VARIATIONS IN THE HYDROGRAPHIC STRUCTURE

OF

PRINCE WILLIAM SOUND

ROBIN D. MUENCH

C. MICHAEL SCHMIDT

IMS Report R75-1
Sea Grant Report R75-1

D. W. Hood, Director
Institute of Marine Science

VARIATIONS IN THE HYDROGRAPHIC STRUCTURE

OF

PRINCE WILLIAM SOUND

Robin D. Muench
G. Michael Schmidt

IMS Report R75-1
Sea Grant Report R75-1

D. W. Hood, Director
Institute of Marine Science

Composite of ERTS images 1387-20275, 1387-20281, 1387-20284,1389-20391,1389-20394 and 1390-20450 on 14 to 16 August 1973.

ACKNOWLEDGEMENTS

This work has been carried out by the Institute of Marine Science using National Science Foundation block ship funding and support from NOAA, Office of Sea Grant, Department of Commerce, under Grant No. 04-3158-41. Appreciation is extended to the crew of the R/V *Acona*, especially Captain Ken Turner and Dolly Dieter for assisting in data collection. Meteorological data were supplied by Harold Searby of the Arctic Environmental Information and Data Center. Special thanks to Mary Brazo, Susan Cutting, Teresa Harrod and Wendy Warren for keypunching the large quantity of data. Computer programming was provided by Dottie Buhler, James Dryden and David Livingstone. Drafting of the numerous figures was done by Judith Henshaw and Fran Sweet. The original text was typed by Anita Burford and the final composer copy was prepared by Kate Barr. Robert Seitz contributed his usual enthusiasm and encouragement. Valuable criticism and advice was provided by Paul Whitfield.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

General Background

Prince William Sound is a complex fjord-type estuarine system located off of the northern Gulf of Alaska (Fig. 1). It connects with the Gulf via Hinchinbrook Entrance and Montague Strait, having limited access through the archipelagic islands at the east and west. The Sound itself is influenced by several outward-radiating fjord systems including Orca Bay, Port Wells and Port Valdez. The waters of the Sound are thought to be affected by mixing with waters of the North Pacific Ocean and by local climatic influences. Prince William Sound may be regarded as a boundary region between the peripheral fjords and the Gulf of Alaska.

Prince William Sound is one of the larger North American estuarine systems not presently influenced by metropolitan activities. Comparable in size to Puget Sound, Washington, its population numbers less than 5,000, most of whom reside in the fishing communities of Valdez, Cordova, Whittier and Tatitlek. Within the next decade, the Sound faces major development as the receiving-loading area for the trans-Alaskan pipeline, recreational and urban stresses from Anchorage and increasing pressure from commercial fisherman.

As of late 1973, there was little available oceanographic information about Prince William Sound. While data had been collected from the area, it had not been compiled or analyzed. This report represents an attempt at analysis and discussion of the physical oceanographic conditions in Prince William Sound, providing information which can be used in making management decisions and planning specific research in the region.

Scientific Background

Prince William Sound may be classified as an estuarine system on the basis of Pritchard's (1967) definition, an estuary being a semi-enclosed coastal body of water which has a free connection with the open sea, and within which sea water is measurably diluted with fresh water derived from land drainage. The glacial origin suggested by the bathymetry (Fig. 2) further classifies the Sound as a fjord-type estuary.

The literature provides sufficient information to suggest processes which may be pertinent to the circulation of the waters in Prince William Sound. These materials include a qualitative analysis of selected southeastern Alaskan fjords (Pickard 1967), and a dynamical analysis of Silver Bay (McAlister, Rattray and Barnes 1959). In addition, Norwegian fjords have been analyzed, particularly with regard to their deep water circulation (Saelen 1967) and a detailed investigation of Oslofjord has been done (Gade 1970). Theoretical investigations of fjord dynamics have been carried out (Rattray and Hansen 1962; Rattray 1967).

Recent research on Alaskan fjords has been carried out primarily by the Institute of Marine Science, University of Alaska. Seasonal advective flushing of deep water was first detected in a southeastern Alaskan fjord, Endicott Arm (Nebert 1972). This mechanism has also been described for Resurrection Bay (Heggie 1973), and Russell Fjord (Muench, Reeburgh and Cooney, in preparation). An intensive hydrographic survey has been carried out in Port Valdez (Muench and Nebert 1973).

It is possible then to define as follows those factors which are expected to play a role in determining the circulation and hydrographic features of Prince William Sound:

1. Fresh water runoff might induce classical estuarine two-layered flow;
2. Surface winds are expected to play a role in moving the near-surface layers of water, due to high regional wind speeds and the large horizontal extent of the system;
3. Tides may contribute to mixing and may induce a net cyclonic circulation (Kelvin wave) within the Sound;
4. Understanding the nature of the Gulf of Alaska source water available to Prince William Sound at sill depth will aid in determining mechanisms of deep water renewal;
5. Local climatic effects such as winter cooling and summer warming may affect vertical stratification;

These factors provide a focus for the discussions in this report.

Geographical and Bathymetrical Description

Oceanographic processes within any system depend to a large extent upon its physical configuration. In the case of Prince William Sound, the dominant physical characteristic is its large breadth, which makes it difficult to regard as a simple fjord. It would, therefore, be expected that appreciable horizontal circulation would occur and would make it impossible to treat the Sound as a simple two-dimensional system having only a classical fjord circulation. There are two openings to the Gulf of Alaska, Montague Strait and Hinchinbrook Entrance, the latter of which constitutes the more direct access. Remaining channels through the islands to the east and west are shallow and tortuous, and probably do not allow sufficient exchange of water between the Sound and the Gulf to affect more than the surface water properties in the immediate vicinity of the openings.

Taken as a whole, the bathymetry of the Sound is complex (Fig. 2). There is a series of deeps extending down to nearly 800 m (400 fm) in the western portion, while the eastern portion consists of a broad north-south trending trough 300 to 400 m (150-200 fm) deep. The limiting sill depth, which occurs somewhat south of Hinchinbrook Entrance on the Gulf of Alaska shelf, is about 180 m (90 fm). The sill outside Montague Strait is somewhat shallower, with limiting depths of slightly more than 100 m (50 fm) being found within the Strait itself. The trough in the eastern portion of the Sound forms, essentially, a basin there having maximum depths of 500 m (250 fm). Taken in the simplest possible sense, the Sound is then a physical system consisting of a 500 m (250 fm) deep basin connected to the open Gulf of Alaska via a channel having a limiting sill depth of about 180 m (90 fm). This definition is important to the deep water renewal processes in particular; the small-scale details in the bathymetry are probably not important in this context except in local special cases such as Port Valdez.

Summary of Regional Meteorology

In a water body having the horizontal extent of Prince William Sound, it would be anticipated that surface winds might exert a significant control on water motion. Vertical stratification in both temperature and salinity is controlled to a large degree by surface warming and addition of freshwater at the surface from terrestrial runoff and precipitation. A general discussion of the regional meteorology is therefore a prerequisite to understanding the distribution of temperature and salinity in the Sound.

No weather data are available from the central portion of the Sound itself. The weather stations are peripherally located at Valdez, Whittier, Cordova, Latouche and Cape Hinchinbrook. The weather data from the above stations are presented as historical summaries (Appendix 1). Data from Cape Hinchinbrook are presented, in addition, as monthly mean values during 1971 to 1973 of wind speed and direction, surface temperature and relative humidity (Appendix 2).

Mean seasonal air temperatures at Cape Hinchinbrook reach maxima of about 55°F (13-14°C) during July to August and minima of about 15°F (-5°C) in January, lagging by about a month the periods of maximum and minimum incoming solar radiation (June and December, respectively). The mean annual temperature at Cape Hinchinbrook is about 42°F (5°C). The monthly mean temperatures for 1971 to 1973 indicate that the winter of 1971 to 1972 was more severe than the winter of 1972 to 1973, as indicated by lower temperatures during the former period. Personal observations in the region at those times support this.

The wind regime in the Prince William Sound region is controlled by the relative positions of the Aleutian Low and the Pacific High (Royer, in press). Dominance of the Aleutian Low brings a series of severe storms during the winter, while the Pacific High normally dominates during the summer and is accompanied by relatively fair weather. Winds up to about 80 kts have been observed at Cape Hinchinbrook during winter (Appendix 2), while similar winter winds have been observed in the central portion of the Sound (personal observations). The winds normally are northeasterly, trending to northerly during the winter and easterly during the summer. A considerable directional variability makes generalization difficult. It is notable that in peripheral fjords such as Port Valdez the steep walls channel winds into an axial direction which may bear little relation to the winds in the central Sound. These fjords are, moreover, affected by local drainage winds whose affects may not extend appreciably beyond the fjord mouths.

