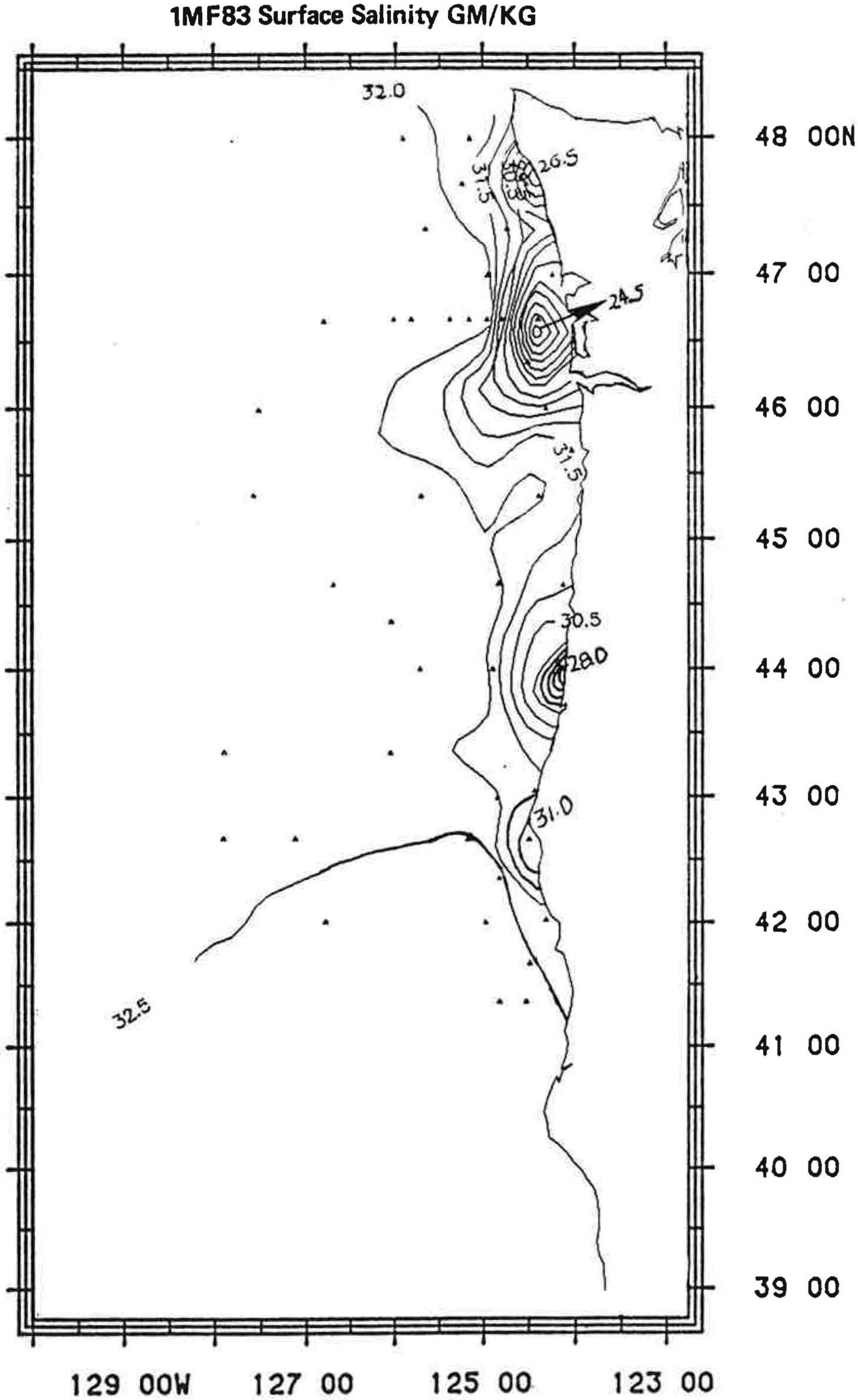

Figure 29.--Surface salinity contours (GM/KG) for cruise 1MF83, November 11th-December 2nd.

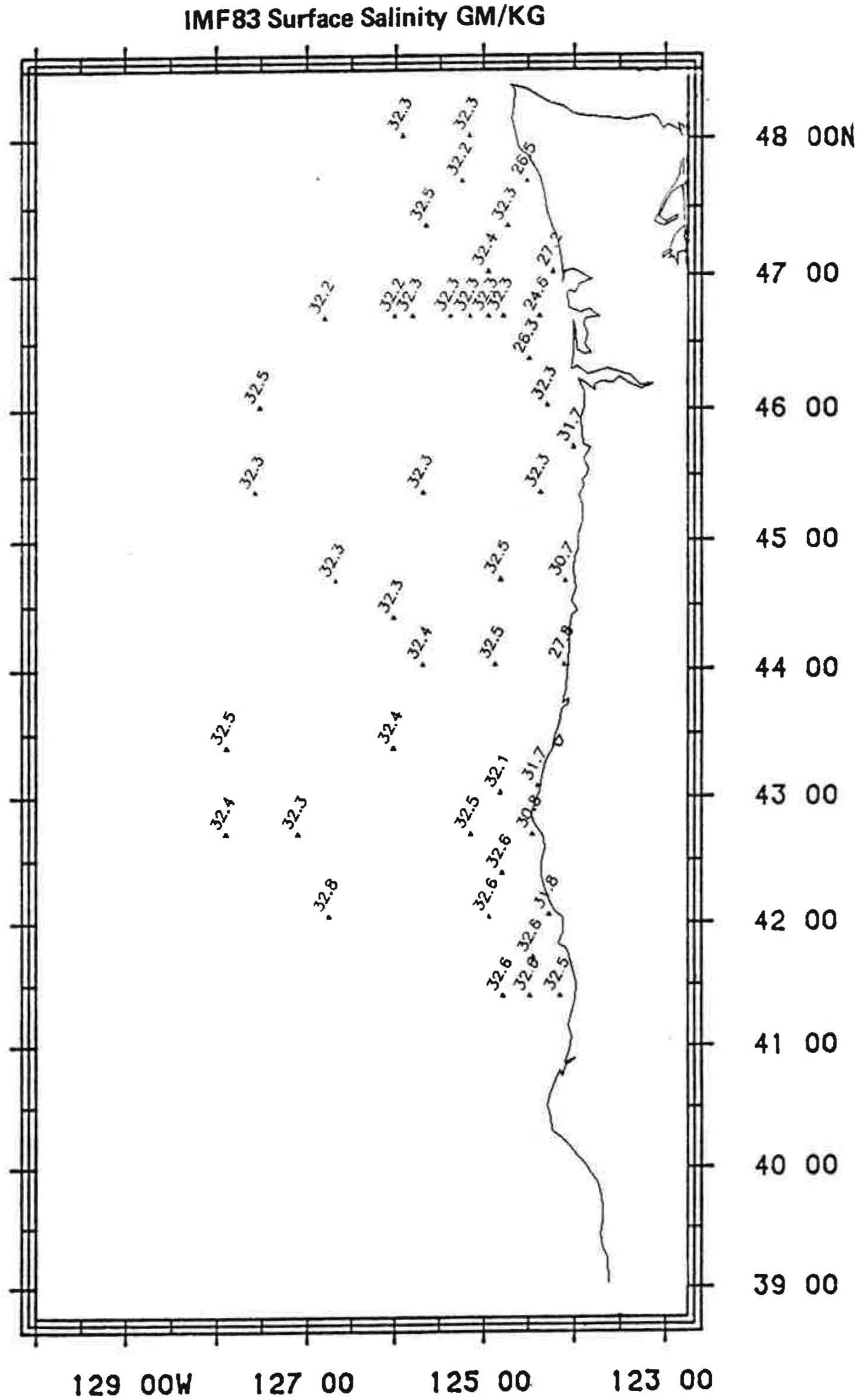

Figure 30.--Surface salinity values (GM/KG) for cruise 1MF83, November 11th-December 2nd.

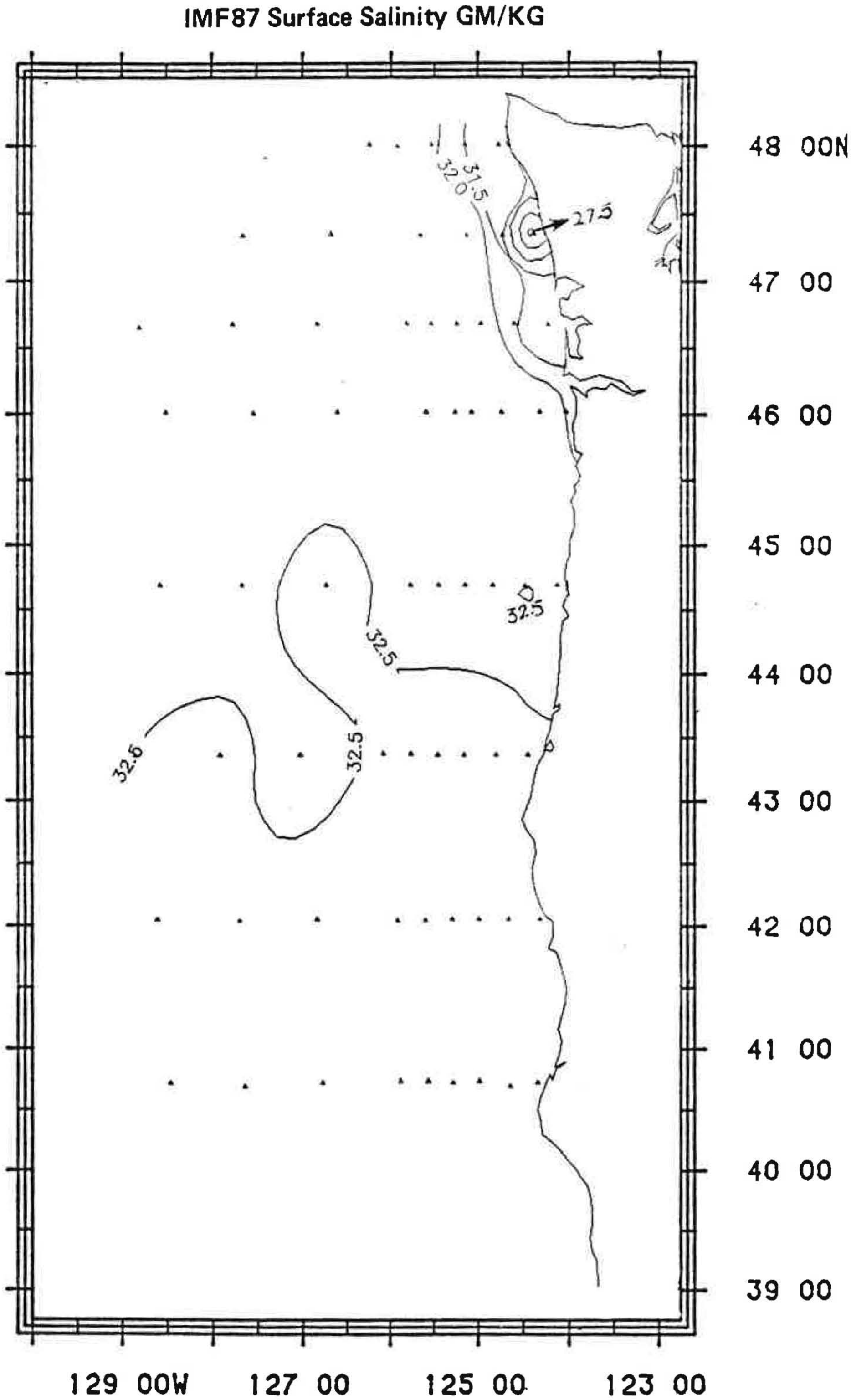

Figure 31.--Surface salinity contours (GM/KG) for cruise 1MF87, January 7th-31st.

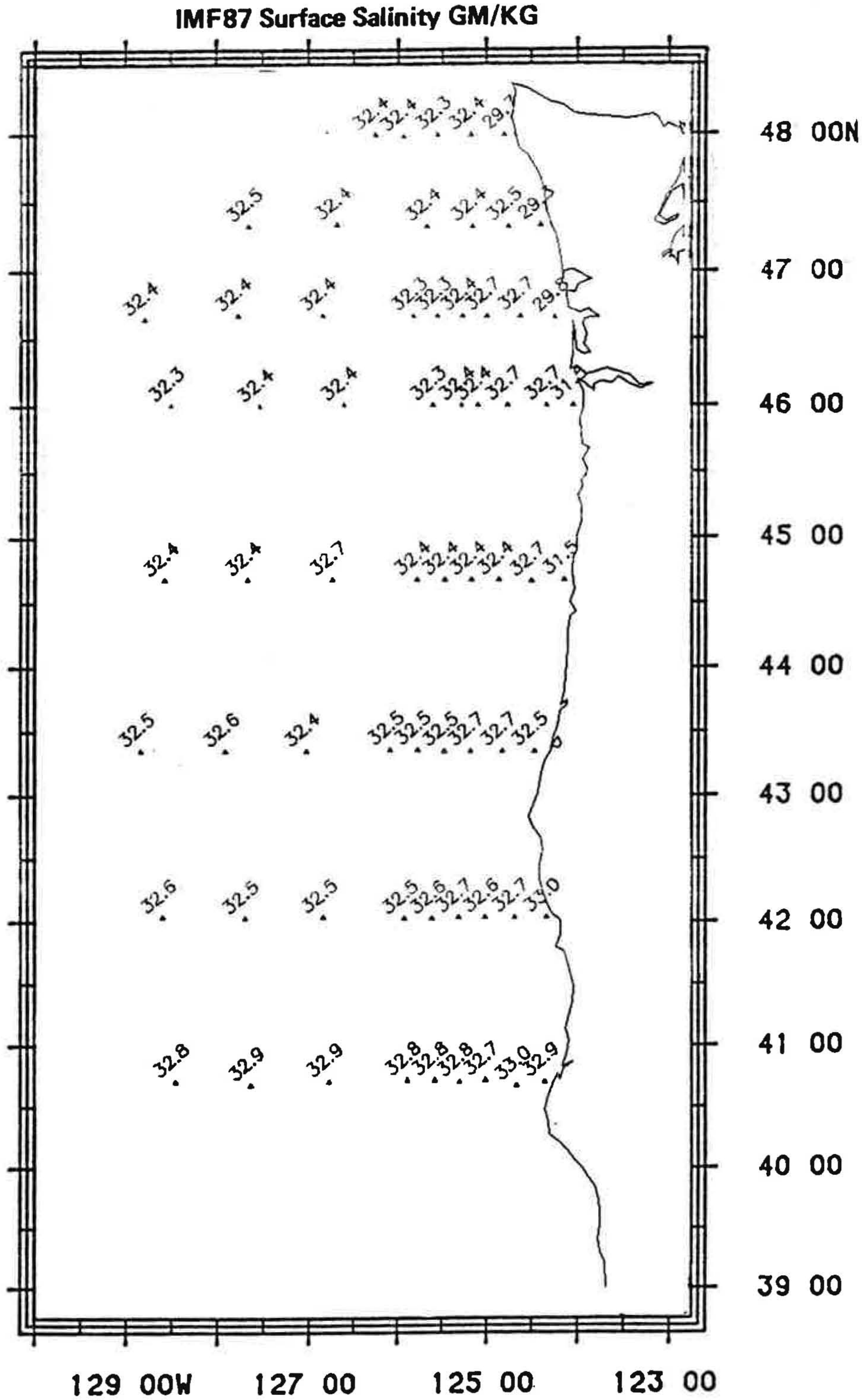

Figure 32.--Surface salinity values (GM/KG) for cruise 1MF87, January 7th-31st.

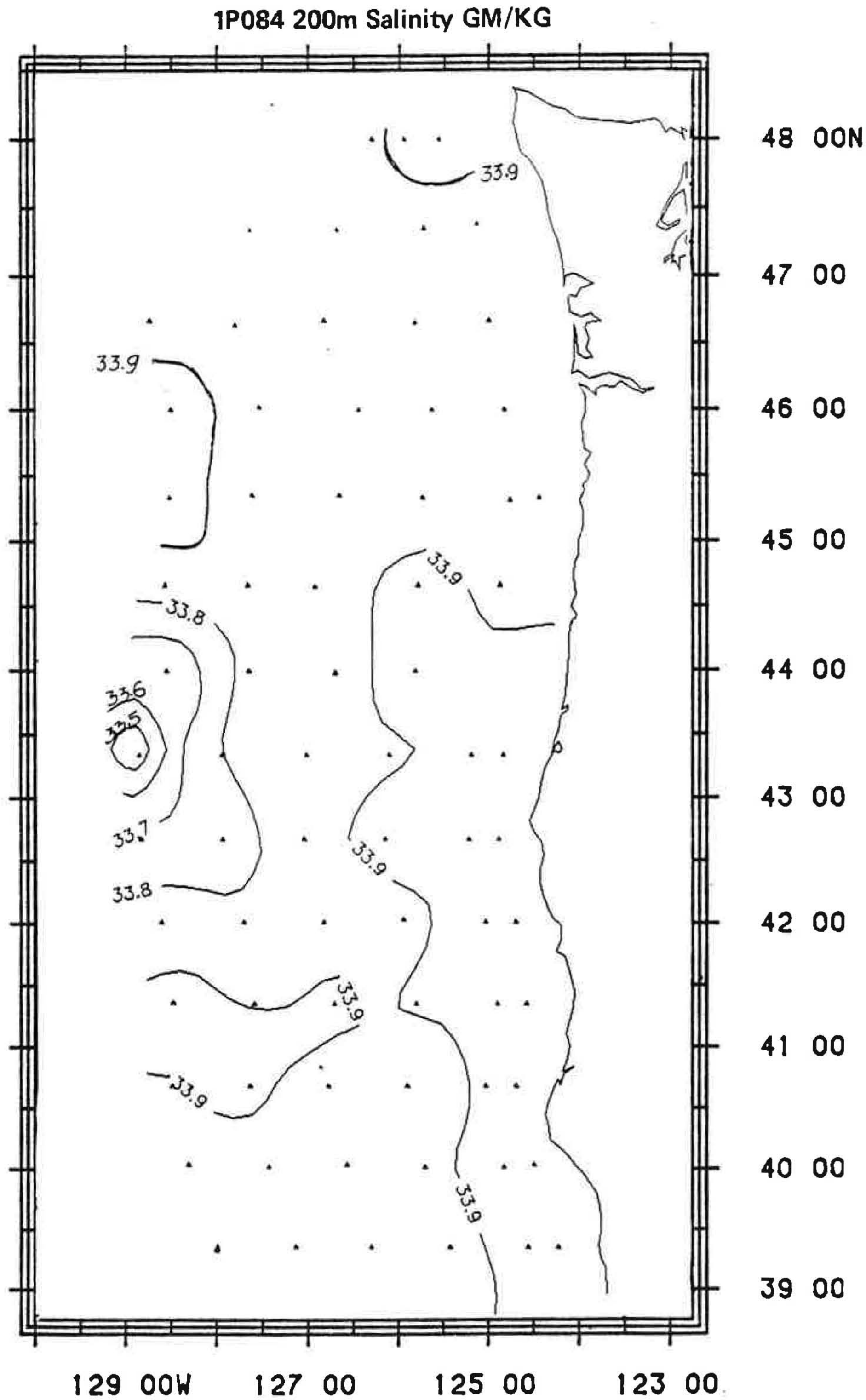

Figure 33.--200 meter salinity contours (GM/KG) for cruise 1P084, March 11th-April 4th, 1984.

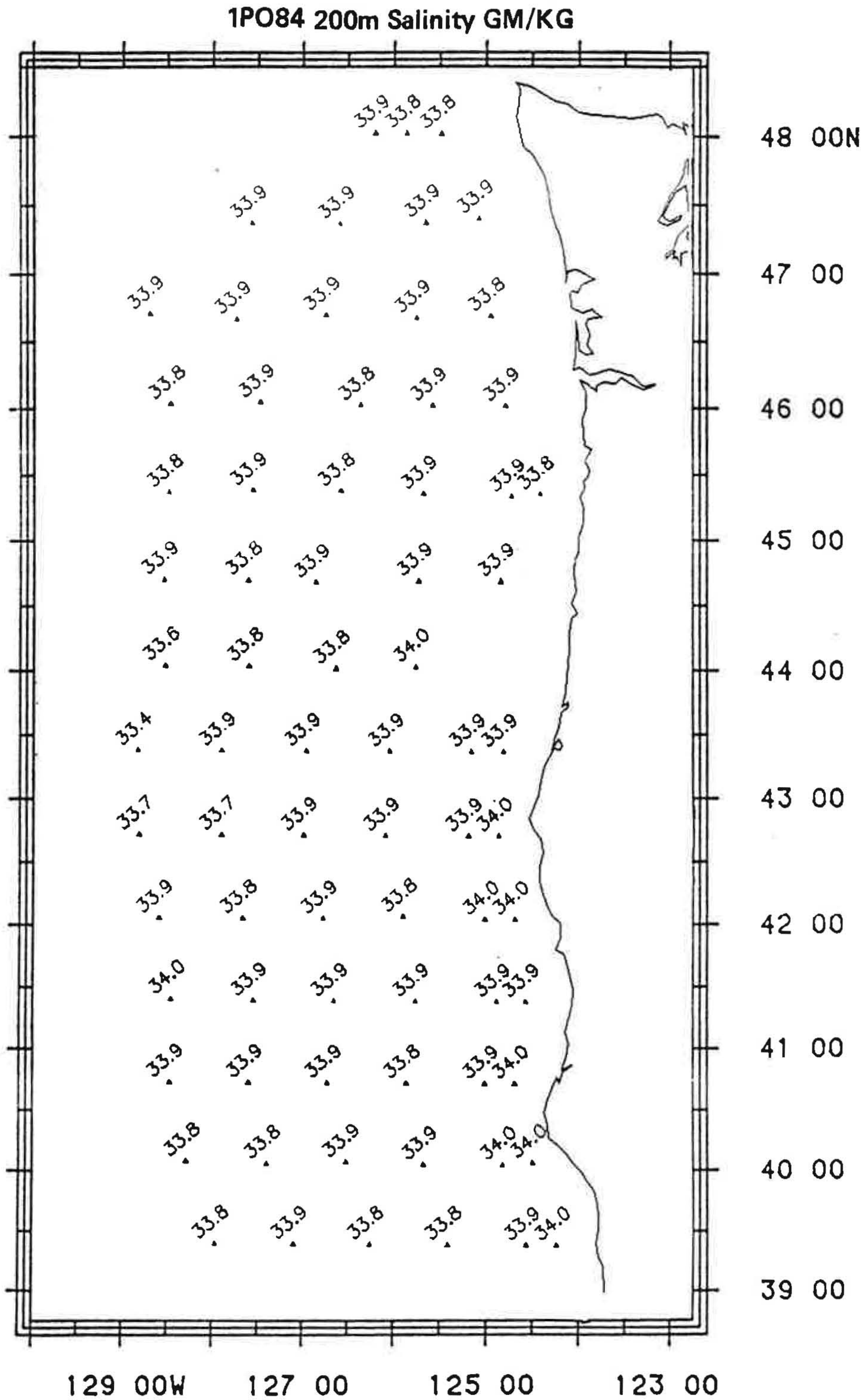

Figure 34.--200 meter salinity values (GM/KG) for cruise 1PO84, March 11th-April 4th, 1984.

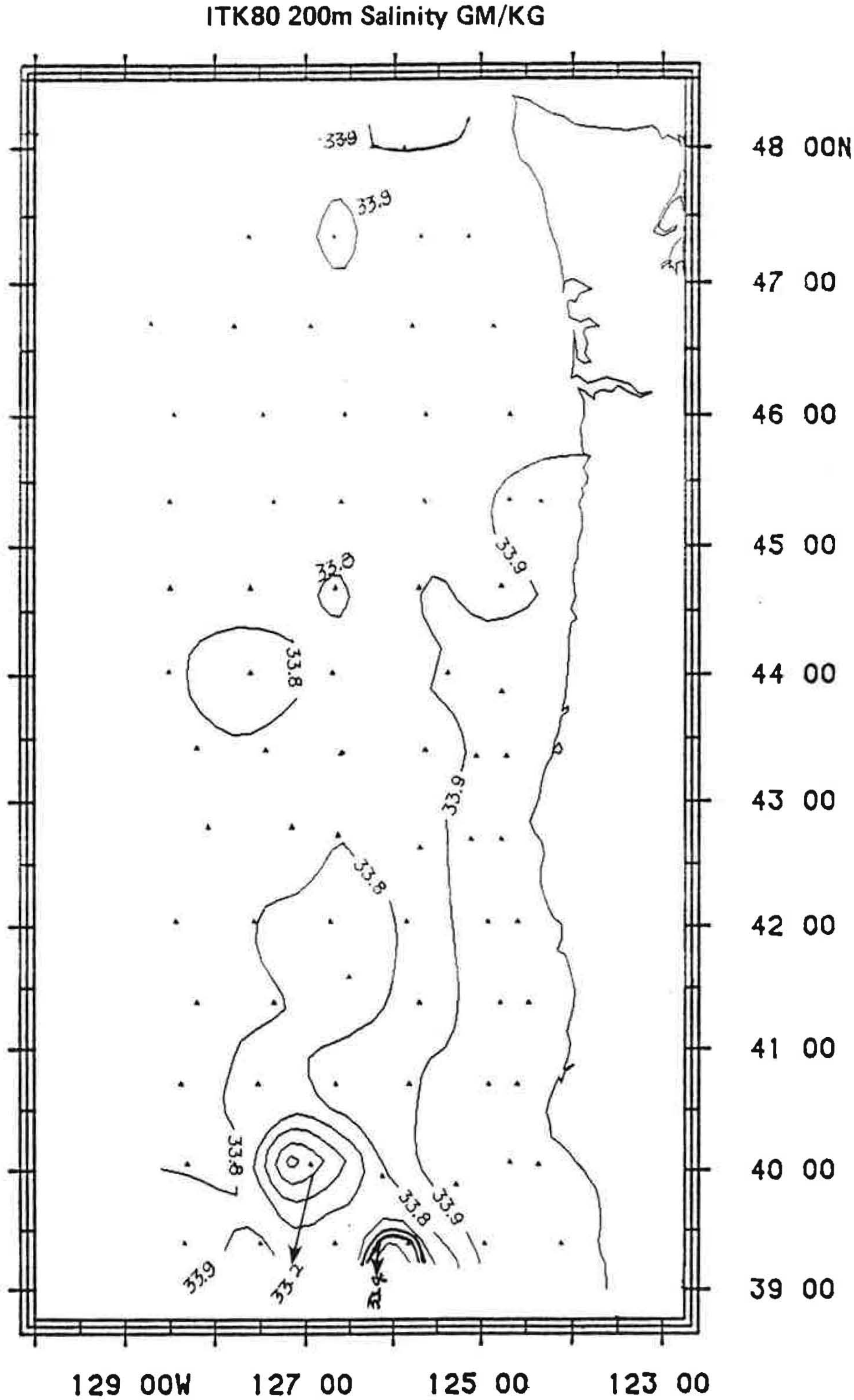

Figure 35.--200 meter salinity contours (GM/KG) for cruise 1TK80, April 20th-May 15th, 1980.

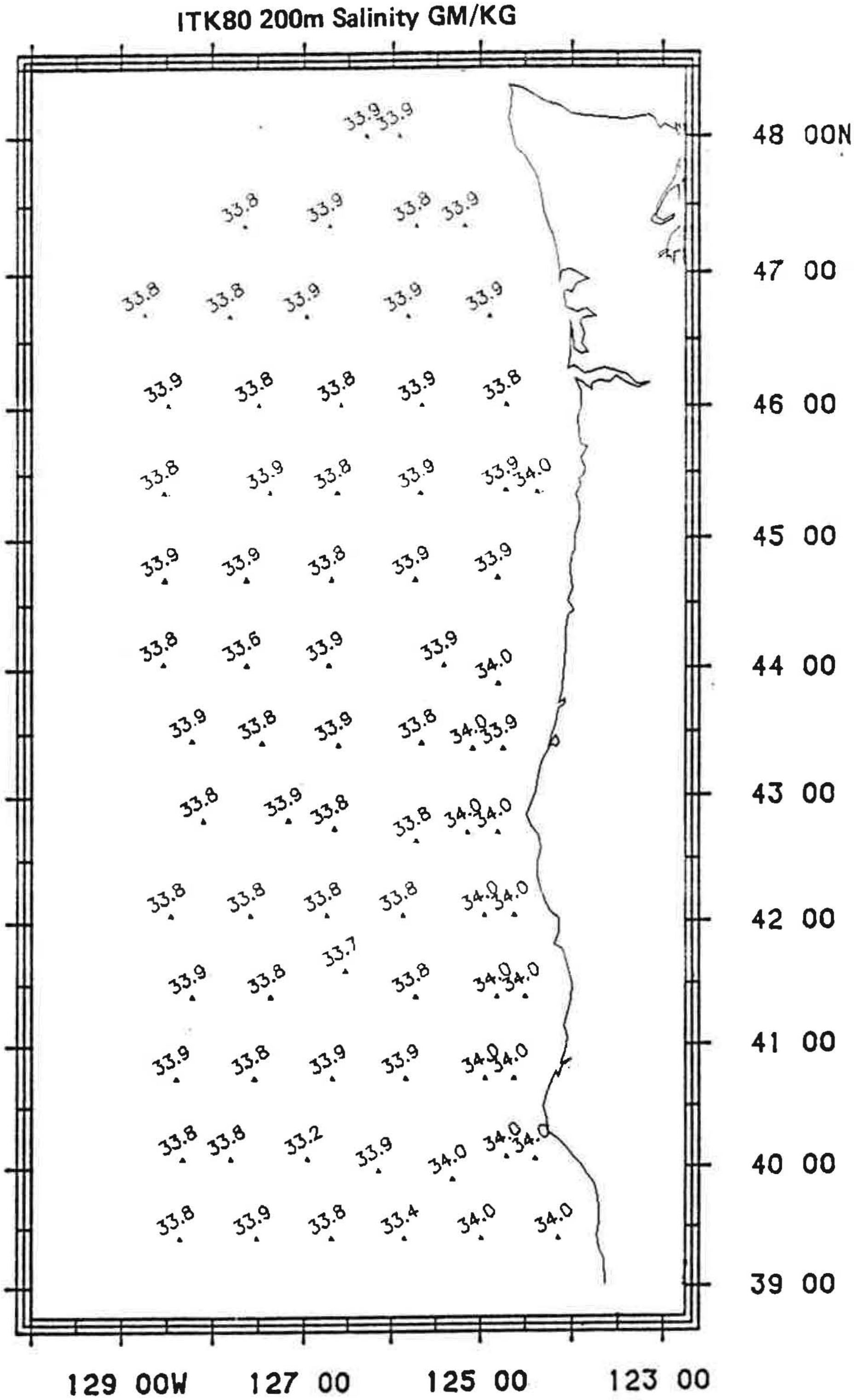

Figure 36.--200 meter salinity values (GM/KG) for cruise 1TK80, April 20th-May 15th, 1980.

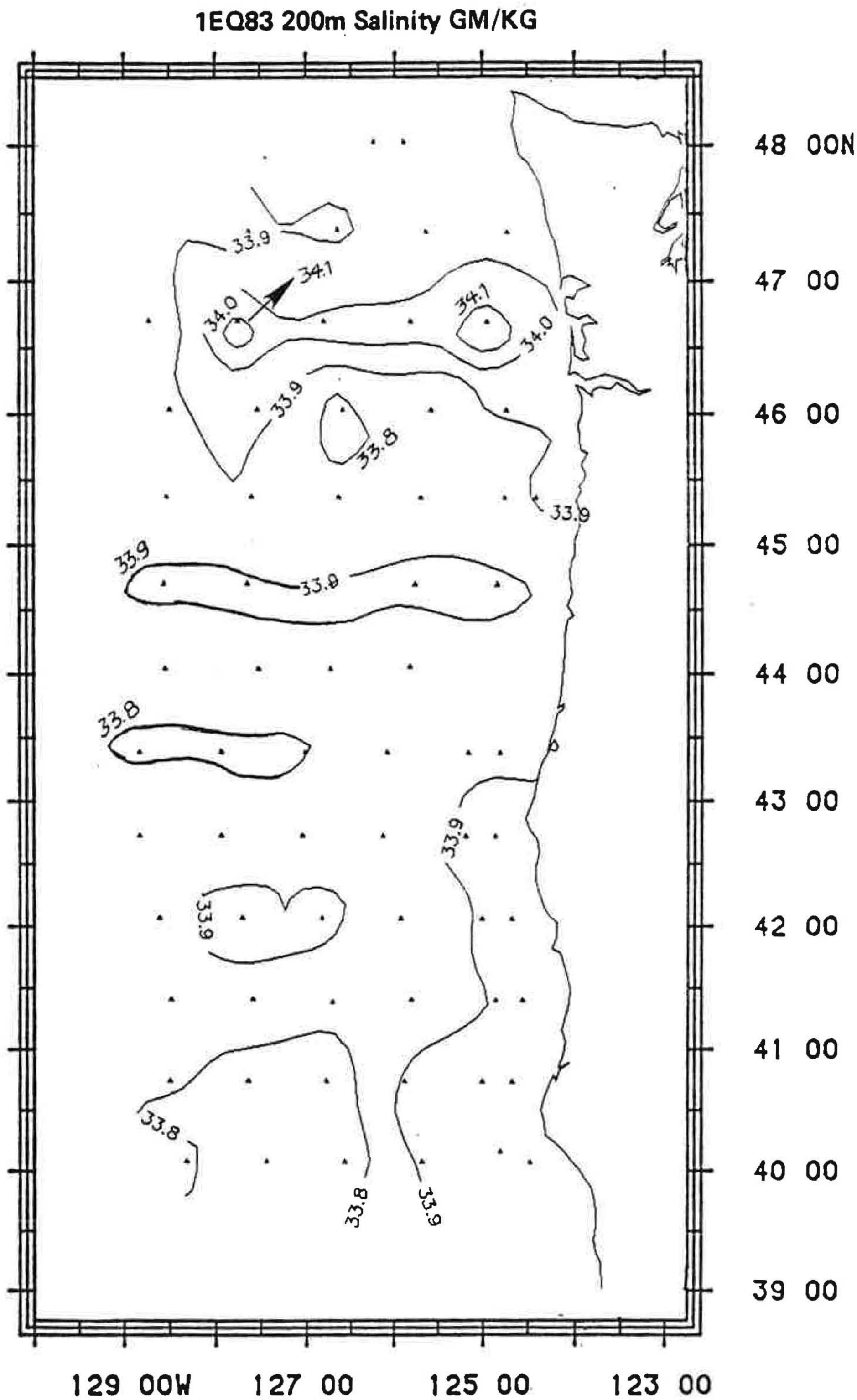

Figure 37.--200 meter salinity contours (GM/KG) for cruise 1EQ83, April 23rd-May 15th, 1983.

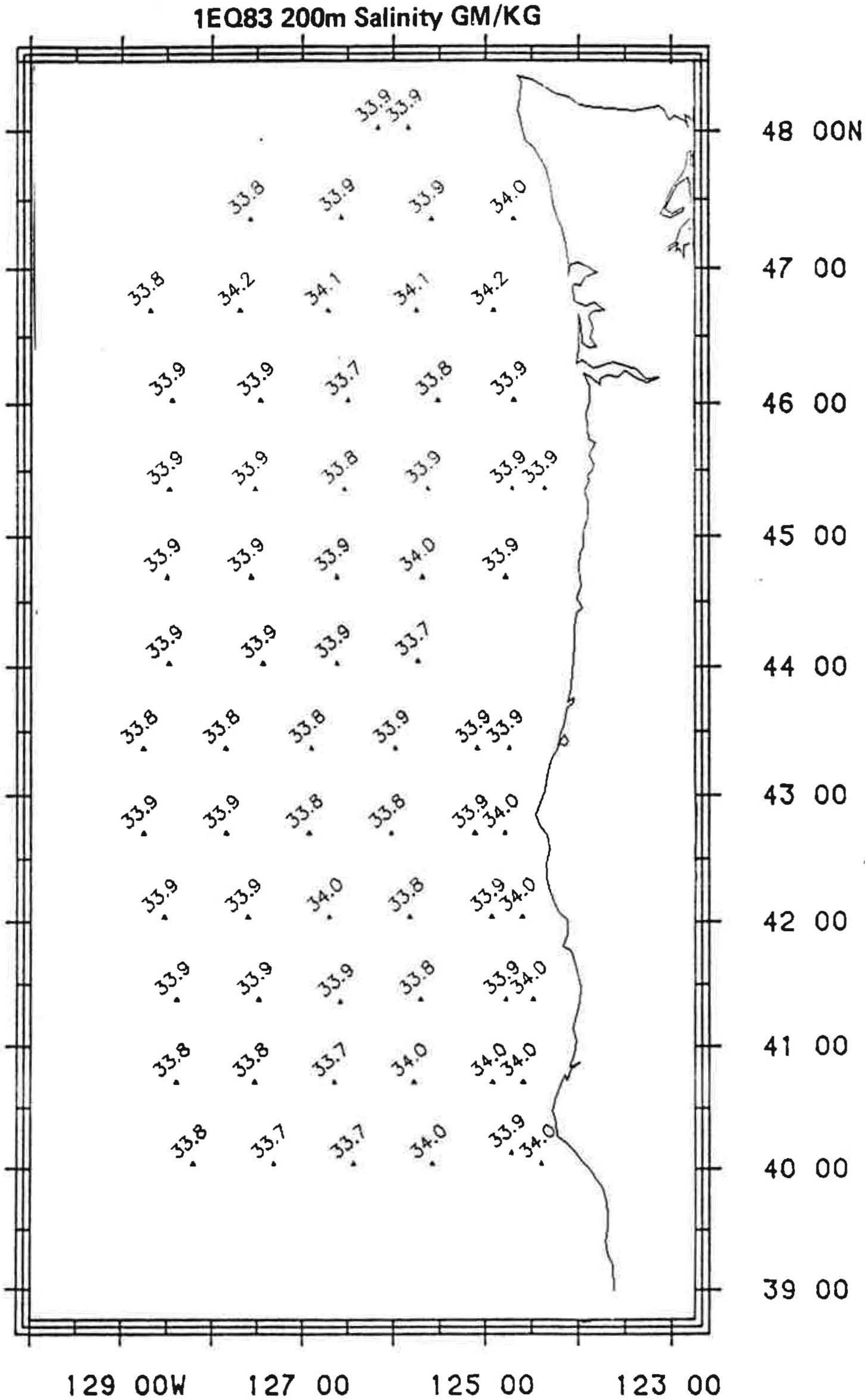

Figure 38.--200 meter salinity values (GM/KG) for cruise 1EQ83, April 23rd-May 15th, 1983.

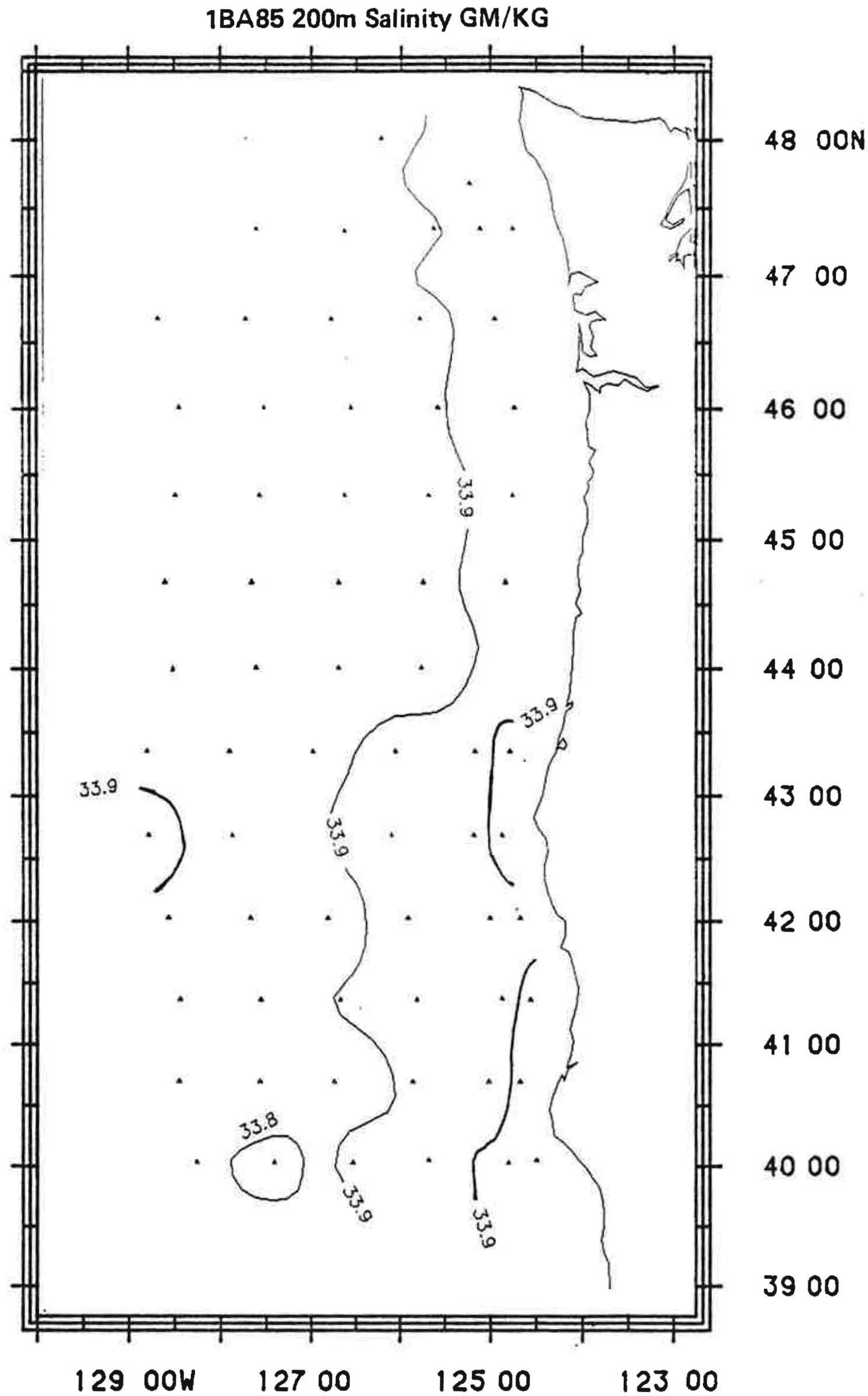

Figure 39.--200 meter salinity contours (GM/KG) for cruise 1BA85, April 19th-May 11th, 1985.

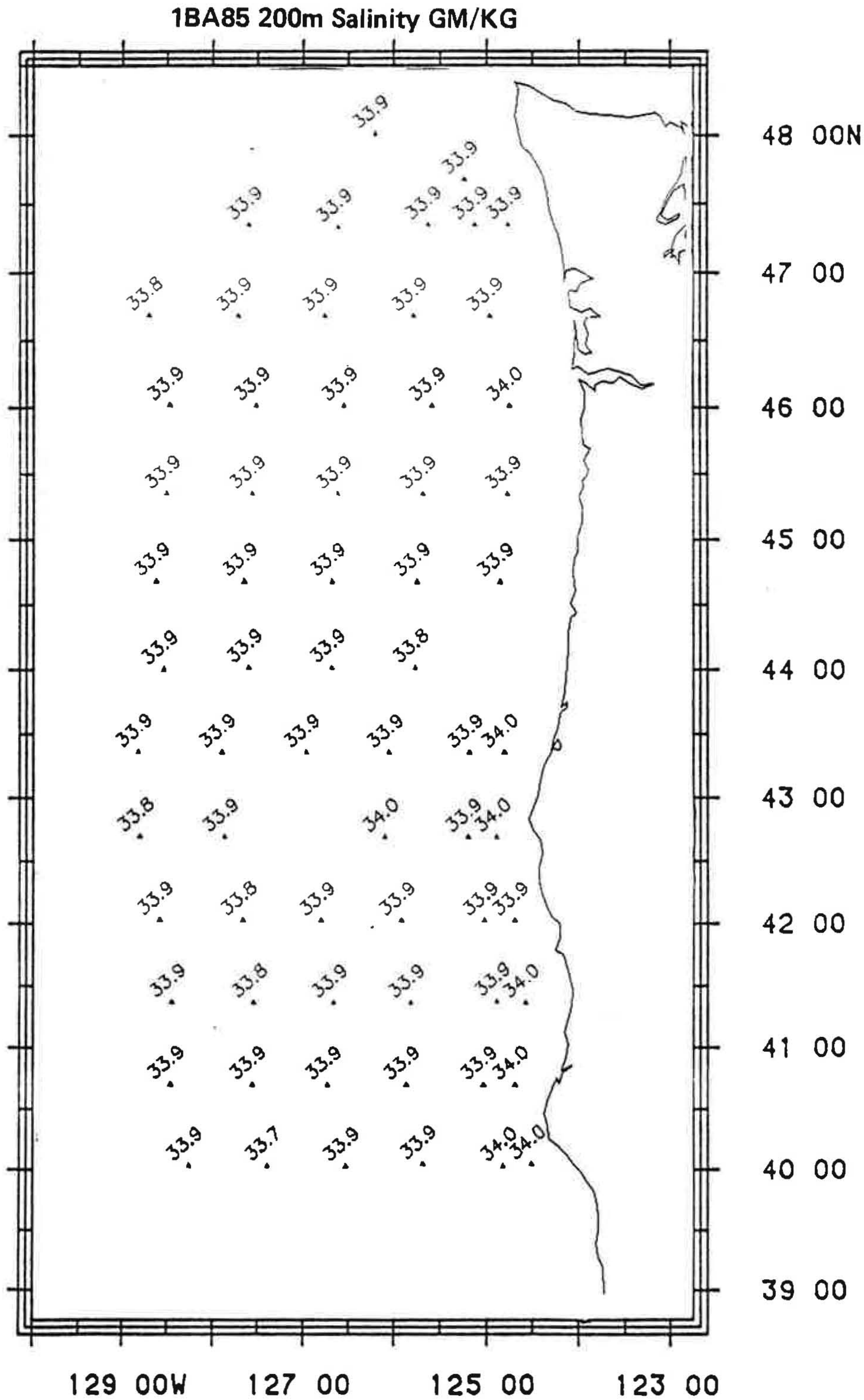

Figure 40.--200 meter salinity values (GM/KG) for cruise 1BA85, April 19th-May 11th, 1985.

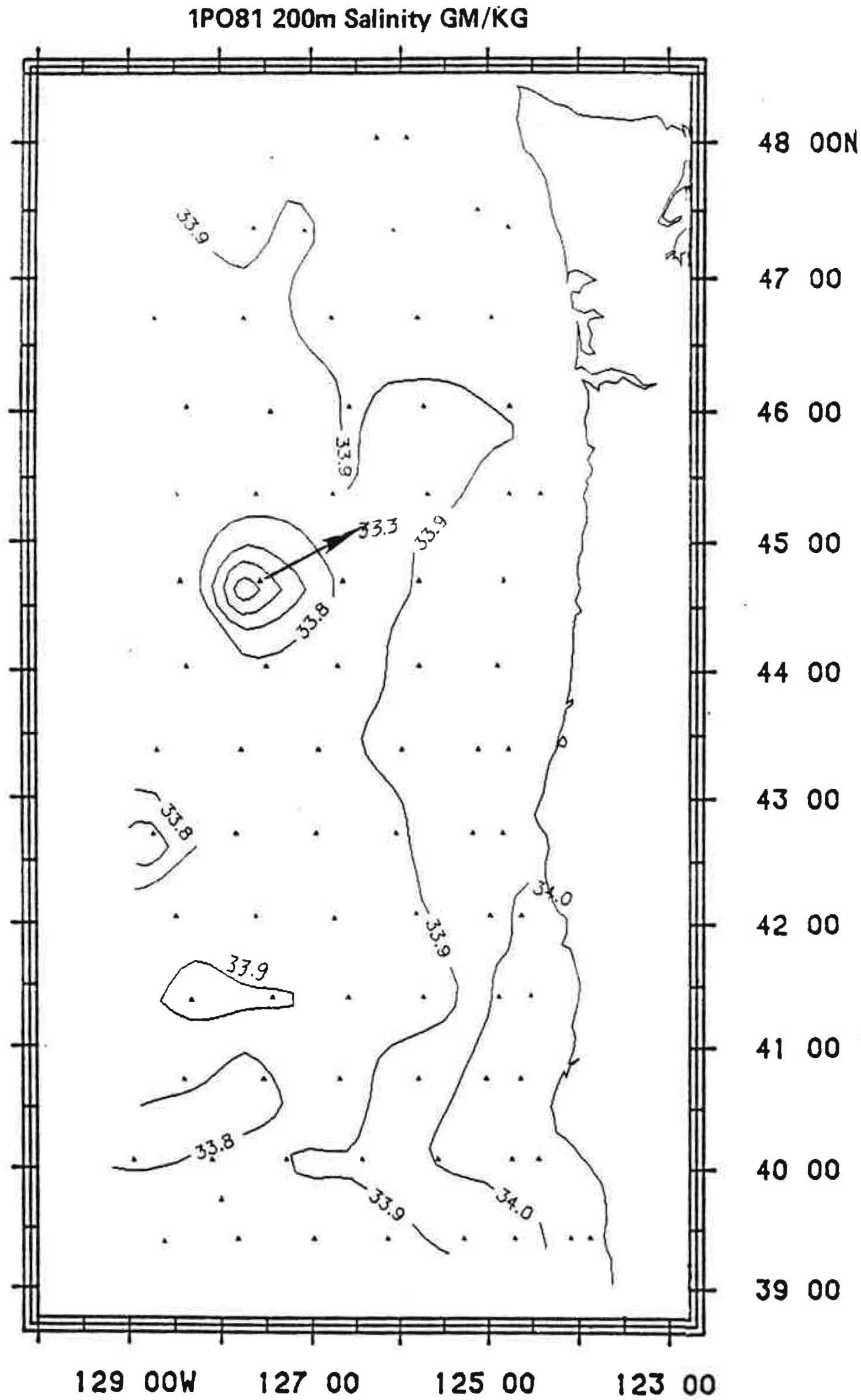

Figure 41.--200 meter salinity contours (GM/KG) for cruise 1PO81, May 9th-June 2nd, 1981.

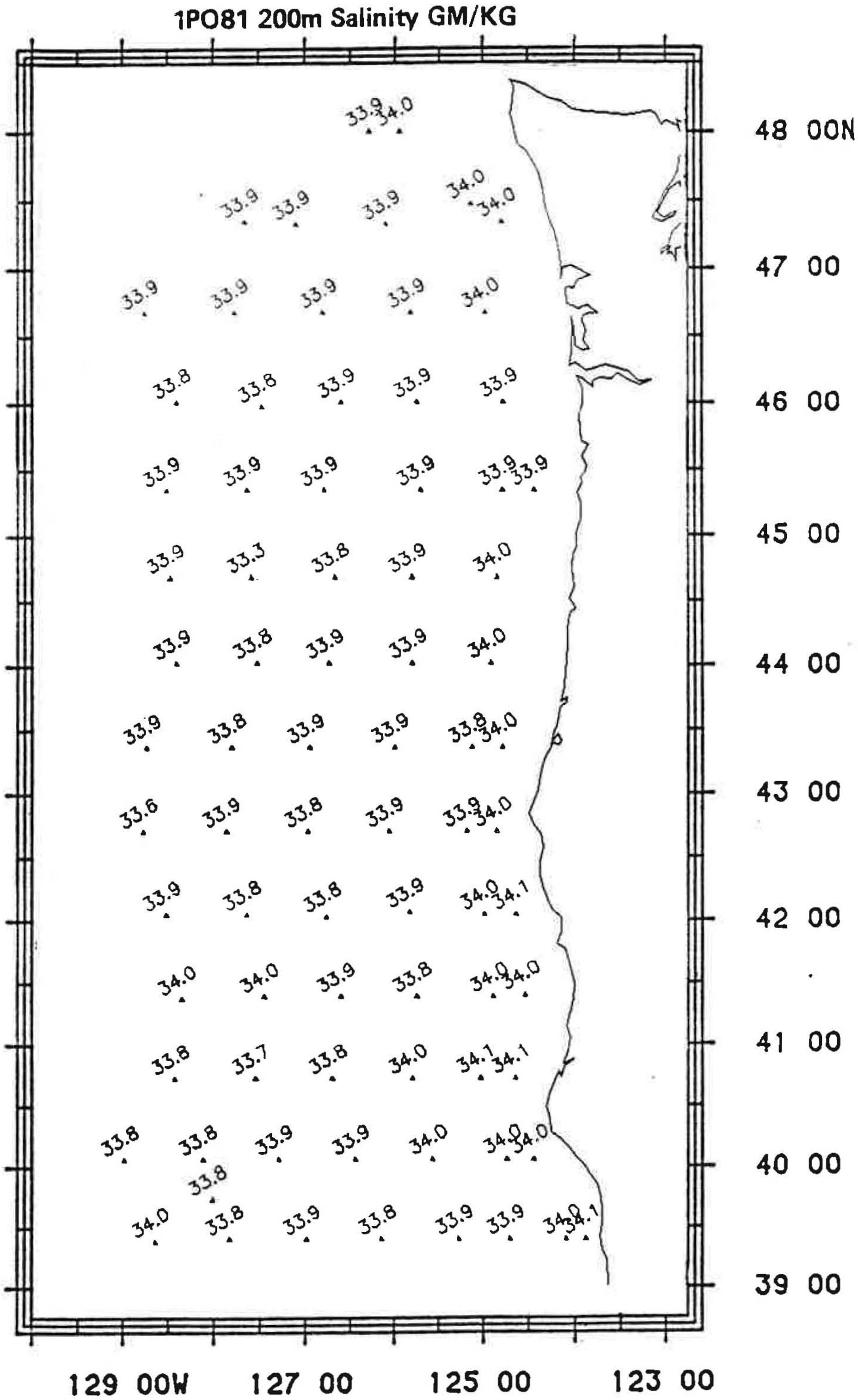

Figure 42.--200 meter salinity values (GM/KG) for cruise 1PO81, May 9th-June 2nd, 1981.

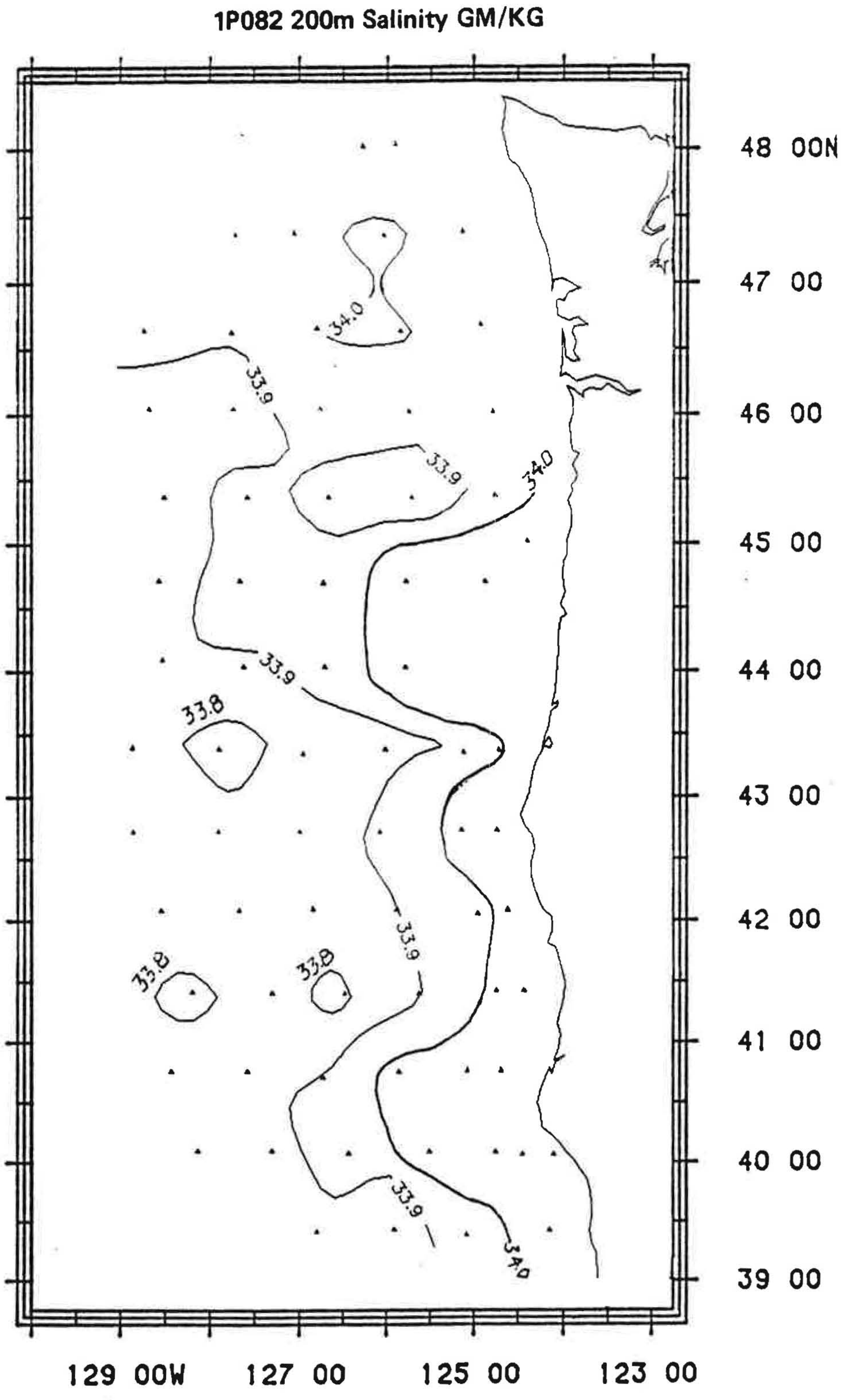

Figure 43.--200 meter salinity contours (GM/KG) for cruise 1PO82, May 3rd-June 1st, 1982.

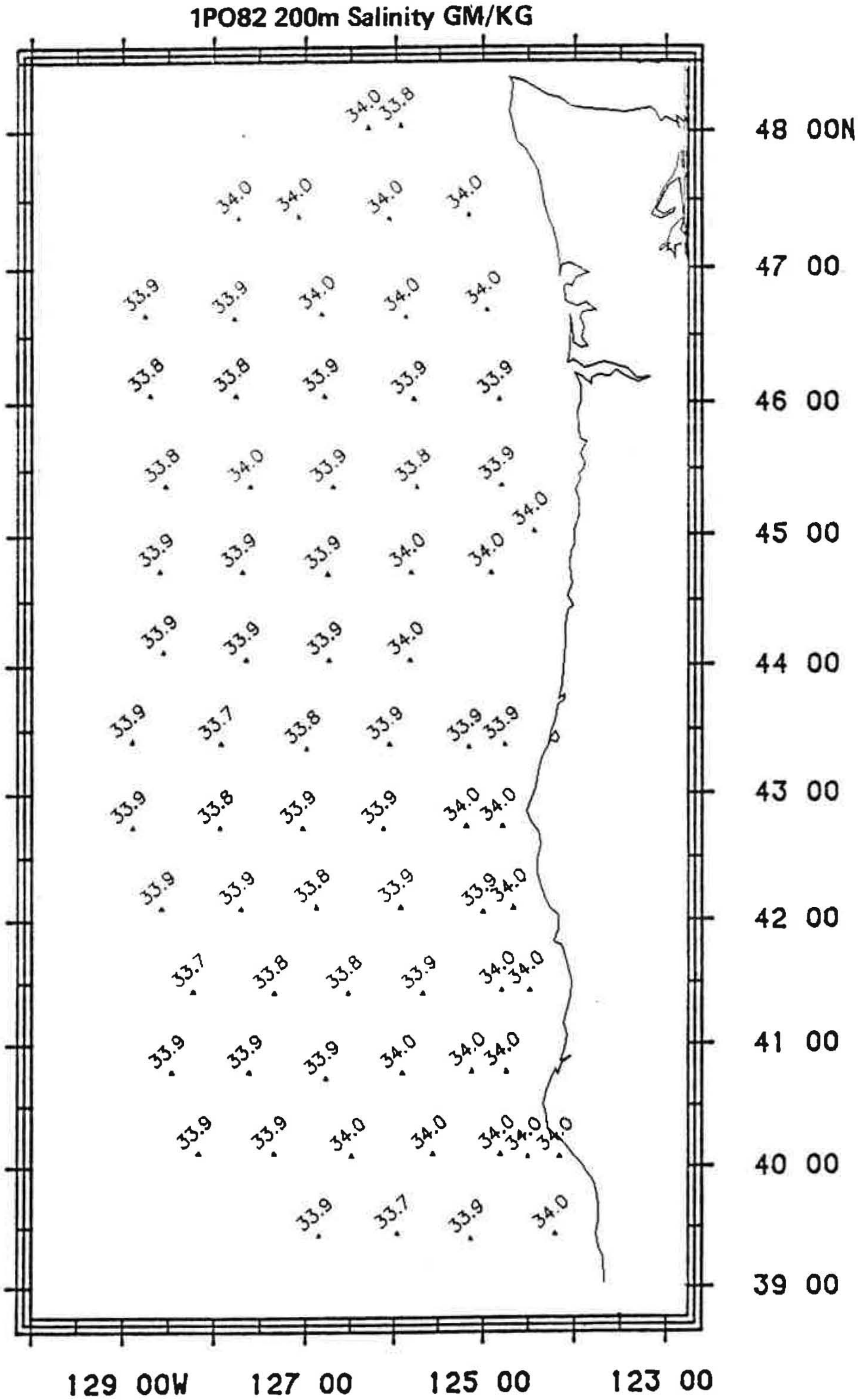

Figure 44.--200 meter salinity values (GM/KG) for cruise 1PO82, May 3rd-June 1st, 1982.

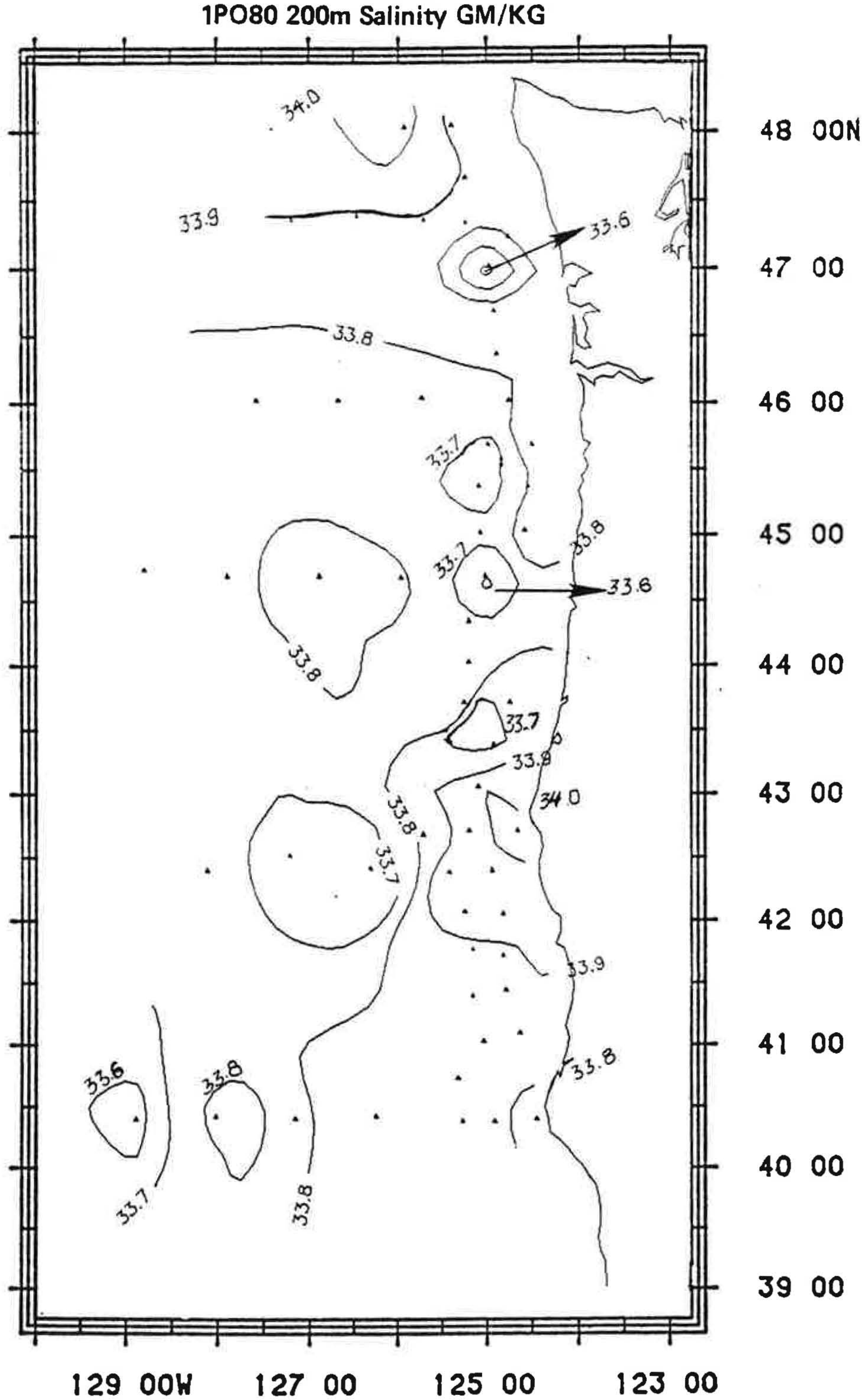

Figure 45.--200 meter salinity contours (GM/KG) for cruise 1PO80, August 1st-20th, 1980.

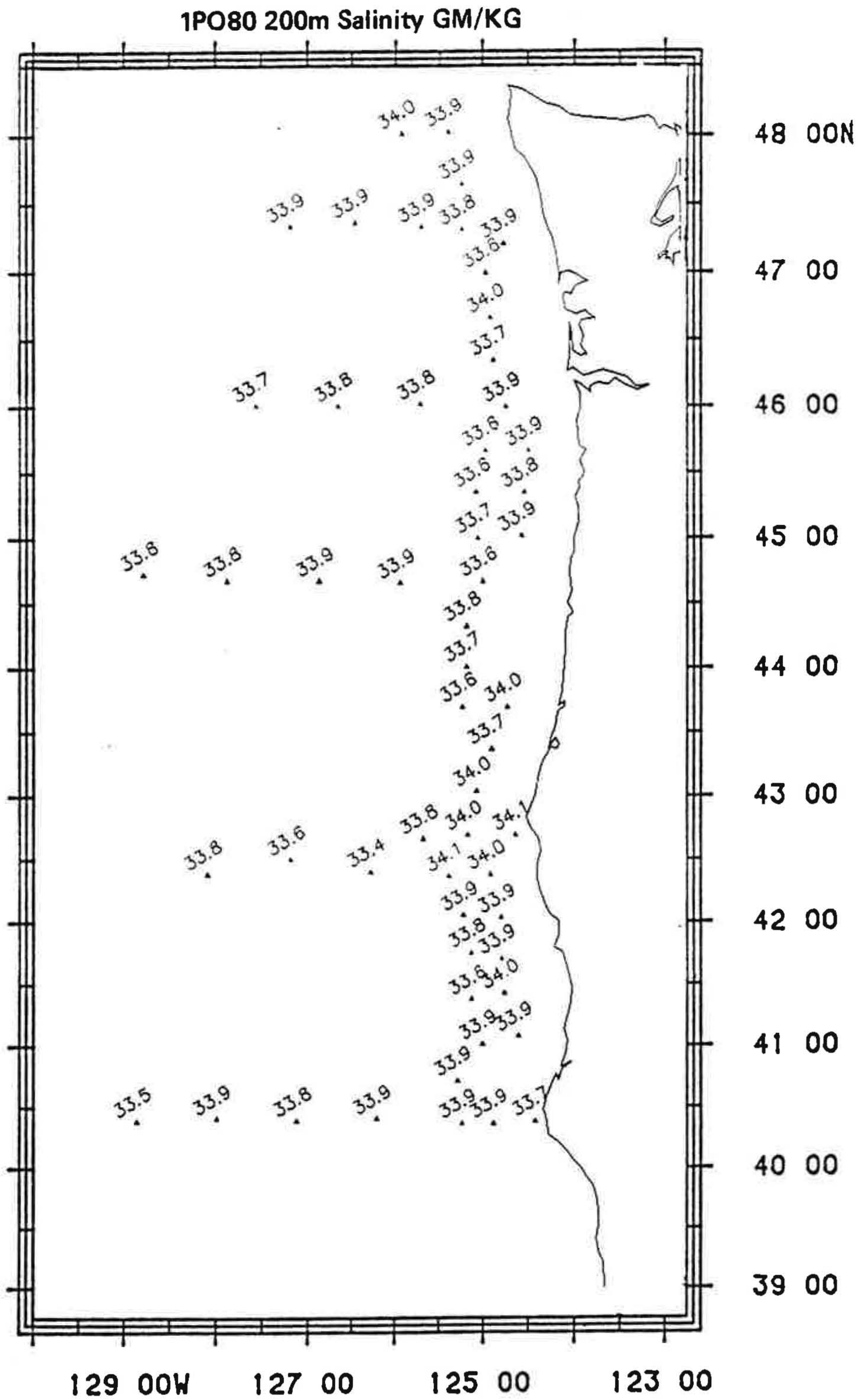

Figure 46.--200 meter salinity values (GM/KG) for cruise 1PO80, August 1st-20th, 1980.

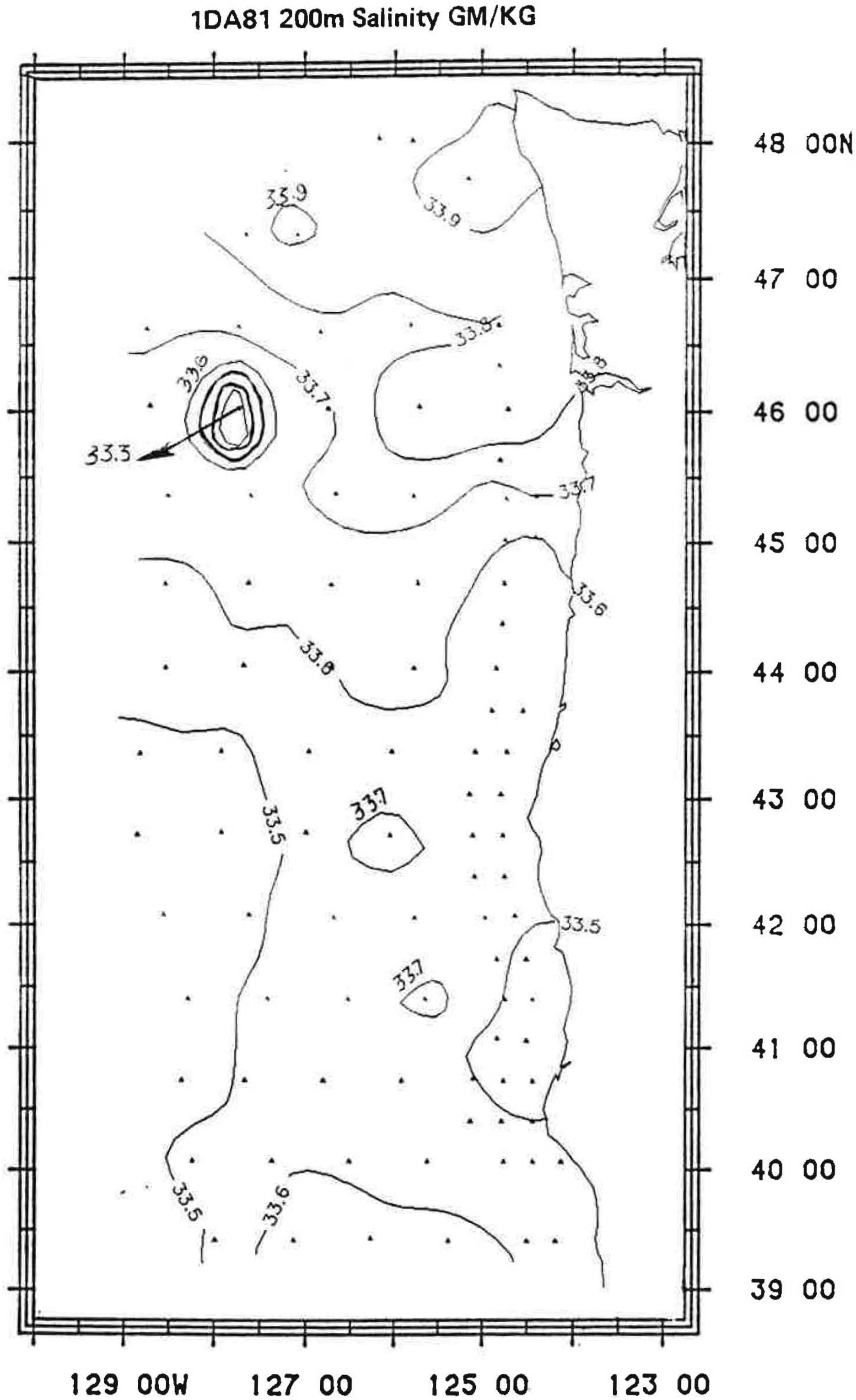

Figure 47.--200 meter salinity contours (GM/KG) for cruise 1DA81, October 24th-November 19th, 1981.

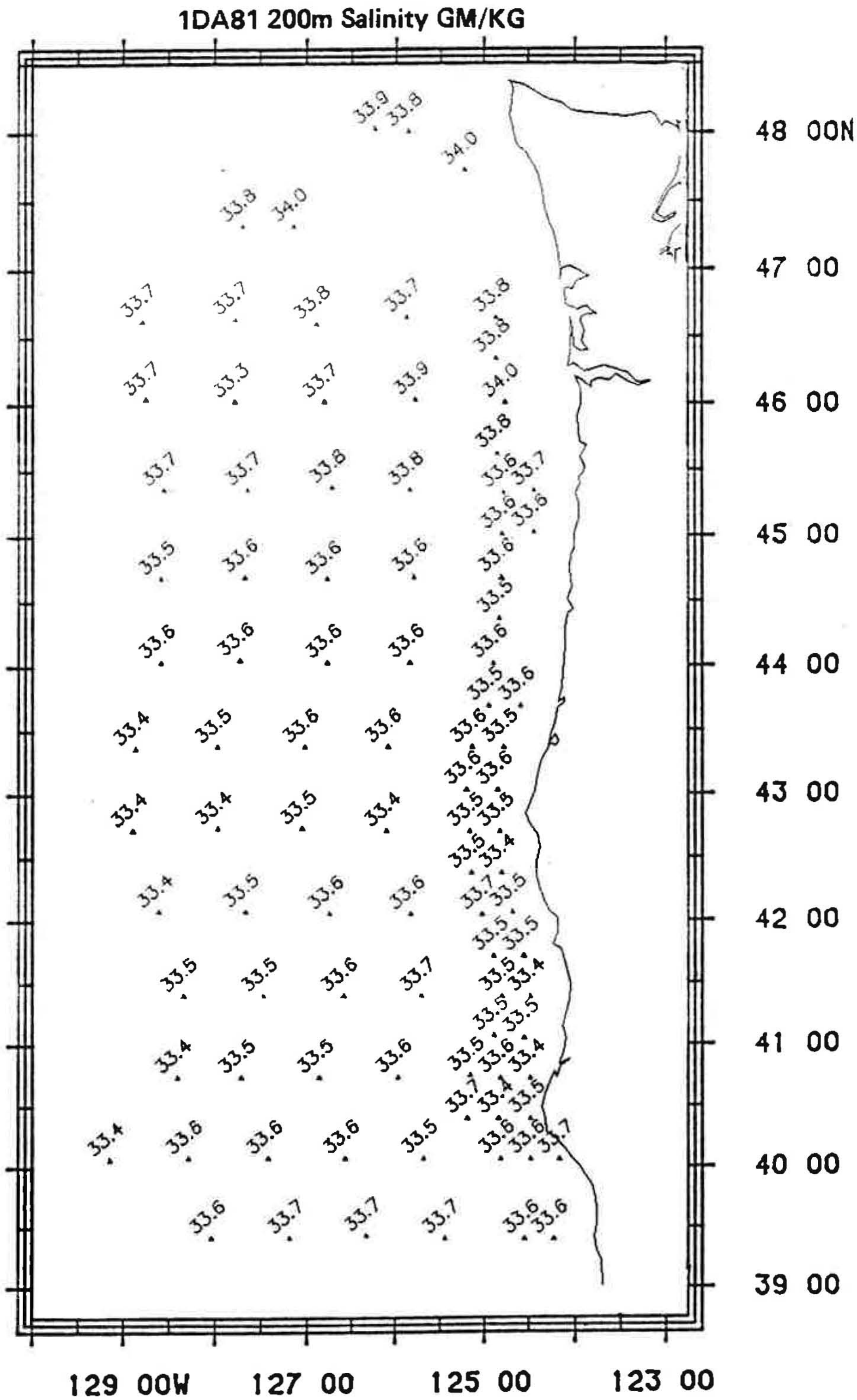

Figure 48.--200 meter salinity values (GM/KG) for cruise 1DA81, October 24th-November 19th, 1981.

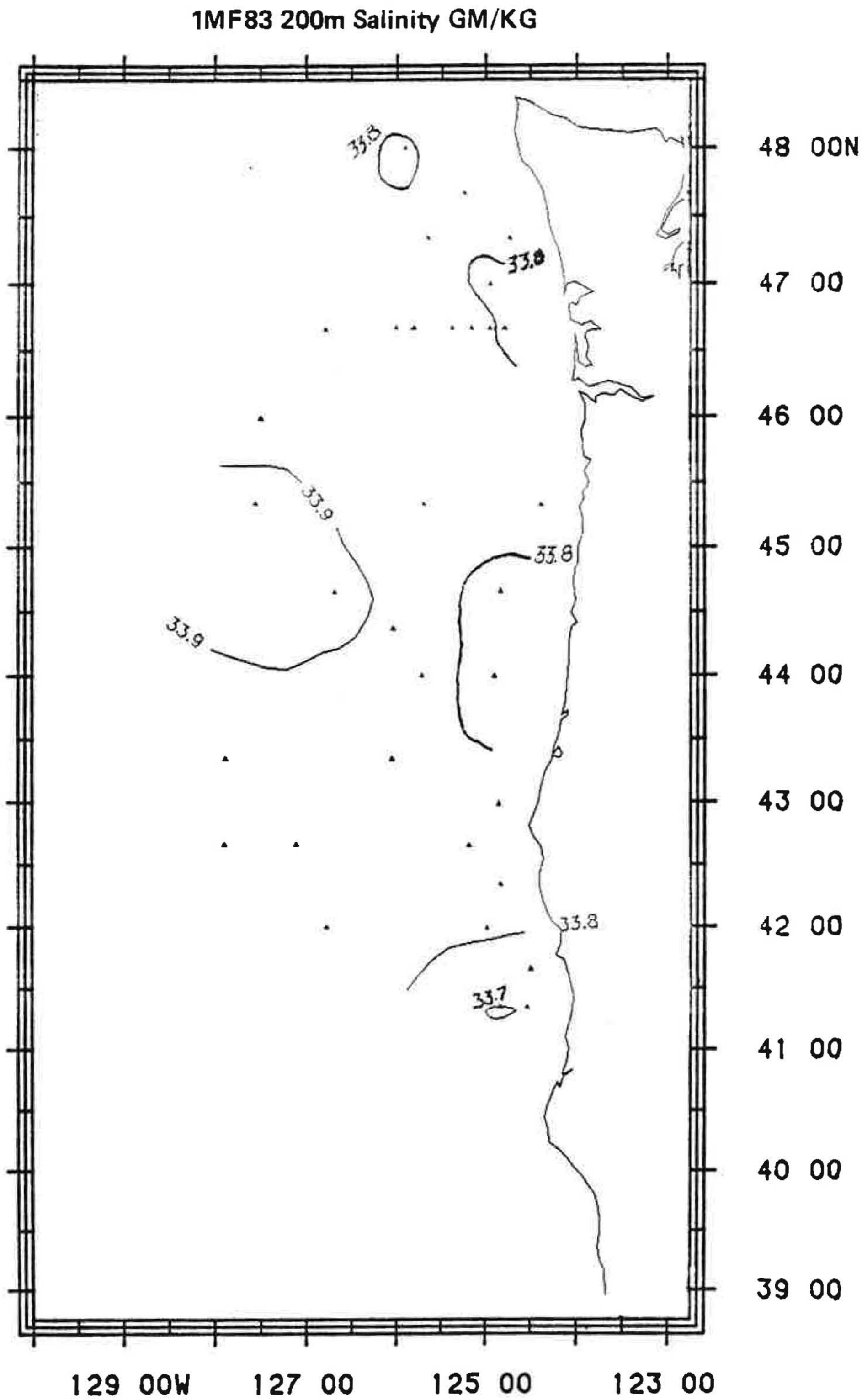

Figure 49.--200 meter salinity contours (GM/KG) for cruise 1MF83, November 11th-December 2nd.

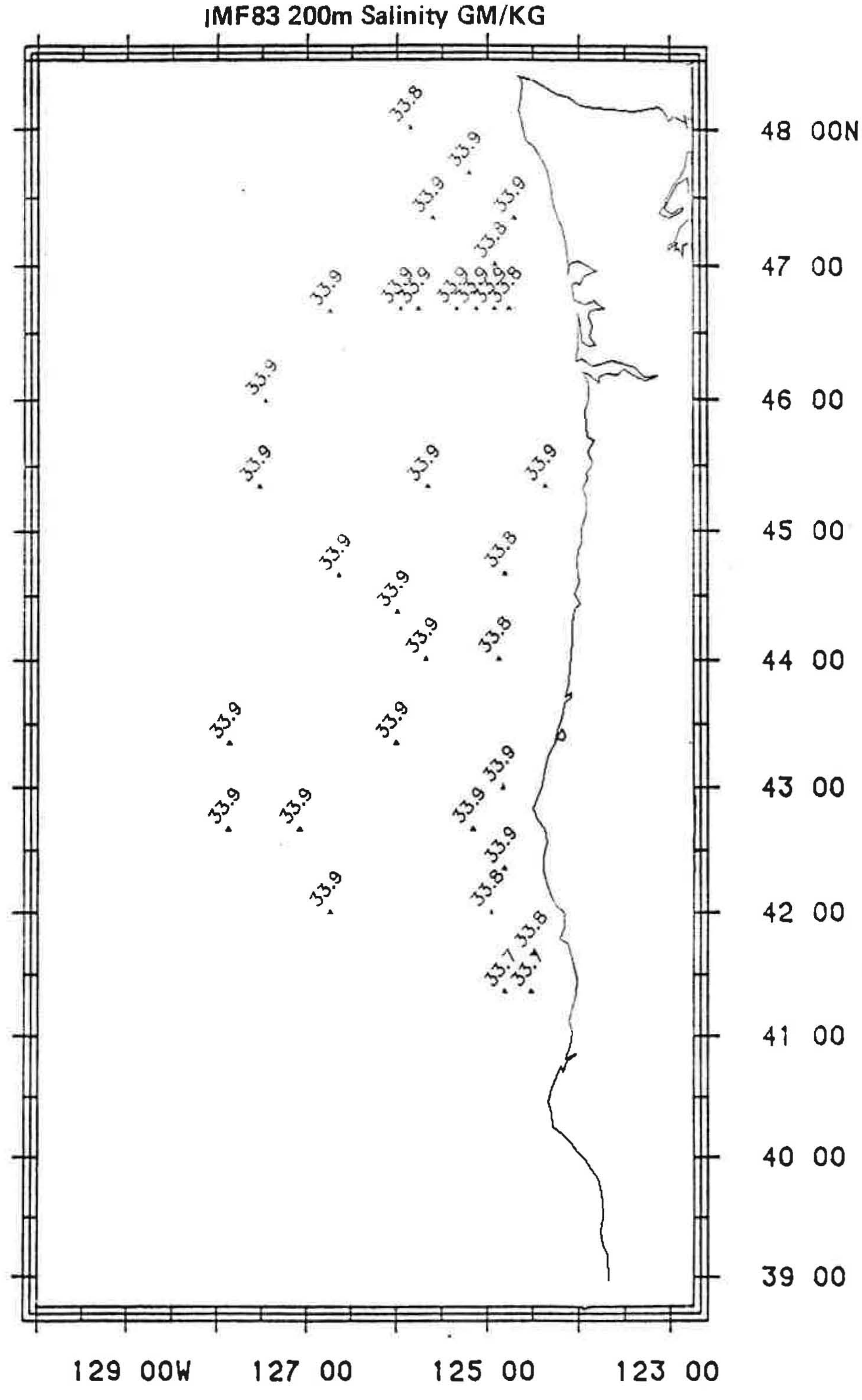

Figure 50.--200 meter salinity values (GM/KG) for cruise 1MF83, November 11th-December 2nd.

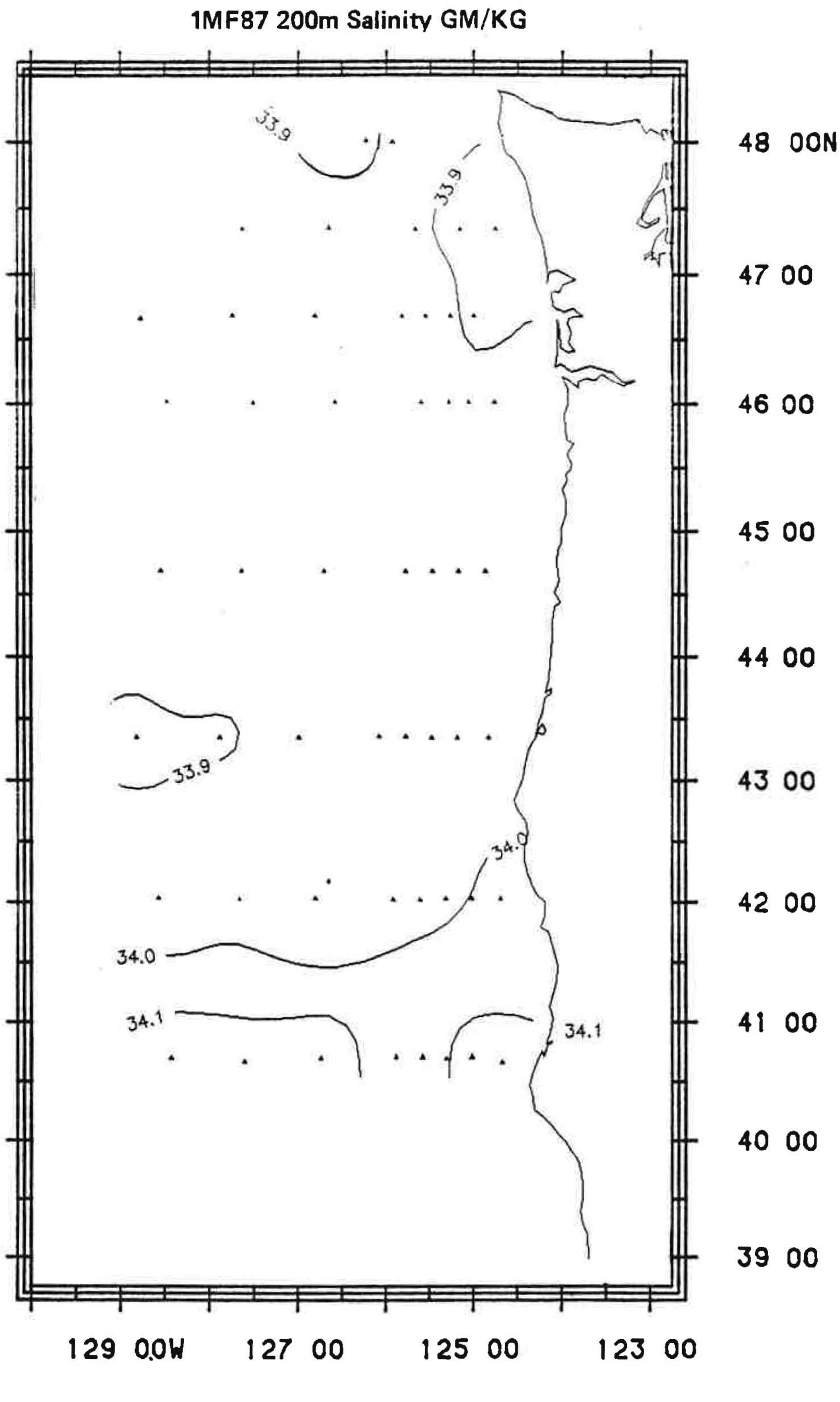

Figure 51.--200 meter salinity contours (GM/KG) for cruise 1MF87, January 7th-31st.

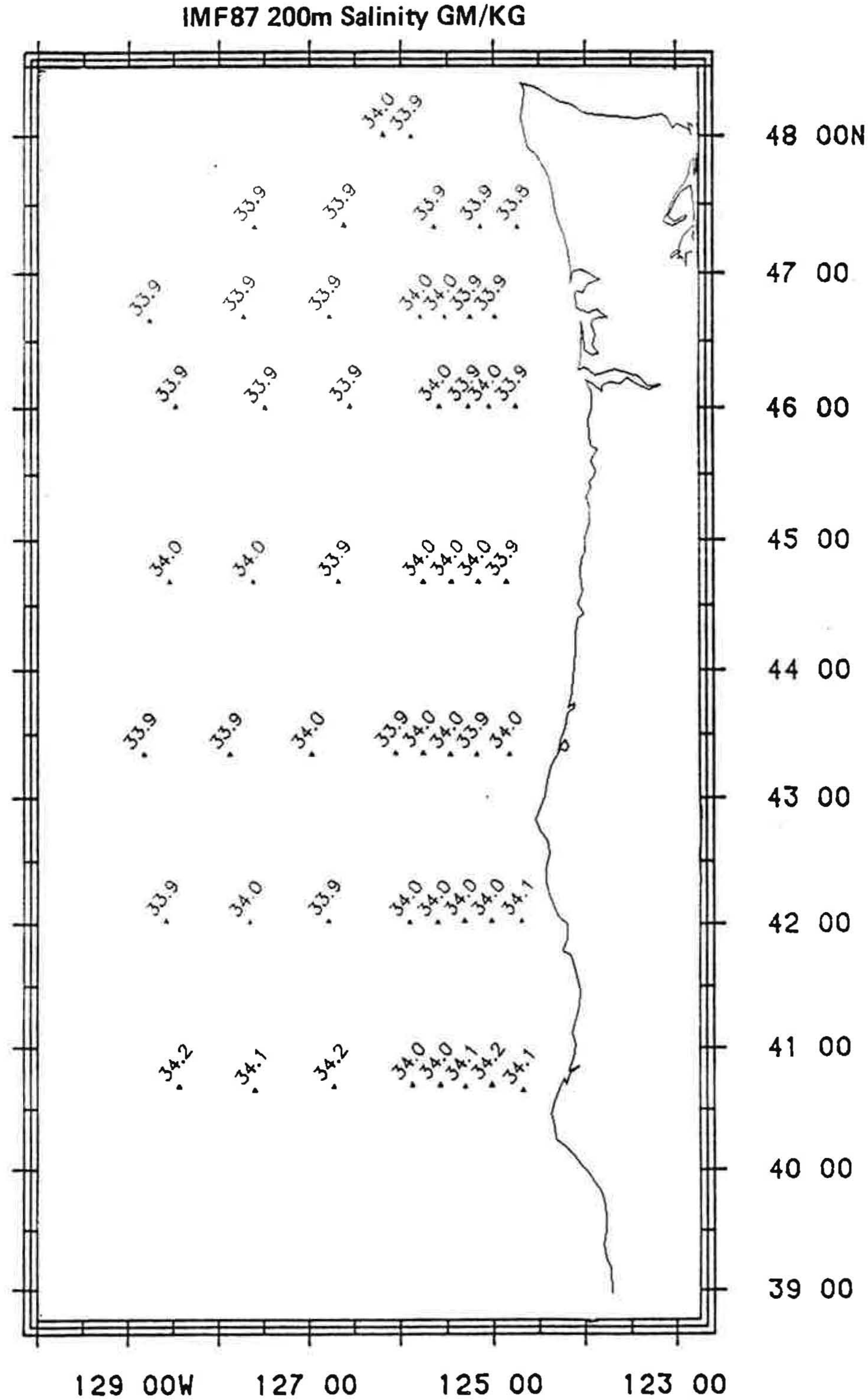

Figure 52.--200 meter salinity values (GM/KG) for cruise 1MF87, January 7th-31st.