The monthly mean precipitation is important to the surface salinity variations in the Sound. It is extremely variable, ranging from about 180 inches at Latouche down to about 62 inches at Valdez. This high variability is further complicated by the fact that winter precipitation occurs as snowfall which is then stored and released during the spring melt period, making it difficult to judge the pattern of fresh water input. This problem has been qualitatively discussed by Pickard (1967). In the Prince William Sound region, precipitation generally occurs as snowfall from about October to March (personal observations). A study of freshwater input into Port Valdez (Carlson *et al.* 1969) suggested maximum input from meltwater into that system during July, while maximum precipitation as rainfall occurred in October. Port Valdez, which has a greater freshwater input for its size than any other portion of the Sound due to the presence of a major river input (the Lowe River) has been oceanographically classified as a low freshwater input estuary (Muench and Nebert 1973).

Upon the basis of this observation, it is expected that Prince William Sound would be classified, also, as a low freshwater input system. Knowledge of local precipitation and of the year-round distribution of melt water input is inadequate, however, for a quantitative assessment of this statement.

FIELD WORK

Summary of Cruises to Prince William Sound

Few physical oceanographic surveys were made in Prince William Sound proper prior to 1971. Scattered oceanographic stations involving measurements of temperature, salinity and dissolved oxygen content were occupied during the summers of 1955, 1959, 1966 and 1969 by various institutions, but were inadequate for an analysis of conditions. As part of an Alyeska Pipeline Service Company - sponsored oceanographic survey of Port Valdez, six oceanographic stations were occupied in eastern Prince William Sound at approximately bi-monthly intervals from May 1971 through April 1972 (Muench and Nebert 1973).

In March 1972, an expanded sampling program in Prince William Sound was started which continued through May 1973. Cruises conducted under this program, summarized in Table 1, were carried out by the Institute of Marine Science using NSF block ship funding and support from the University of Alaska Sea Grant Program. Some data have been obtained, during 1974, on cruises carried out in Prince William Sound by other projects. Station locations for all cruises are given in Appendix 3, and a summary of stations occupied during each cruise is given in Appendix 4.

Continuing research in the Gulf of Alaska, up to and including Hinchinbrook Entrance, is being conducted by the Institute of Marine Science under the auspices of the Bureau of Land Management. Data collected by this program are currently providing valuable information on the nature of source waters available to the Sound at Hinchinbrook Entrance.

Collection of Hydrographic Data

Temperature and salinity data were obtained at all Prince William Sound stations during the 1971-1972 period using a Bissett-Berman Model 9040 salinity/temperature/depth measuring unit (STD). These data were calibrated at frequent intervals, generally every third or fourth station, against data from discrete Nansen bottle samples. Surface water temperatures were measured with a bucket thermometer at each oceanographic station.

TABLE 1

Summary of Data Collected from Prince William Sound

Number of Cruises	Year	Month	Measurements
1	1955	May	T, S, & 0_2
1	1959	May	T, S, & 0_2
1	1966	July	T, S, & 0_2
1	1969	August	T & S
4	1971	May, July October, December	T, S, 0_2 & some nutrients
5	1972	March, April, June September, December	T, S, 0_2 & nutrients (5 stations)
3	1973	January, March, May	T, S, 0_2 & nutrients
1	1974	May	T & S

Data from the STD were obtained in the form of charts showing continuous analog traces of temperature and salinity vs. depth. This information was simultaneously recorded in digital form on magnetic tape at 0.2 second intervals (about every 10 cm) during lowering of the STD underwater unit. The analog traces were intended to detect possible malfunctioning of the STD while on station. Digital data were forwarded to the Institute of Marine Science in Fairbanks for post-cruise processing and intercalibration with the Nansen bottle data.

Temperatures were obtained at each sample depth during Nansen casts from a pair of deep-sea protected reversing thermometers. Salinities of samples decanted from the Nansen bottles were measured using a Bissett-Berman Model 6220 or 6230 Portable Laboratory Salinometer. Depths of samples from below 200 m were computed using unprotected deep-sea thermometer readings in conjunction with the amount of wire out.

Allowing for instrument drift and human errors, temperature and salinity data obtained using the STD were estimated to be accurate to $\pm$ 0.03°C and $\pm$ 0.03‰ respectively, as compared to $\pm$ 0.02°C and $\pm$ 0.02‰ for data from Nansen casts. The lower accuracy of the STD was used in the following analysis of the data.

At some stations, Nansen samples were analysed for dissolved oxygen and nutrients using a modified Winkler technique and an Autoanalyzer, respectively. Accuracy of the dissolved oxygen determination was estimated to be $\pm$ 0.25 ml/ℓ, and of the nutrients about $\pm$ 10 percent.

The raw data are too voluminous for inclusion in this report. They are available from the National Oceanographic Data Center, Rockville, Maryland 20852.

OCEANOGRAPHIC CONDITIONS

Presentation of the Hydrographic Data

Hydrographic data collected from Prince William Sound during 1971 to 1974 are presented below as:

1. Vertical sections showing the distributions of temperature, salinity and density. The longitudinal section is aligned in a north-south direction along eastern Prince William Sound and is situated so as to include both the deep basin in the central eastern portion and the channel through Hinchinbrook Entrance to the Gulf of Alaska. Shorter sections at right angles to this north-south section are also presented and were selected to show details in the distributions.

2. Plan views showing the surface distributions of temperature and salinity during each cruise to the region.

3. Time series of temperature and salinity data from two stations in the central portion of the Sound.

It is apparent from the station locations (Fig. 3) that it would have been possible to construct more cross-sections and vertical profiles than are presented. Analysis of the data indicated, however, that no additional information would have been gained by the inclusion of additional sections.

It should be noted that occupation of the stations along many of the sections encompassed a long enough period of time so that appreciable portions of a tidal cycle were spanned during the sampling. Analysis of the data has suggested than any noise introduced by tidal motions is negligible compared to larger-scale, long-term (e.g. seasonal) variations. This is to be expected in light of the large physical size of the area and its large volume of water relative to the tidal prism. Tidal motions will therefore be neglected in the discussions which follow, except inasmuch as they may explain anomalous details.

Time series plots of temperature and salinity from 1971 to 1973 were constructed using two separate stations which were in close geographical proximity to each other. The series is broken into two portions as each portion presents data from a separate station; they may be regarded, however, as a single continuous series due to the proximity of the stations.

The Distribution of Temperature

The temperature distribution in Prince William Sound is presented as vertical sections, surface temperature distributions and time series (Figs. 4-28). In order to simplify presentation and discussion of a large quantity of data, these will be covered by season.

The distribution of temperature during winter

Minimum water temperatures occurred, relative to other seasons, during winter 1972 and 1973. It should be noted that winter is defined as the December to March period here; oceanographic winter, identified by minimum water temperatures, lags climatological winter by 2 to 3 months due to the time required for the water to respond to surface cooling.

It was impossible to trace in detail the development of low water temperatures during winter 1972 because no data were obtained prior to March, at which time the low temperatures were already well-developed (Figs. 4-8) with minima down to 0.4°C (Fig 4 station 011). It is possible, however, to interpolate from the time series observed in central Prince William Sound (Figs. 9 and 10), and thus trace the time development of cooling and vertical mixing leading to the March 1972 temperature structure.

Temperatures ranged from below 2°C near the surface to as high as about 4.7°C near the bottom at that time. These temperatures, low relative to the following winter (see below), may have been due in part to the severity of the 1972 winter relative to that of 1973 (personal observations and U.S. Weather Bureau Records), with subsequent strong cooling. The surface temperatures were lowest (<1°C) in the southern Sound, and tended to increase to the north and west reaching values above 2.4°C in the northern portion of the Sound (Fig. 11).

Development of low temperatures due to cooling was also observed during December 1972 to March 1973 (Figs. 12-19). At the onset of strong cooling in December a strong temperature maximum (about 6.5°C) present at about 75 m represented the remnant of the preceding summer's warm surface layer (Fig. 12). A deeper minimum (about 3.8°C) at 250 m may have represented either a remant of the preceding winter's cold strata or an advective addition of water from the Gulf of Alaska. By January 1973 (Fig. 13) cooling had progressed appreciably, and the maximum temperature was lower than in December (about 4.5°C) and deeper (200-250 m). The deep temperature maximum present in December was no longer evident. By March (Figs. 14-16), the cooling had progressed to the maximum extent observed in 1973; temperatures at that time increased monotonically with depth from 2 to 3°C at the surface to about 4.3°C at the greatest depths observed Thermohaline convection had created vertical uniformity down to depths of 30 to 50 m

The sections across the Sound during March 1973 (Figs. 15 and 16) indicate that appreciable cross-Sound structure was present, particularly in Hinchinbrook Entrance (Fig 15) where the strong east-west slope of the 3°C isotherm may have been related to the flow. The cross-section slightly farther north (Fig. 16) indicated a tendency for isotherms to rise toward a central part of the Sound, which was the manifestation of a domed structure present on the north-south section during March 1972 and during the entire winter of 1973 (see below).

A pronounced upward bowing of the isotherms in the central portion of the Sound occurred during winter, as best exemplified by the 2°C isotherm in March 1972 (Fig 4). This feature, best shown by the 4°C isotherm during January (Fig. 13), was less well-developed during winter 1973.

Development of the domed structure was also evident in the surface temperature distributions (Figs. 11 and 17-19) as a maximum temperature region in the eastern central Sound. Its more prominent development during 1972 than during 1973 may have been related to the severity of the winter, i.e. vertical convection and possibly wind mixing. Water south of the structure was generally of lower temperature and less vertically stratified than that to the north, suggesting a possible relation to coastal upwelling in the Gulf of Alaska This will be discussed below in more detail.

The intensity of vertical mixing as evidenced by vertical homogeneity was observed to very tremendously from place to place within the Sound. During the winter of 1972 for example, the water column within Port Valdez had mixed completely to the bottom by March, a depth of about 230 m (Muench and Nebert 1973). Mixing to this depth was not observed anywhere else within the Sound, although data were available. The reason for these regional variations in vertical mixing may rest in local climatic conditions. Cooling and winds within Port Valdez during winter 1972 might well have been more severe than elsewhere in the Sound, although weather data are insufficient to test this hypothesis. It is noteworthy that convection in Port Valdez during winter 1973 did not extend significantly deeper than elsewhere in Prince William Sound (unpublished data).

The distribution of temperature during spring

The spring periods during these years are represented by June, 1972 and May, 1973 and 1974 (Figs. 20-24). During this period the water column was characterized by warming of the near-surface layers, resulting in surface temperatures as high as about 11.8°C by June 1972 (Fig. 20) and up to 5 to 6°C during May 1973 and 1974 (Figs. 22-24). The remnant of the preceding winter's cold convective layers occurred in each case at 100 to 150 m depth. The lowest spring temperatures observed during the spring within this cold core (as low as 2.37°C) occurred during June 1972 (Fig. 20), probably due to the severity of the winter of 1972. Cold core temperature minima during May 1973 and 1974 were higher (2.76°C and 3.00°C, respectively), reflecting the milder winters even though the 1973 and 1974 data were obtained a month earlier in the warming season than the 1972 data.

Maximum surface warming would be expected to occur during June, since this month has generally lower cloud cover at Valdez than other spring-summer months and the sun is at its maximum elevation above the horizon. The ensuing high insolation was reflected in the relatively high surface temperatures (11.84°C at station 107) observed during June 1972 (Fig. 20).

Surface temperatures were higher in the eastern central and northeastern portion of the Sound than in the southern part near Hinchinbrook Entrance (Figs. 21 and 23). This may have reflected longer exposure of the water there to solar warming than near the Entrance. The temperature time series (Figs. 9 and 10), clearly indicates that temperatures increased in the near-surface waters down to about 100 m during the spring. Little variation was observed in deeper water temperatures during this period.

The distribution of temperature during summer

Oceanographic summer, with maximum temperatures in the water column, occurs during August to September in southcentral Alaska. Summer data sufficient for construction of a vertical section were available only during September 1972; these indicated that maximum temperatures relative to those observed at other times of year occurred throughout the water column (Figs. 25-28). Surface temperatures were on the order of 12°C, with temperatures decreasing to a subsurface minimum of about 3°C at 150 m. Temperatures then increased with depth from the minimum to the bottom, with bottom temperatures above 4°C. The greatest observed temperature stratification during this period occurred in the upper 75 m. The strength of the stratification decreased toward Hinchinbrook Entrance, possibly due to the presence of tidal mixing there. This did not, however, result in appreciable lowering of surface temperatures near Hinchinbrook Entrance.

Surface temperatures were maximum (> 12.5°C) in the eastern central portion of the Sound (Fig. 28). A tongue of lower temperature (< 10°C) water in the northern portion was probably due to presence of the lower temperature fresh water plume from the Columbia Glacier system. Surface temperatures in Hinchinbrook Entrance were only slightly lower (11.8°C) than farther north.

The time series (Figs. 9 and 10) indicates that warming of the water column, particularly in the upper layers, was still occurring during early September 1972 and 1973; maximum temperatures occurred in mid-late September just prior to the onset of fall cooling. Deep water temperatures showed little variation during the summer, however.

The distribution of temperature during autumn

Although data gathered during the period from September to December were insufficient to construct cross-sections, conditions may be inferred from the temperature distributions at either end of this period and from the time series (Figs. 9 and 10). With the cessation of appreciable solar warming in September, there followed a sharp decrease in surface temperatures which had resulted, by December, in the isolation of a subsurface warm layer representing a remnant of the preceding summer's warm surface water. The deeper cold core had higher minimum temperatures in December than during September. This was probably due in part to the continual diffusion of heat from overlying and underlying waters into this core, and possibly showed the effects of horizontal advection of water.

The temperature time series plots (Fig. 9 and 10) indicate clearly the decrease in surface temperature during the autumn and suggest a downward diffusion of heat from the near-surface layers as shown by the 5°C isotherm. Temperature changes in the deep water were small, relative to changes in the surface waters, during this season.

The Distribution of Salinity

The distribution of salinity is illustrated below by means of cross-sections. surface views and time series (Figs. 29-53). Like temperature, salinity serves as a useful indicator of water sources and sinks and of mixing.

The distribution of salinity during winter

Salinities attained maximum surface values (about $32^{0}/oo$) and minimum vertical subsurface stratification throughout the water column during March 1972 and January to March 1973 (Figs. 29-38). Development of this winter salinity distribution is also clearly indicated on the 1971 to 1973 time series (Figs. 39 and 40). The time series indicates a tendency for deep water salinity to decrease slightly over the winter, as exemplified by the downward vertical migration of the $32.5^{0}/oo$ isohaline.

The vertical sections for March and December 1972 and January to March 1973 each indicate that a pronounced upward bowing of the isohalines occurred in the eastern central portion of the Sound and was centered at about station 13 (Figs. 29 and 34-36). This was also reflected by high surface salinities in that region (Figs. 41-44). This hump in the isohalines coincided with that in the isotherms (see The distribution of temperature during winter) and was even more pronounced. The cross-section through station 55 (Fig. 33) indicated evidence of the structure in a cross-sound direction. It was not clearly defined in a cross-sound direction, however, by the remaining cross-sections (Figs. 30-32), suggesting a complex configuration.

The general salinity increase observed during winter may be attributed to a cessation of freshwater input into the system coupled with advective fluxes through Hinchinbrook Entrance. Appreciable ice formation has never been observed in Prince William Sound except in isolated locales such as the head of Port Valdez, where freshwater input forms a brackish surface layer which may freeze (personal observation). Salt exclusion from ice formation is, therefore, not a likely contributing agency toward salinity increase in the water column.

The distribution of salinity during spring

The spring salinity distributions are represented by cross-sections showing data from June 1972, May 1973 and May 1974 (Figs. 45-47), and by surface distributions during June 1972 and May 1973 (Figs. 48 and 49). Data were insufficient for construction of a plan view for May 1974.

By June 1972, fresh water addition had lowered surface salinities down to below $25^{o}/oo$, establishing a strong vertical salinity gradient in the upper 15 to 20 m (Fig. 45) and strong horizontal gradients in surface salinity across the entire Sound (Fig. 48). Development of the vertical features with time can be seen in the time series from the central Sound (Figs. 39 and 40). There was a tendency for the surface salinity to be minimum in the eastern portion of the Sound, while maximum salinities ($> 30.4^{o}/oo$) occurred at the central location where both isotherms and isohalines had been observed to bow upwards during the winter (Fig. 48).