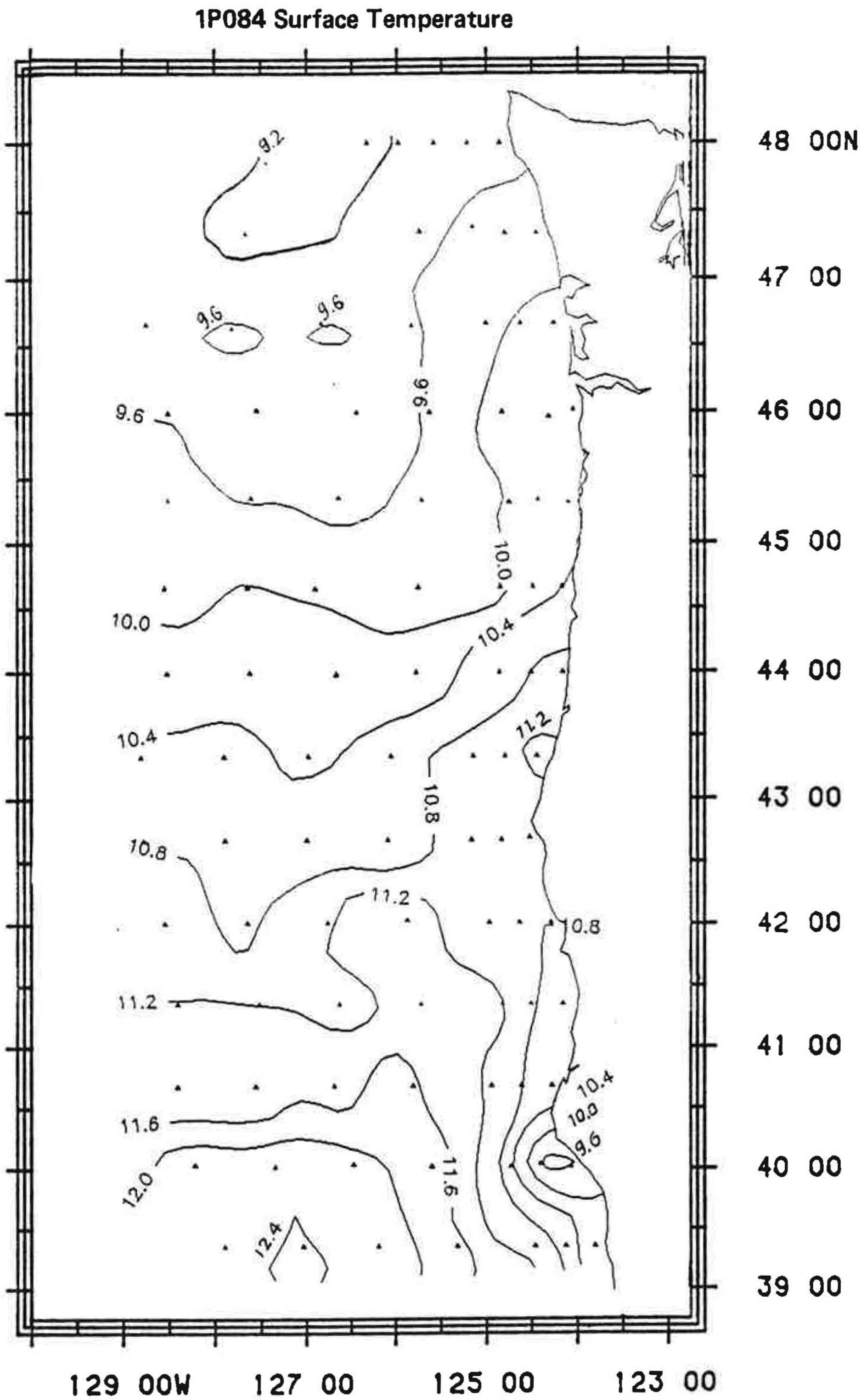

Figure 53.--Surface temperature contours (°C) for cruise 1P084, March 11th-April 4th, 1984.

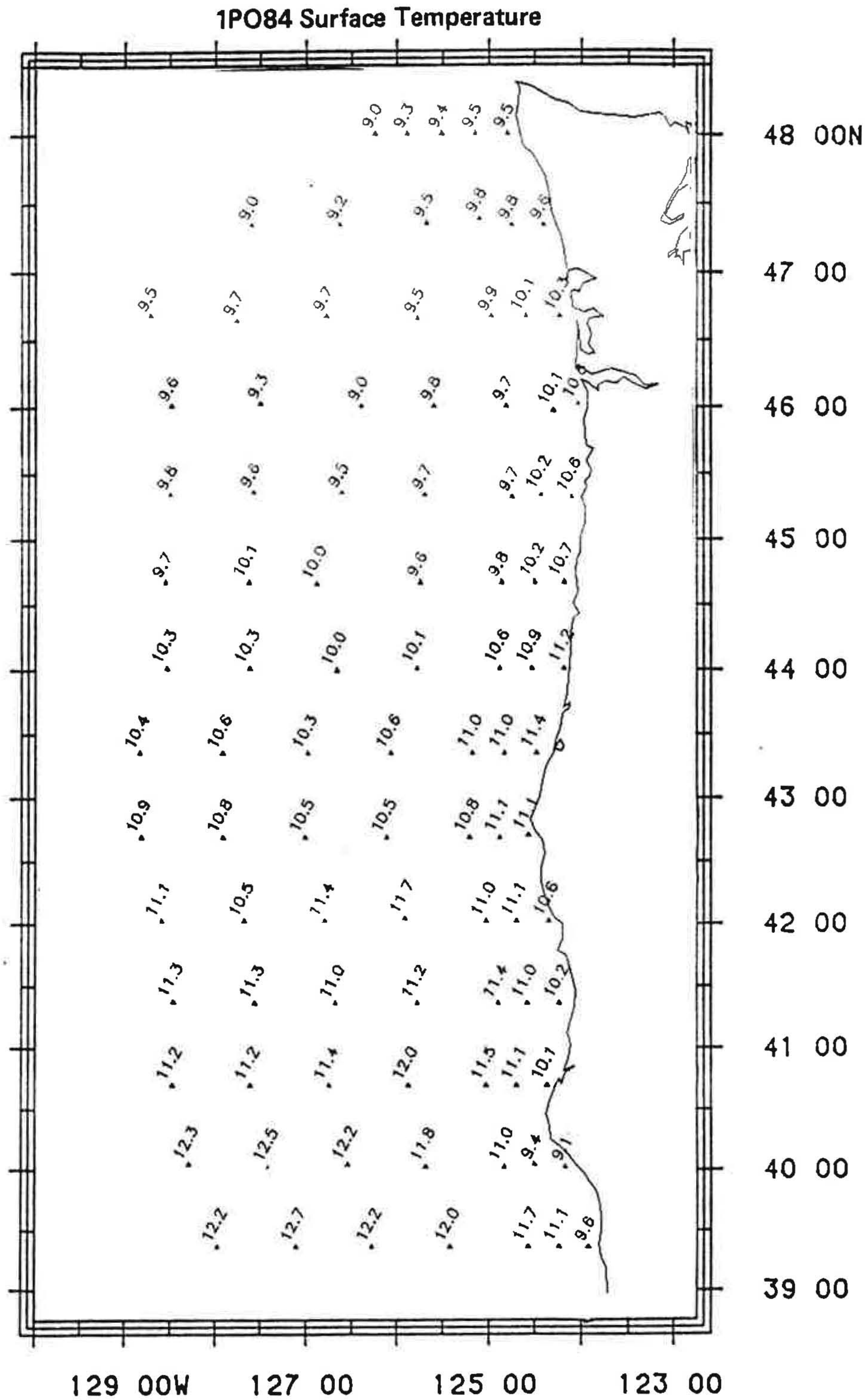

Figure 54.--Surface temperature values (°C) for cruise 1PO84, March 11th-April 4th, 1984.

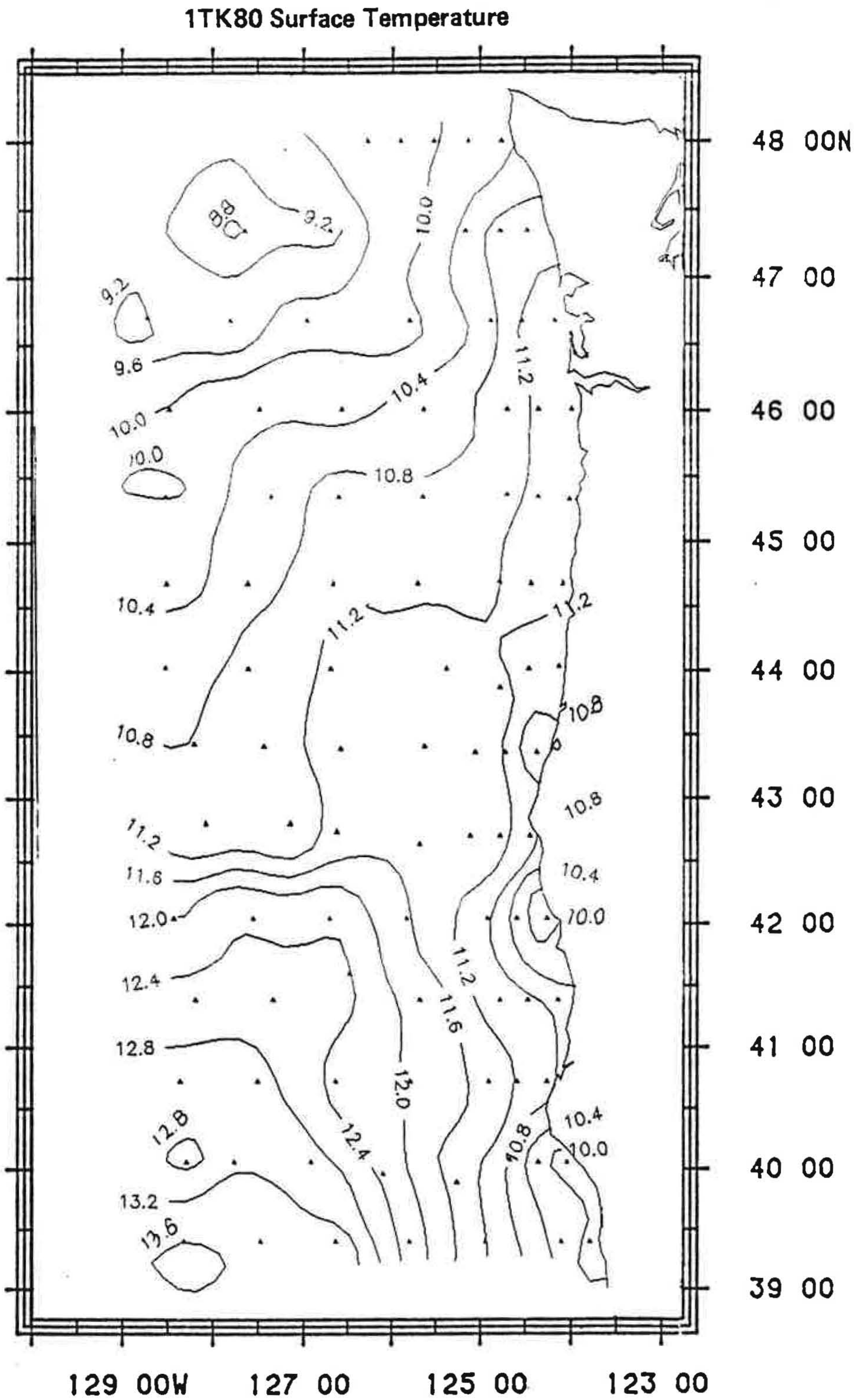

Figure 55.--Surface temperature contours (°C) for cruise 1TK80, April 20th-May 15th, 1980.

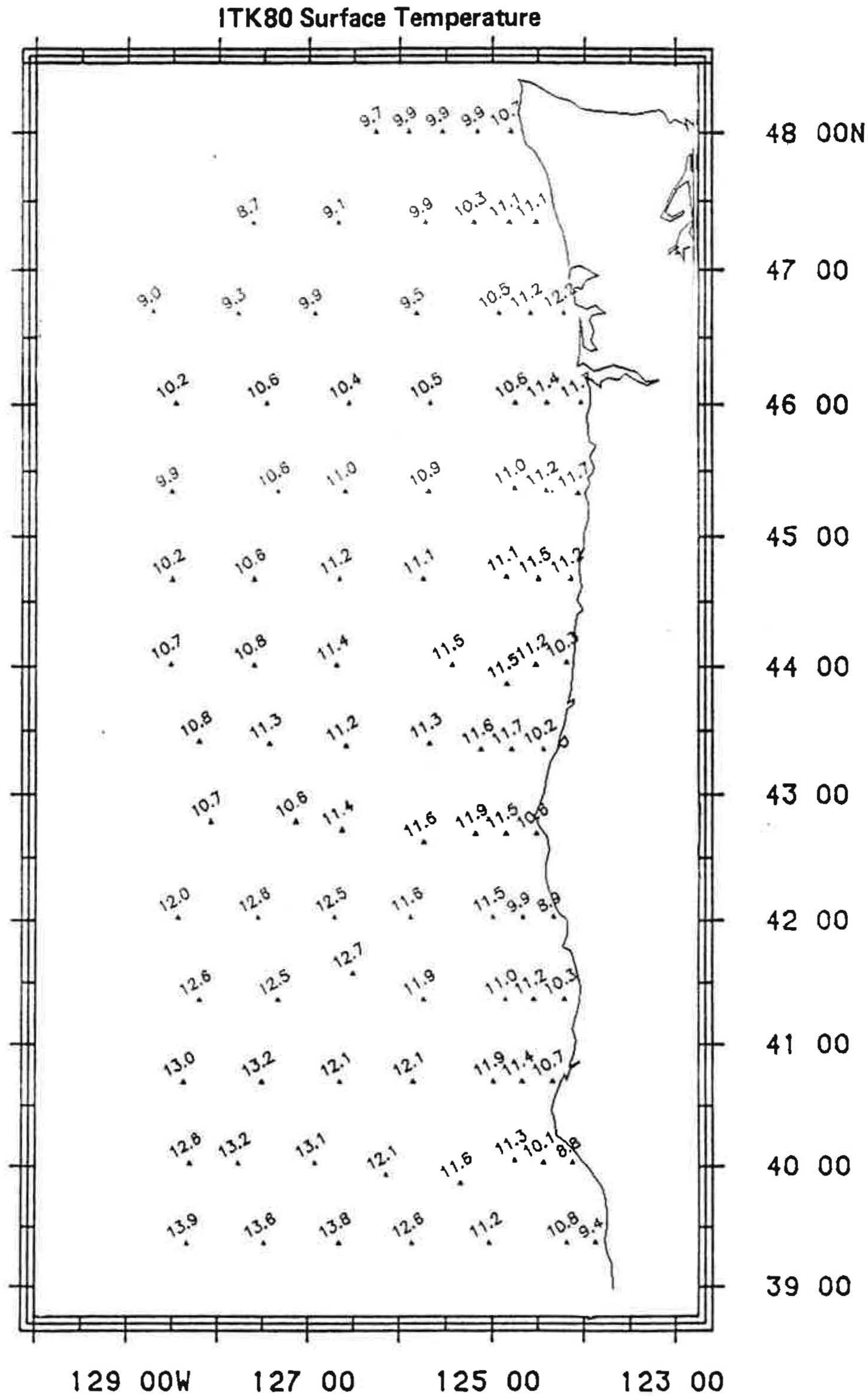

Figure 56.--Surface temperature values (°C) for cruise 1TK80, April 20th-May 15th, 1980.

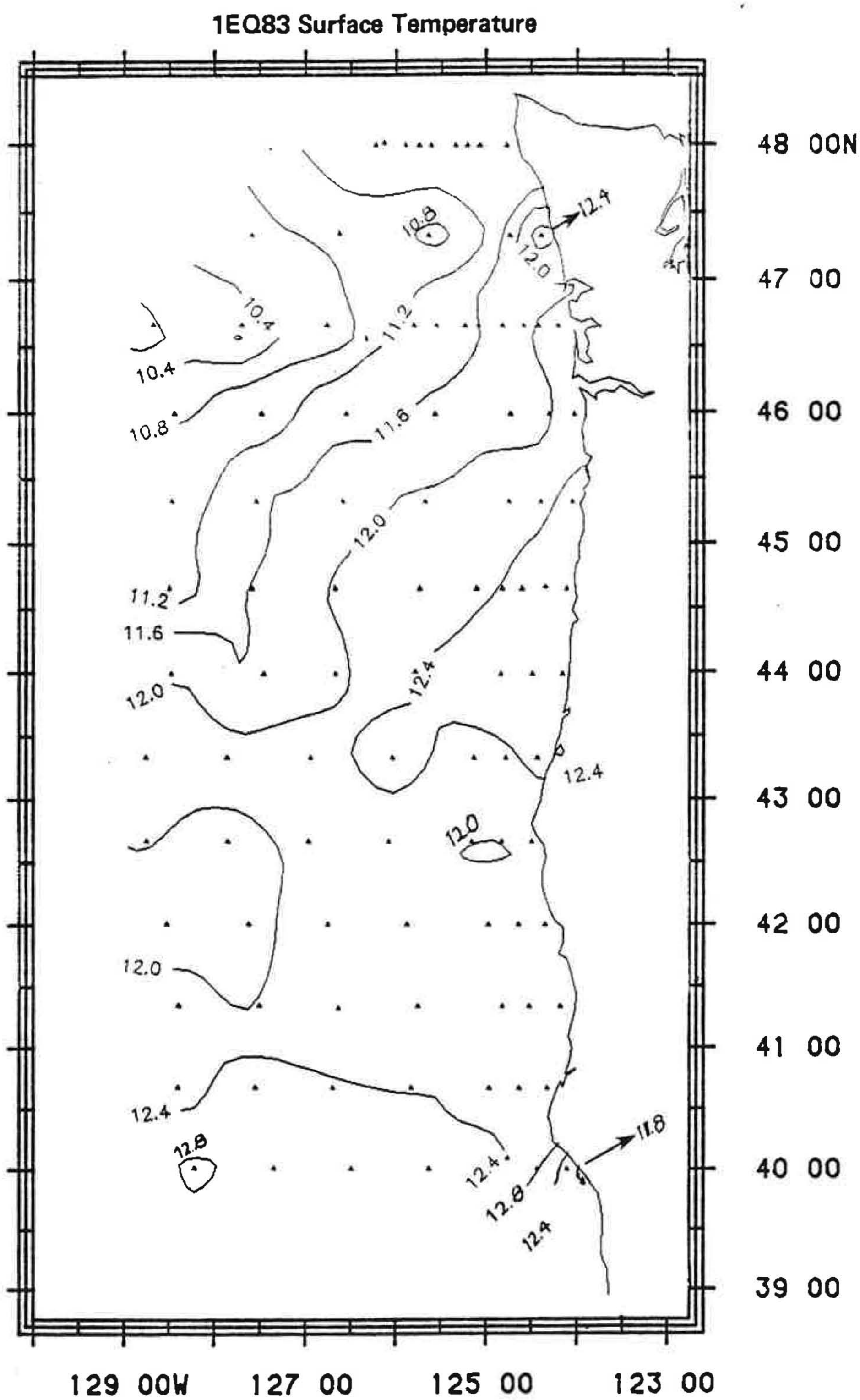

Figure 57.--Surface temperature contours (°C) for cruise 1EQ83, April 23rd-May 15th, 1983.

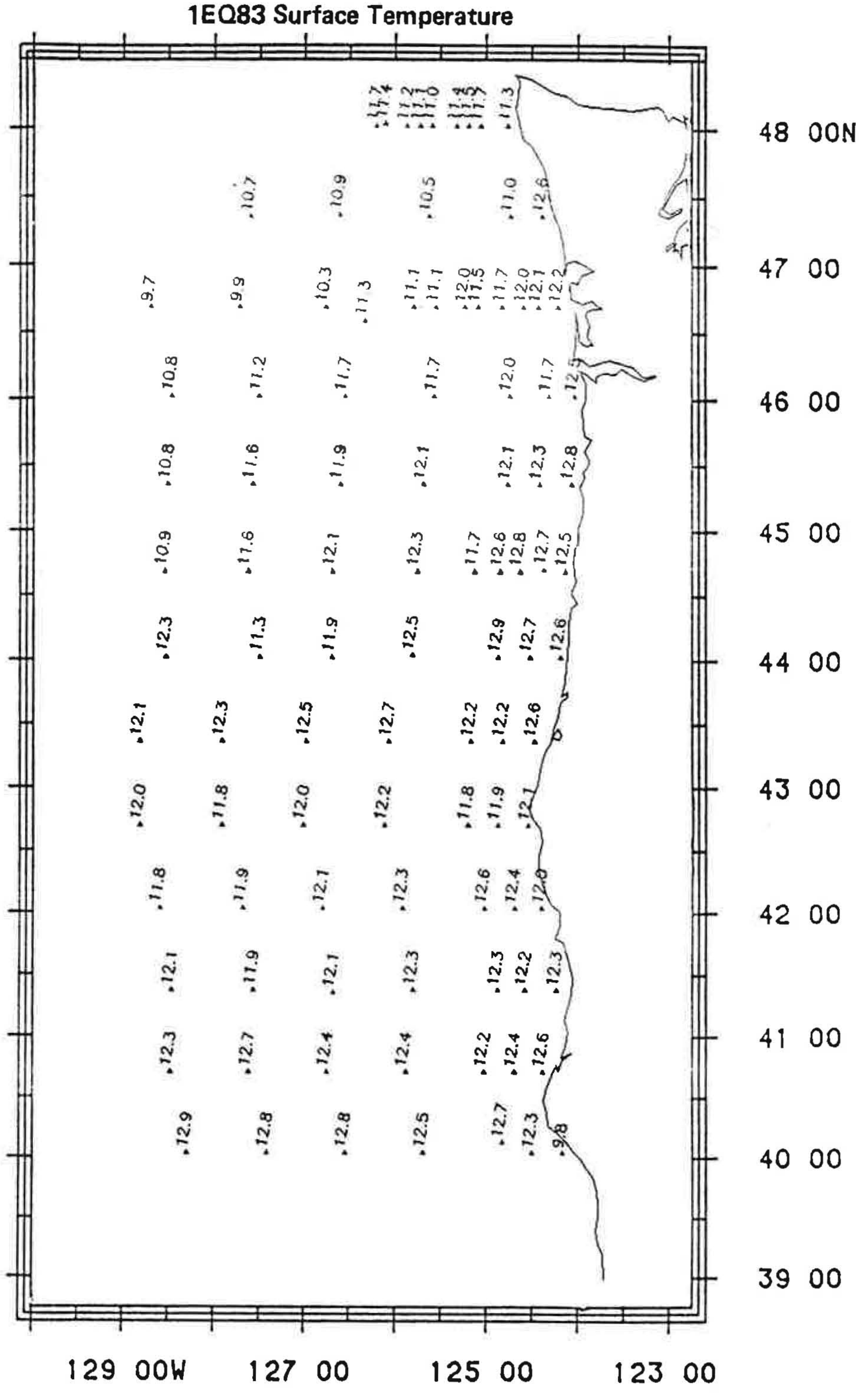

Figure 58.--Surface temperature values (°C) for cruise 1EQ83, April 23rd-May 15th, 1983.

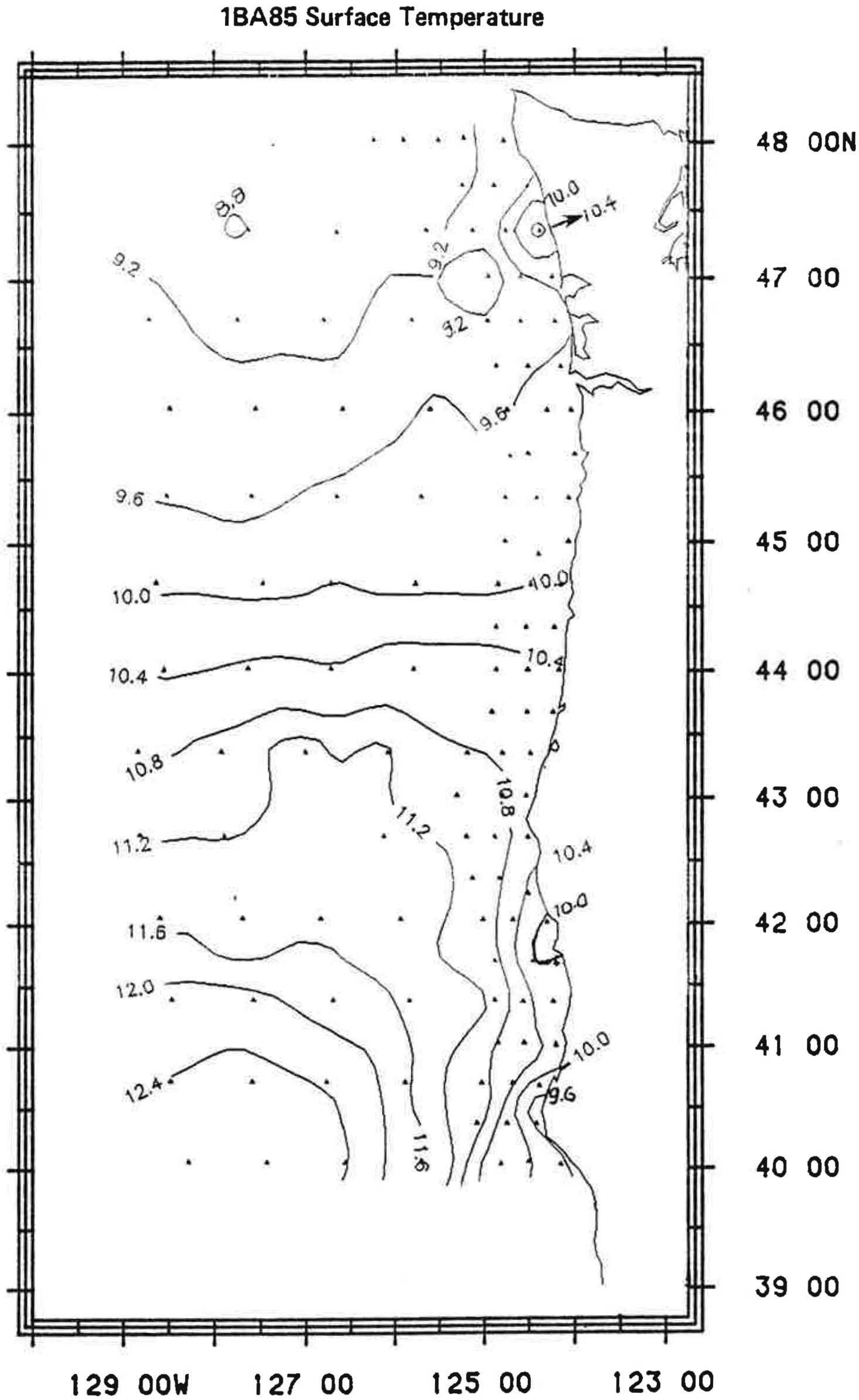

Figure 59.--Surface temperature contours (°C) for cruise 1BA85, April 19th-May 11th, 1985.

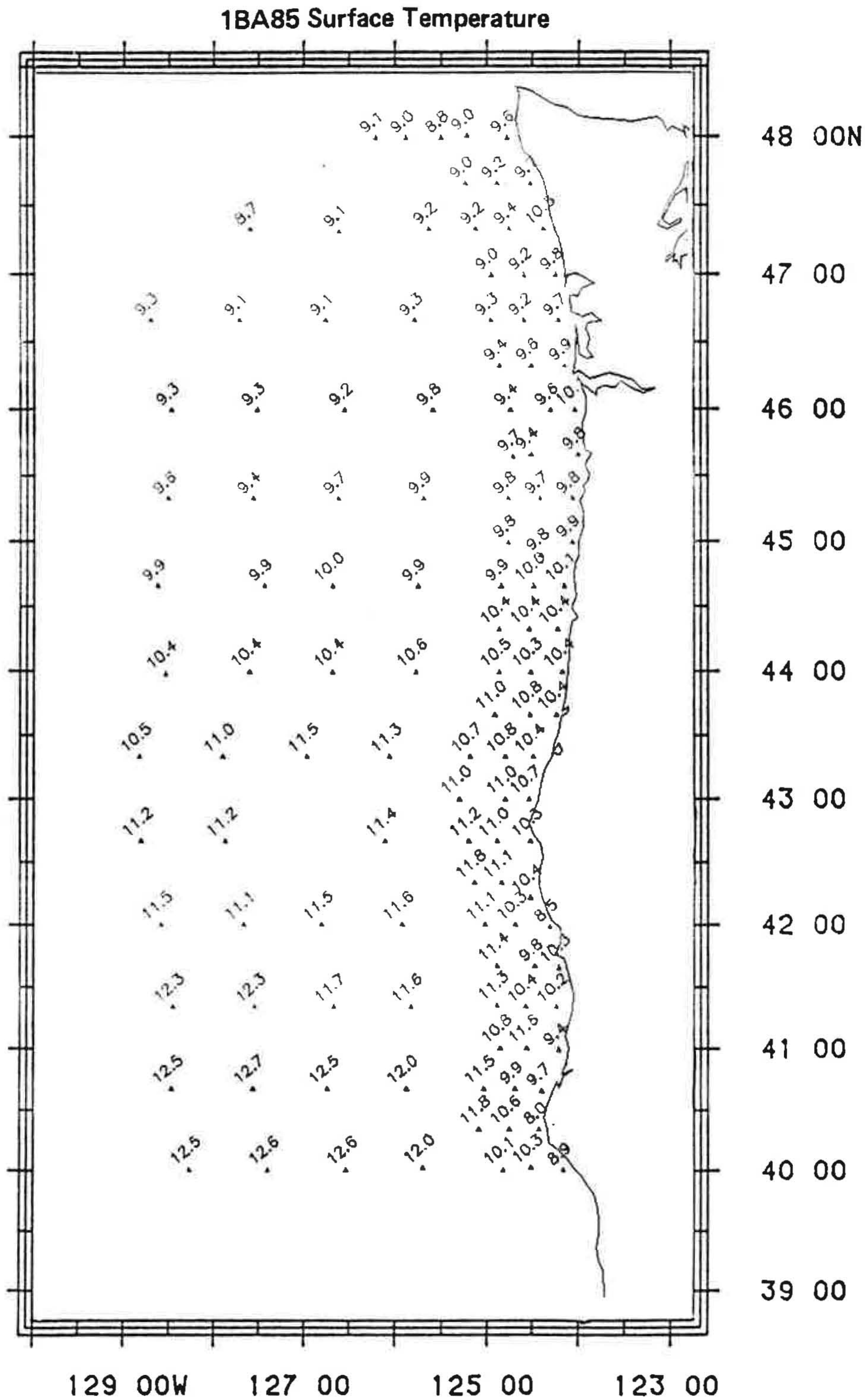

Figure 60.--Surface temperature values (°C) for cruise 1BA85, April 19th-May 11th, 1985.

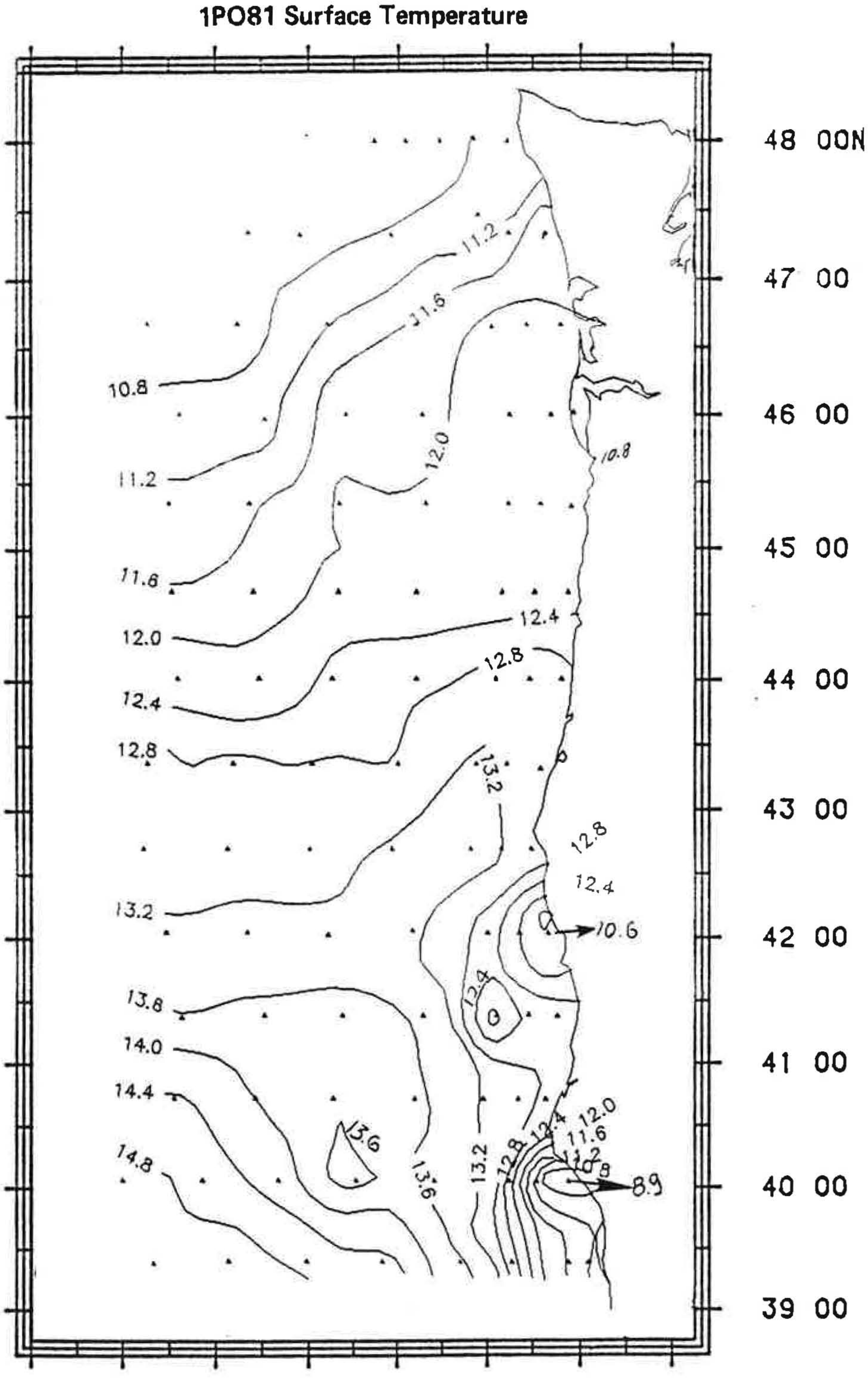

Figure 61.--Surface temperature contours (°C) for cruise 1PO81, May 9th-June 2nd, 1981.

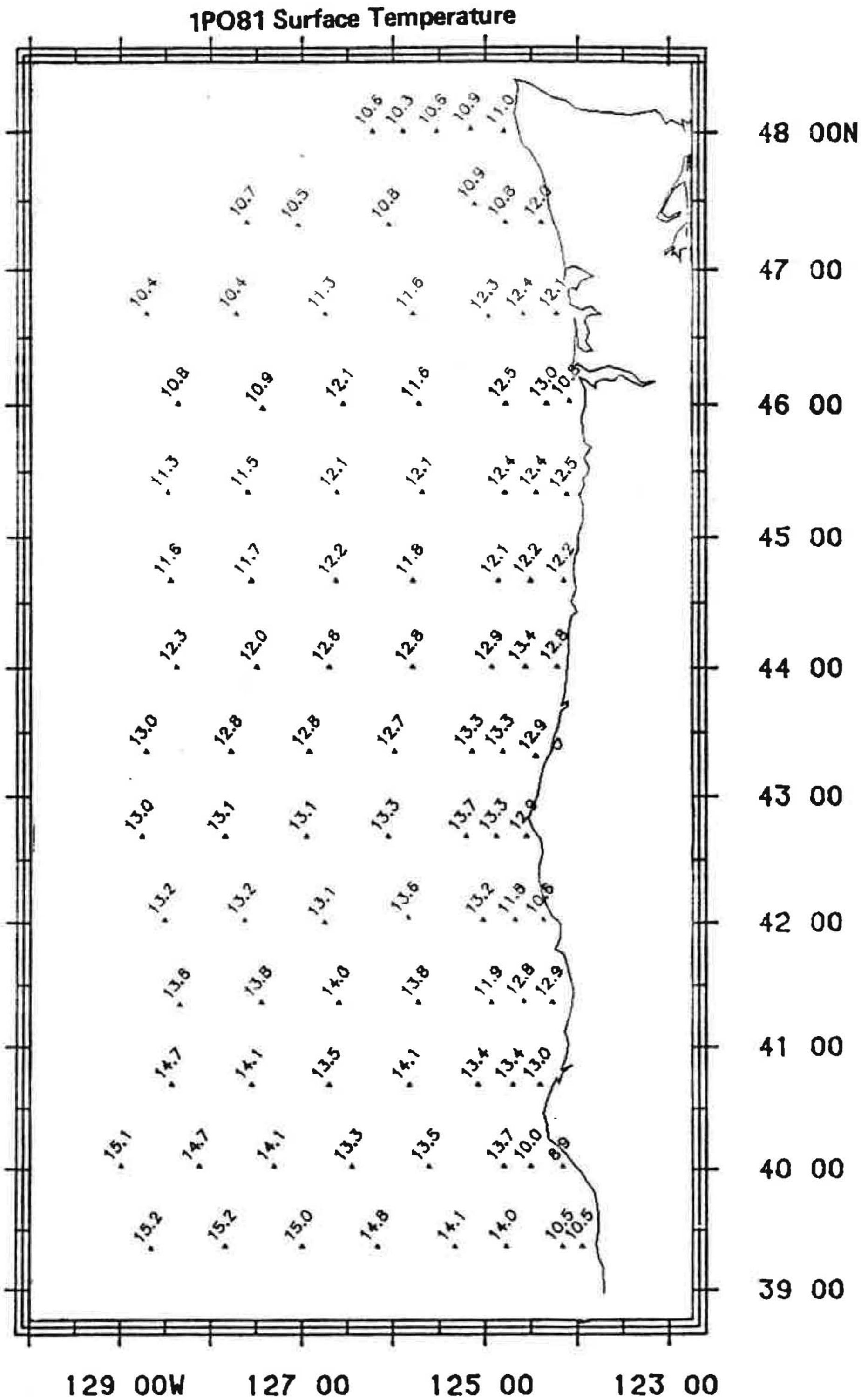

Figure 62.--Surface temperature values (°C) for cruise 1PO81, May 9th-June 2nd, 1981.

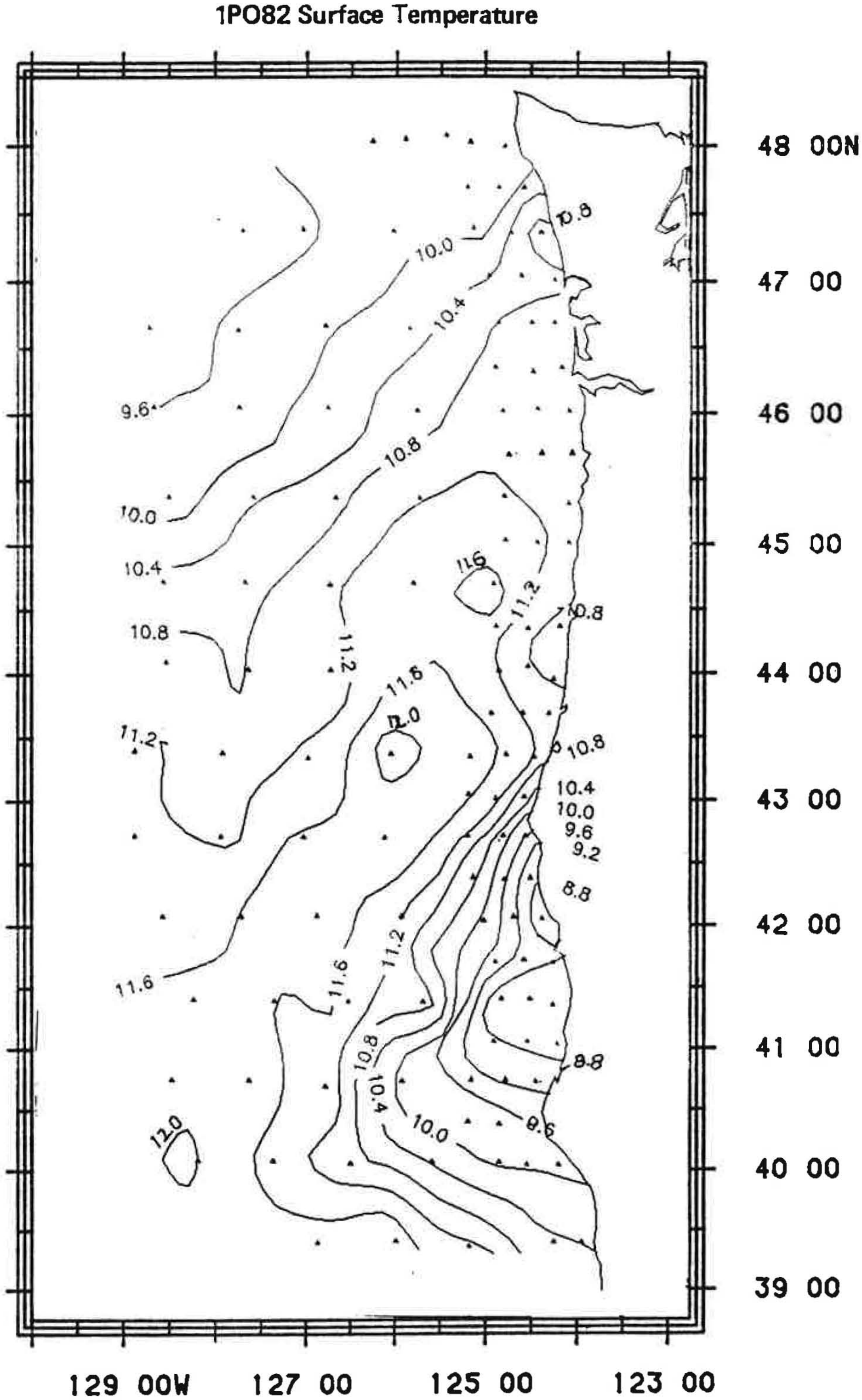

Figure 63.--Surface temperature contours (°C) for cruise 1PO82, May 3rd-June 1st, 1982.

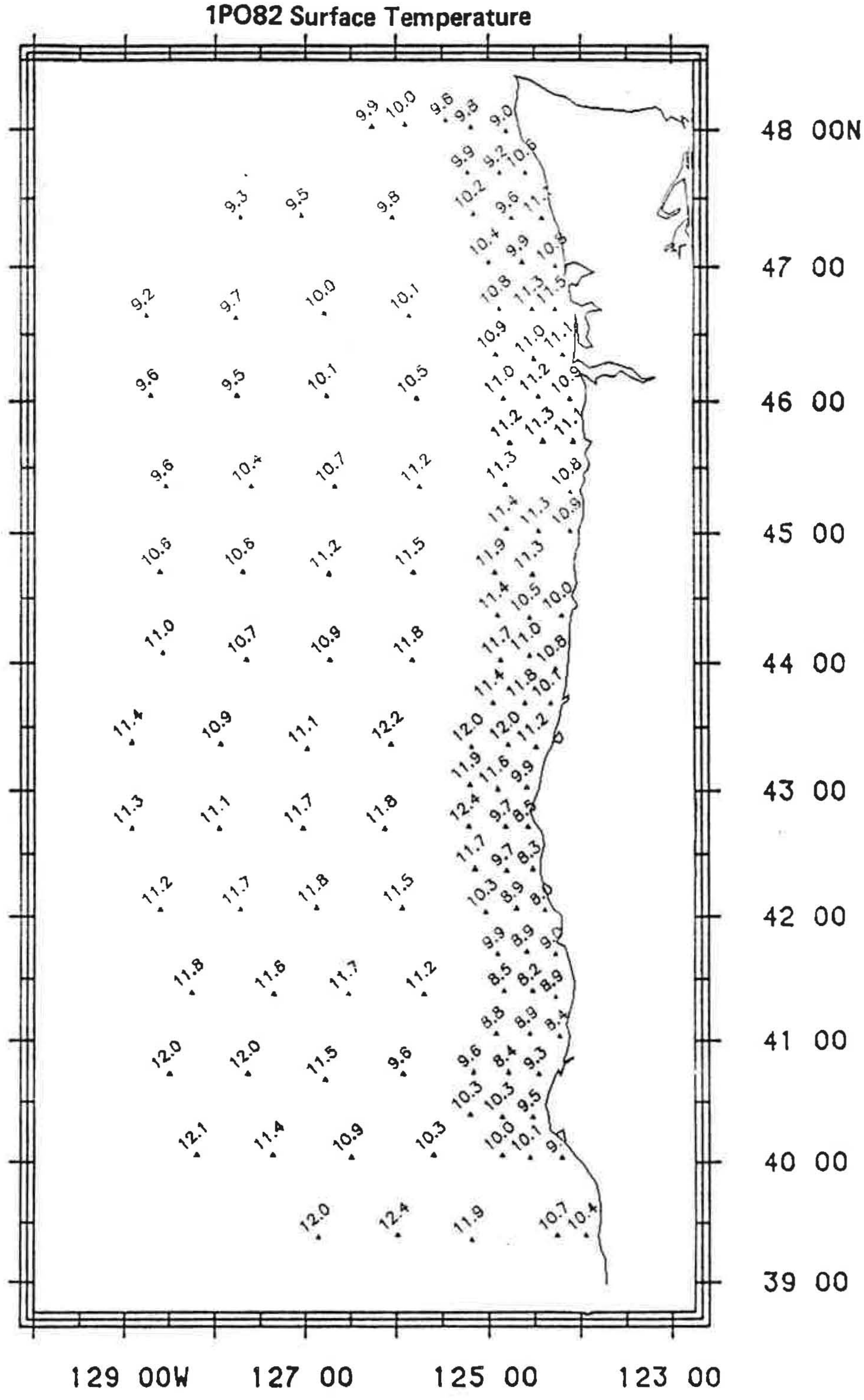

Figure 64.--Surface temperature values (°C) for cruise 1PO82, May 3rd-June 1st, 1982.