Salinities at mid-depths (100-200 m) were generally somewhat lower in May 1973 than in May 1974, as indicated by the depth of the $32^{o}/oo$ isohaline (Figs. 46 and 47). Sufficient freshwater runoff had apparently not accumulated to have lowered the near-surface salinities appreciably; a plume-like surface feature having salinities below $30.2^{o}/oo$ in the northern Sound during May 1973 was probably due to runoff from the Columbia Glacier and Port Valdez systems (Fig. 49). During May 1973, the surface $31.4^{o}/oo$ isohaline delineated the area occupied by the dome-like subsurface winter structure in the central Sound, but not in such a pronounced way as it had done in June 1972.

The salinity time series suggests, in general, that the May to June (spring) period is one when surface salinities decrease while deep salinities, as exemplified by the $32.5^{o}/oo$ isohaline, increase appreciably (Figs. 39 and 40). This will be discussed further below as it relates to regional circulation.

The distribution of salinity during summmer

Summer is represented by the vertical sections for September 1972 (Figs. 50-52), the surface salinity distribution (Fig. 53) and in general by the time series (Figs. 39 and 40). The layers above about 100 m exhibited their lowest observed salinities during summer ($< 32^{o}/oo$), while the salinity at about 250 m was maximum during this period ($> 32.5^{o}/oo$); this was a manifestation of surface decrease and coincident deep increase in salinity which had been occurring throughout the spring (see above section on The distribution of salinity during spring). The vertical sections indicated the most horizontally homogeneous distribution of salinity observed during the study, particularly in the deep water as exemplified by the $32.5^{o}/oo$ isohaline (Figs. 50-52). The north-south variation in temperature stratification (see above section on The distribution of temperature during summer) was not reflected in the salinities.

The vertical salinity gradient in the upper 50 m reached a maximum during this period, due to the summer's near-surface accumulation of fresh water, and suggests that little vertical mixing was occurring in this layer (Figs. 39, 40 and 50-52). Surface salinities (Fig. 53) were lowest of any observed during the study (24-26^{0}/oo), and freshwater input from the Columbia Glacier and Port Valdez systems was evident in the low salinity plume extending southward from the northern part of the Sound, bounded by the 25^{0}/oo isohaline. This is probably a common feature during the summer due to the freshwater inputs concentrated in the northeastern portion of the Sound.

The distribution of salinity during autumn

Since data obtained from Prince William Sound during the autumn (September-December) were insufficient to construct vertical sections, salinity variations were obtained by interpolation from the time series plots (Figs. 39 and 40). Salinity generally appears to have increased during this period in the upper 100 m, while salinity of the deeper water (below 100 m) underwent a gradual decrease as shown by the downward migration of the 32.0^{0}/oo and 32.5^{0}/oo isohalines.

The Distribution of Density (σ_t)

Due to the nonlinear nature of the equation of state for seawater, density at the low temperatures encountered in Prince William Sound is a function primarily of the salinity. The density distributions (Figs. 54-69) are therefore qualitatively similar to the salinity distributions and will be discussed in less detail here than temperature or salinity. They are of interest primarily as they affect the internal mass distribution, hence, the dynamics of water movements.

The distribution of density during winter

Density reached maximum values, during the winter, of about 25.3 to 26.0 (Figs. 54-63). The variations during the winter were most pronounced in the upper 50 to 100 m, and may be seen in the December 1972 to March 1973 progression when surface densities increased from about 24.5 to 25.3, with the accompanying development of a near-surface mixed layer extending down to about 50 m. This density increase may be explained qualitatively as due to winter cooling coupled with a cessation of freshwater input and subsequent near-surface salinity increase.

Densities throughout the water column were slightly lower in March 1973 (Fig. 61) than during March 1972 (Fig. 54), probably due to the relative harshness of the winter of 1972.

The upward bowing of isopycnals in the central Sound during the winter, most pronounced during March 1972, coincided with similar bowing of the isotherms and isohalines but was displaced somewhat southward. The internal mass distribution was therefore affected by this feature, centered about stations 12 and 13, it is probably a regular winter feature, and may be related to a cyclonic circulation cell in the eastern central Sound. This will be discussed further below.

The distribution of density during spring

During the spring, as represented by June 1972 (Fig. 64) and May 1973 and 1974 (Figs. 65 and 66), there was a general tendency for density of the near-surface layers (above about 100 m) to decrease due to a combination of warming and freshwater input (leading to a vertical density stratification in those layers significantly greater than observed during the winter). Densities near the bottom had decreased from their winter values of more than 26.0 to about 26.0 or slightly less, probably due to downward diffusion of heat, upward diffusion of salt or an advective renewal of water from Hinchinbrook Entrance.

The isocpycnal surfaces were relatively horizontal except during May 1974 when some upward bowing was present centered at station 13. This may have been the remnant of a structure similar to those observed during winter 1972 and 1973.

The distribution of density during summer 1972

By September 1972 (Figs. 67-69) the density had reached its minimum values in the portion of the water column above about 100 m while the density of the deeper water had increased slightly to more than 26, coincident with the deep salinity increase. Since diffusion would have accounted only for a decrease in density during the June to September 1972 period, some advective mechanisms must have renewed the deep water at least in part. Surface densities down nearly to 12 at station 107 indicated the presence of the freshwater runoff entering the system via Port Valdez (Fig. 66). The isopycnals were, as during June 1972 and May 1973, relatively flat.

The distribution of density during autumn

As for temperature and salinity, no data were available for the autumn period. Interpolating between the summer and winter observations, density underwent a general increase in the upper layers as solar warming and freshwater input ceased. Density in the deeper layers did not change appreciably during this period.

DISCUSSION

The purpose of this section is to attempt to explain qualitatively the observed distribution of temperature and salinity in terms of circulation and mixing processes within the Sound. This will be done primarily using conservation of heat and salt, but will rely to some degree on general knowledge concerning regional climate and tides.

Mixing Processes

Mixing processes may be divided for our purposes onto two general categories; mixing which derives energy from the mean water motion via turbulence, and mixing which derives energy from buoyant forces, i.e., thermohaline convection. The temperature and salinity distributions suggest that both types are present in Prince William Sound.

Thermohaline convection has been observed during the winter in Prince William Sound in the near-surface waters and, due to the severe climate, is probably a routine occurrence. This convection is due to atmospheric cooling of the surface water coupled with cessation of freshwater input, which allows the surface salinity to increase as saline marine water is advected inward from the Gulf of Alaska. Density of the surface water can thus be increased to the point where it is denser than the underlying water and will mix vertically. Conversely, presence of fresh water at the surface during summer tends to inhibit such mixing.

In other high latitude regions (e.g. the Bering Sea shelf) formation of surface ice may exclude salt into the underlying water and increase its density, thus contributing to the vertical convective mixing. Formation of sea ice has not been observed in Prince William Sound except in small isolated locales such as the heads of bays. Salt exclusion due to ice formation is therefore not reckoned to be a significant factor in affecting thermohaline mixing.

In addition to thermohaline mixing, some vertical mixing of the near-surface layers may occur due to wind energy. Since this energy input tends to be maximum during storms when cooling and hence also thermohaline mixing would be maximum, it is impossible to separate the two. Knowledge of regional heat fluxes and of the general partition of wind energy as it relates to vertical mixing are generally poorly understood. It is therefore impossible to quantitatively discuss the factors involved in such near-surface mixing.

The effects of this vertical mixing were reflected in the winter (December-March) distributions of temperature, salinity and density (see Oceanographic Conditions). This mixing generally extended down to depths of 30 to 50 m in the central portion of the Sound and exhibited no apparent pattern of mixed layer depth variations. Vertical mixing within Port Valdez has been observed to extend down to about 230 m (the bottom) (Muench and Nebert 1973). This occurred during the unusually severe winter of 1972. During the following winter (1973) mixing occurred only down to about 50 m, or the same depths as for the remainder of the Sound (unpublished data). The reasons for these regional variations are uncertain. They are probably related to local climatic variations coupled with varying advective replacement of the surface layers.

The distributions of temperature and salinity are also affected throughout the water column by turbulent diffusion which derives its energy from the water motion. Turbulent diffusion processes are generally difficult to identify, since without adequate measurements it is impossible to separate them from advective processes related to water motion. Therefore, diffusive processes will be discussed here only in a qualitative way.

Tides provide a significant source of energy for mixing in an estuarine system. The tides within Prince William Sound have ranges on the order of 3 to 4 m; tidal currents through Hinchinbrook Entrance may be as high as 2 to 3 kts (ship drift observations). The concentration of tidal energy near Hinchinbrook Entrance may be related to the observation that during several of the cruises there was lower stratification there than elsewhere in the Sound (See Oceanographic Conditions). Lowered stratification might have been a reflection of vertical mixing due to the strong tidal currents through the Entrance. That such lowered stratification was not always present might be explained by a dependence of this feature upon the phase of the tide; mixing could be more or less pronounced on flood or ebb tide as the currents might vary in intensity. This possible dependence remains unresolvable because most of the longitudinal sections span more than one tidal cycle.

Vertical diffusion within the Sound was evidenced by the downward migration and concurrent decrease in magnitude of temperature maxima and minima layers resulting from surface heating and cooling. This migration was particularly well-documented during winter 1972 and 1973. A warm surface layer forms during the summer which, with the onset of surface cooling in the fall, is isolated as a warm core by the cold surface layer resulting from cooling. As surface cooling continues, the cold surface layer thickens and the warm layer progresses downward due to diffusion of heat, while maximum temperatures within the layer continually decrease. Downward migration of the cold layer proceeds similarly when during spring the previous winter's cold surface layer is isolated from the surface by a warm layer. This ensuing layered temperature structure was particularly well-developed during December 1972 as vertically alternating layers of temperature maxima and minima (Fig. 12).

The subsurface temperature and salinity distributions may also be affected by horizontal advection of water. In the absence of direct current measurements it is impossible to judge the significance of these processes other than to state that they do in fact occur (see subsequent section). Typically, the distribution of variables deep within a fjord is controlled by a balance between vertical diffusion as discussed above and horizontal advection (Rattray 1967).

Deep-water Renewal Processes

Features of Prince William Sound bathymetry which are relavent to deep-water renewal are the 400 m deep eastern basin and the 180 m sill just outside Hinchinbrook Entrance (see Geographical and Bathymetrical Description). Montague Strait will be neglected as it may pertain to exchange of deep water with the Gulf of Alaska because it is relatively shallow (about 100 m) and long, with numerous passages branching off. Contributions of Gulf of Alaska water to Prince William Sound via Montague Strait are probably relatively dilute due to mixing with ambient water along the length of the Strait, as opposed to water from Hinchinbrook Entrance which may flow directly into the eastern Sound.

Deep water replenishment in southcentral and southeast Alaskan fjords has been studied by Nebert (1972), Heggie (1973) and Muench *et al.* (1975). This mechanism depends upon annual density variations in the marine source water at sill depth coupled with vertical mixing within the fjord. At that time of the year when source water density is maximum at or above sill depth, this water can flow into the fjord basin and replace the bottom water, whose density has been decreased since the previous renewal by mixing with overlying water. During periods when the source water at sill depth is less than maximum density it may enter the fjord but, rather than replacing the bottom water, will seek its own density level and enter as an advective tongue along that level. Advective renewal of deep and bottom waters may therefore occur during an appreciable proportion of the year, depending upon the source waters and mixing within the fjord itself.

Although few data are available documenting the characteristics of marine source water directly outside Hinchinbrook Entrance, a four-year series of data has been obtained from a station off Resurrection Bay, about 150 km to the west. Since the westerly Alaska Current tends to parallel isobaths along the continental shelf, it would be expected that conditions off Resurrection Bay would closely resemble those off Hinchinbrook Entrance. These data have in fact been used successfully in a study of deep water formation in Russell Fjord, several hundred km to the southeast, along the coast (Muench *et al.* 1975). Accordingly, the temperature and density as represented by time series for these data are assumed to be representative of the source water off Hinchinbrook Entrance (Figs. 70 and 71). A time series for salinity is not presented because it is virtually identical to that for density. Moreover, density is the variable of primary interest in terms of deep water formation.

The temperature time series indicates clearly the effects of winter surface cooling and vertical mixing in the Gulf of Alaska (Fig. 70). Minimum temperatures occurred late during each winter (March) in the upper 180 m of the water column. Lower temperatures ($< 2^{\circ}C$) during 1971 and 1972 than during 1973 and 1974 (2-3°C) reflected the relative harshness of the winters of 1971 and 1972. Maximum annual near-surface temperatures (8-12°C) occurred during the summer (July-October) as a result of surface warming.

Annual variations are also evident on the density time series (Fig. 71), with density maxima occurring in the near-surface waters (0-150 m) during late winter-spring (March-April) and minima occurring during late summer (October). In deeper water (below 150 m) the maxima occurred during October and November. The density variations are due to seasonal temperature and salinity variations, which are a function in turn of annual variations in solar warming and freshwater input, and variations in coastal upwelling due to wind stress in the Gulf of Alaska. Water of maximum density in the 0 to 150 m layer, that which might flow inward over the sill and replace the water in Prince William Sound, therefore occurs during about March and April of each year, while bottom water renewal (180 m) is most likely in October and November.

The annual cycle of density variations in the Gulf of Alaska shelf regions is closely related to wind-driven coastal upwelling (Royer, in press). During winter, the strong easterly winds of the Aleutian Low transport surface waters northward (shoreward). This downwelling flushes the shelf with cold, low salinity water. During summer, the weak westerly winds of the North Pacific High causes a small southerly (offshore) transport of surface waters. This very weak upwelling places warm high salinity water on the shelf off Hinchinbrook Entrance. These tendencies for upwelling and downwelling in the northern Gulf of Alaska have been computed (Bakun 1973) and are graphically presented to indicate the degree of upwelling and downwelling during 1972 to 1974 (Fig. 72).

The hydrographic features observed within Prince William Sound reflected the varying characteristics of the Gulf of Alaska source waters, as may be seen from the temperature and salinity time series (Figs. 9, 10, 39 and 40). The effect appeared most pronounced in the salinity distribution, with a winter decrease in salinity below about 150 m as shown by the downward migration of the $32.5^{o}/oo$ isohaline and a late spring-summer increase as evidenced by upward migration of the same isohaline. This coincided with the occurrence off Hinchinbrook Entrance (inferred from Fig. 71) of low salinity water during the winter and high salinity water during the summer. The salinity fluctuations are correlated to the point where it seems reasonable that at least part of the variation is due to advective inflow of water through Hinchinbrook Entrance. That deep salinity increase occurs at a time, moreover, when the near-surface salinity is decreasing and vice-versa, suggesting that different mechanisms are responsible for deep and near-surface variations.

Temperature variations in the deep water are less pronounced than the salinity variations (Figs. 9 and 10), with annual temperature variations being on the order of $1^{o}C$. During 1971 maximum temperatures ($> 4^{o}C$) occurred during late summer and fall, lagging slightly the presence of warm water in the Gulf of Alaska. During 1972 temperatures increased steadily during this period and did not reach maximum values until winter 1973. This may have been related to the fact that near-surface temperatures in the Gulf of Alaska during 1972 were lower (about $8^{o}C$) than during either 1971 or 1973 (about $12^{o}C$) so that an influx of water may not have caused a true maximum. Downward diffusion of heat from overlying warmer waters might also have an appreciable effect upon deep temperature variations.

Densities in the bottom waters during the winter were of the same order (about 26.0) as just above sill depth in the Gulf, suggesting that these bottom waters may have originated there. By May of both 1973 and 1974 the density of this water had decreased by about 0.1 from slighlty greater than 26.0 to slightly less than 26.0. This variation may have been due to vertical diffusion of heat and salt, advection of lower density water through Hinchinbrook Entrance in agreement with a decreasing density in the Gulf at that time, or most likely some combination of these.

Dissolved oxygen values from deep stations inside Prince William Sound for the period September 1972 to March 1973 were tabulated in an attempt to detect oxygen depletion due to biological consumption, should renewal of the deep water not be occurring. Variations in the deep oxygen proved to be too small to differentiate the effects of mixing and depletion. If deep water replacement were only occurring during one season of the year, however, work in the same area (Hood and Patton 1973) has indicated that the oxygen depletion would be quite noticeable, or on the order of more than 1 ml/ℓ between deep water renewals. The fact that depletion of this magnitude was not observed in Prince William Sound suggests that bottom water renewal may be at least a quasi-continuous process rather than occurring annually at only one time of year.

Circulation within Prince William Sound

In the absence of direct current measurement, the circulation within Prince William Sound can only be discussed in a general, qualtitative sense using the observed distribution of temperature, salinity and density (see Oceanographic Conditions).