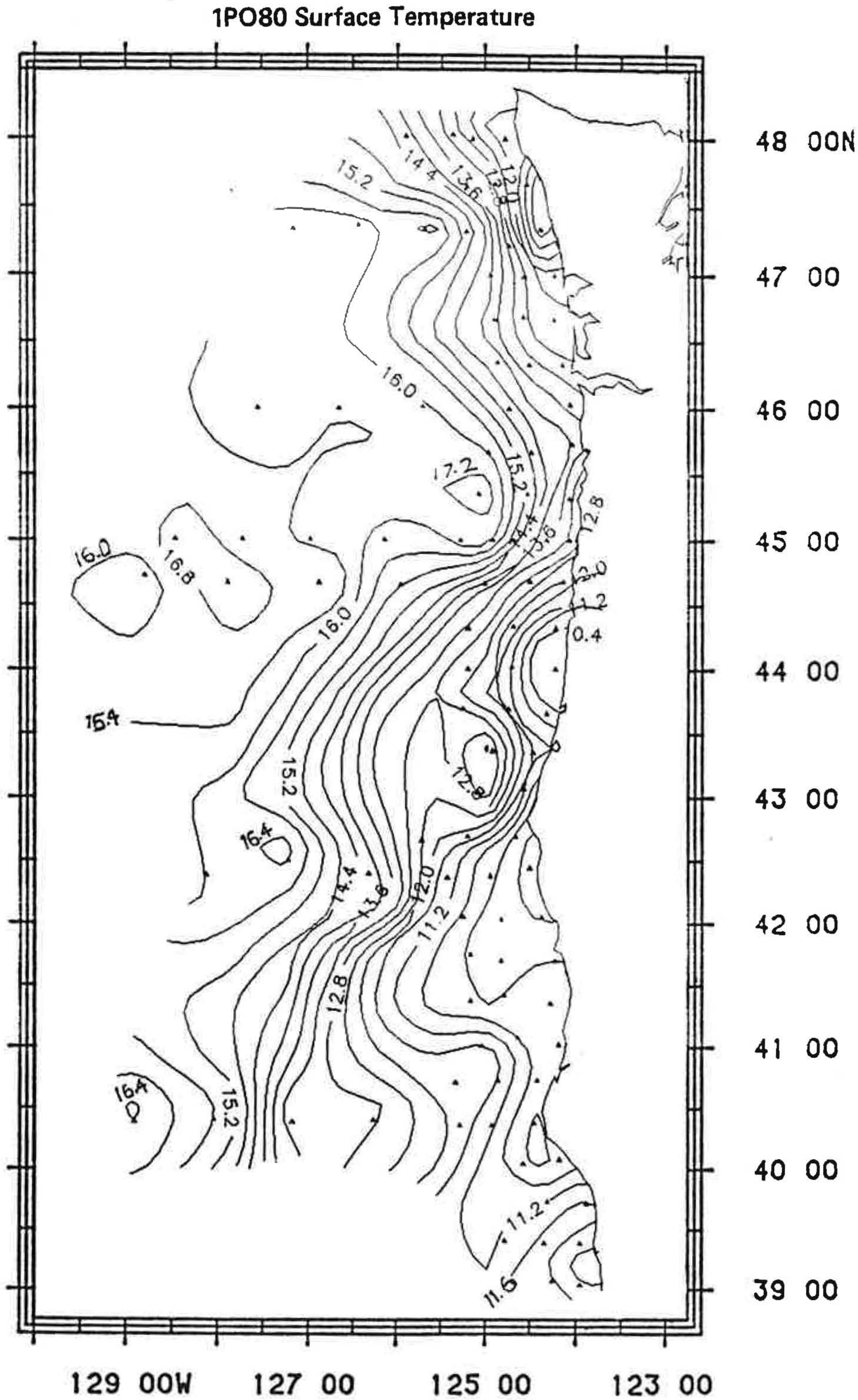

Figure 65.--Surface temperature contours (°C) for cruise 1PO80, August 1st-20th.

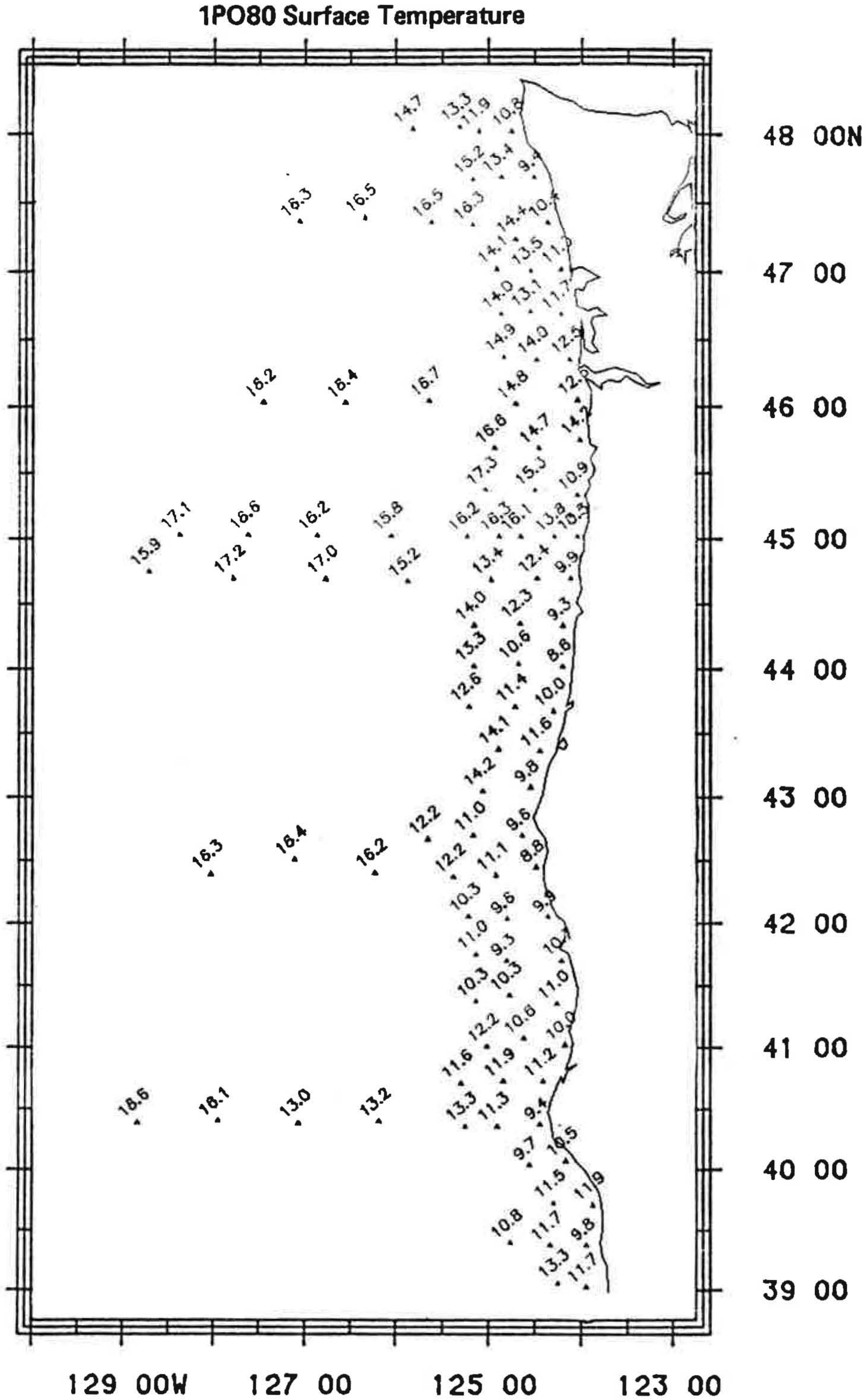

Figure 66.--Surface temperature values (°C) for cruise 1PO80, August 1st-20th.

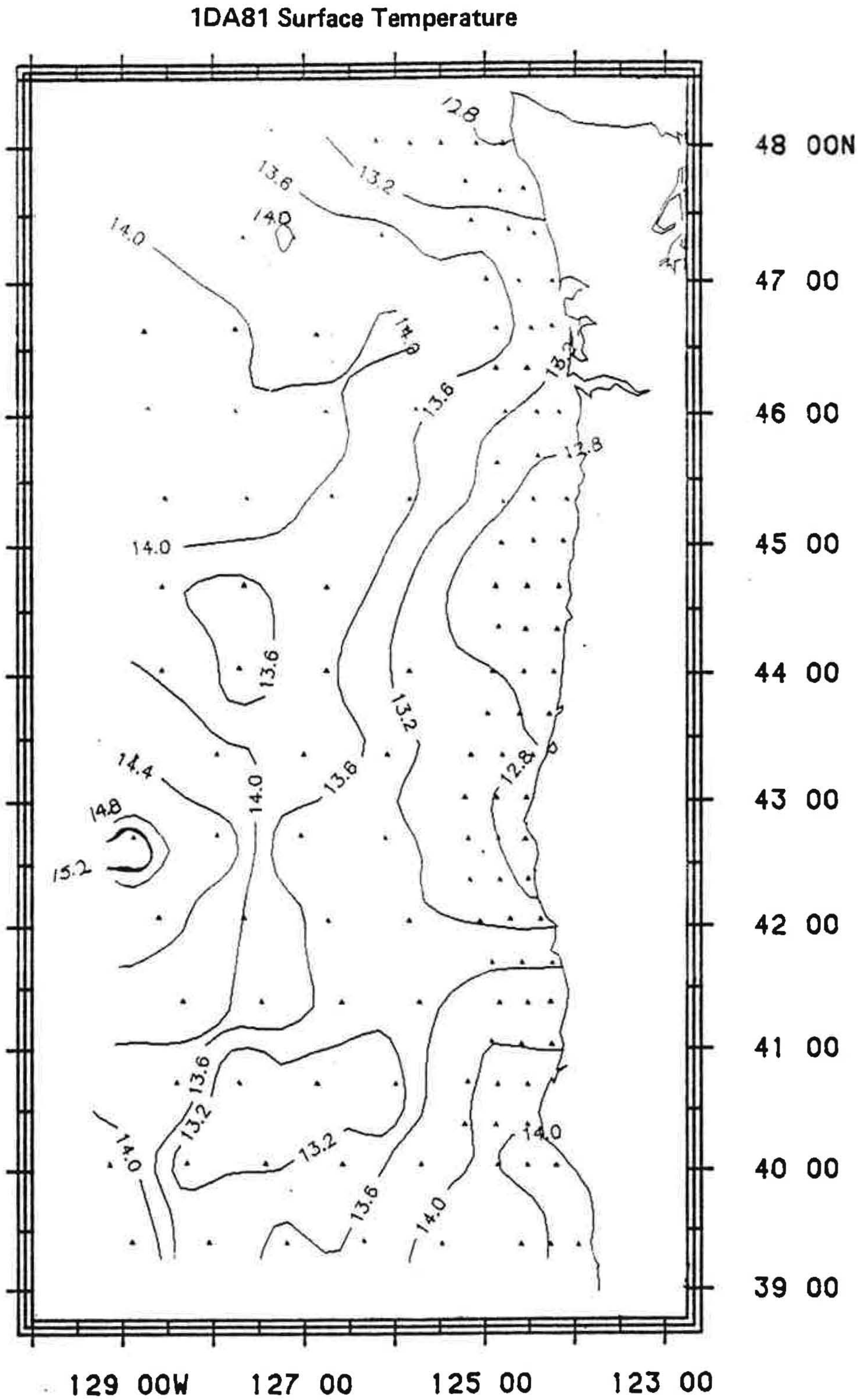

Figure 67.--Surface temperature contours (°C) for cruise 1DA81, October 24th-November 19th, 1981.

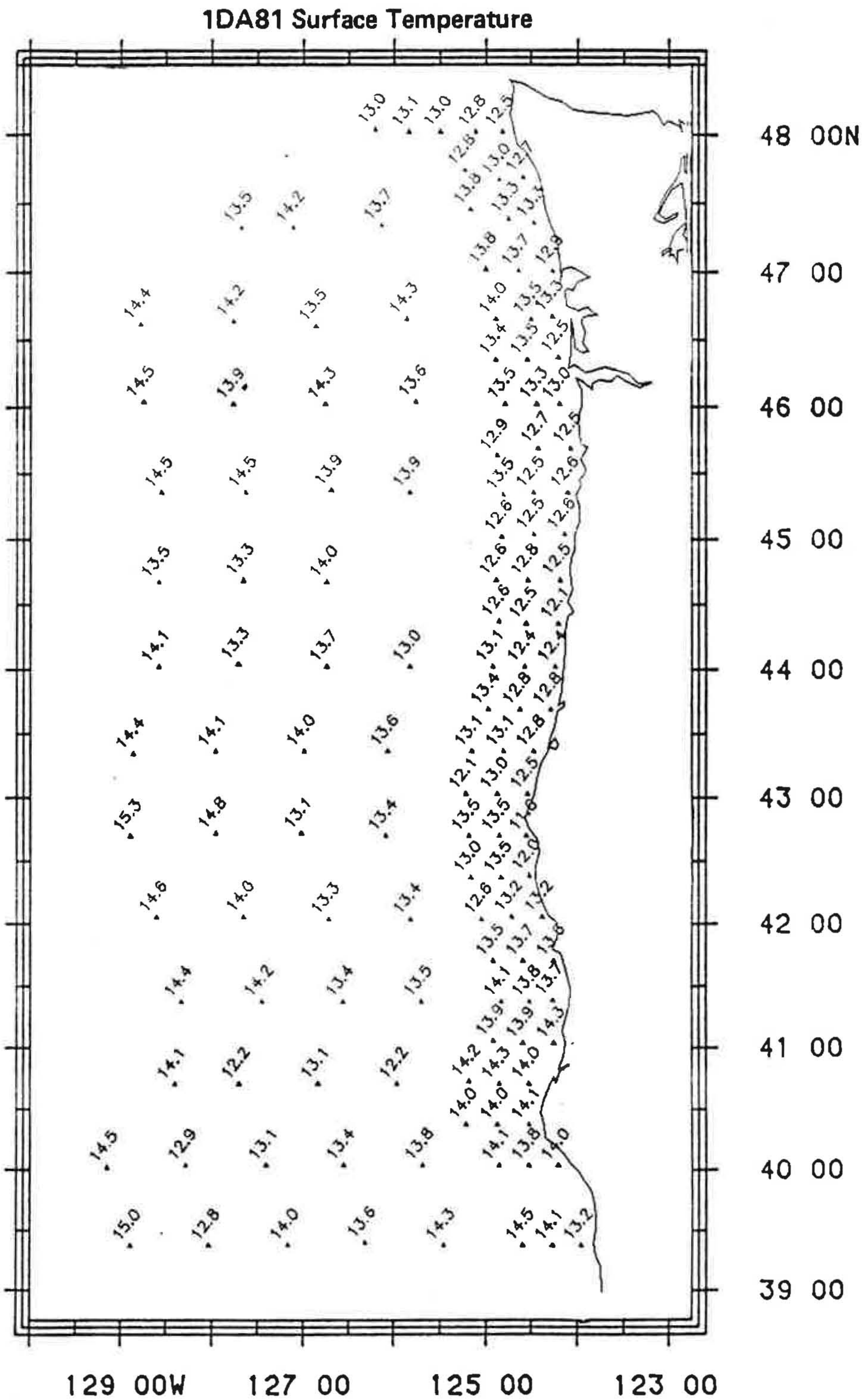

Figure 68.--Surface temperature values (°C) for cruise 1DA81, October 24th-November 19th, 1981.

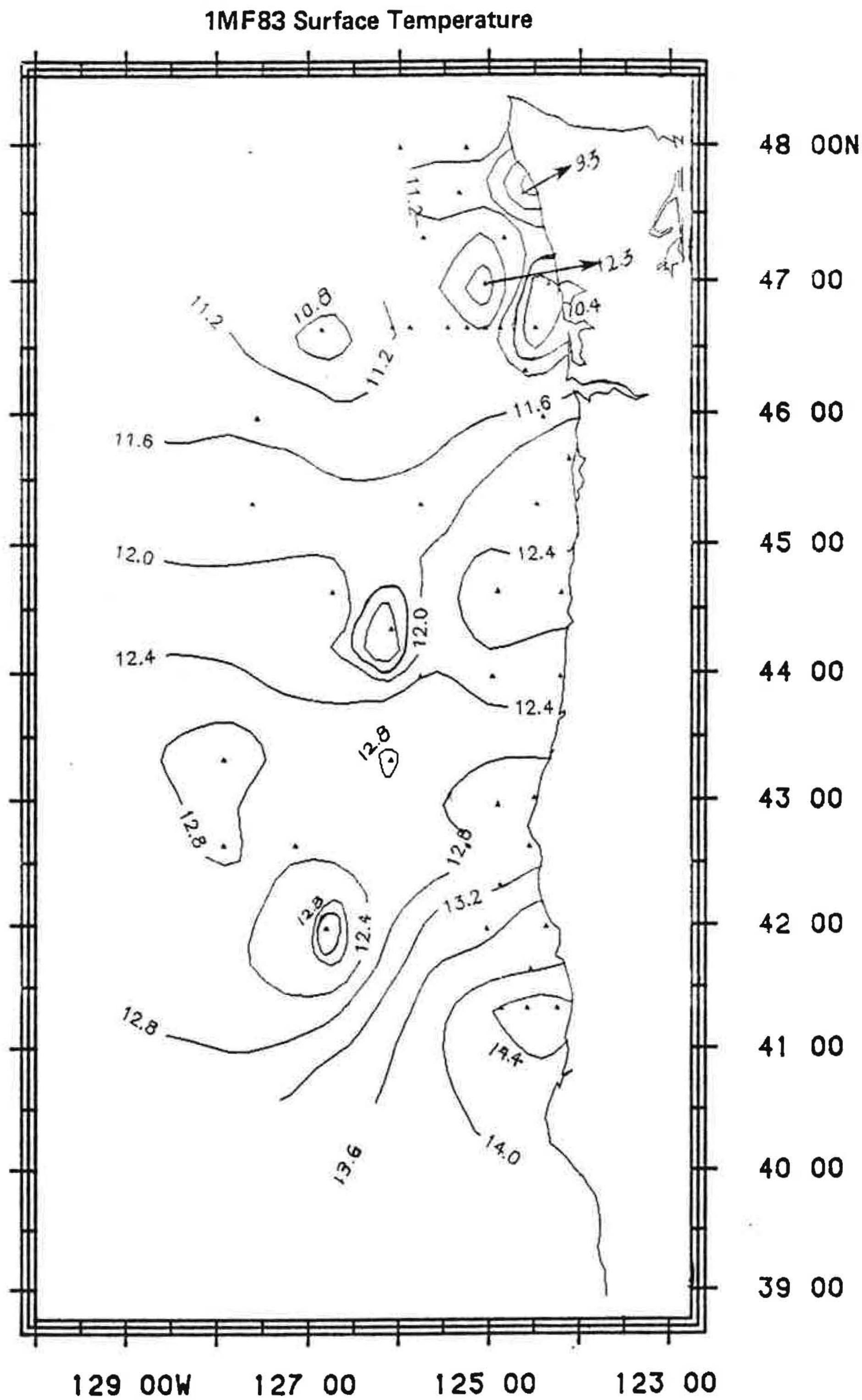

Figure 69.--Surface temperature contours (°C) for cruise 1MF83, November 11th-December 2nd, 1983.

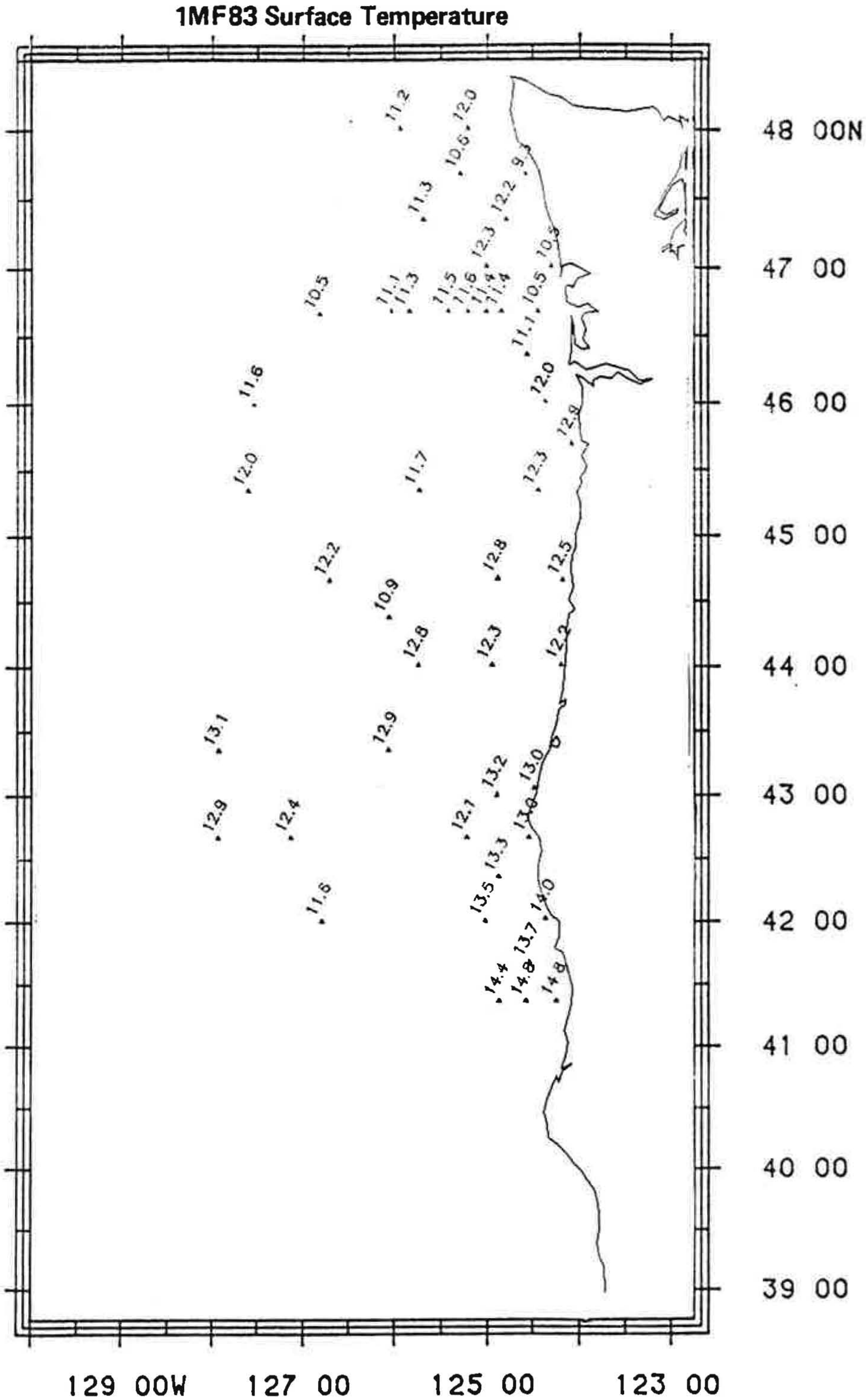

Figure 70.--Surface temperature values (°C) for cruise 1MF83, November 11th-December 2nd, 1983.

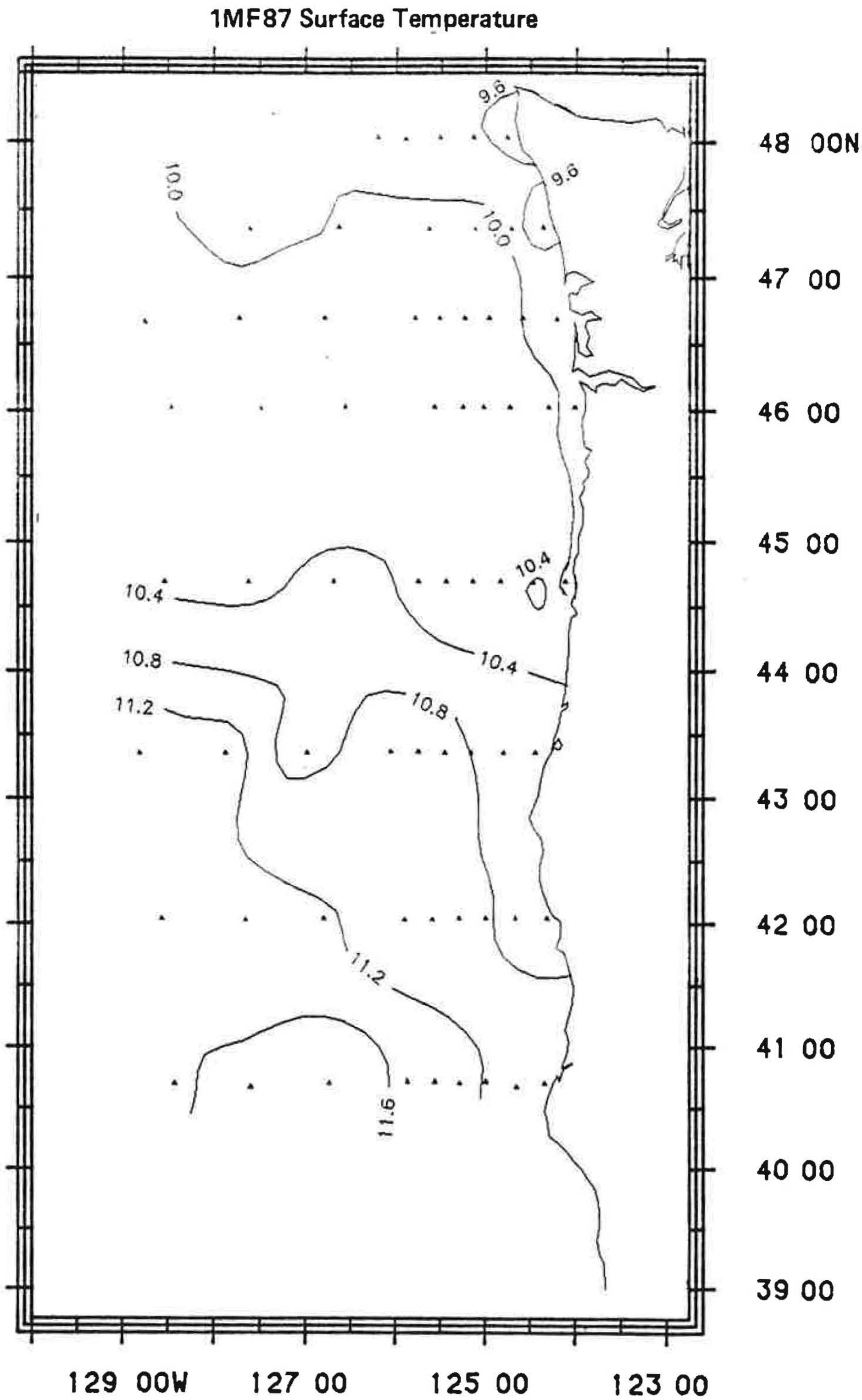

Figure 71.--Surface temperature contours (°C) for cruise 1MF87, January 7th-31st, 1987.

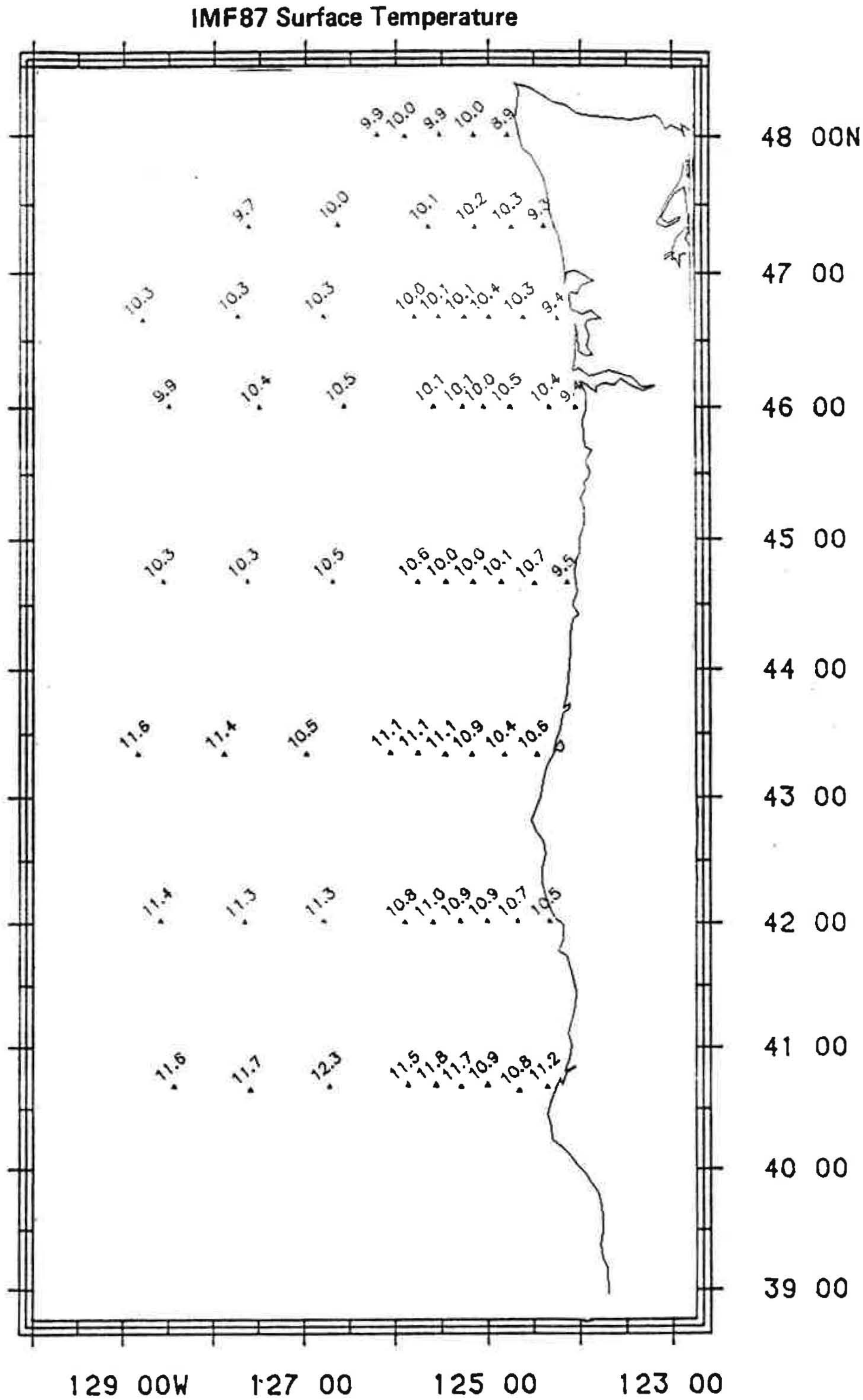

Figure 72.--Surface temperature values (°C) for cruise 1MF87, January 7th-31st, 1987.

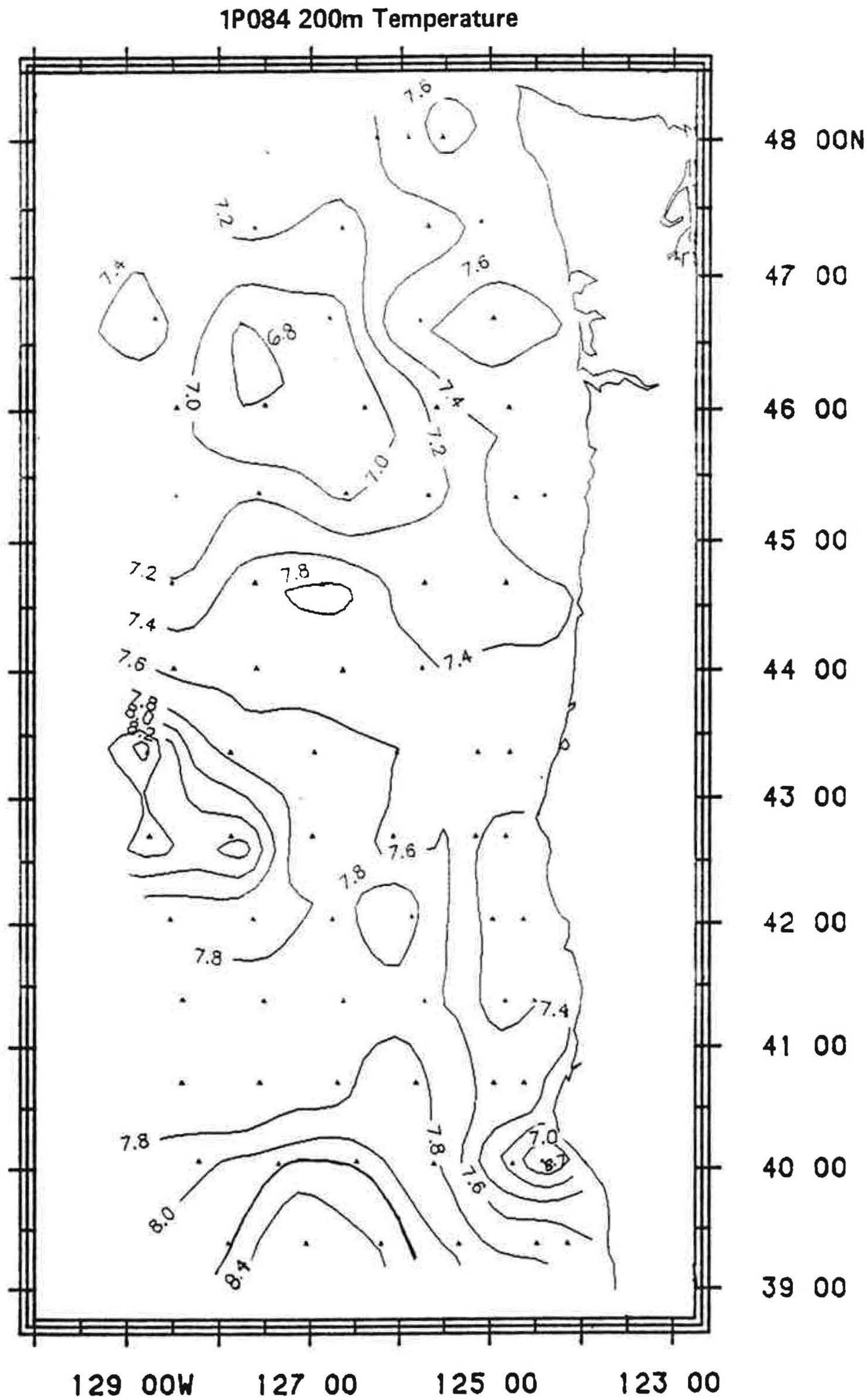

Figure 73.--200 meter temperature contours (°C) for cruise 1P084, March 11th-April 4th, 1984.

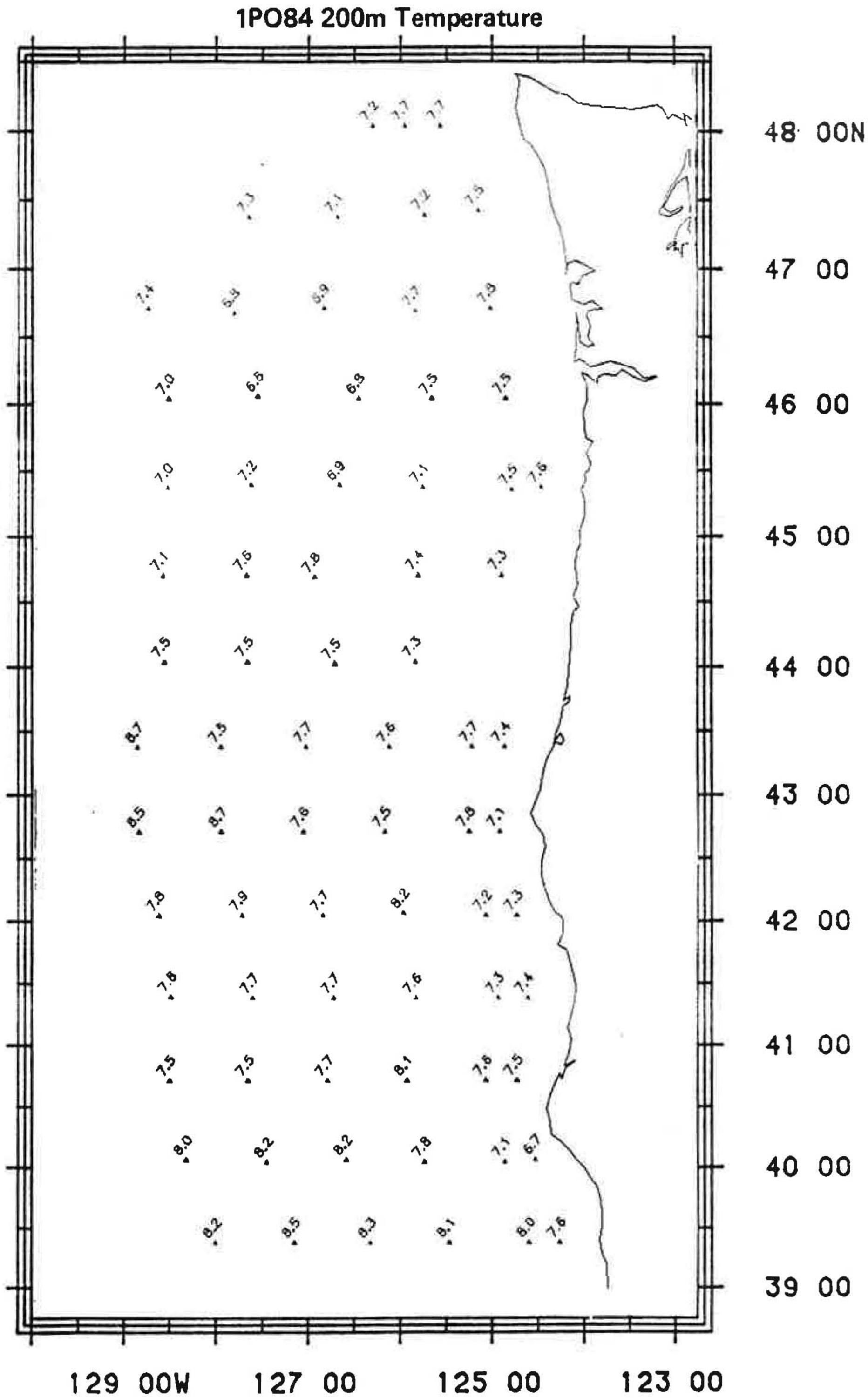

Figure 74.--200 meter temperature values (°C) for cruise 1PO84, March 11th-April 4th, 1984.

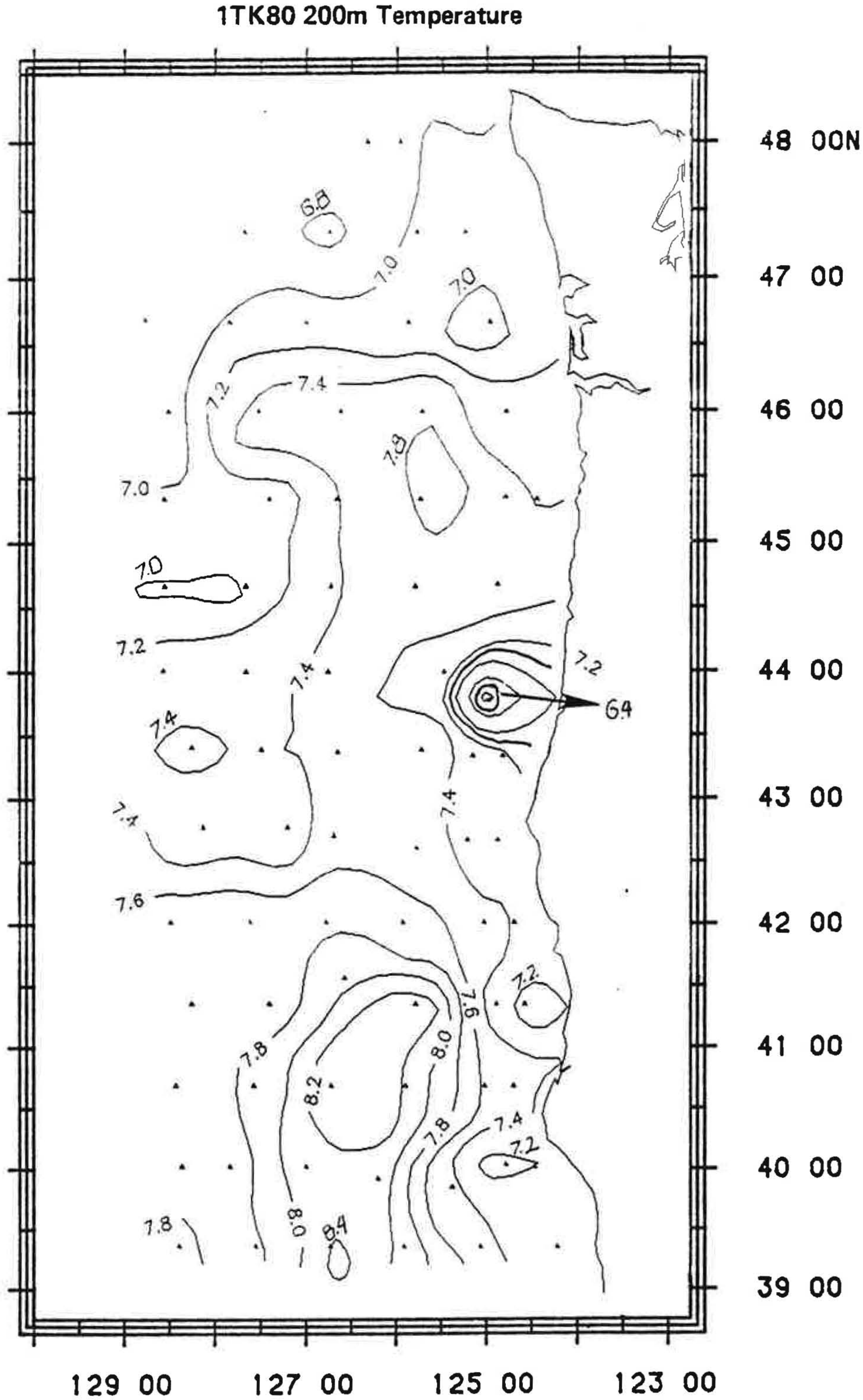

Figure 75.--200 meter temperature contours (°C) for cruise 1TK80, April 20th- May 15th, 1980.

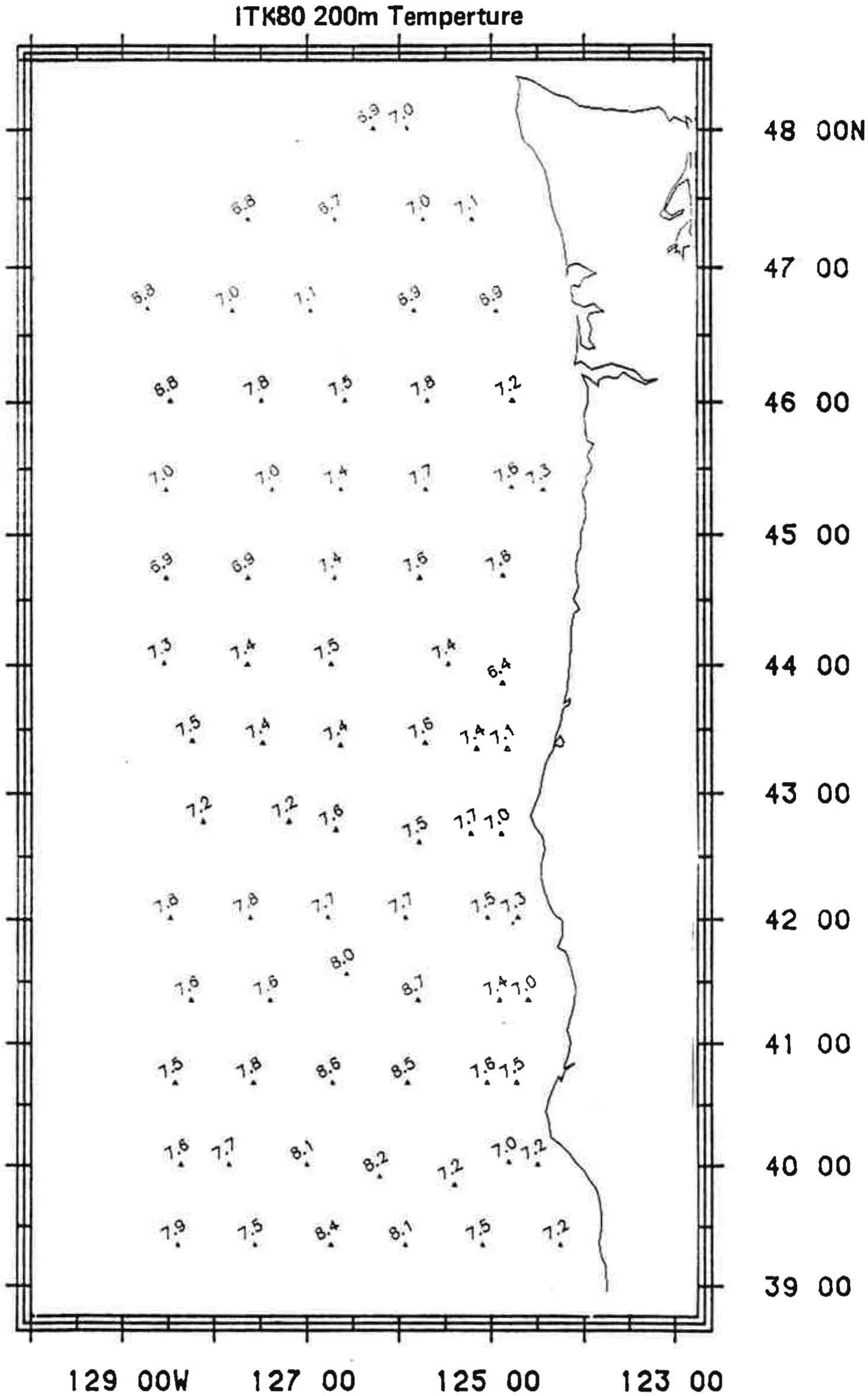

Figure 76.--200 meter temperature values (°C) for cruise 1TK80, April 20th- May 15th, 1980.