The prominent subsurface structural feature observed in the sound was the dome-like rise in the isolines of salinity, temperature and density in the central eastern portion. This structure suggests that, particularly during the winter, a cyclonic circulation pattern with a tendency for upwelling was occurring. The surface distributions did in fact show higher salinities and temperatures in the central Sound when the feature was well-developed. Although it seems unlikely that such a gyre would be in geostrophic equlibrium, due to the probable presence of frictional and time-dependent terms, a cyclonic circulation would in fact tend to satisfy the force balance suggested by the isopycnais.

The most pronounced example of a surface distribution which suggested a circulation cell occurred during June and September 1972 when high salinity occurred at the surface in the center of the gyre region (Figs. 48 and 53). The lower surface salinities from Hinchinbrook Entrance probably reflect the influence of the Copper River plume, which enters the Gulf of Alaska upstream from the Entrance. The surface salinity distribution could then be interpreted to indicate a cyclonic flow of water north of Hinchinbrook Entrance, with the salinity becoming lower particularly in the northeast portions of the Sound due to the concentration of freshwater input from Port Valdez and the Columbia Glacier.

The inclination of the isopycnals, as may be related to the strength of the cyclonic circulation, varied considerably from virtually horizontal (during May 1973) to extreme upward bowing (during March 1972) (Figs. 65 and 54). In general, the features appeared most pronounced below the surface during the winter months and were noticeable primarily on the surface temperature and salinity distributions during the summers. These variations might have been due in part to variations in the strength of tidal currents, assuming that the gyre is due to these currents. The seasonality suggests, however, that they may be related to climatic variations as well, possibly through wind stress or thermohaline mixing. Detailed direct measurements of water currents and regional atmospheric parameters would be required to attempt resolving these relationships.

The reason for the presence of such a cyclonic circulation can be speculated upon. Due to the relatively small horizontal extent of the Sound compared to oceanic systems, it seems unlikely that the gyre would be due to wind stress variations. It might be due in part to a Kelvin wave circulation connected with the local tides, which are appreciable (on the order of 3-4 m range, and semidiurnal mixed in nature). A more satisfying explanation would be that the gyre is due to the inertial tendency for water flowing inward through Hinchinbrook Entrance on the flood tide to continue in a straight line north along the eastern edge of the interior basin. The ebb tide would have no specific directional tendency within the Sound, but would tend to drain uniformly. The net effect would be to set up a cyclonic circulation such as that suggested by the temperature, salinity and density distributions. Surface currents through Hinchinbrook Entrance have been observed to be on the order of 2 to 3 kts by ship drift observations on a flood tide; currents of this magnitude would be expected to play a significant role in the dynamics of the regional circulation.

SUMMARY

Prince William Sound is a complex fjord-type estuarine system located off of the northern Gulf of Alaska. It connects with the Gulf via Hinchinbrook Entrance and Montague Strait, having limited access through the archipelagic islands at the east and west. In the simplest sense, the Sound is a system consisting of a 500 m (250 fm) deep basin connected to the Gulf by a channel having a limiting sill depth of about 180 m (90 fm).

Seasonal Variations in Hydrographic Conditions

The distribution of temperature

Minimum surface temperatures of less than 2°C were observed during winter (March) with summer (September) maxima being in excess of 12°C. The vertical temperature structure shows large seasonal variations (< 2°C-12.5°C) in the upper 75 m with much smaller variations (3°C to 6°C) below 75 m. Temperature maximum ( ) and minimum ( ) layers migrated vertically during the year in response to winter cooling and summer warming. A pronounced upward bowing of the isotherms in the central Sound were observed during winter. This domed structure was also evident in the surface temperature distribution as a maximum temperature region in the central Sound.

The distribution of salinity

The salinity of the surface water in Prince William Sound appeared to fluctuate inversely with the seasonal changes in surface temperature. A surface salinity maximum of about 32°/oo was reached in March with a minimum of about 15°/oo in September. The salinity structure showed large variations (25°/oo-32°/oo) in the upper 75 m with much smaller variations (32°/oo-32.8°/oo) below 250 m. In the upper 75 m, the salinity decreased from early spring to late summer and then increased into winter. This is expected since maximum runoff and freshwater input are expected during July and August. Salinity in the deep water increased slightly from June to September and then decreased from September through the winter. In conjunction with the winter isotherms, upward bowing of the isohalines was also observed in the central Sound. High surface salinities were also observed.

The distribution of density (σ_t)

In the cold waters of high latitudes, change of temperature is less effective in changing density than is change of salinity. The discussion of the seasonal variations of salinity can be applied to density. A surface density maximum of about 26.8 was observed in late winter and a minimum of 18.5 in late summer. Surface densities as low as 11.0 were observed near areas of high freshwater input. The vertical density structure showed the same seasonal variations in the upper layer as did salinity. Large seasonal changes (18-25) occurred in the upper 75 m, while below 250 m, density varied only between 25.8 and 26.0. In the upper 75 m, the density decreased from early spring to late summer and then increased into winter. As with salinity, the density of the water in the deep basin increased slightly during summer and early fall, but decreased during the winter.

Circulation and Mixing

An attempt is made to explain qualitatively the observed distribution of temperature and salinity in terms of circulation and mixing processes within Prince William Sound. This is done using conservation of heat and salt and general knowledge concerning regional climate and tides.

Mixing processes

The temperature and salinity distributions suggest that both vertical diffusion and thermohaline convection were present. Thermohaline convection was evident during the winter in the upper 30 to 50 m. Due to the severe climate, it is probably a routine occurrence. This convection is due to atmospheric cooling of the surface water coupled with cessation of freshwater input, which allows the surface density to increase as saline water is advected inward from the Gulf of Alaska. Occurrence of vertical diffusion within the Sound was evidenced by the downward migration and concurrent decrease in magnitude of temperature maxima and minima layers resulting from surface heating and cooling.

Deep-water renewal processes

Deep-water renewal appears to be at least a quasi-continuous process, rather than one occurring annually at only one time of year. Features of the bathymetry which are relevant to deep-water renewal are the 500 m deep eastern basin and the 180 m sill outside Hinchinbrook Entrance. The character of the marine source water between 150 to 200 m in the Gulf is the primary factor influencing deep water renewal. Density time series measurements indicated that the marine source water was more dense than deep basin water throughout the year except during late winter. The greatest density difference occurred in October and November when deep water renewal is generally most likely.

Circulation within Prince William Sound

The prominent subsurface structural feature observed in the Sound was the dome-like rise in the isolines of salinity, temperature and density in the central eastern portion. This structure suggests, particularly during winter, that a cyclonic circulation pattern with a tendency for upwelling was occurring. The surface distributions did in fact show higher salinities and temperatures in the central Sound when the feature was well-developed. Such a cyclonic circulation would tend to satisfy the force balance suggested by the isopycnals.

The reason for the presence of such a cyclonic circulation can be speculated upon. The gyre may be due to the inertial tendency for water flowing inward through Hinchinbrook Entrance on the flood tide to continue in a straight line north along the eastern edge of the interior basin. The ebb tide would have no specific directional tendency and the net effect would be to set up a cyclonic circulation.

REFERENCES

Bakun, Andrew. 1973. Coastal upwelling indices: West Coast of North America. NOAA Technical Report NMFS SSRF-671.

Carlson, R. F., J. Wagner, C. W. Hartman and R. S. Murphy. 1969. Freshwater studies: Baseline data survey for Valdez pipeline terminal environmental data study, D. W. Hood, ed. Institute of Marine Science Report R69-17, University of Alaska, Fairbanks, pp 7-41.

Gade, Herman G. 1970. Hydrographic investigations in the Oslofjord: A study of water circulation and exchange processes. Geophysical Institute, University of Bergan, Report 24, Norway.

Heggie, D. T. 1973. Annual flushing of Resurrection Bay: An Alaskan fjord estuary. Presented at fall 1973 AGU meeting (abstract).

Hood, D. W. and C. J. Patton. 1973. Chemical oceanography *In* Port Valdez environmental baseline study. Institute of Marine Science Occasional Publication No. 3, University of Alaska, Fairbanks, pp 199-221.

McAlister, W. B., M. Rattray and C. A. Barnes. 1959. The dynamics of a fjord estuary: Silver Bay, Alaska. UWDO Rech. Report No. 62.

Muench, R. D. and D. L. Nebert. 1973. Physical oceanography. *In* Port Valdez environmental baseline study. Institute of Marine Science Occasional Publication No. 3, University of Alaska, Fairbanks, pp 101-149.