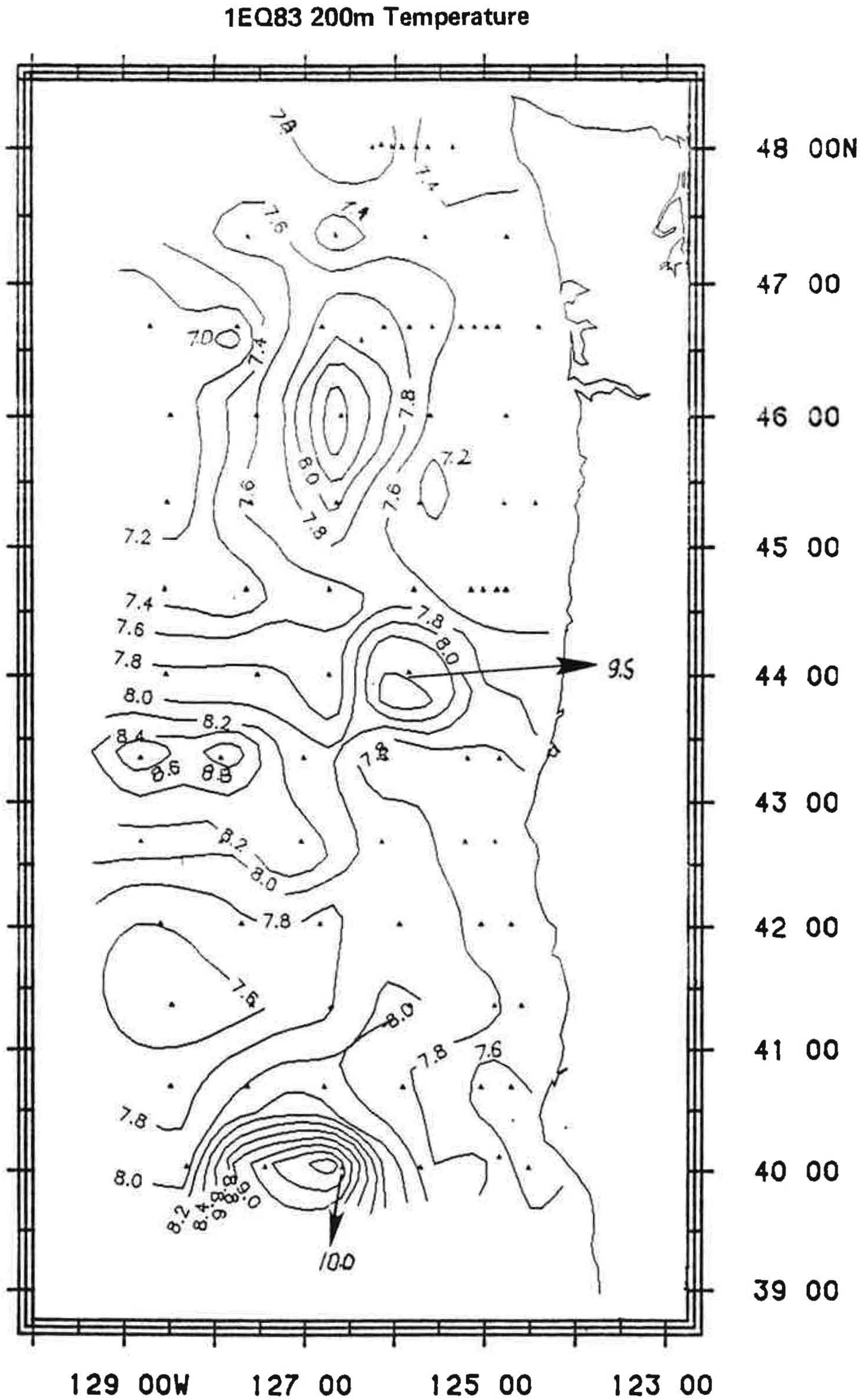

Figure 77.--200 meter temperature contours (°C) for cruise 1EQ83, April 23rd-May 15th, 1983.

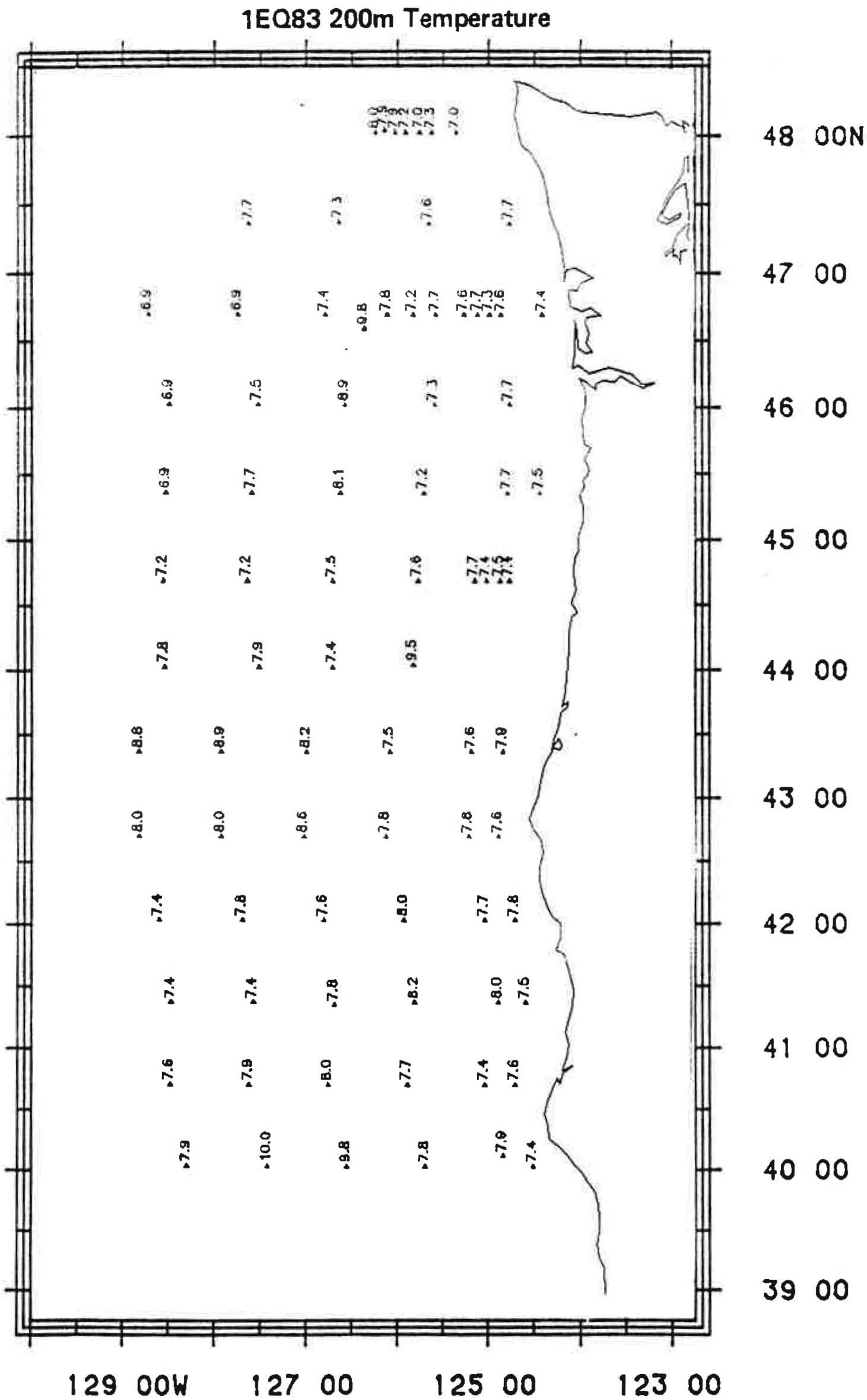

Figure 78.--200 meter temperature values (°C) for cruise 1EQ83, April 23rd-May 15th, 1983.

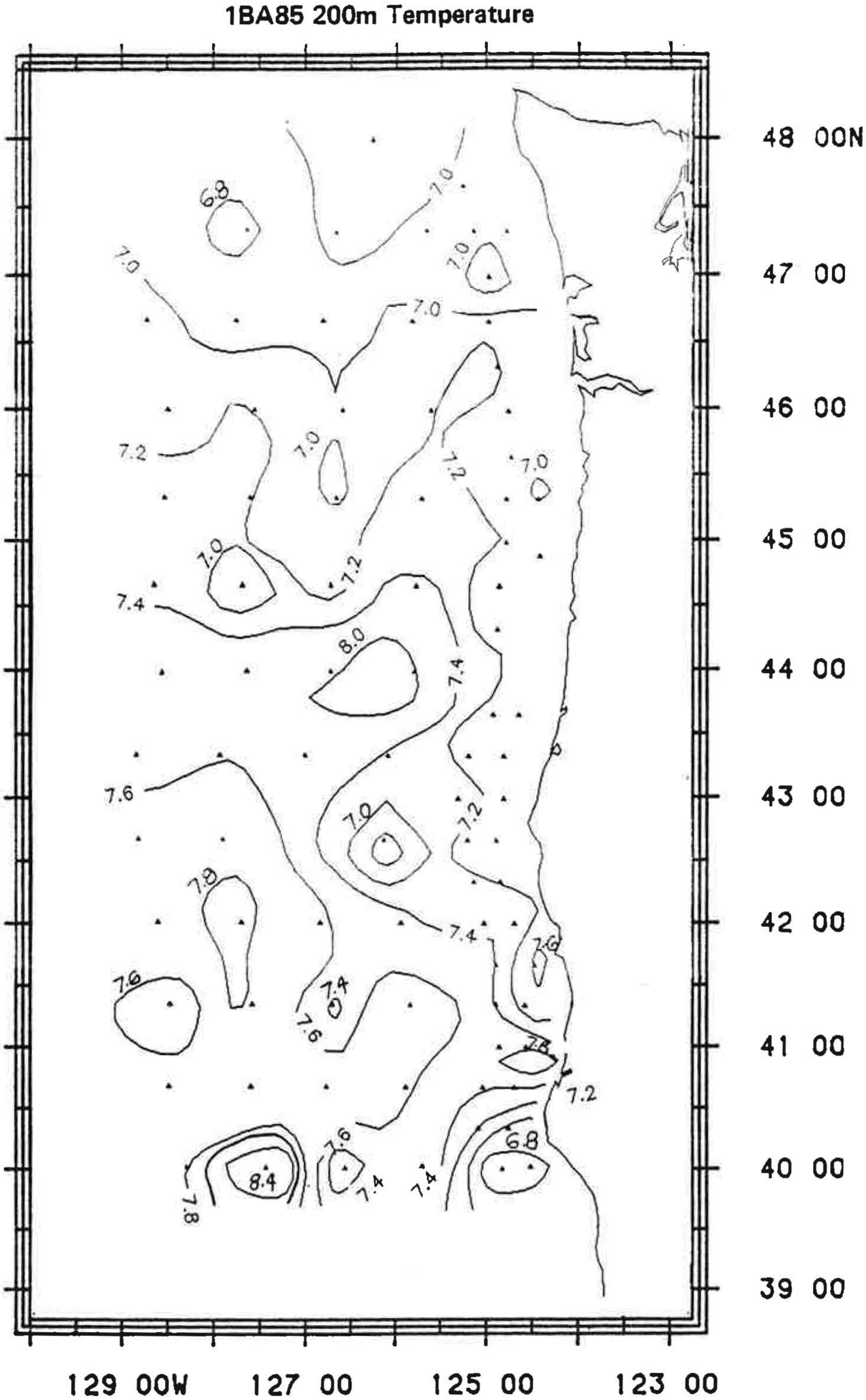

Figure 79.--200 meter temperature contours (°C) for cruise 1BA85, April 19th-May 11th, 1985.

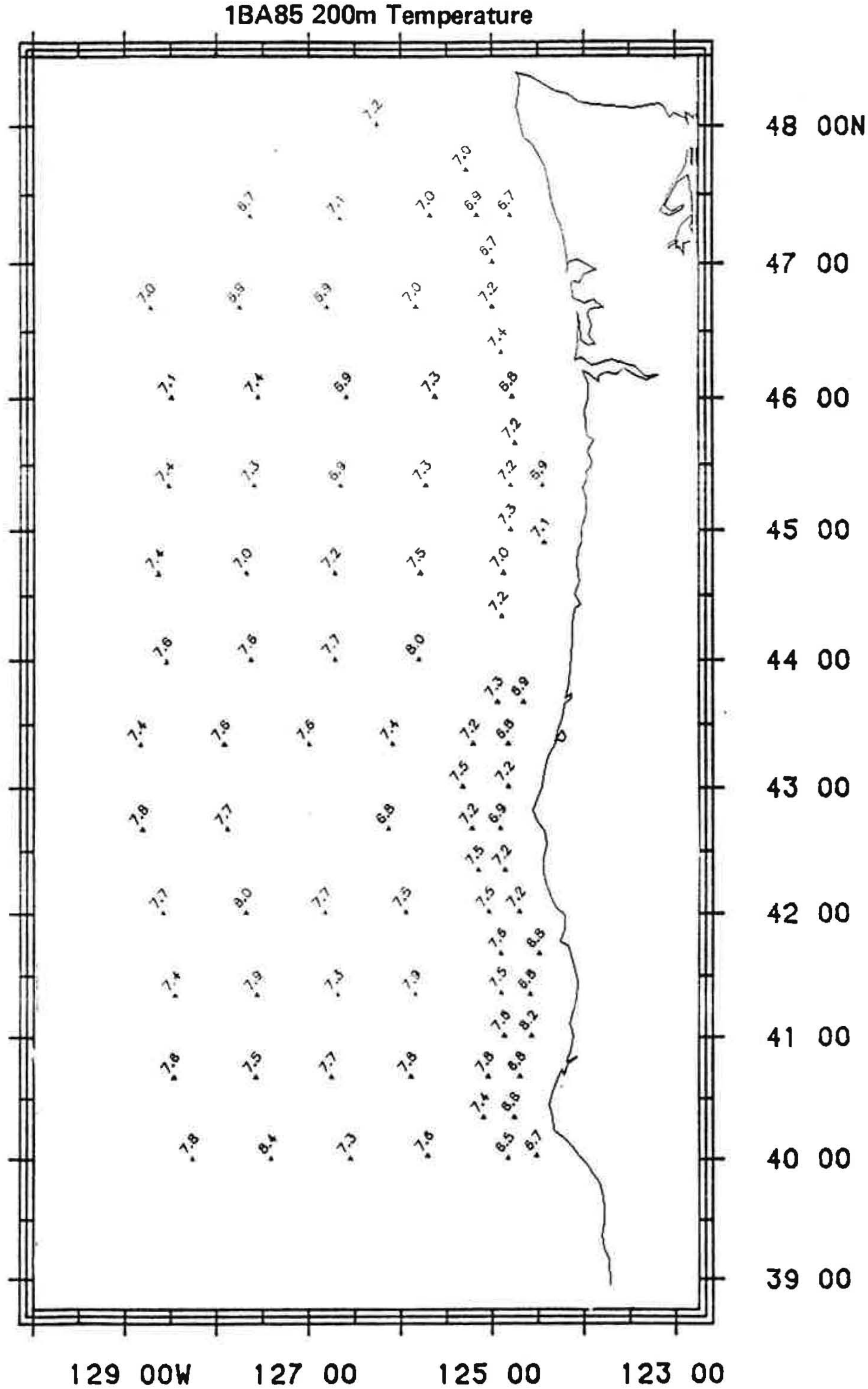

Figure 80.--200 meter temperature values (°C) for cruise 1BA85, April 19th-May 11th, 1985.

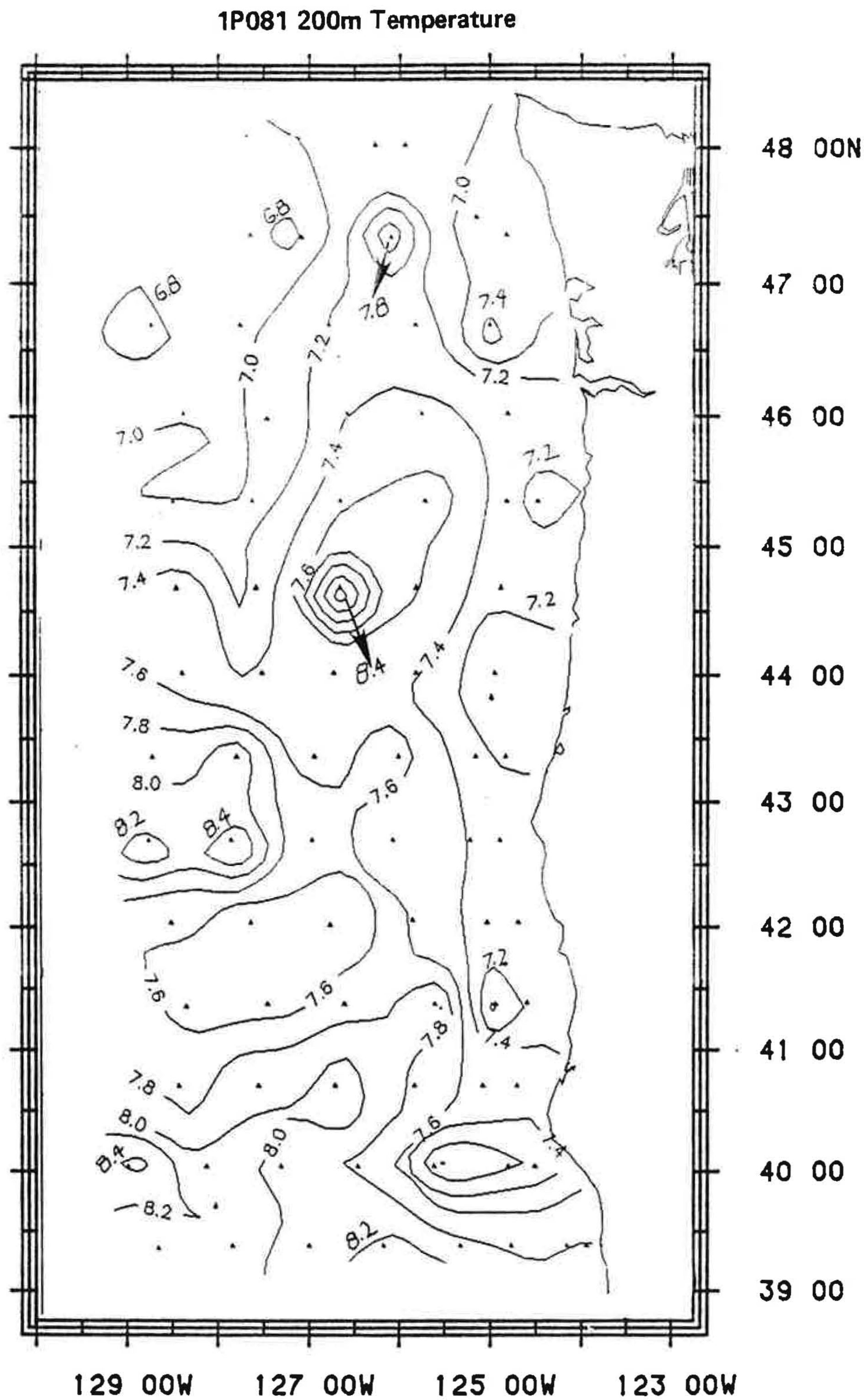

Figure 81.--200 meter temperature contours (°C) for cruise 1P081, May 9th-June 2nd, 1981.

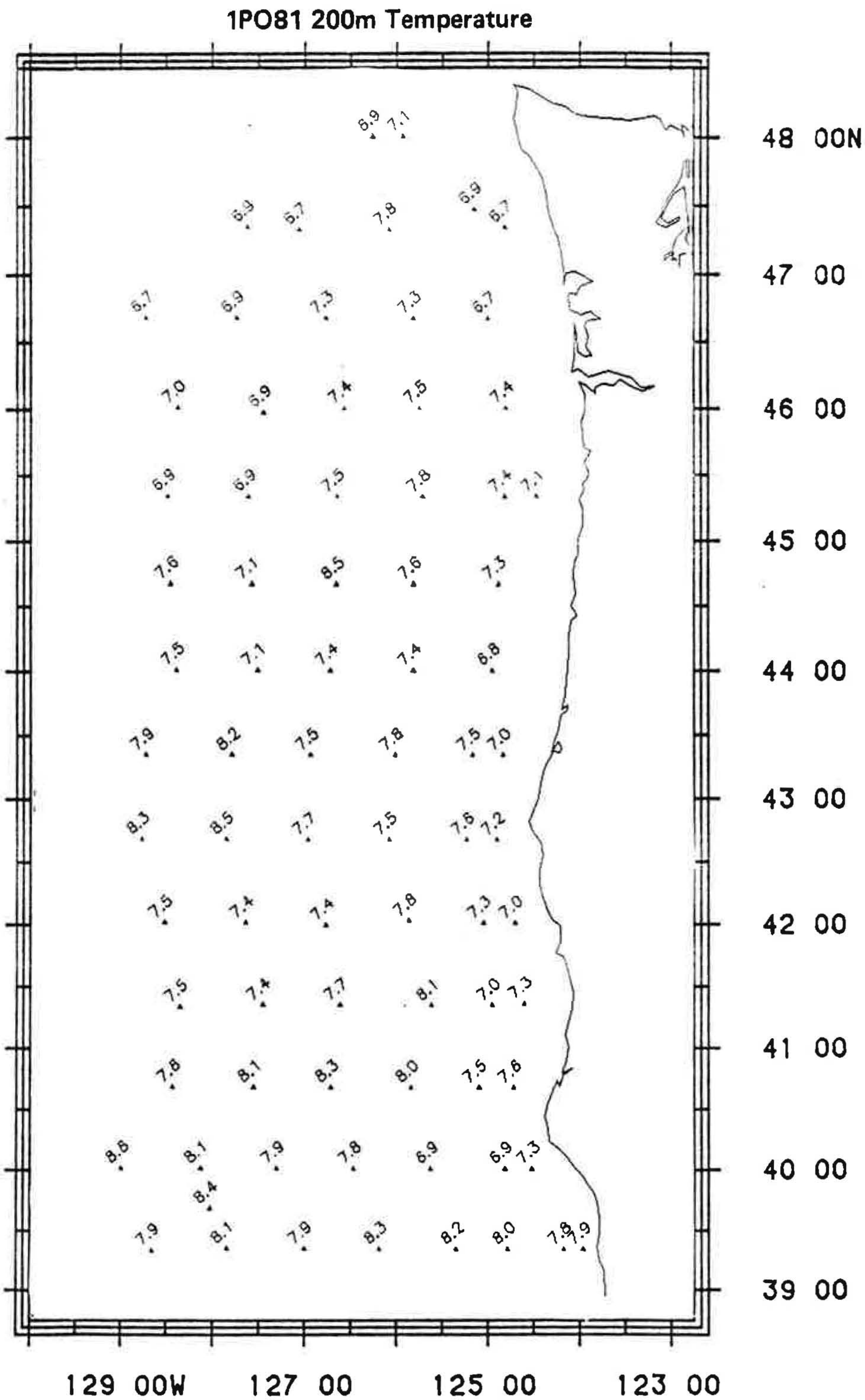

Figure 82.--200 meter temperature values (°C) for cruise 1PO81, May 9th-June 2nd, 1981.

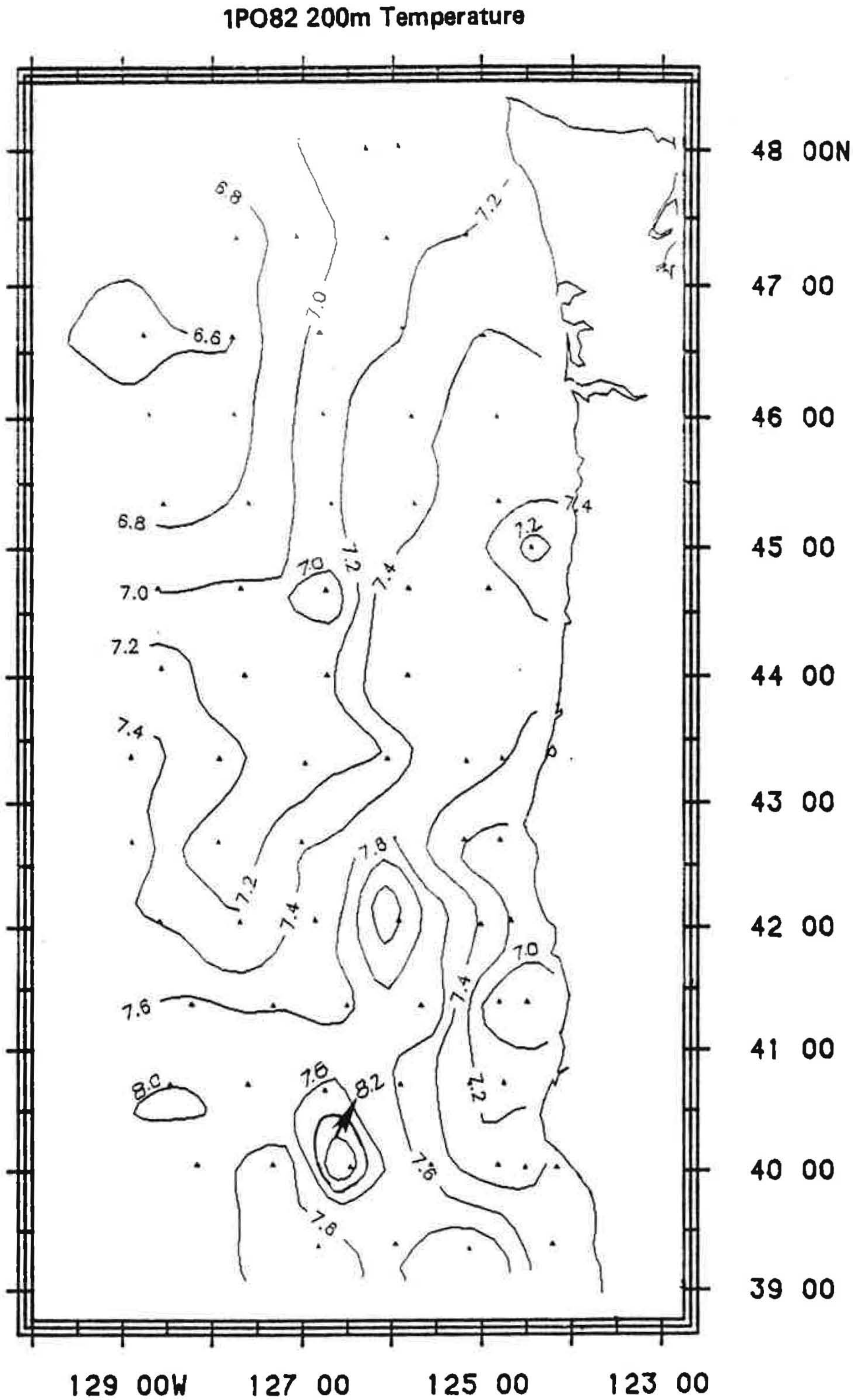

Figure 83.--200 meter temperature contours (°C) for cruise 1PO82, May 3rd-June 1st, 1982.

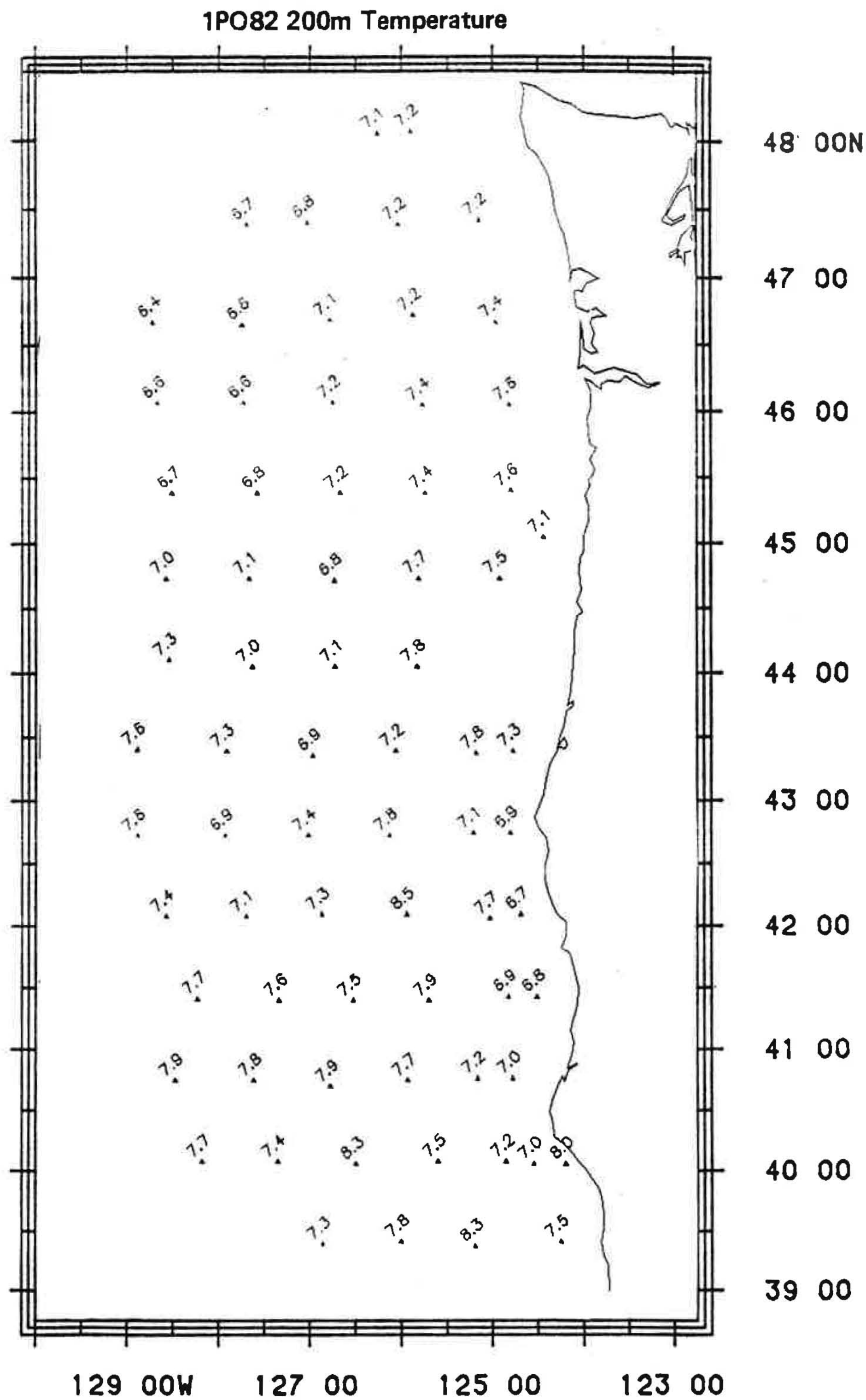

Figure 84.--200 meter temperature values (°C) for cruise 1PO82, May 3rd-June 1st, 1982.

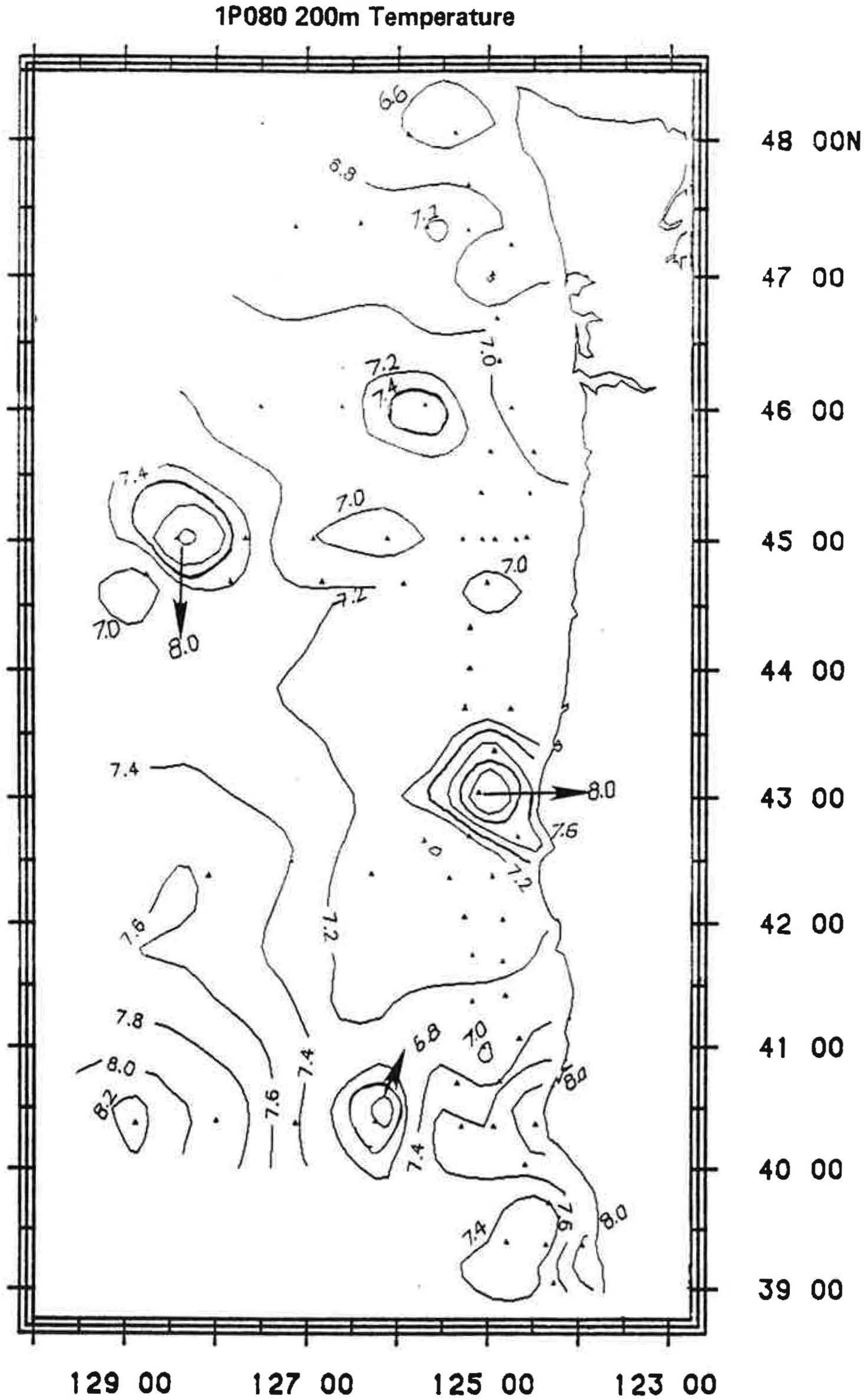

Figure 85.--200 meter temperature contours (°C) for cruise 1P080, August 1st-20th, 1980.

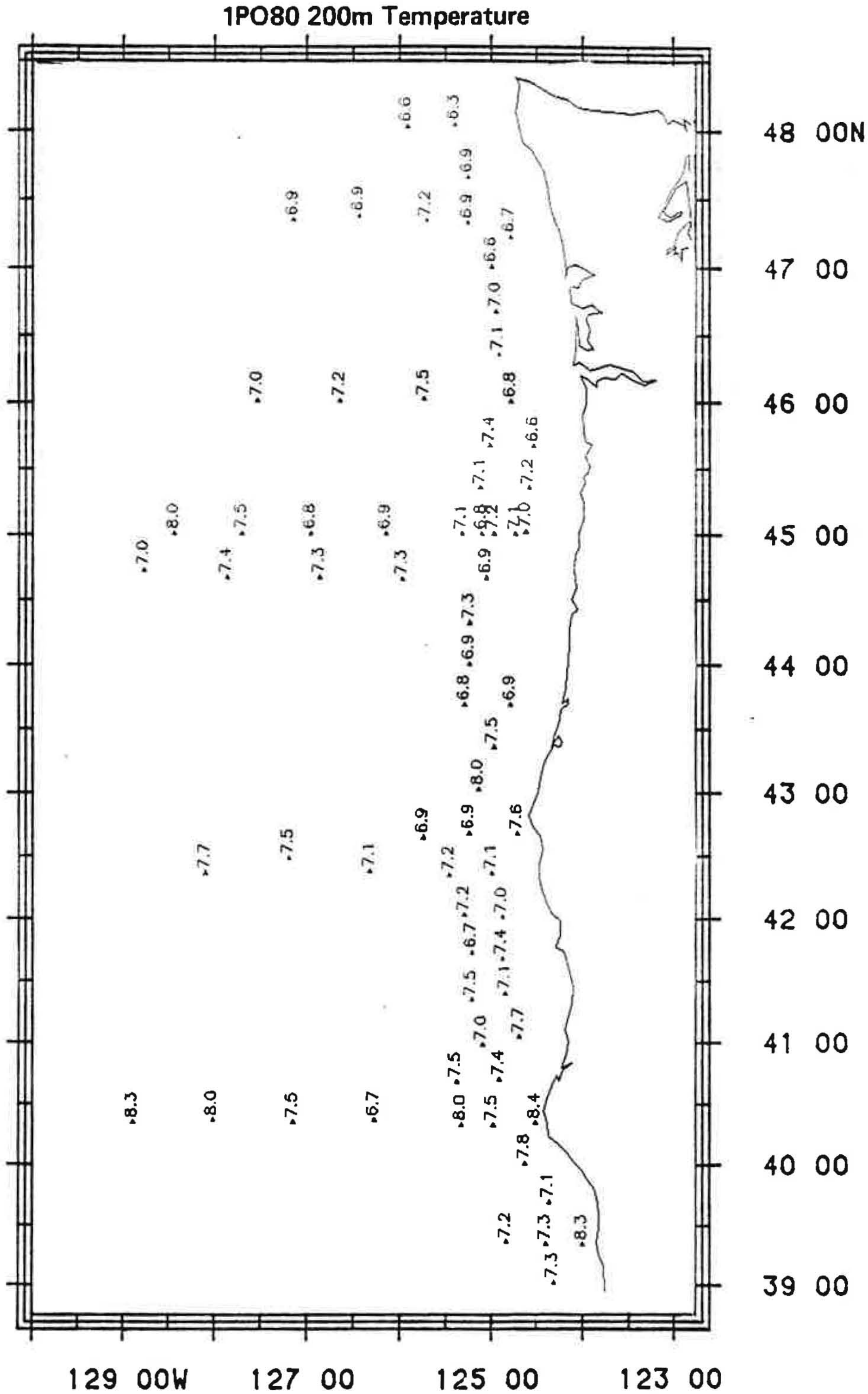

Figure 86.--200 meter temperature values (°C) for cruise 1PO80, August 1st-20th, 1980.

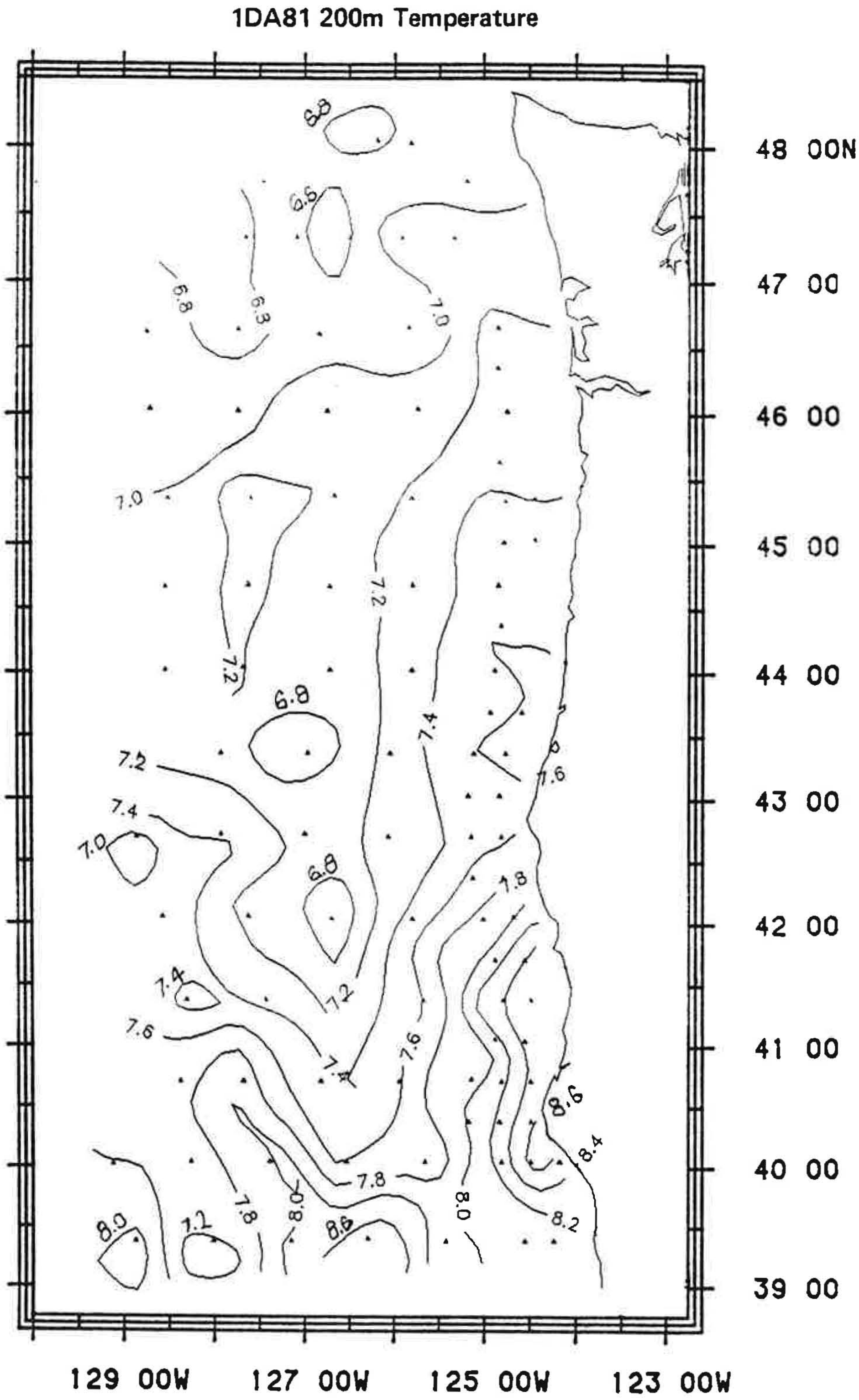

Figure 87.--200 meter temperature contours (°C) for cruise 1DA81, October 24th-November 19th, 1981.

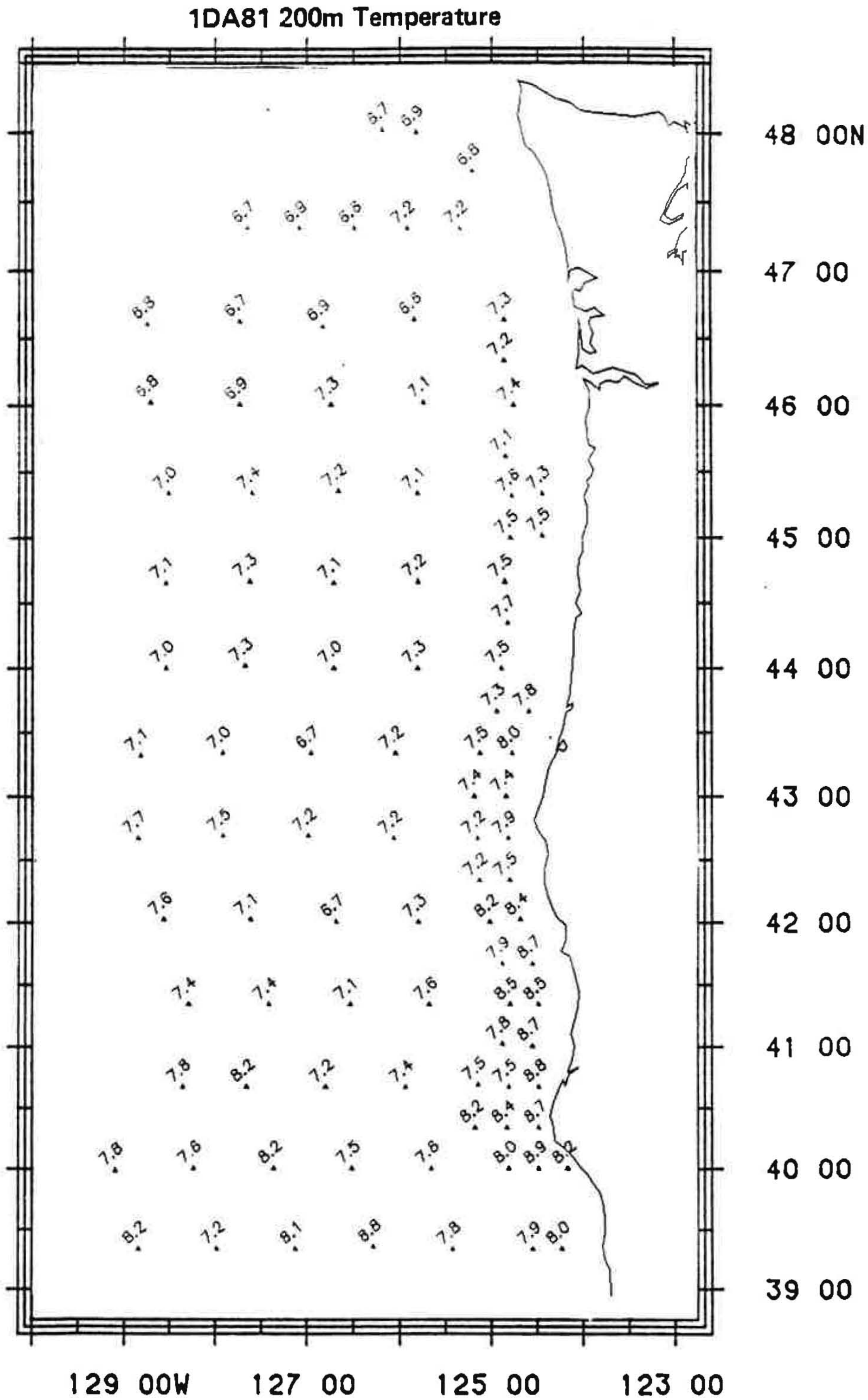

Figure 88.--200 meter temperature values (°C) for cruise 1DA81, October 24th-November 19th, 1981.