Muench, R. D., W. S. Reeburgh and R. T. Cooney. 1975. Oceanographic conditions during 1973 in Russell Fjord, Alaska (submitted).

Nebert, D. L. 1972. A proposed circulation model for Endicott Arm: an Alaskan fjord. University of Alaska, M.S. Thesis, 90 p.

Pickard, G. L. 1967. Some oceanographic characteristics of the larger inlets of southeast Alaska. *J. Fish. Res. Bd. Canada* 24(7):1475-1506.

Pritchard, D. W. 1967. What is an estuary? Physical viewpoint. *In* ESTUARIES. AAAS, Washington, D.C. pp 3-5.

Rattray, M. 1967. Some aspects of the dynamics of circulation in fjords. *In* ESTUARIES. AAAS, Washington, D.C. pp 52-62.

Rattray, M. and D. V. Hansen. 1962. A similarity solution for circulation in an estuary. *J. Mar. Res.* 20(2):121-133.

Royer, T. C. 1975. Seasonal variations of surface waters in the northern Gulf of Alaska. *Deep Sea Research* (in press).

Saelen, O. H. 1967. Some features of the hydrography of Norwegian fjords. *In* ESTUARIES. AAAS. Washington, D.C. pp 63-70.

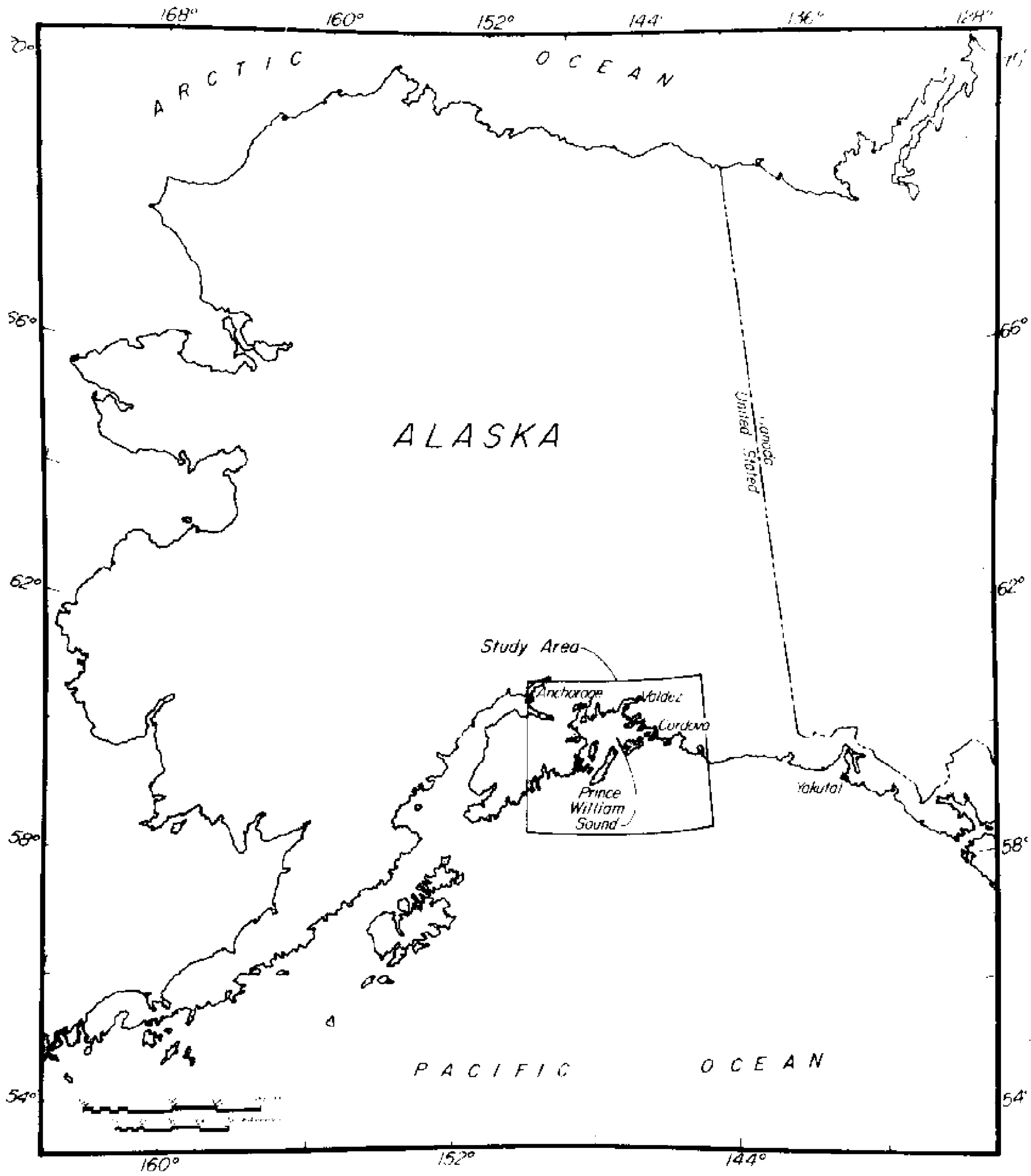

Figure 1. Geographical location of the Prince William Sound region.

Figure 2. Bathymetry of the Prince William Sound basin.

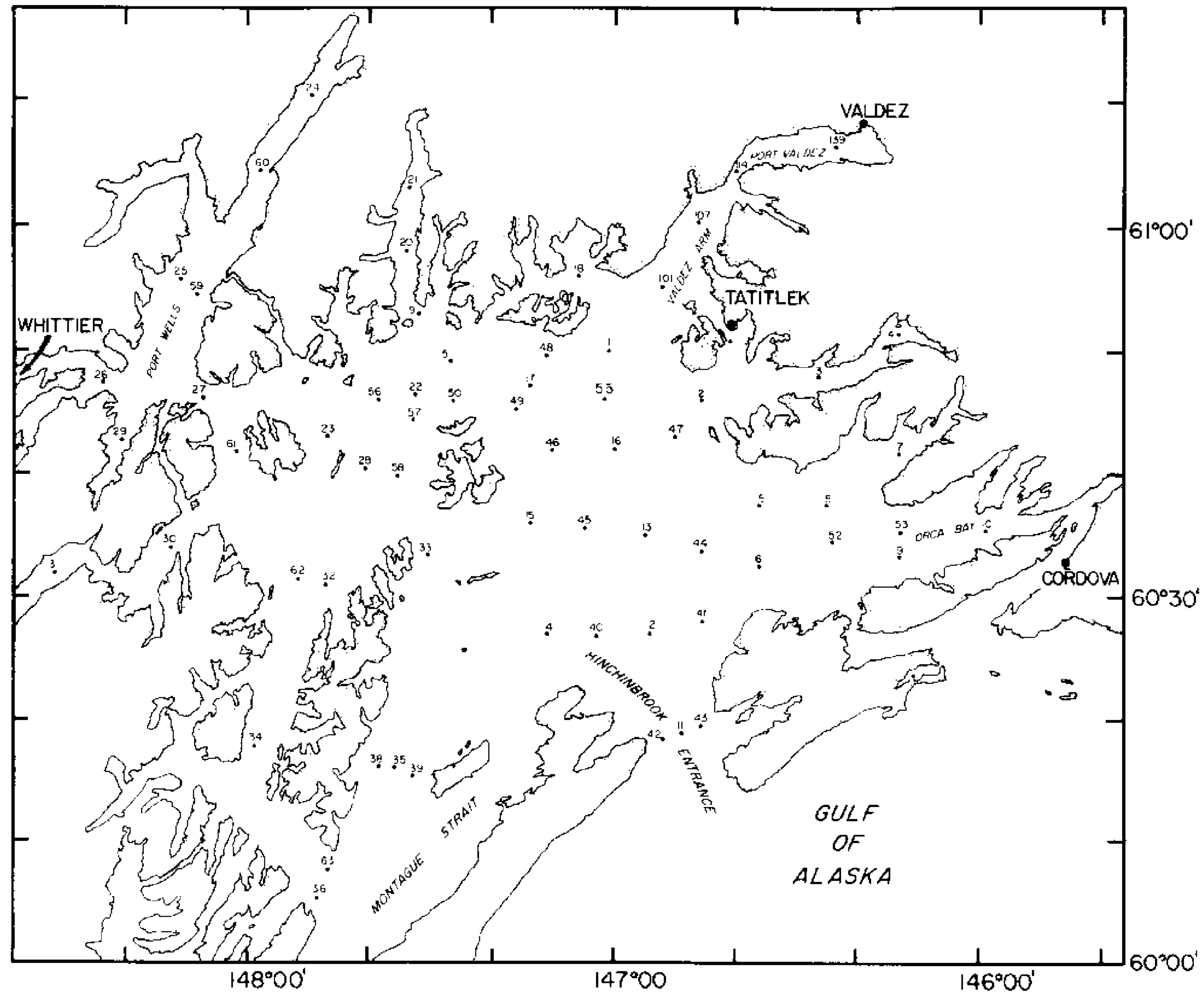

Figure 3. Location of oceanographic stations.