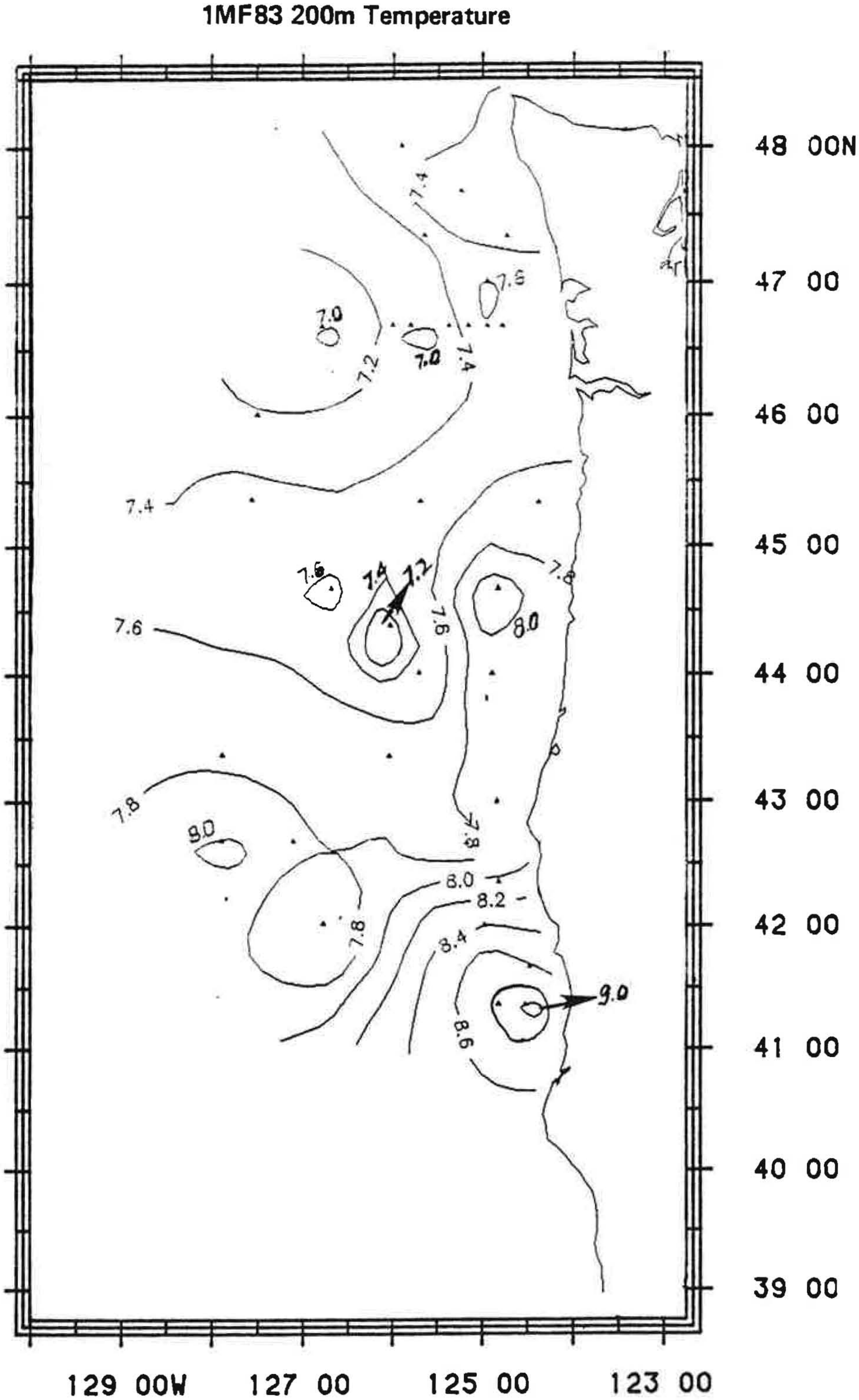

Figure 89.--200 meter temperature contours (°C) for cruise 1MF83, November 11th-December 2nd, 1983.

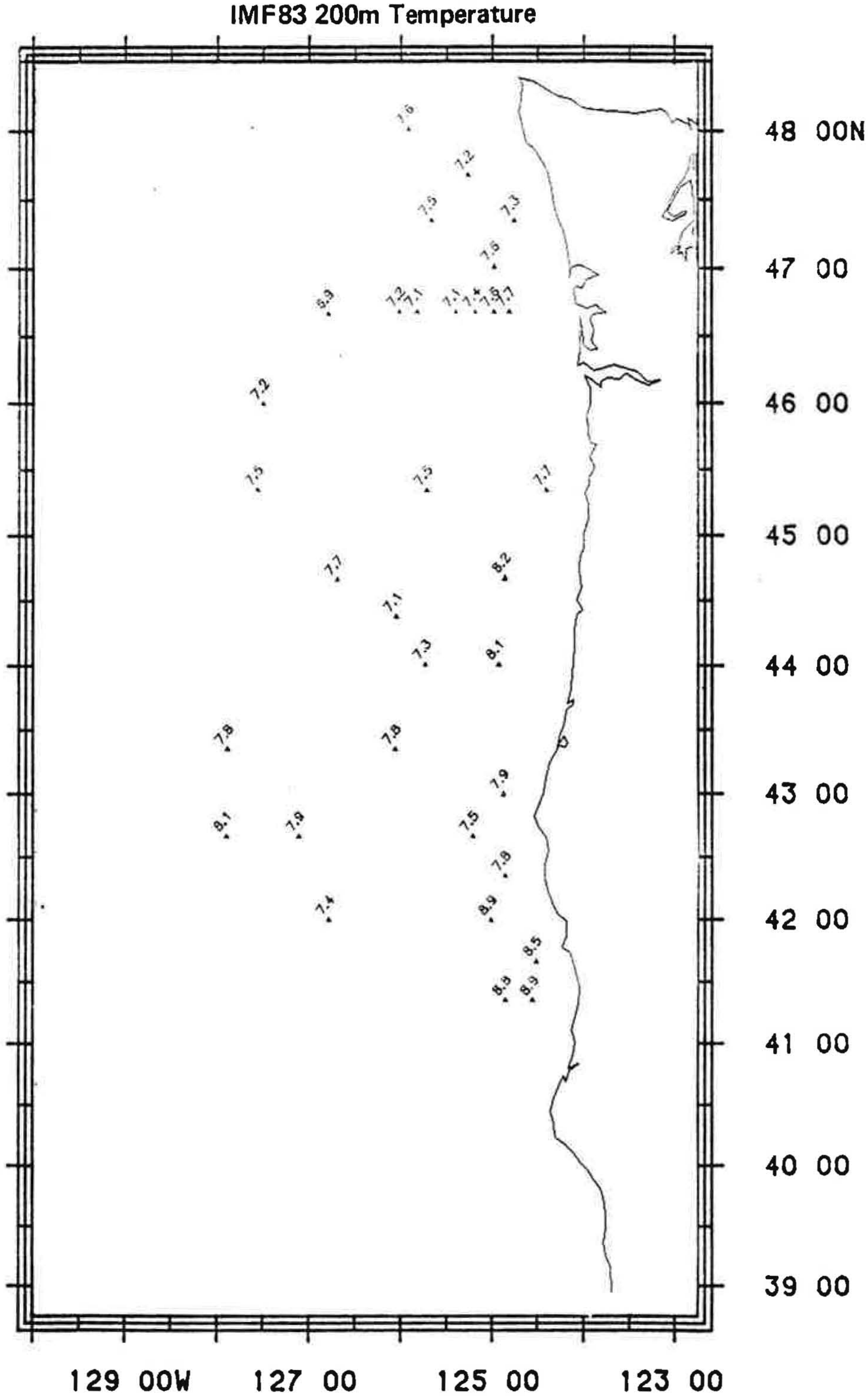

Figure 90.--200 meter temperature values (°C) for cruise 1MF83, November 11th-December 2nd, 1983.

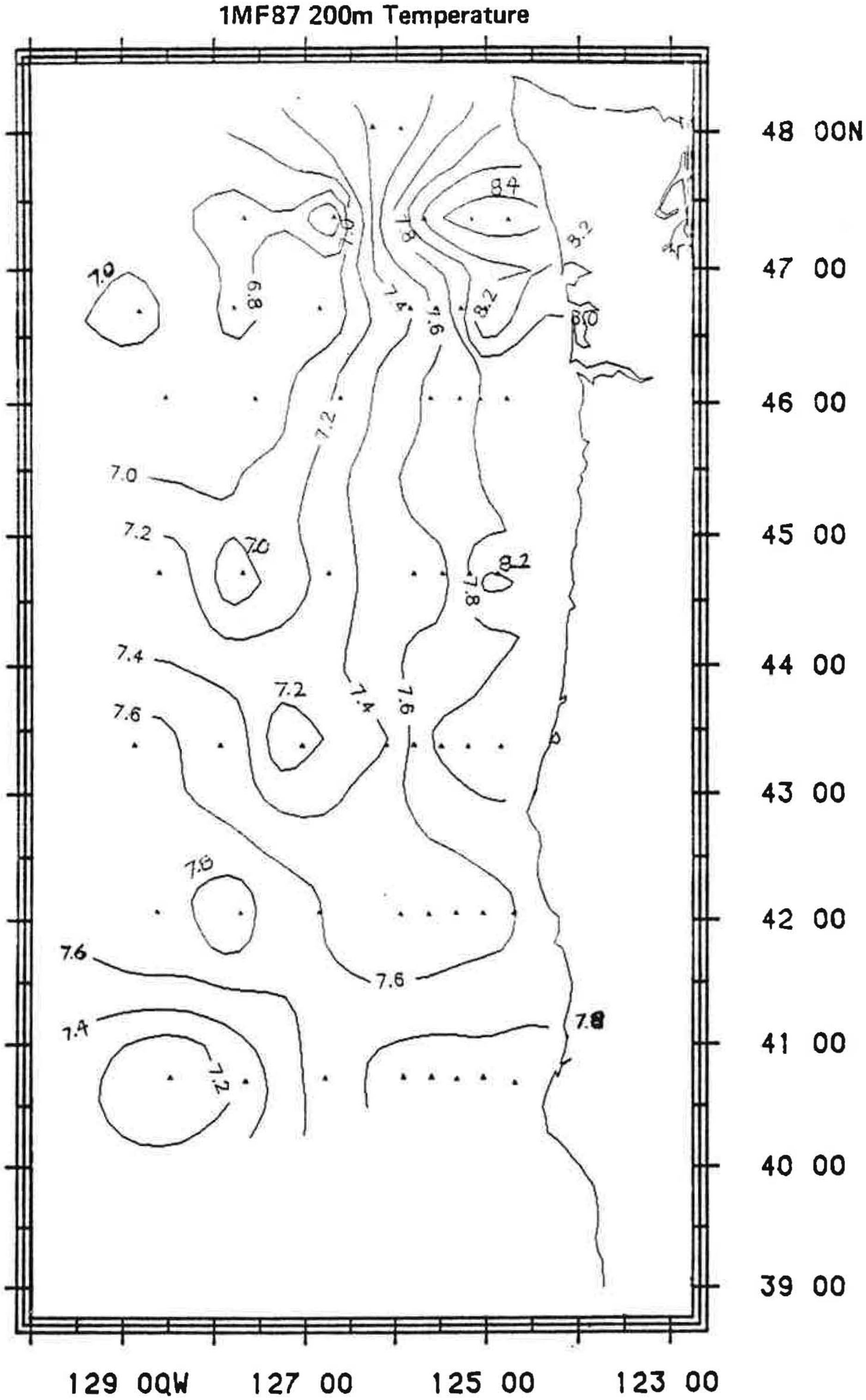

Figure 91.--200 meter temperature contours (°C) for cruise 1MF87, January 7th-31st, 1987.

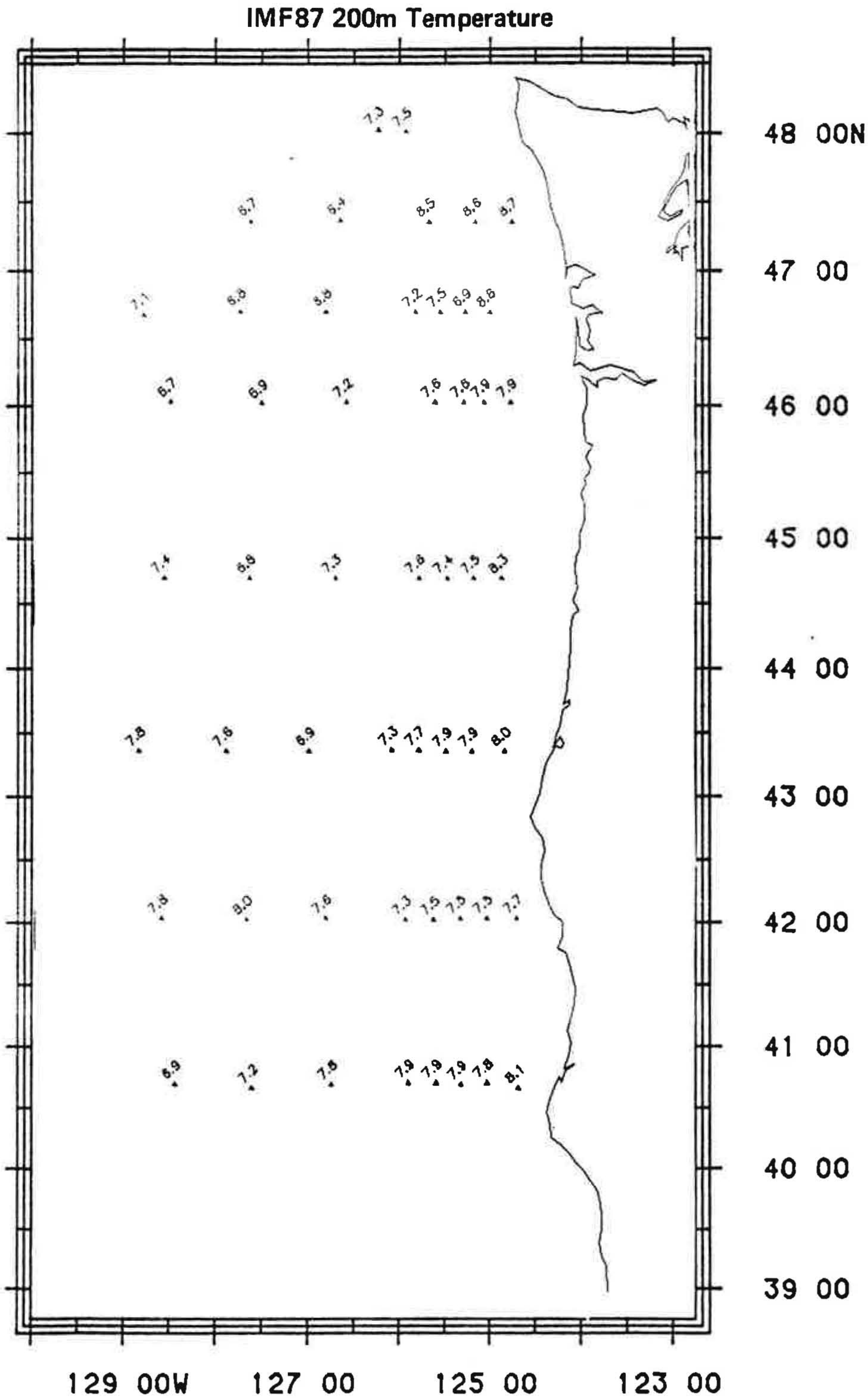

Figure 92.--200 meter temperature values (°C) for cruise 1MF87, January 7th-31st, 1987.

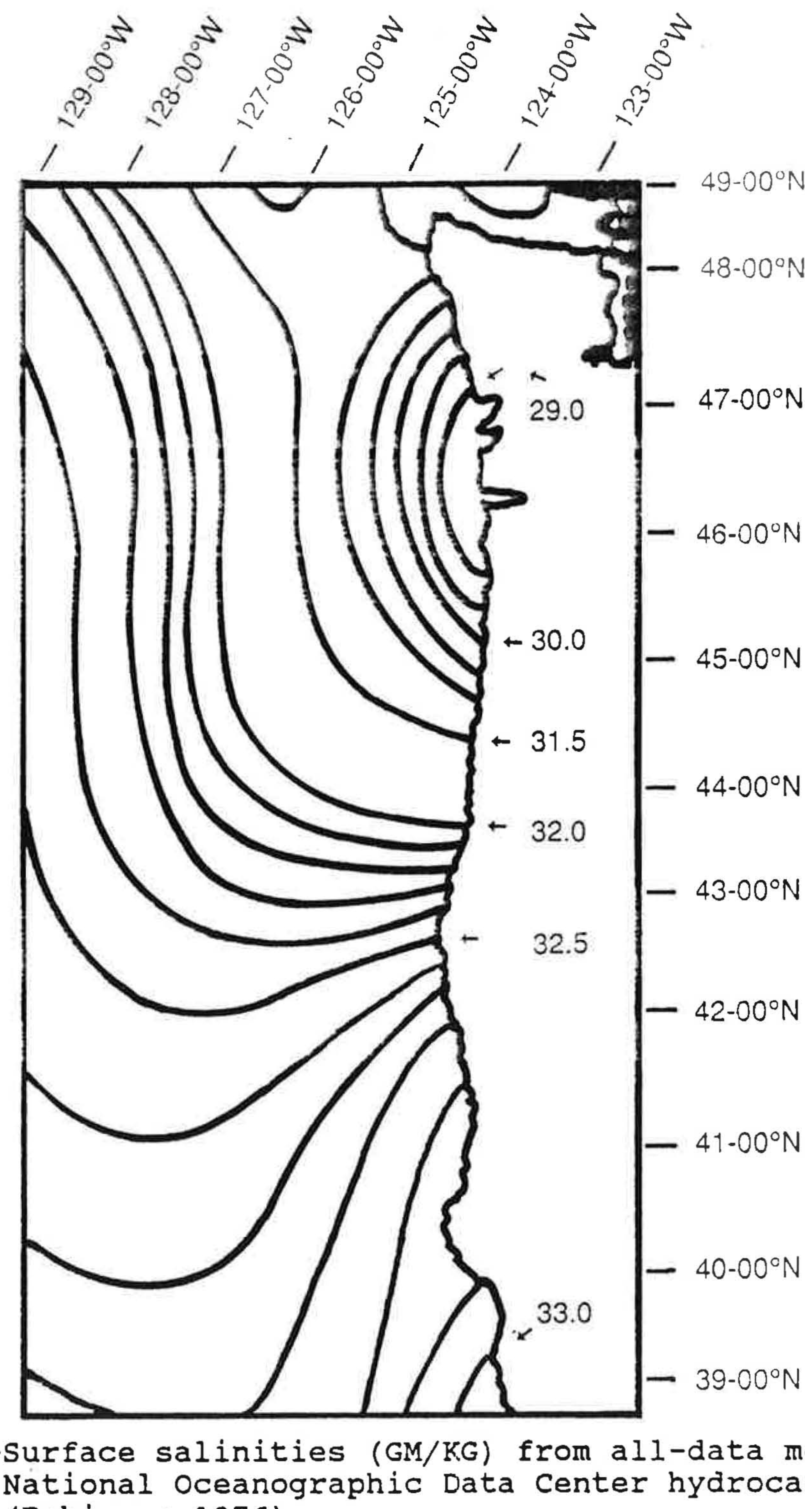

Figure 93.--Surface salinities (GM/KG) from all-data means, 1969 National Oceanographic Data Center hydrocast tapes (Robinson 1976).

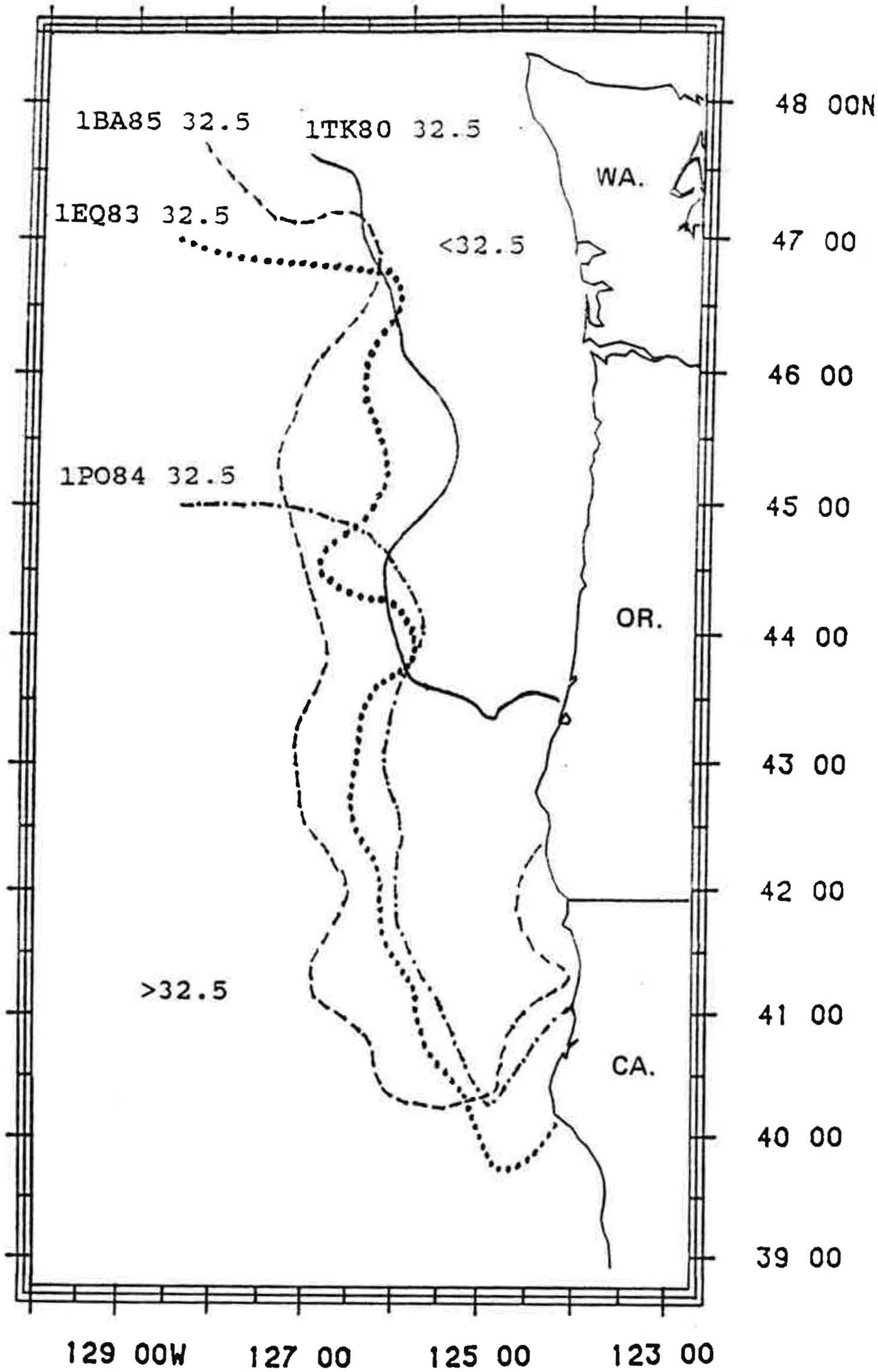

Figure 94.--Surface salinity comparisons (32.5 GM/KG contour) for spring cruises 1TK80 (April-May 1980), 1EQ83 (April-May 1983), 1BA85 (April-May 1985), and 1PO84 (March-April 1984).

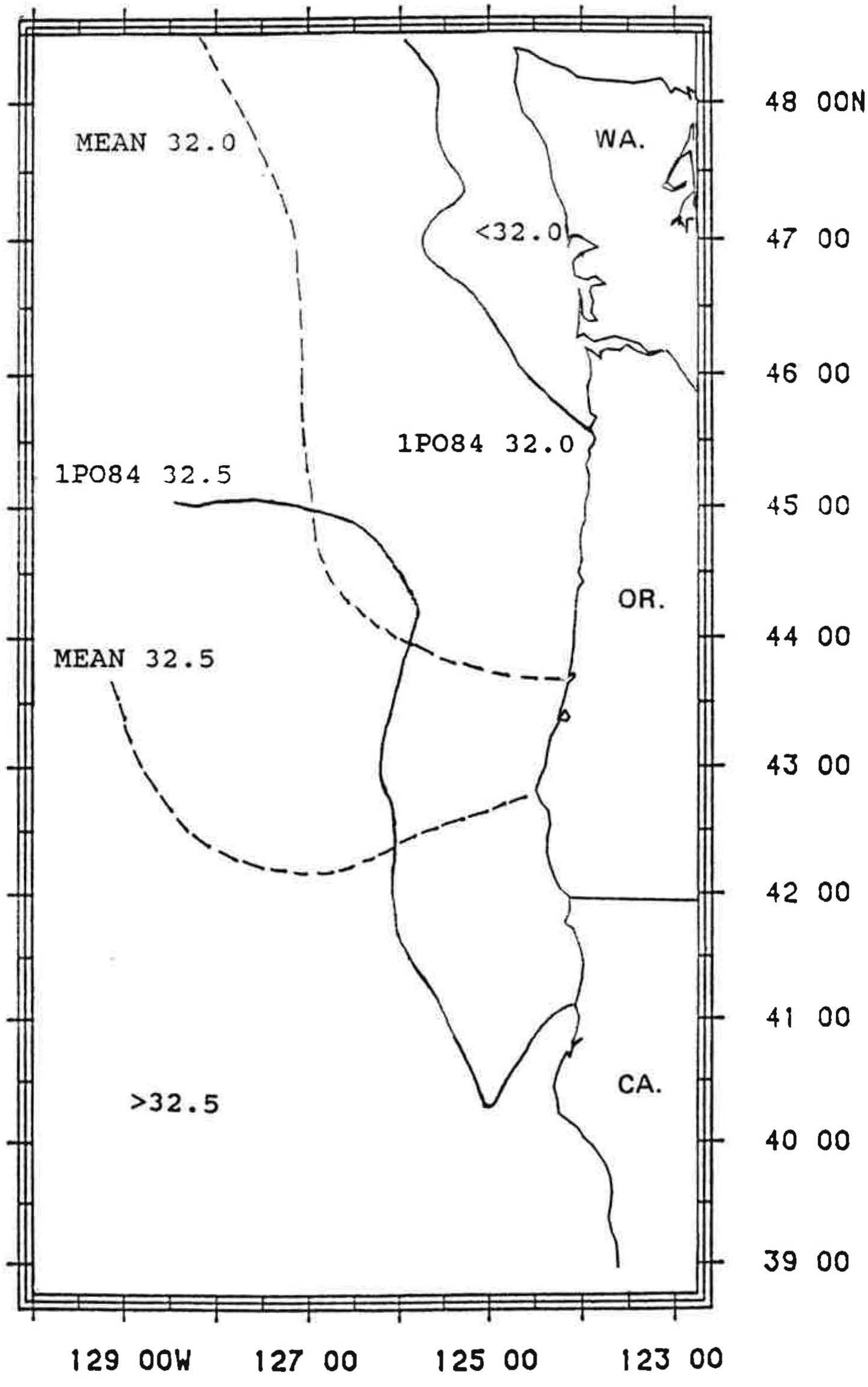

Figure 95.--Surface salinity comparisons (32.0 GM/KG and 32.5 GM/KG contours) for cruise 1PO84 (March-April 1984) and all-data means (Robinson 1976).

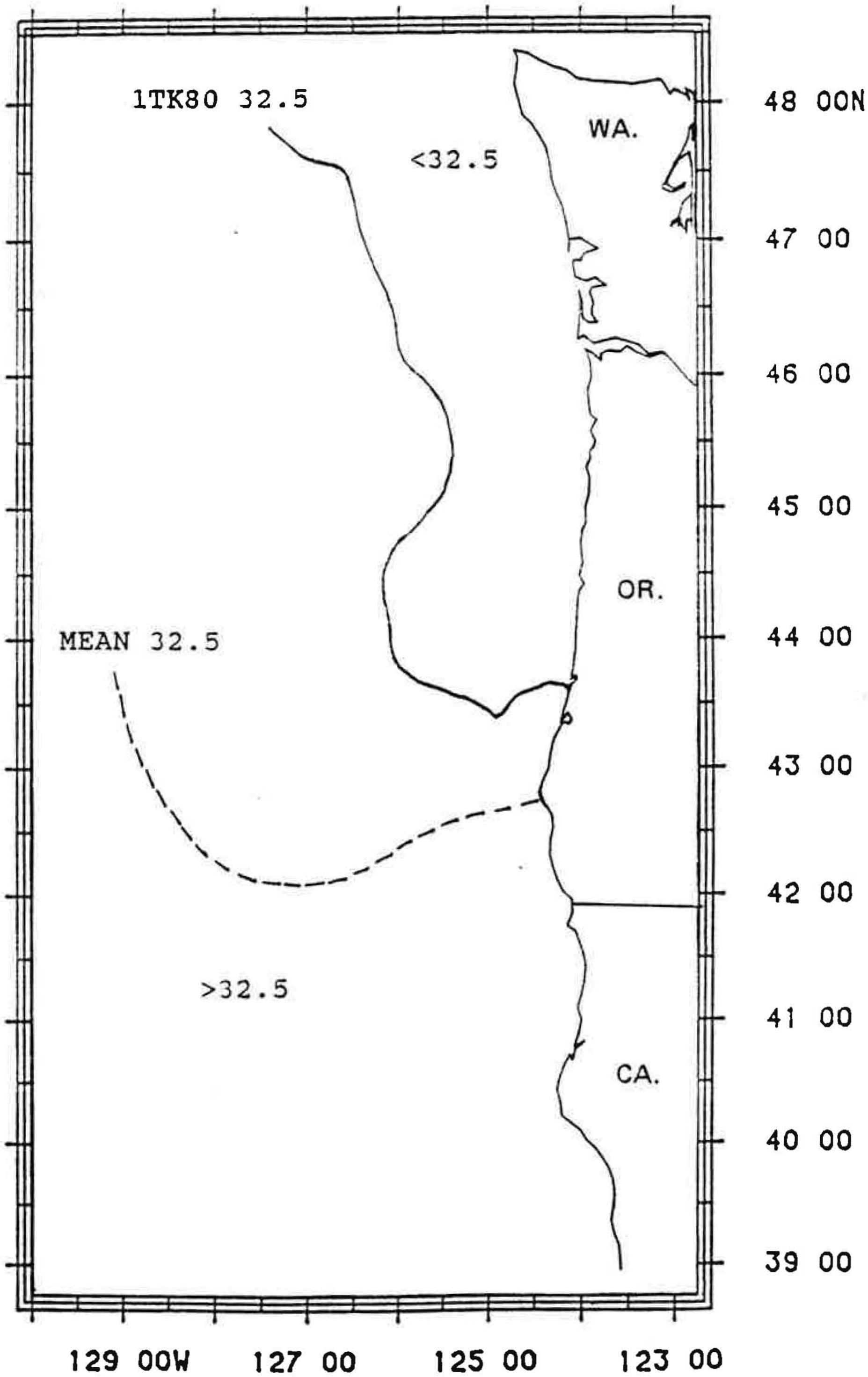

Figure 96.--Surface salinity comparisons (32.5 GM/KG contour) for cruise 1TK80 (April-May 1980) and all-data means (Robinson 1976).

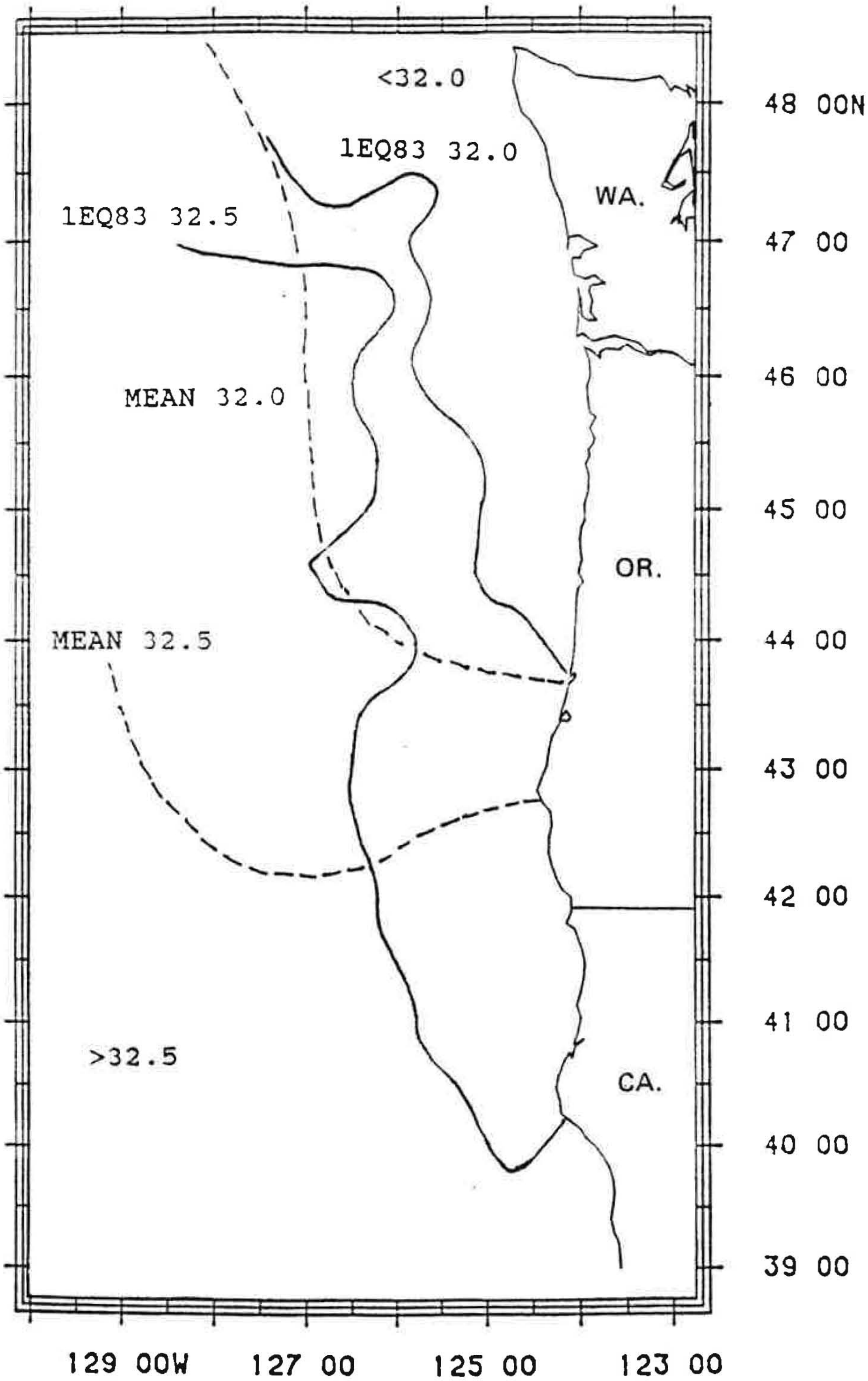

Figure 97.--Surface salinity comparisons (32.0 GM/KG and 32.5 GM/KG contours) for cruise 1EQ83 (April-May 1983) and all-data means (Robinson 1976).

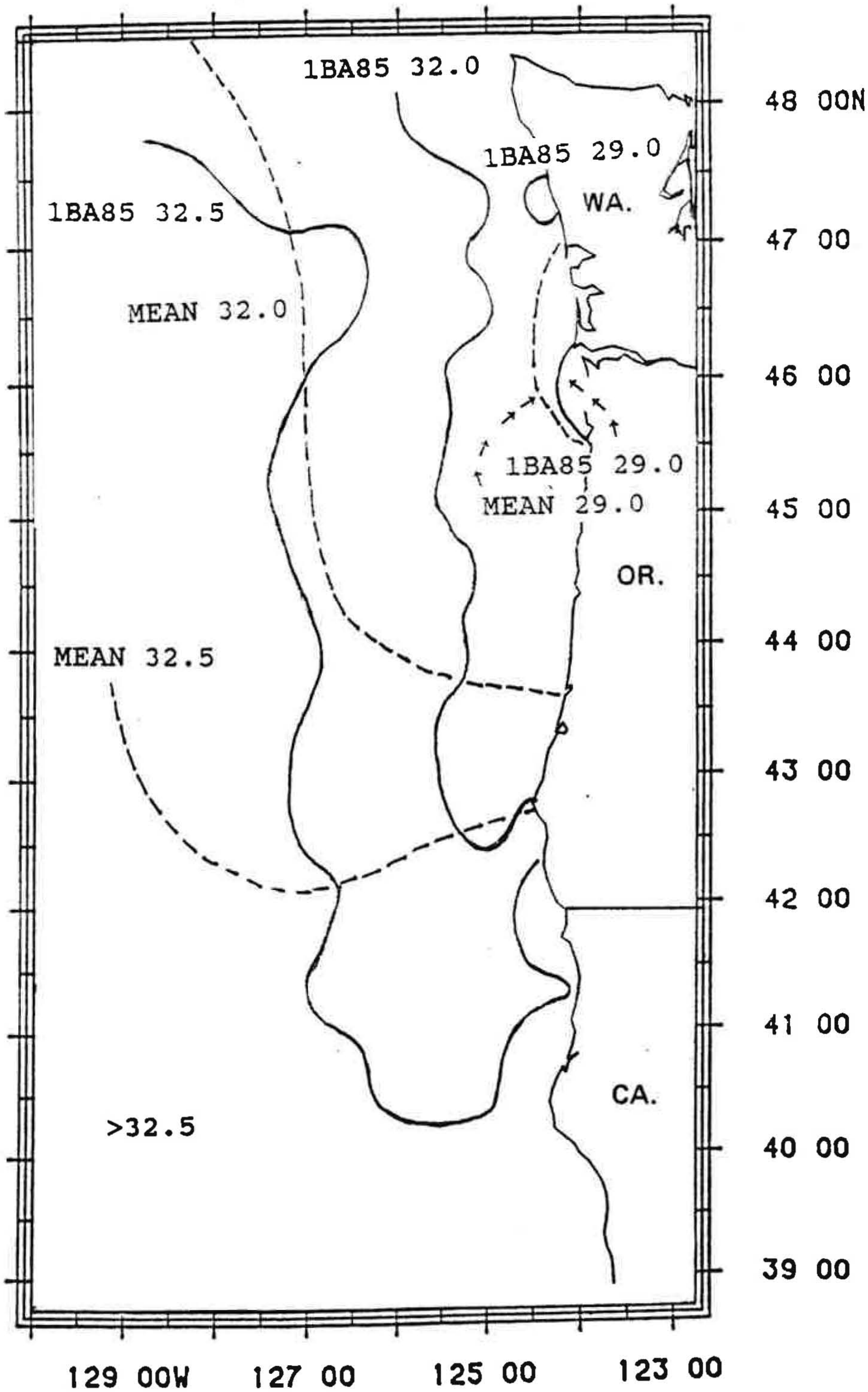

Figure 98.--Surface salinity comparisons (29.0 GM/KG, 32.0 GM/KG, and 32.5 GM/KG contours) for cruise 1BA85 (April-May 1985) and all-data means (Robinson 1976).

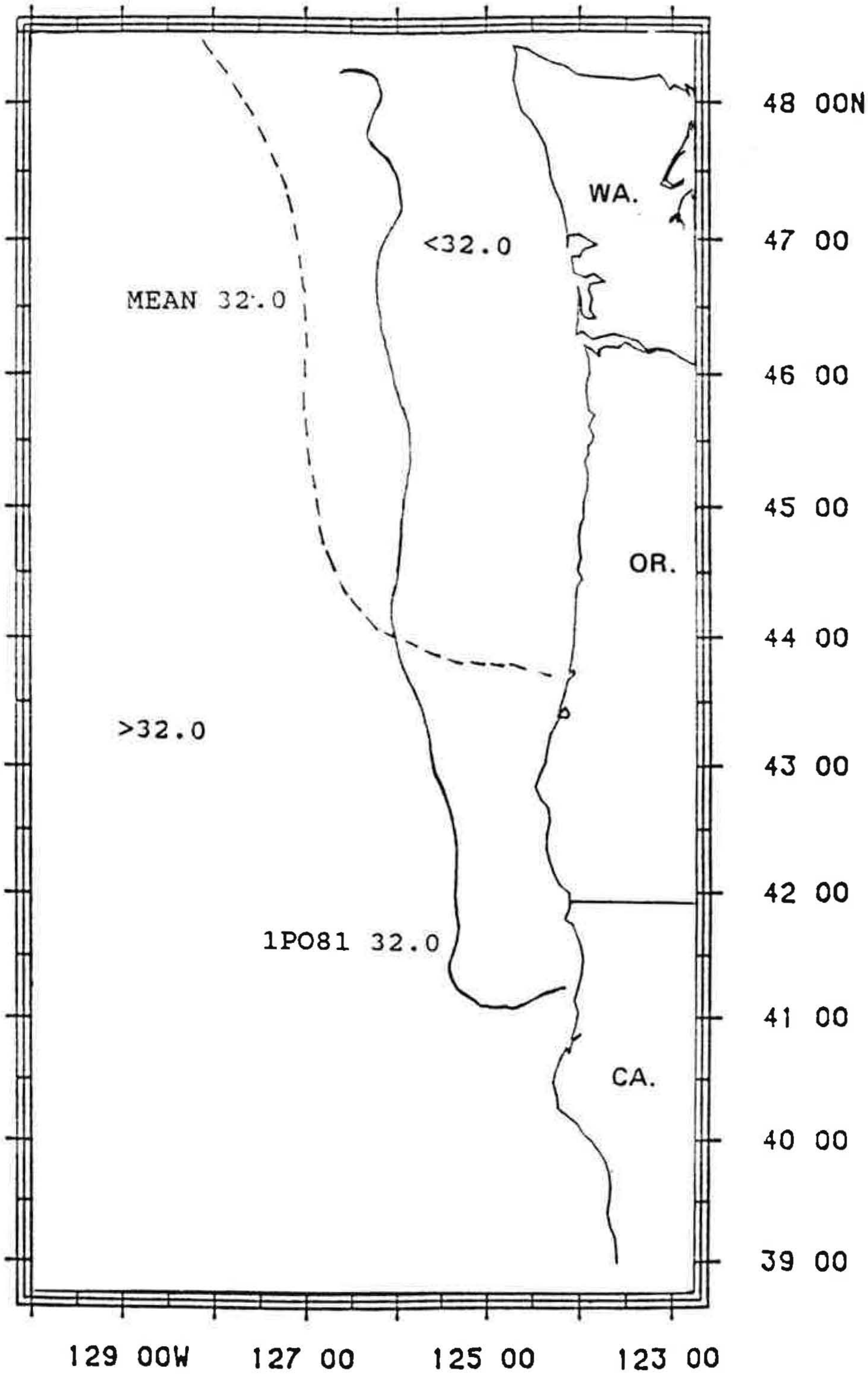

Figure 99.--Surface salinity comparisons (32.0 GM/KG contour) for cruise 1PO81 (May 1981) and all-data means (Robinson 1976).

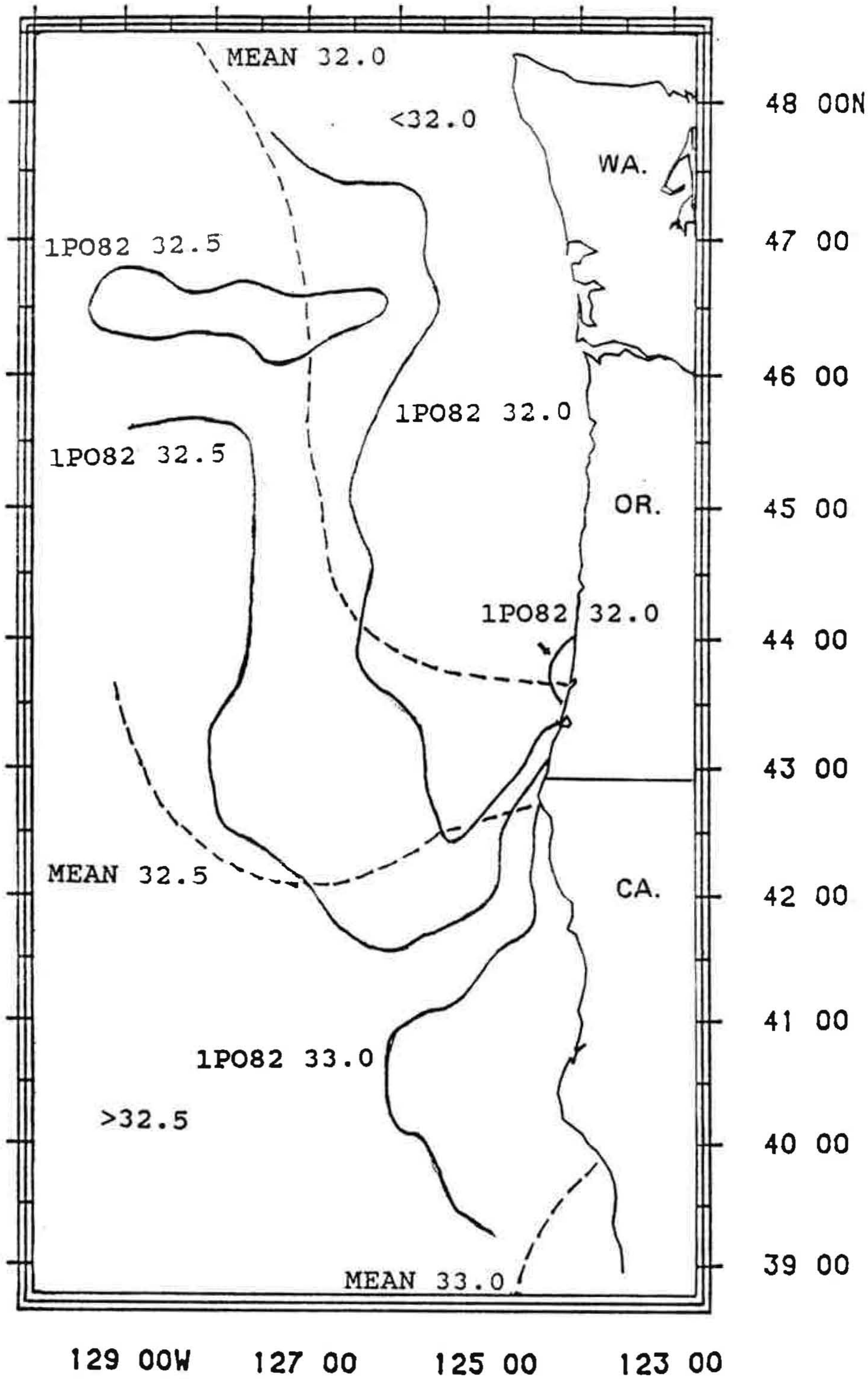

Figure 100.--Surface salinity comparisons (32.0 GM/KG, 32.5 GM/KG, and 33.0 GM/KG contours) for cruise 1PO82 (May 1982) and all-data means (Robinson 1976).

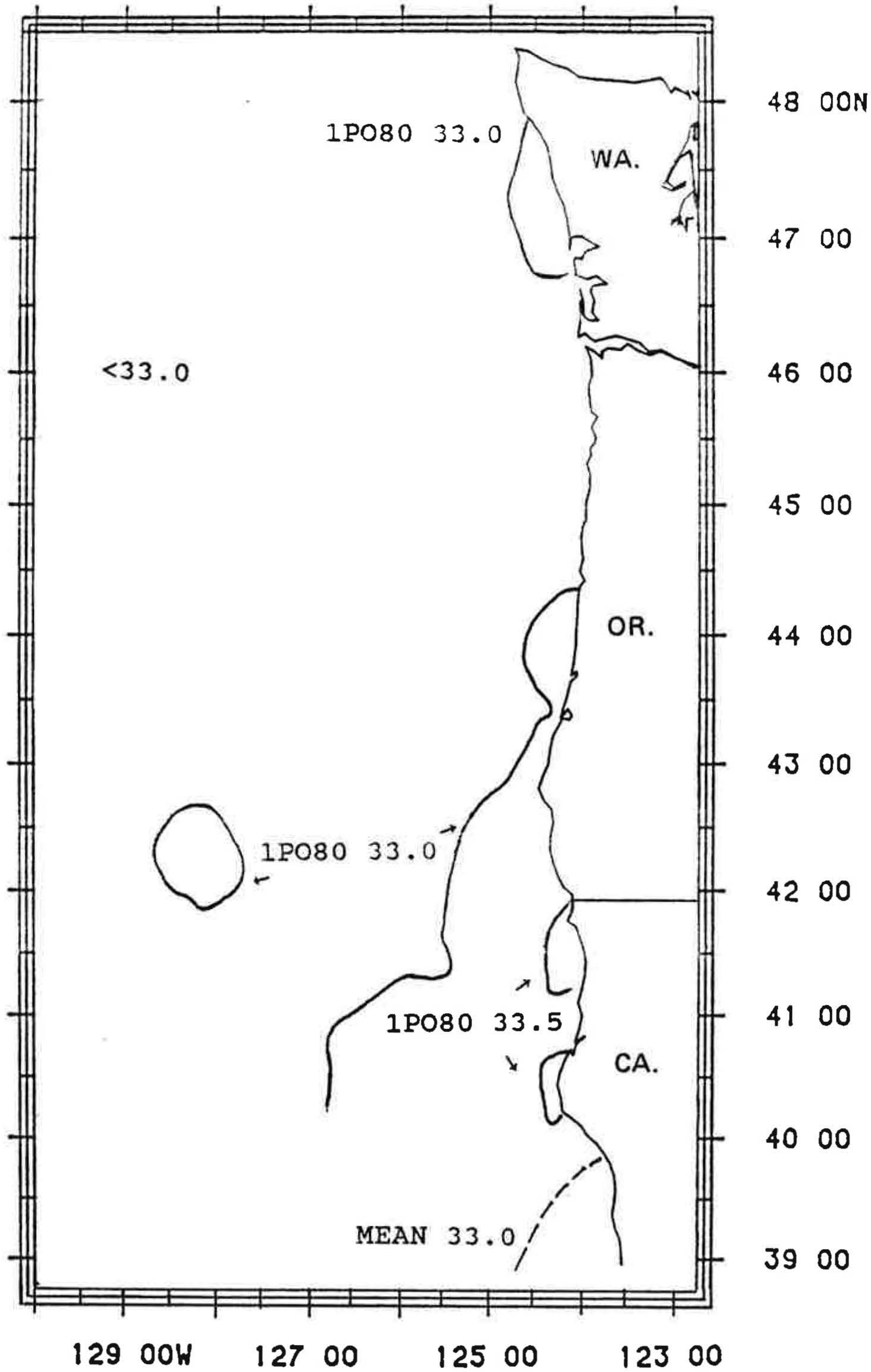

Figure 101.--Surface salinity comparisons (33.0 GM/KG and 33.5 GM/KG contours) for cruise 1PO80 (August 1980) and all-data means (Robinson 1976).

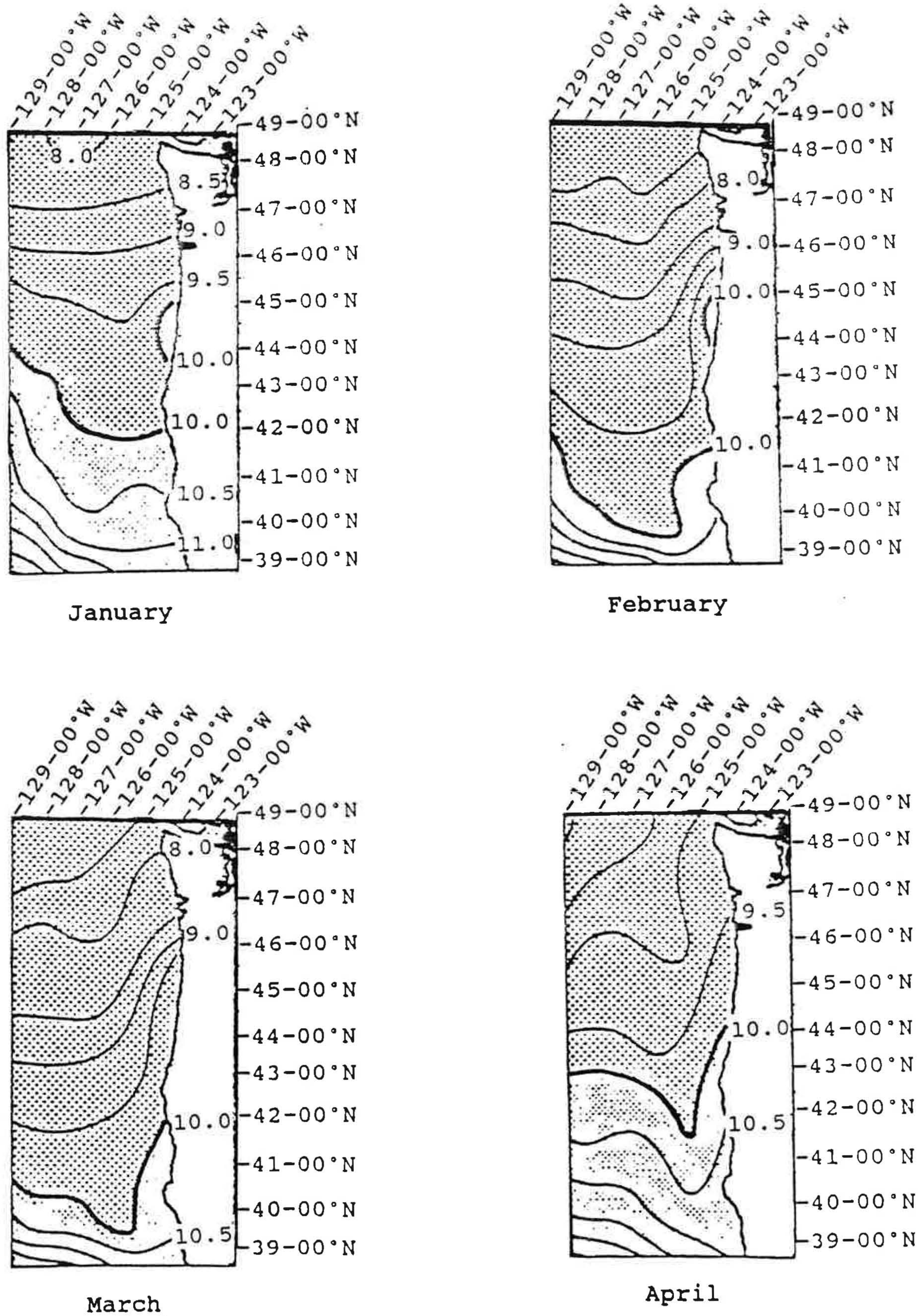

Figure 102A.--Monthly average sea surface temperatures (°C) from bathythermograph and hydrocast data, 1942-1969, Naval Oceanographic Office (Robinson 1976).

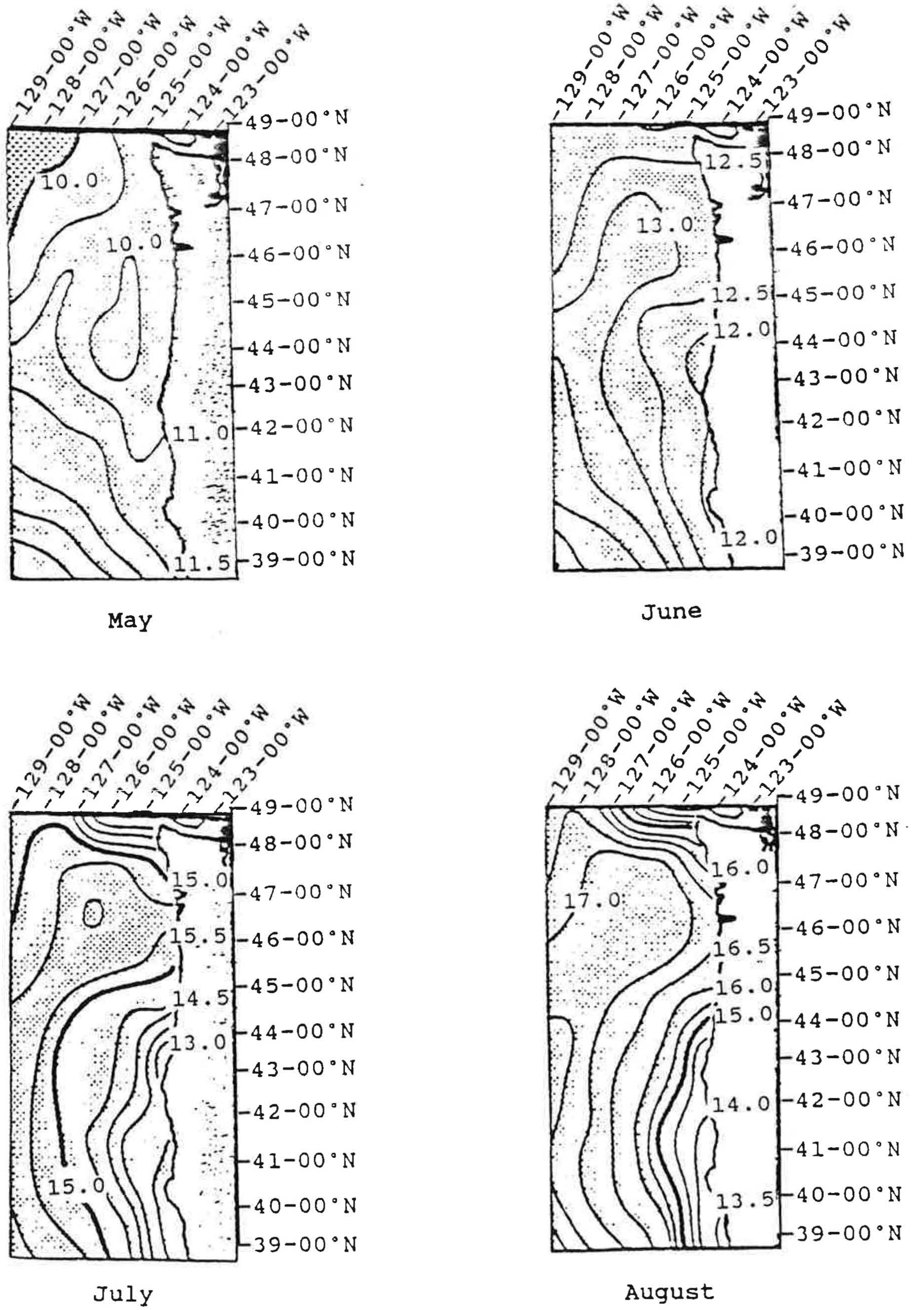

Figure 102B.--Monthly average sea surface temperatures (°C) from bathythermograph and hydrocast data, 1942-1969, Naval Oceanographic Office (Robinson 1976).

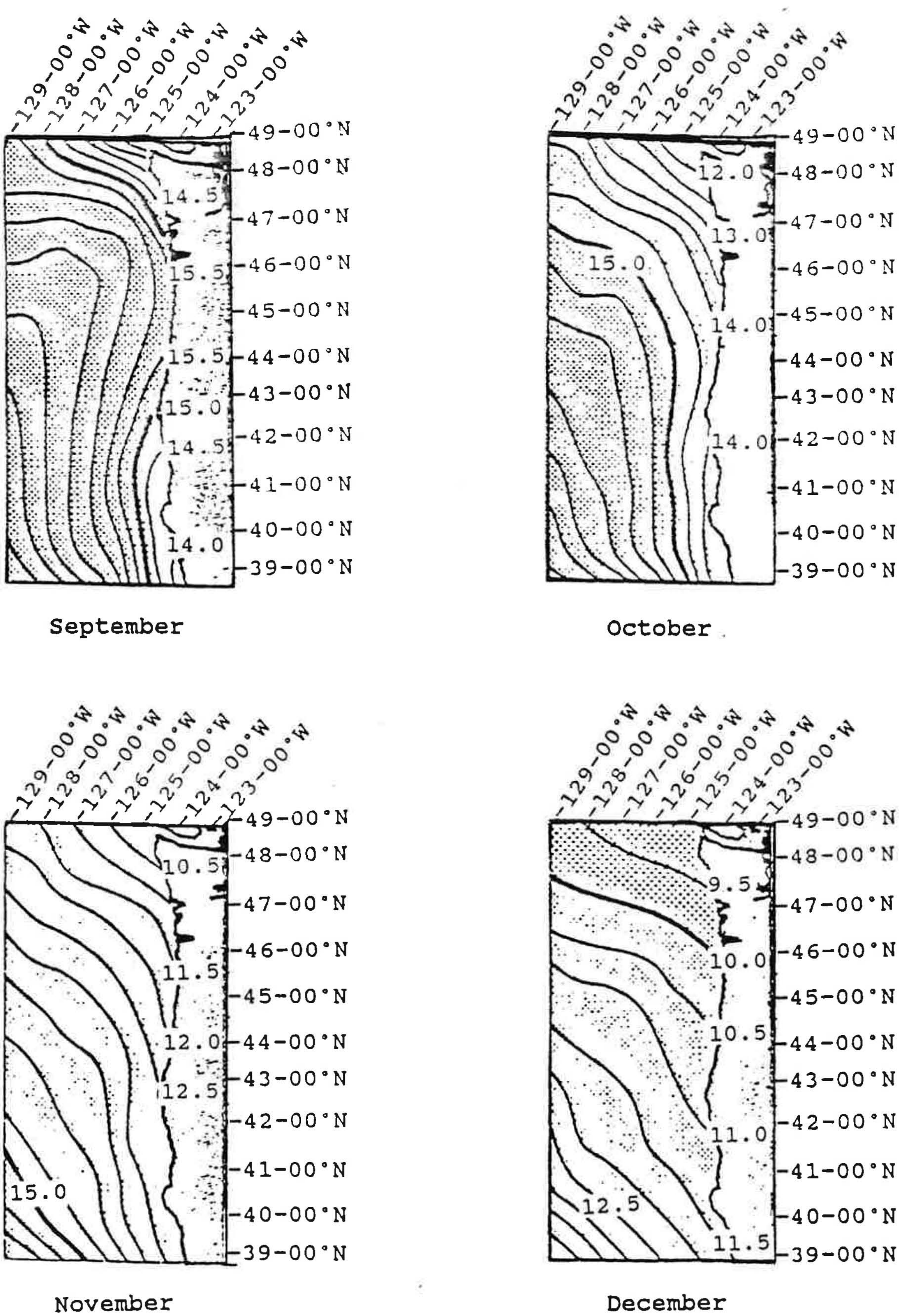

Figure 102C.--Monthly average sea surface temperatures (°C) from bathythermograph and hydrocast data, 1942-1969, Naval Oceanographic Office (Robinson 1976).

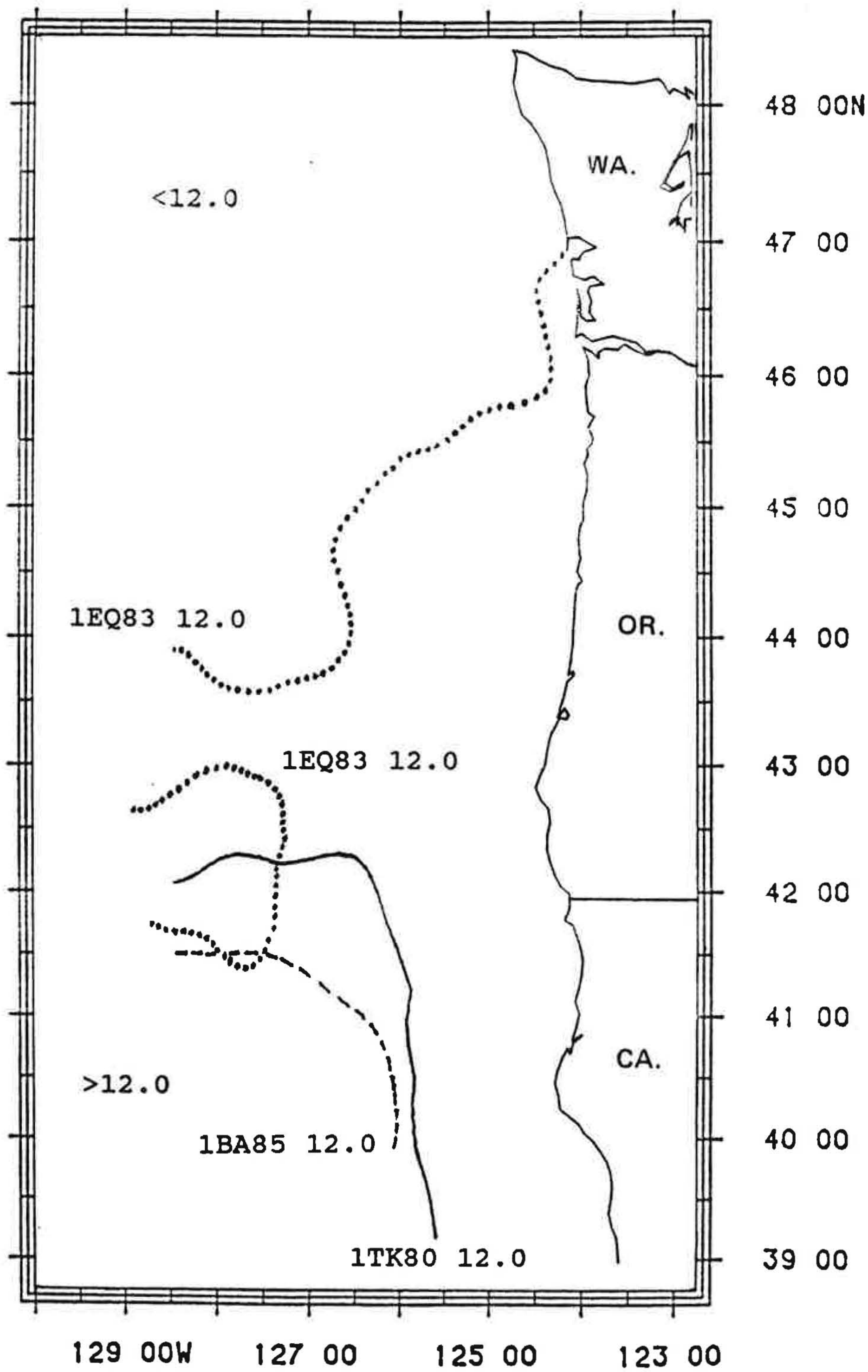

Figure 103.--Surface temperature comparisons (12.0 °C contour) for cruises 1TK80 (April-May 1980), 1EQ83 (April-May 1983), and 1BA85 (April-May 1985).

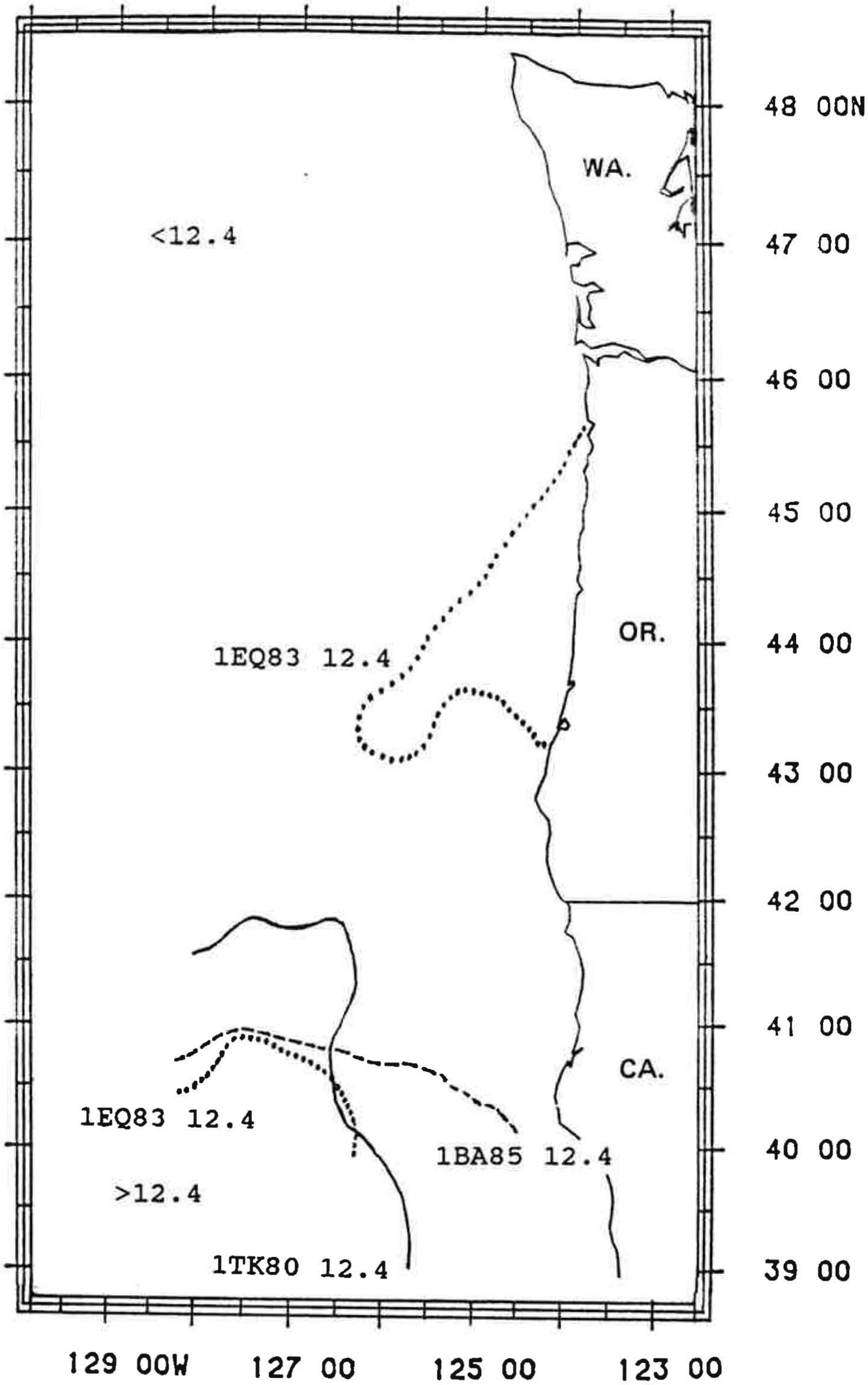

Figure 104.--Surface temperature comparisons (12.4 °C contour) for cruises 1TK80 (April-May 1980), 1EQ83 (April-May 1983), and 1BA85 (April-May 1985).

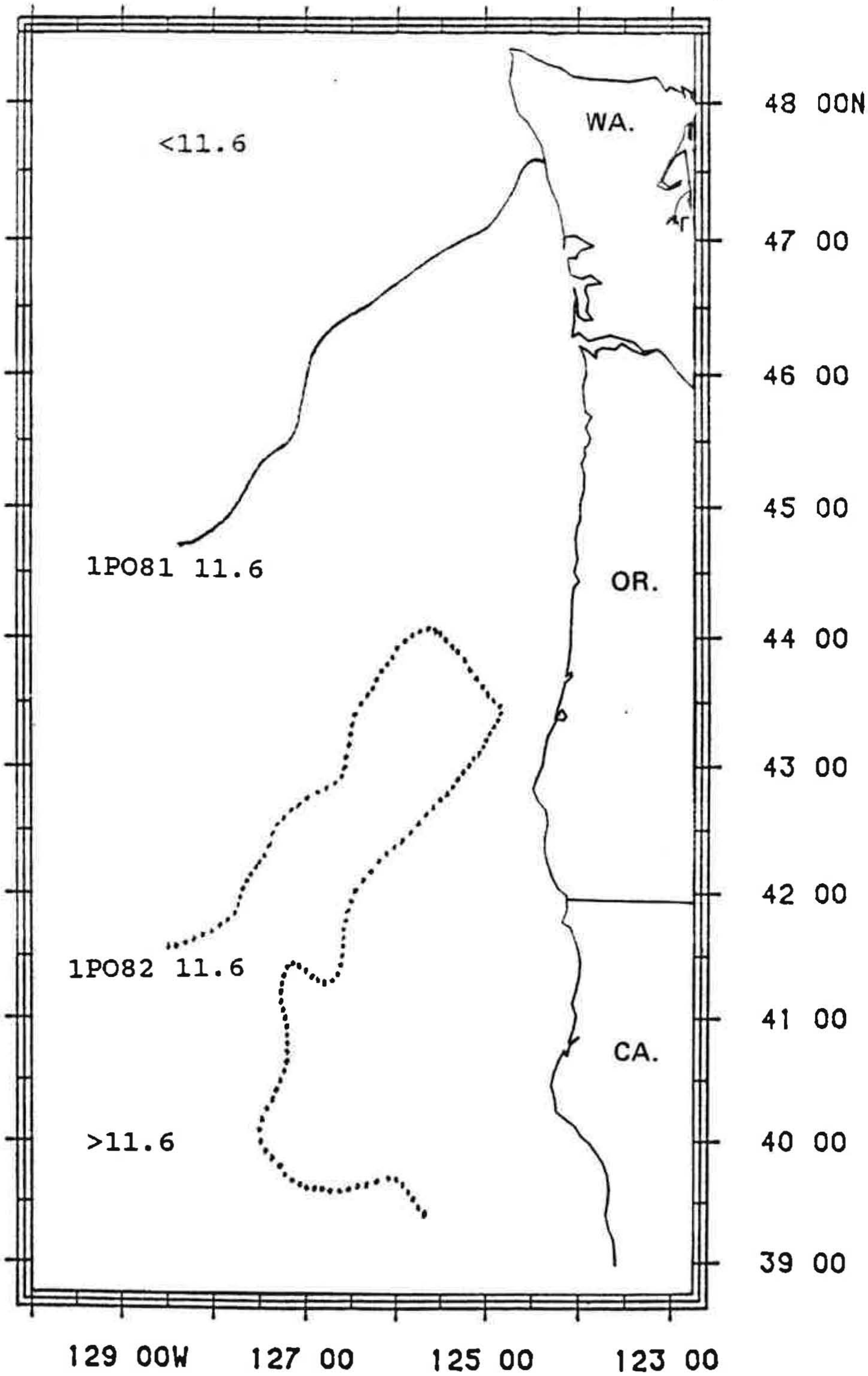

Figure 105.--Surface temperature comparisons (11.6 °C contour) for cruises 1PO81 (May 1981) and 1PO82 (May 1982).

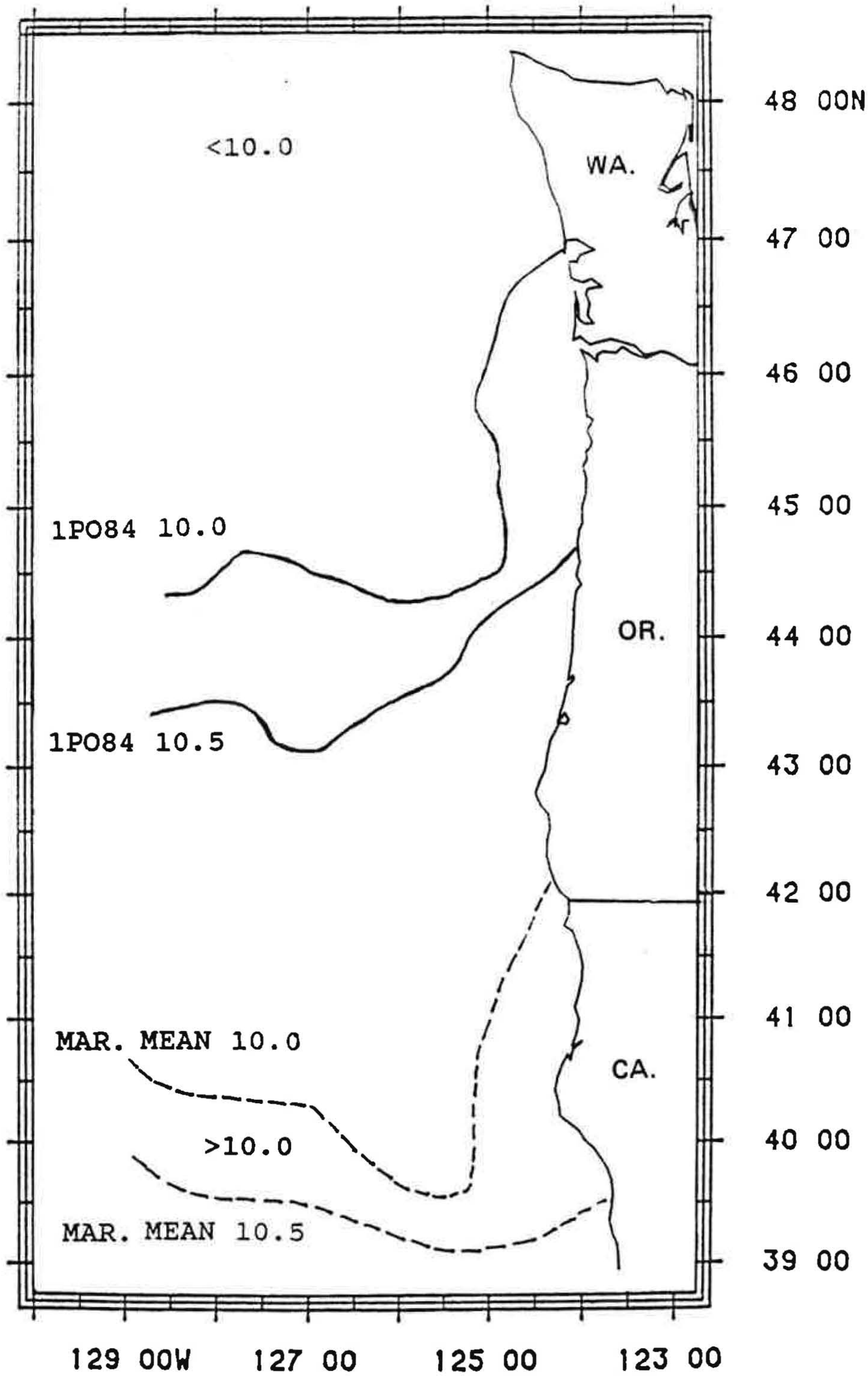

Figure 106.--Surface temperature comparisons (10.0 °C and 10.5 °) for cruise 1PO84 (March-April 1984) and March average sea surface temperatures from Naval Oceanographic Office (Robinson 1976).

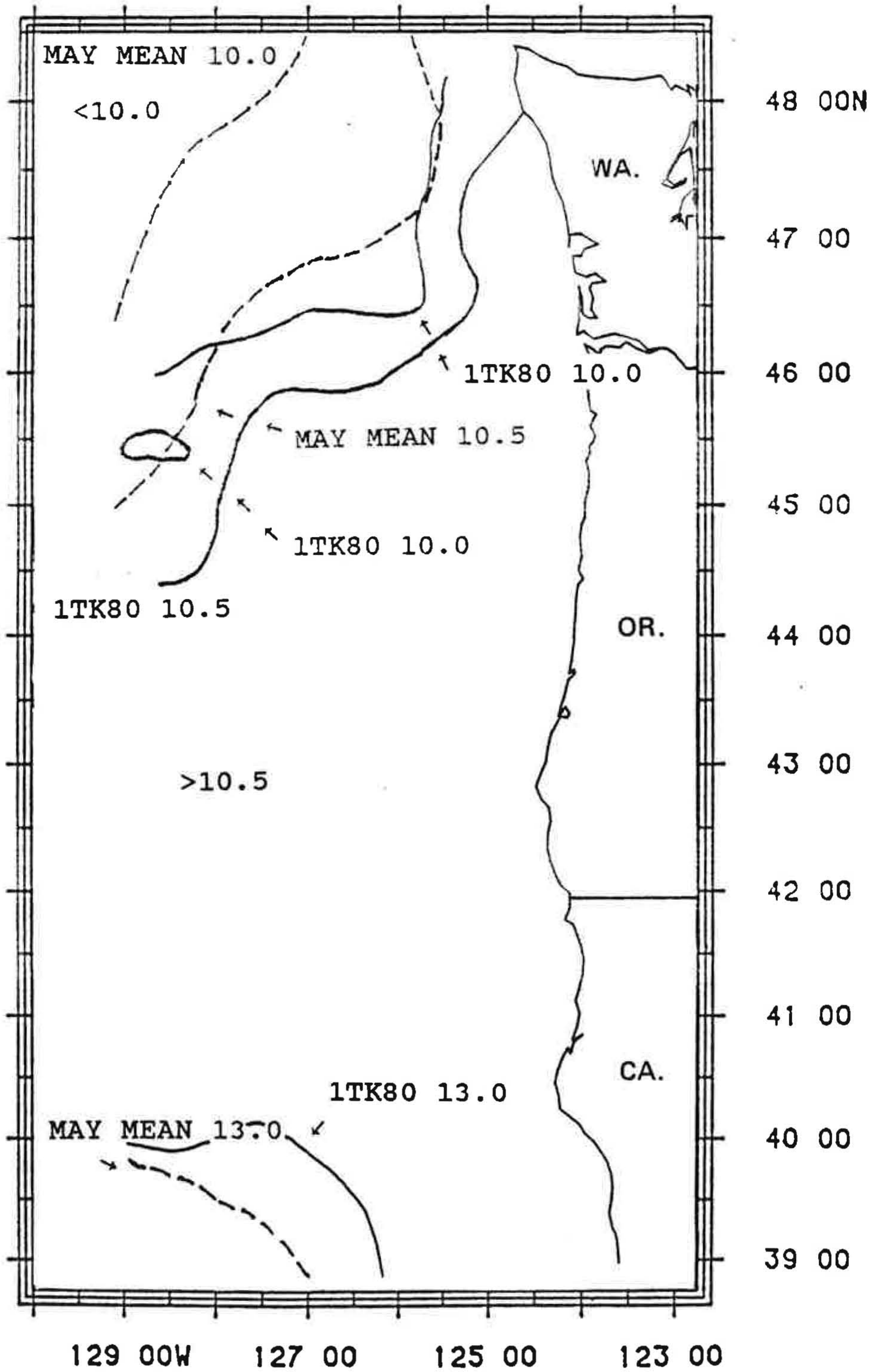

Figure 107.--Surface temperature comparisons (10.0 °C, 10.5 °C, and 13.0 °C contours) for cruise 1TK80 (April-May 1985) and May average sea surface temperatures (°C) from Naval Oceanographic Office (Robinson 1976).

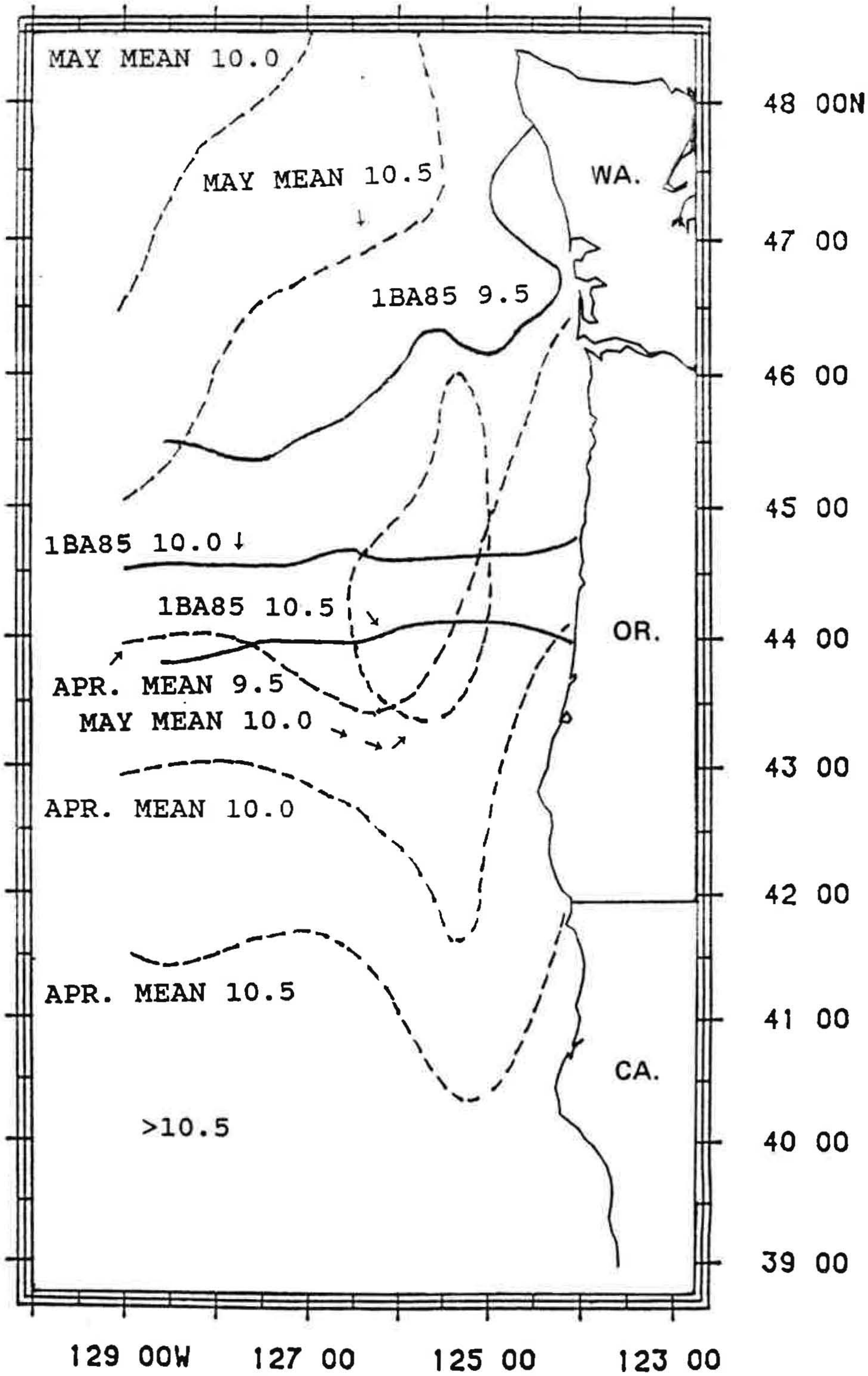

Figure 108.--Surface temperature comparisons (9.5 °C, 10.0 °C, and 10.5 °C contours) for cruise 1BA85 (April-May 1985) and April and May average sea surface temperatures (°C) from Naval Oceanographic Office (Robinson 1976).

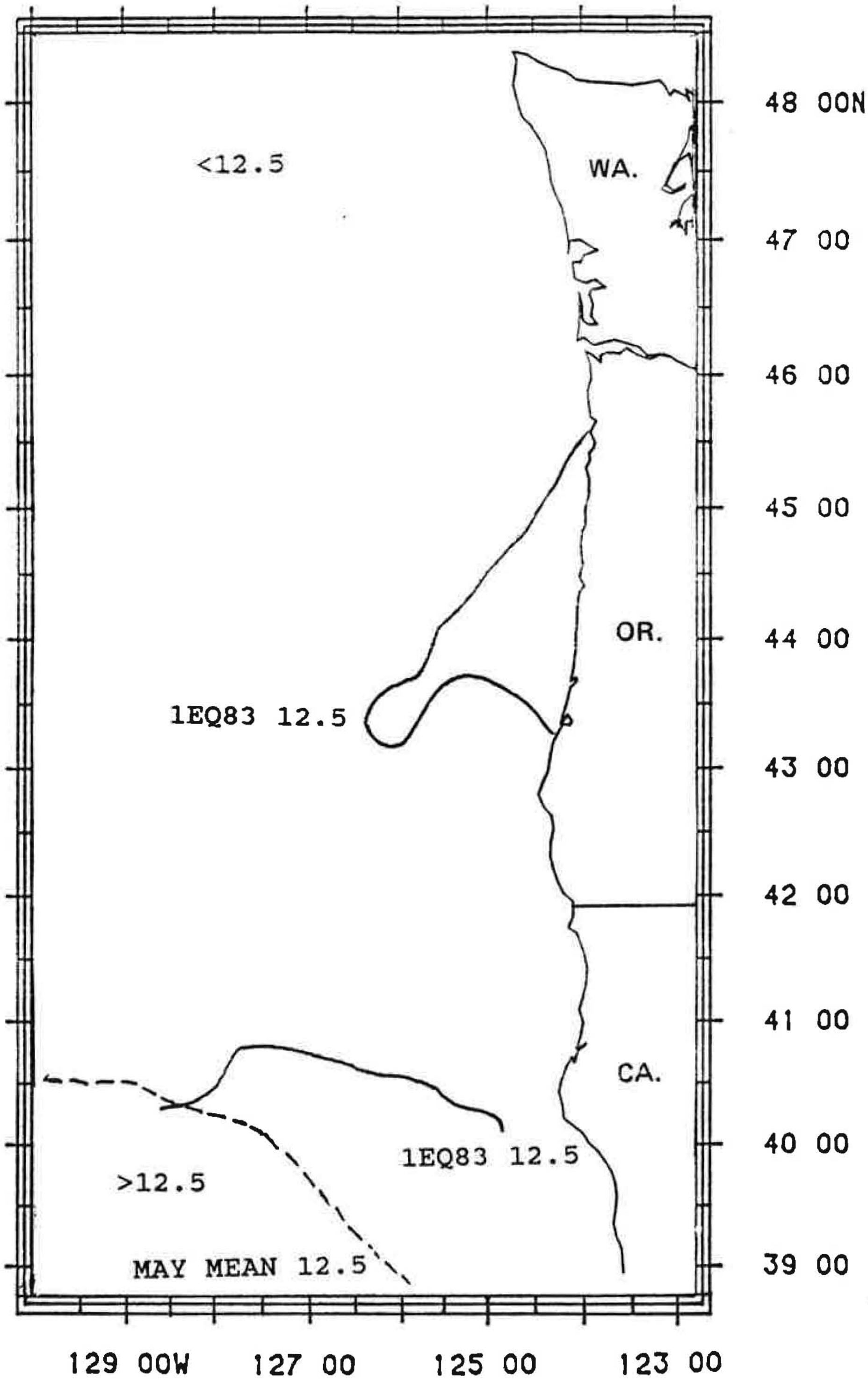

Figure 109.--Surface temperature comparisons (12.5 °C contour) for cruise 1EQ83 (April-May 1983) and May average sea surface temperature (°C) from Naval Oceanographic Office (Robinson 1976).

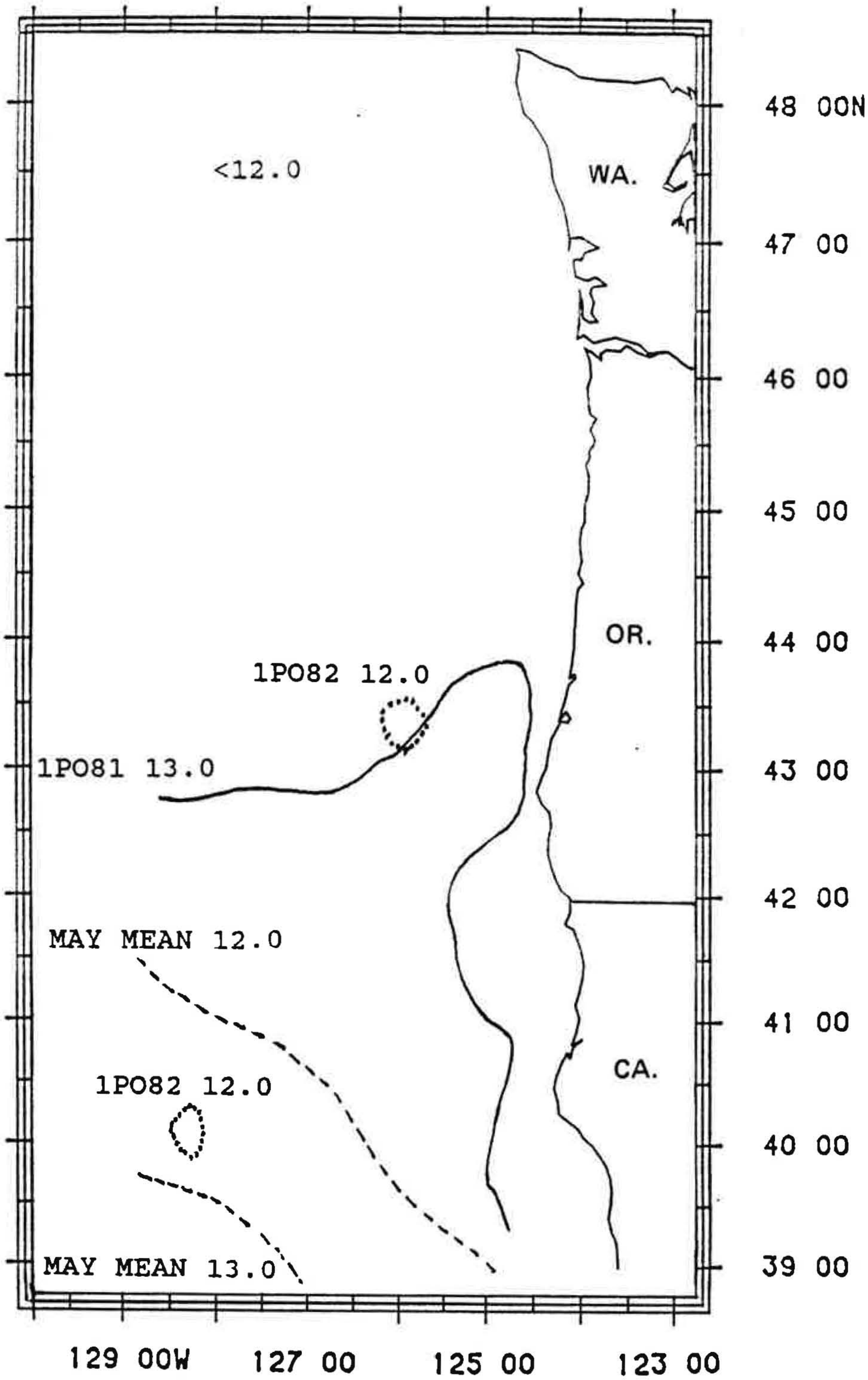

Figure 110.--Surface temperature comparisons (12.0 °C and 13.0 °C contours) for cruises 1PO81 (May 1981) and 1PO82 (May 1982) and May average sea surface temperatures (°C) from Naval Oceanographic Office (Robinson 1976).

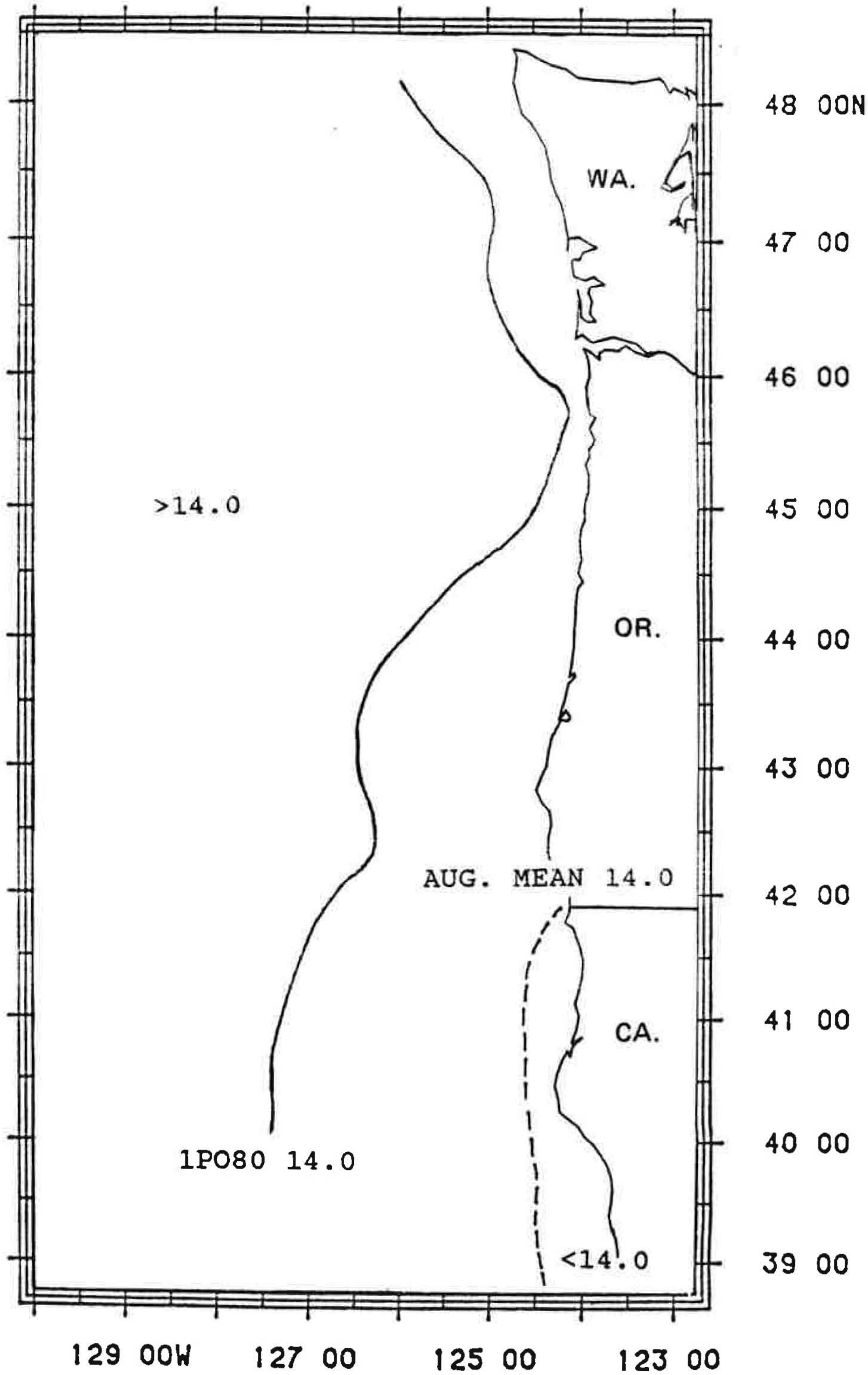

Figure 111.--Surface temperature comparisons (14.0 °C contour) for cruise 1PO80 (August 1980) and August average sea surface temperature (°C) from Naval Oceanographic Office (Robinson 1976).

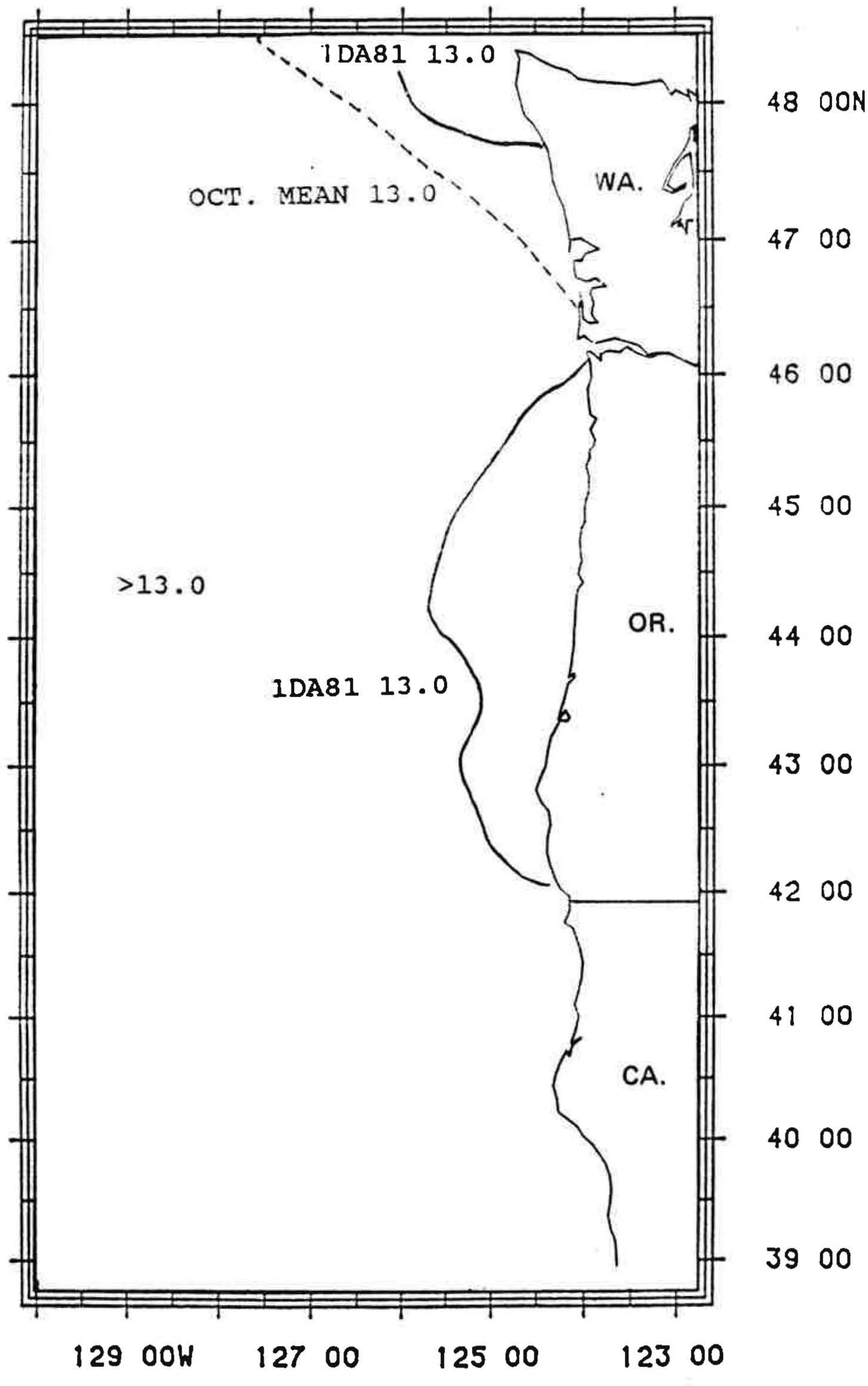

Figure 112.--Surface temperature comparisons (13.0 °C contour) for cruise 1DA81 (October-November 1981) and October average sea surface temperature (°C) from Naval Oceanographic Office (Robinson 1976).

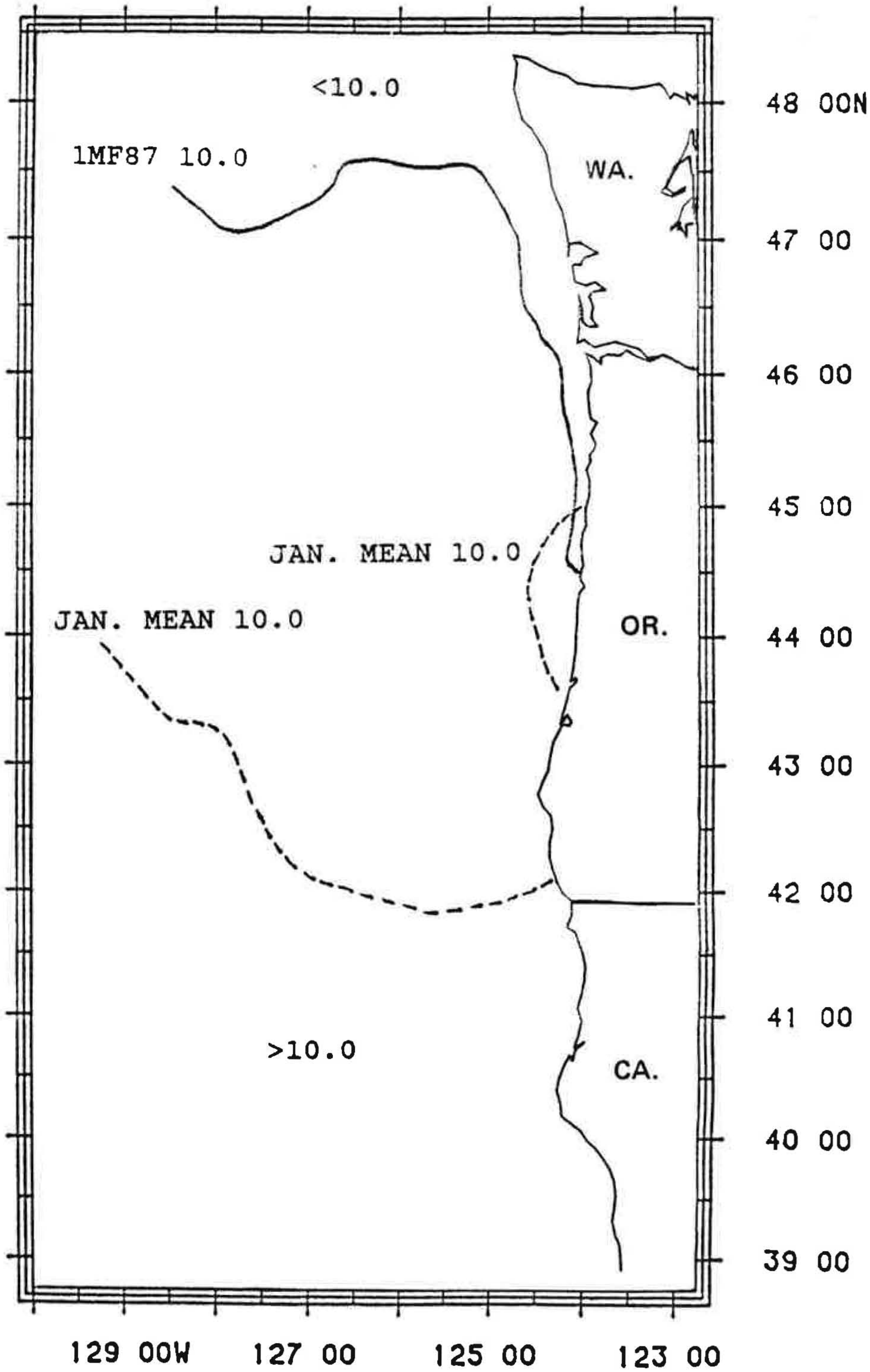

Figure 113.--Surface temperature comparisons (10.0 °C) for cruise 1MF87 (January 1987) and January average sea surface temperature (°C) from Naval Oceanographic Office (Robinson 1976).

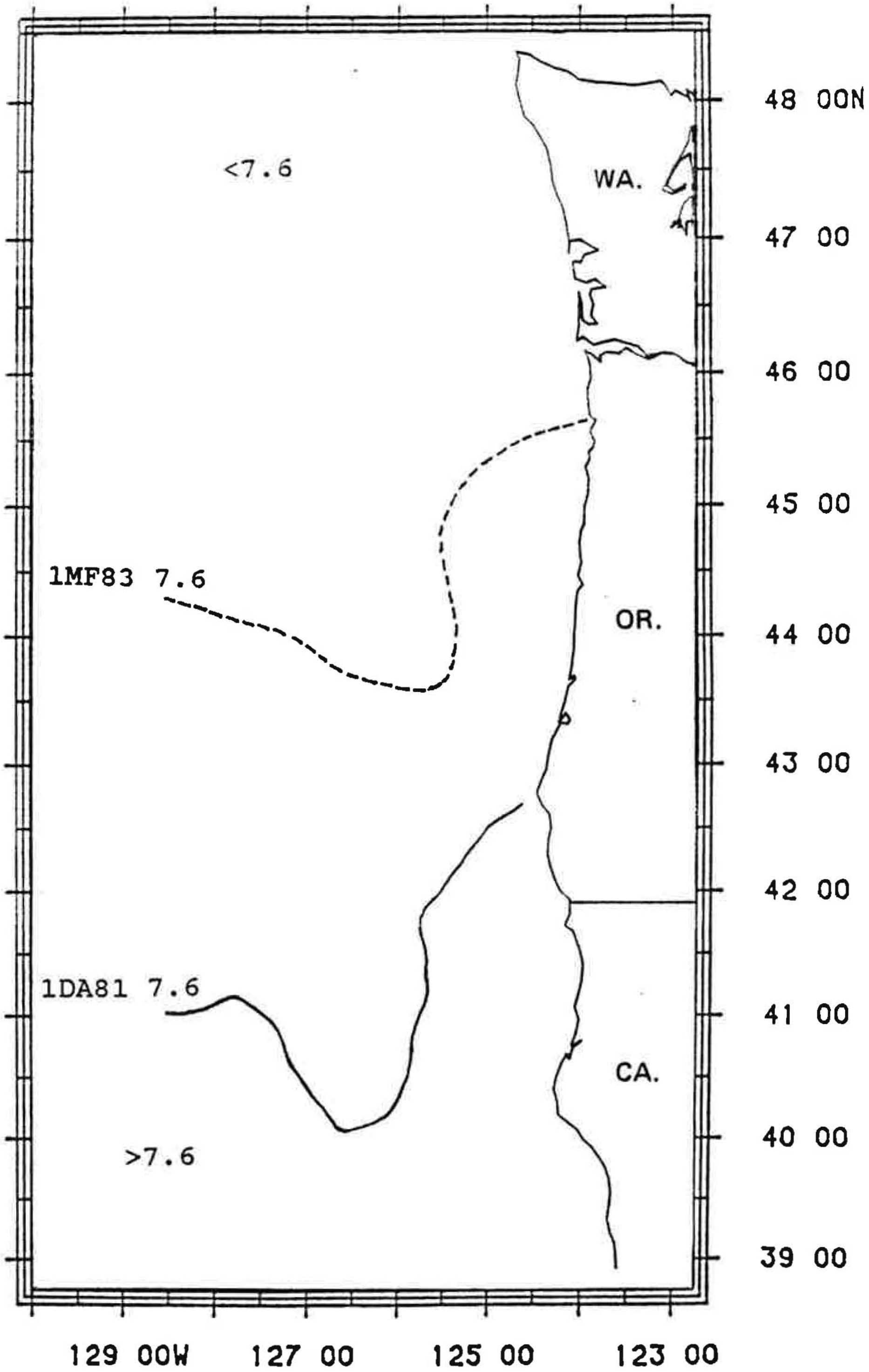

Figure 114.--200 meter temperature comparisons (7.6 °C contour) for cruises 1DA81 (October-November 1981) and 1MF83 (November 1983).

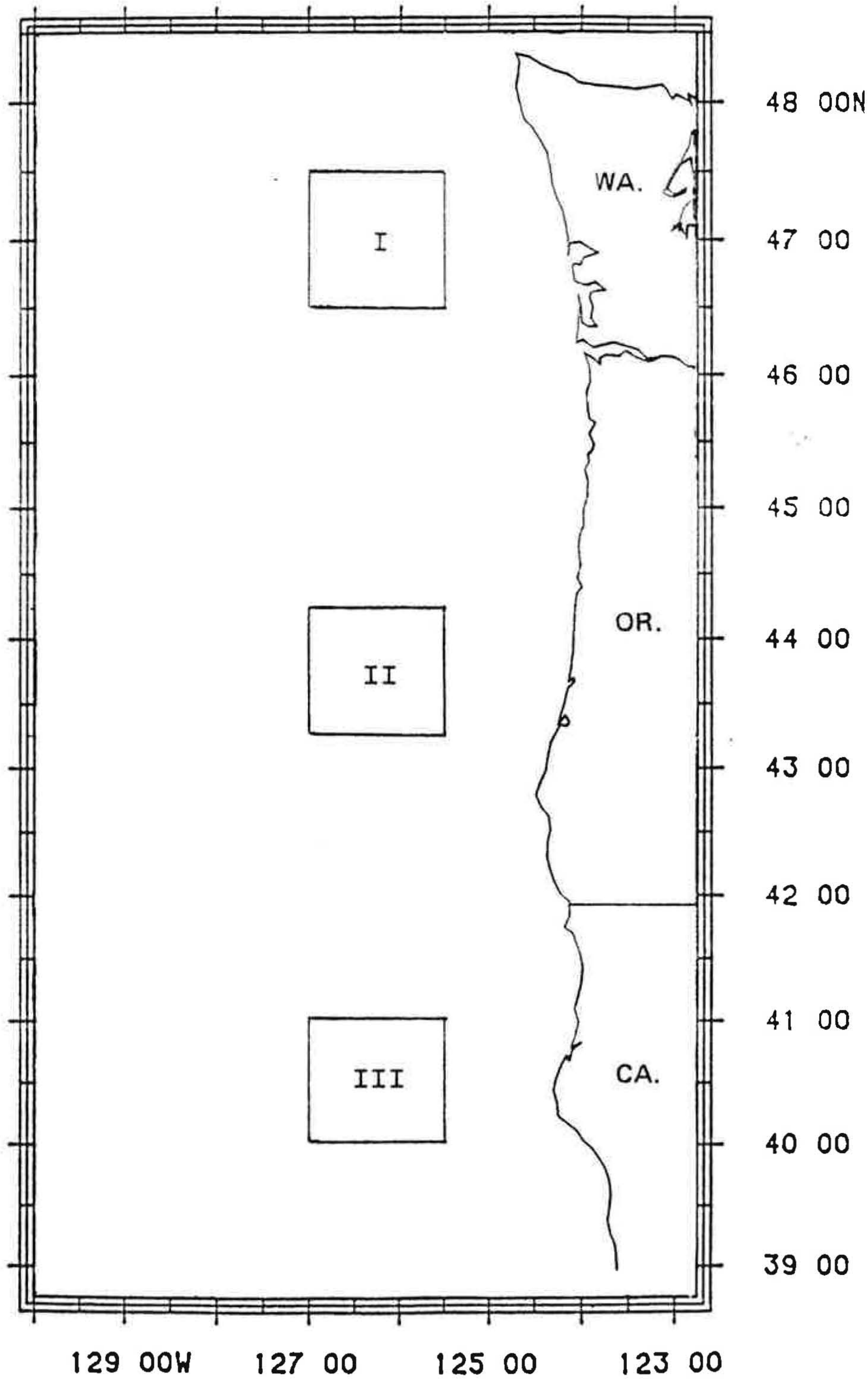

Figure 115.--Selected regions (Areas I-III) for comparison of temperatures and salinities at the surface and 200 meters.

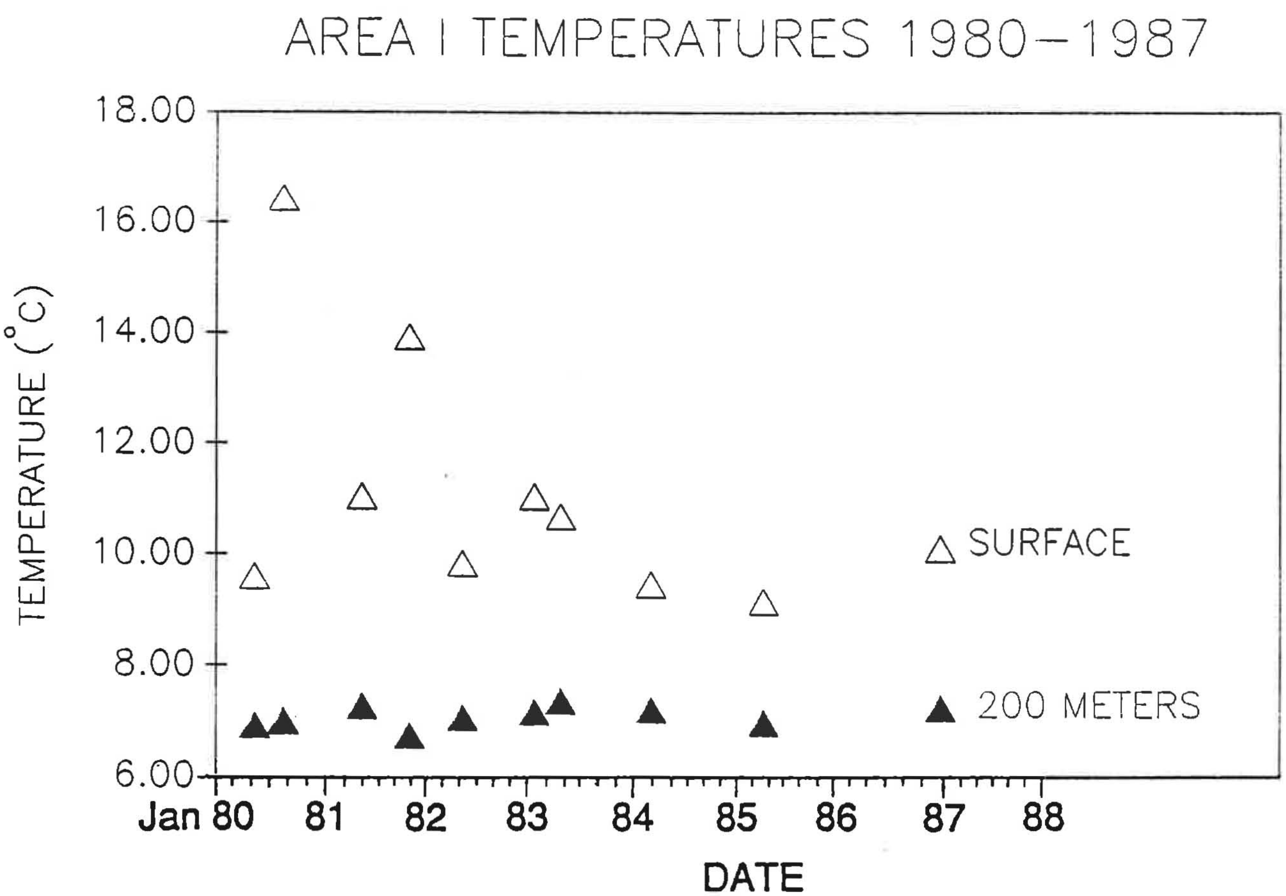

Figure 116.--Scatter-plots of temperatures at the surface and 200 meters for Area I from 1980-1987.

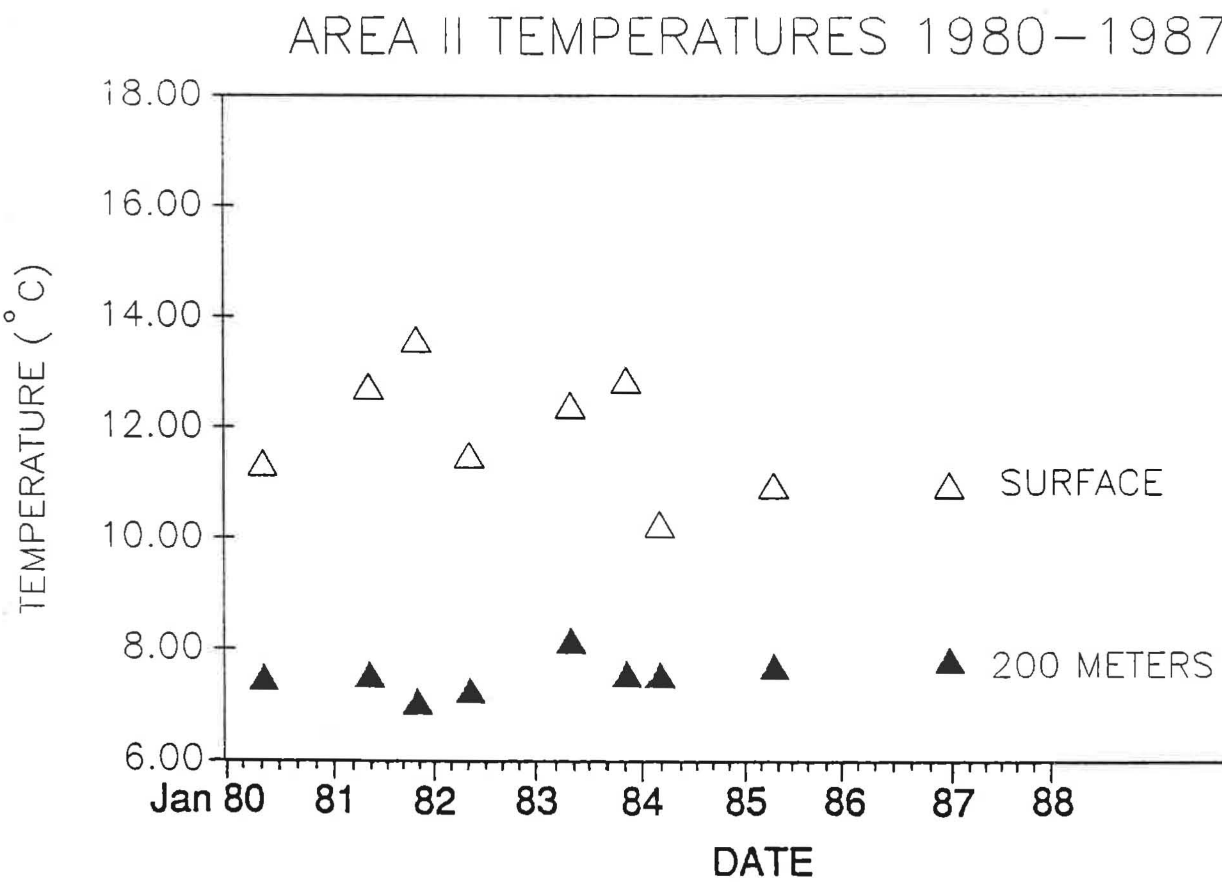

Figure 117.--Scatter-plots of temperatures at the surface and 200 meters for Area II from 1980-1987.

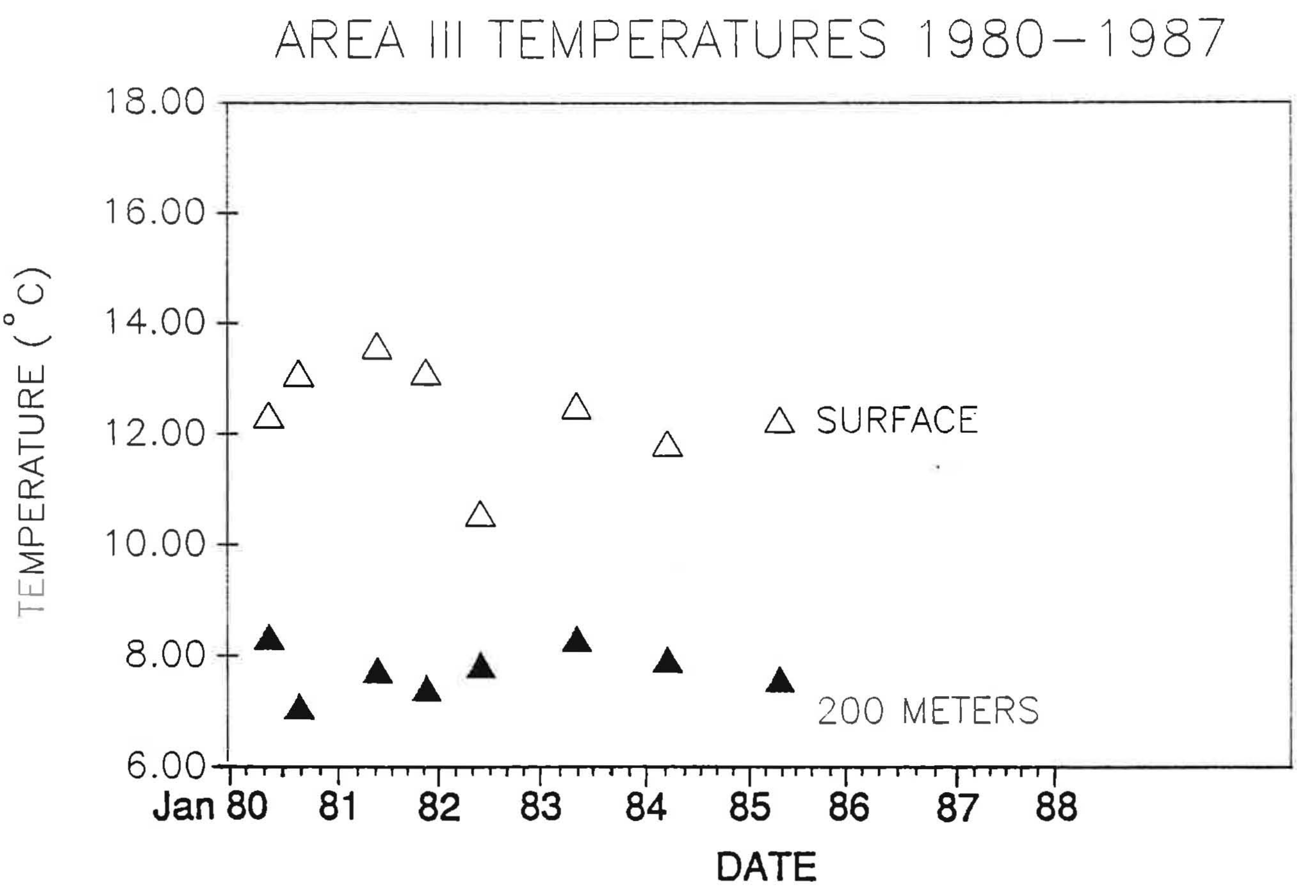

Figure 118.--Scatter-plots of temperatures at the surface and 200 meters for Area III from 1980-1987.

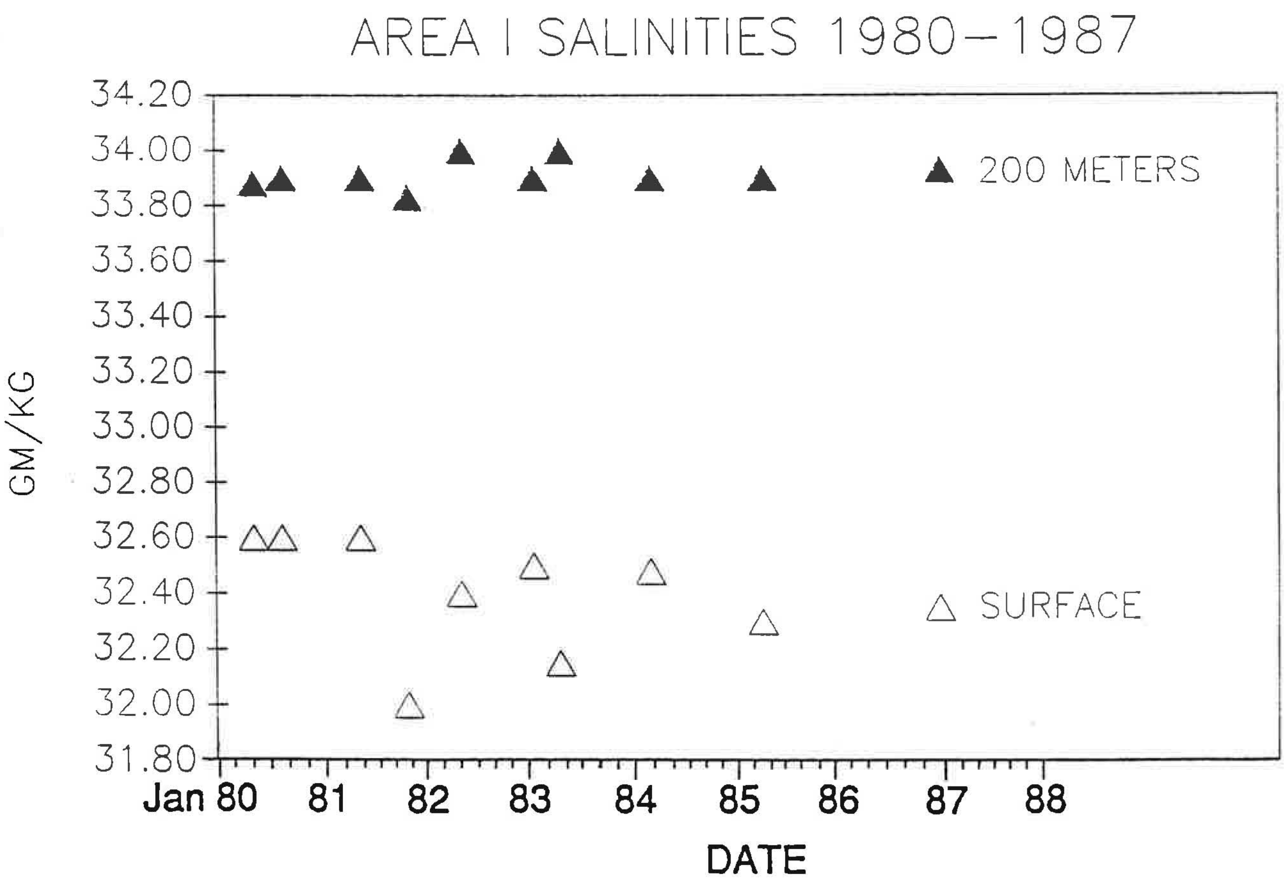

Figure 119.--Scatter-plots of salinities at the surface and 200 meters for Area I from 1980-1987.

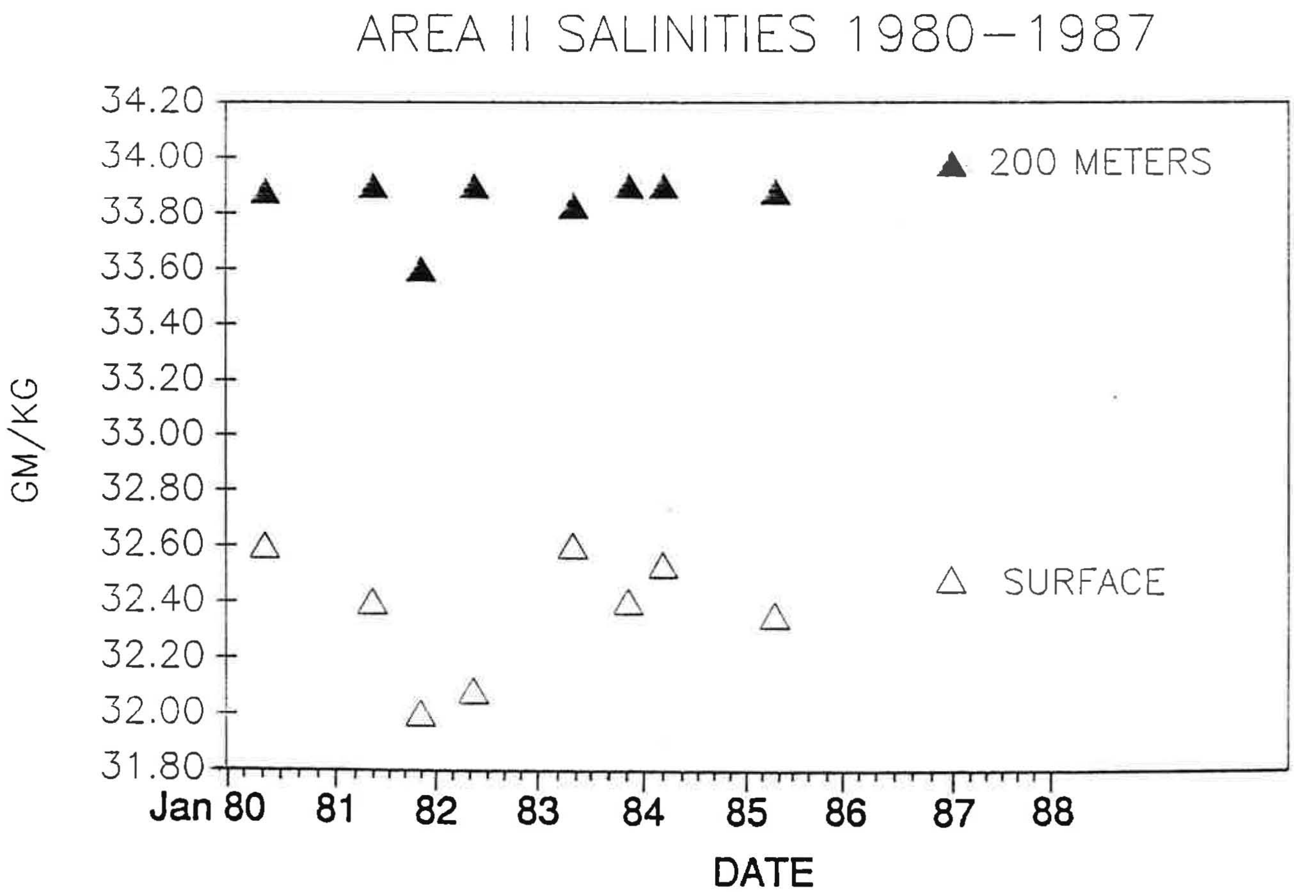

Figure 120.--Scatter-plots of salinities at the surface and 200 meters for Area II from 1980-1987.

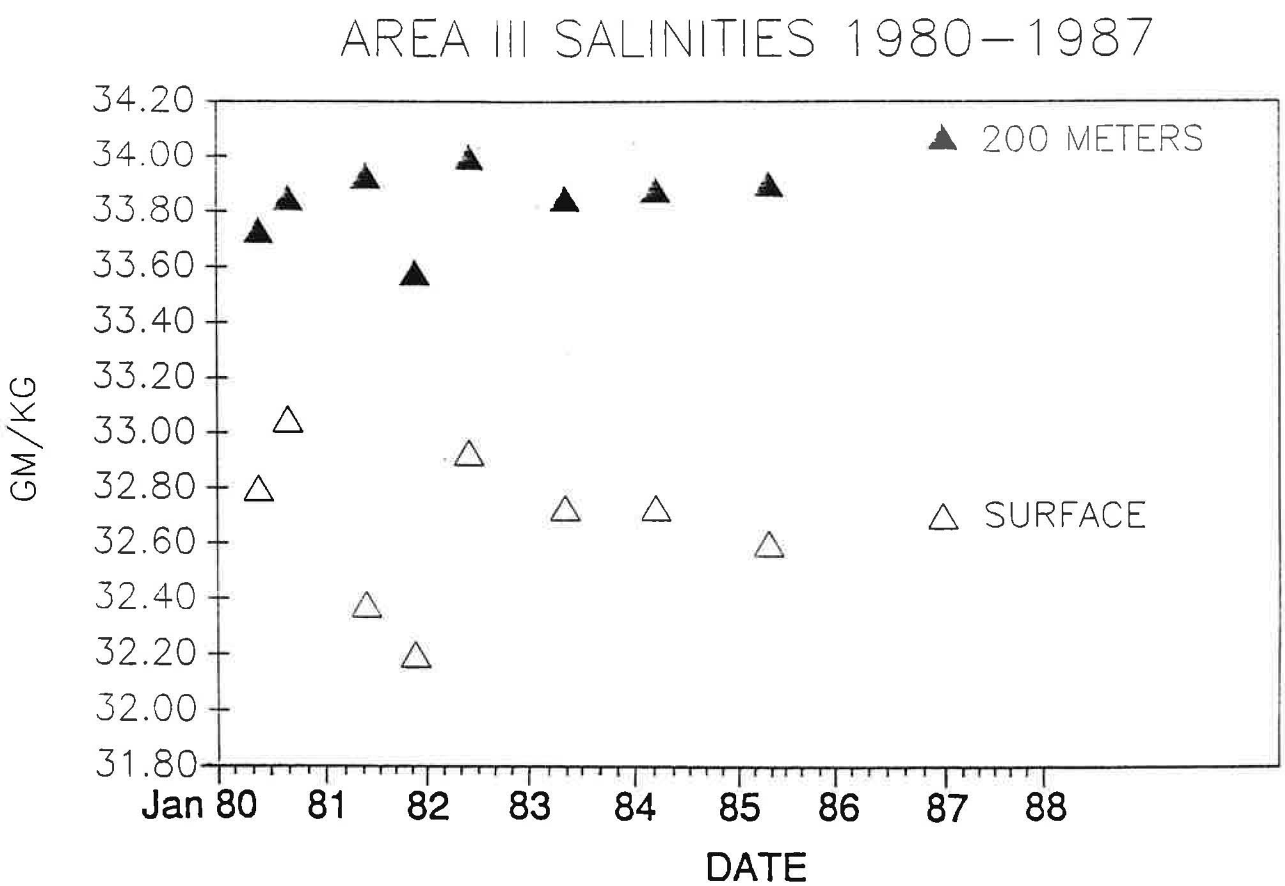

Figure 121.--Scatter-plots of salinities at the surface and 200 meters for Area III from 1980-1987.