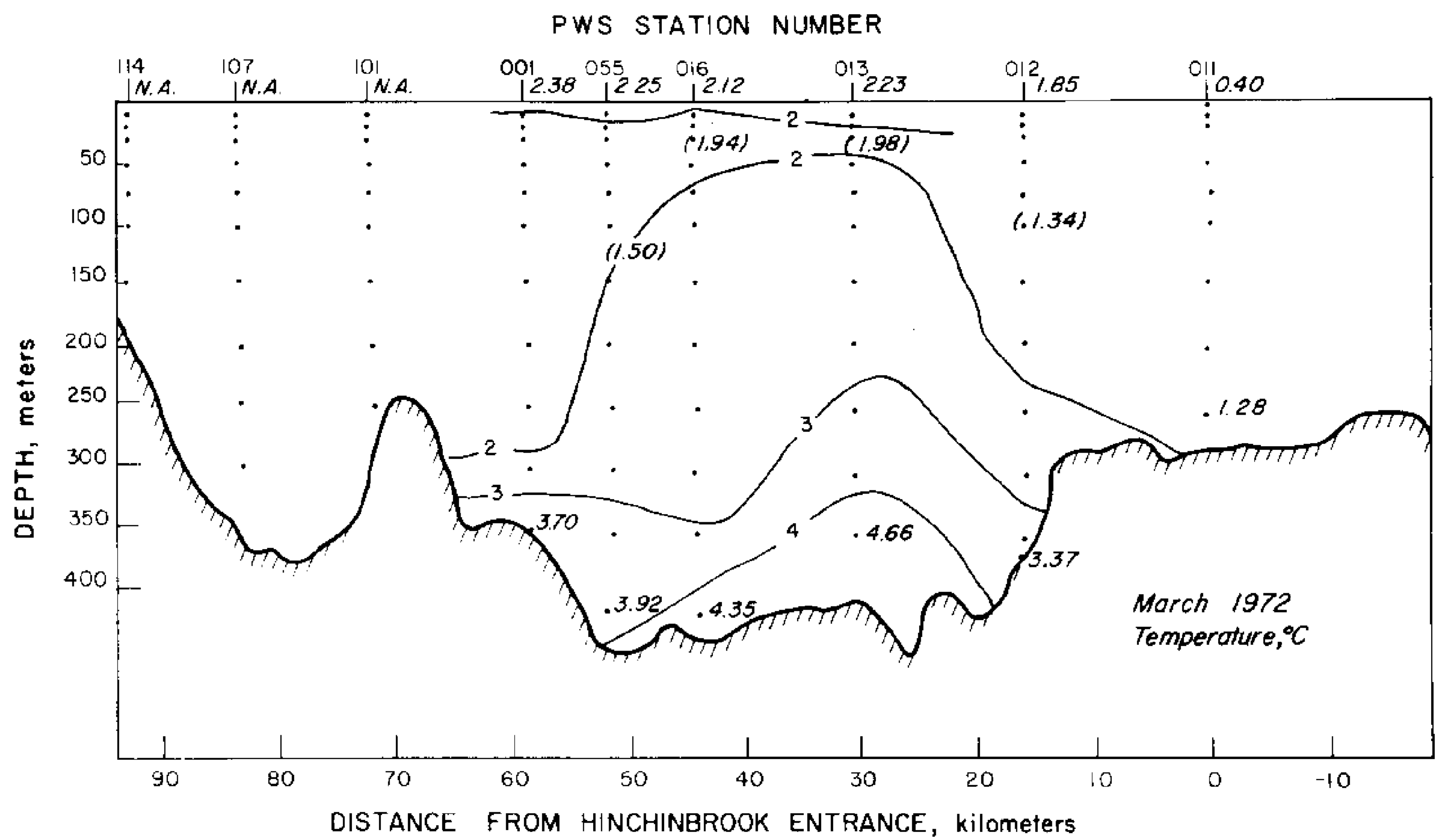

Figure 4. Vertical distribution of temperature in the longitudinal section, March 1972.

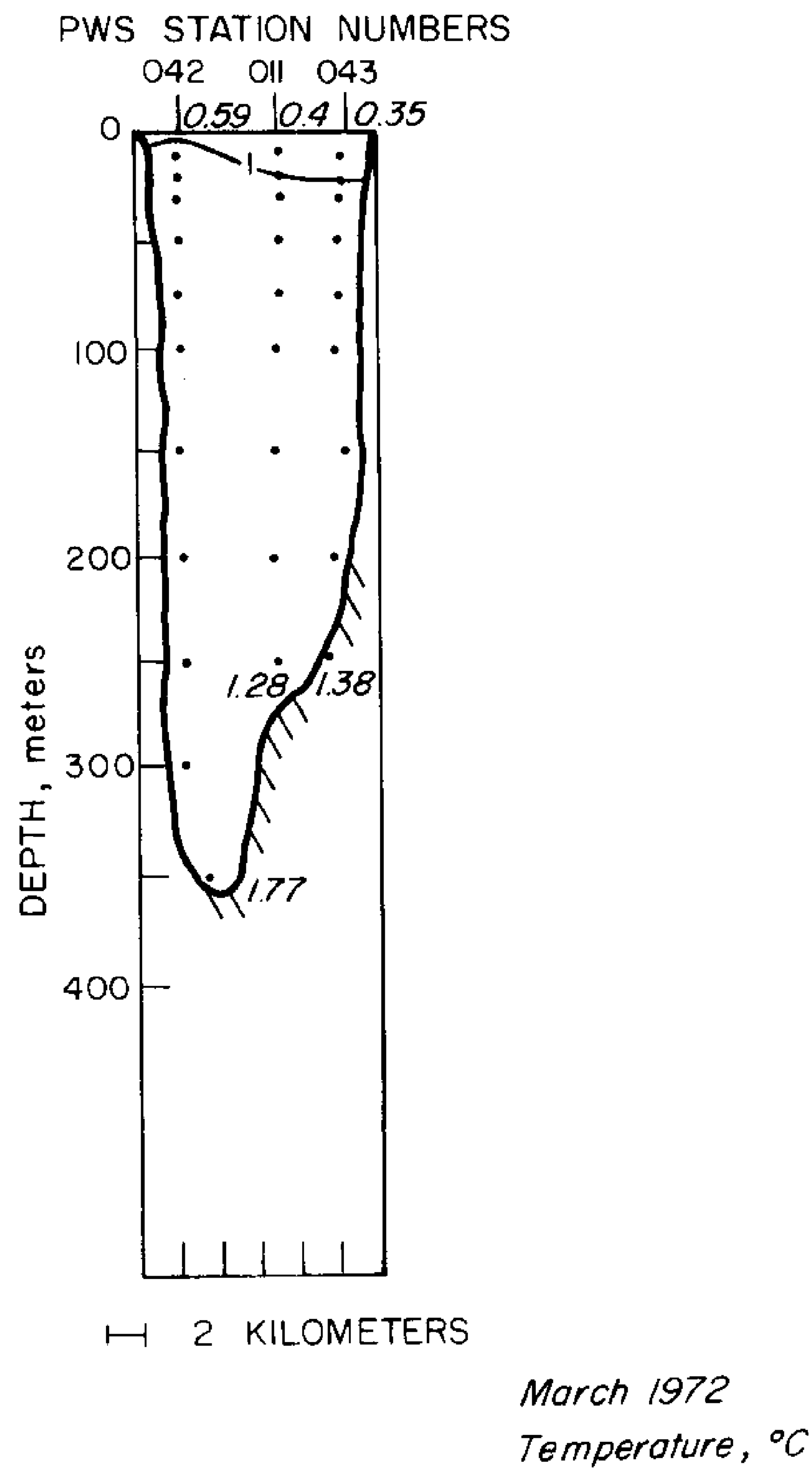

Figure 5. Vertical distribution of temperature in cross-section I, March 1972.

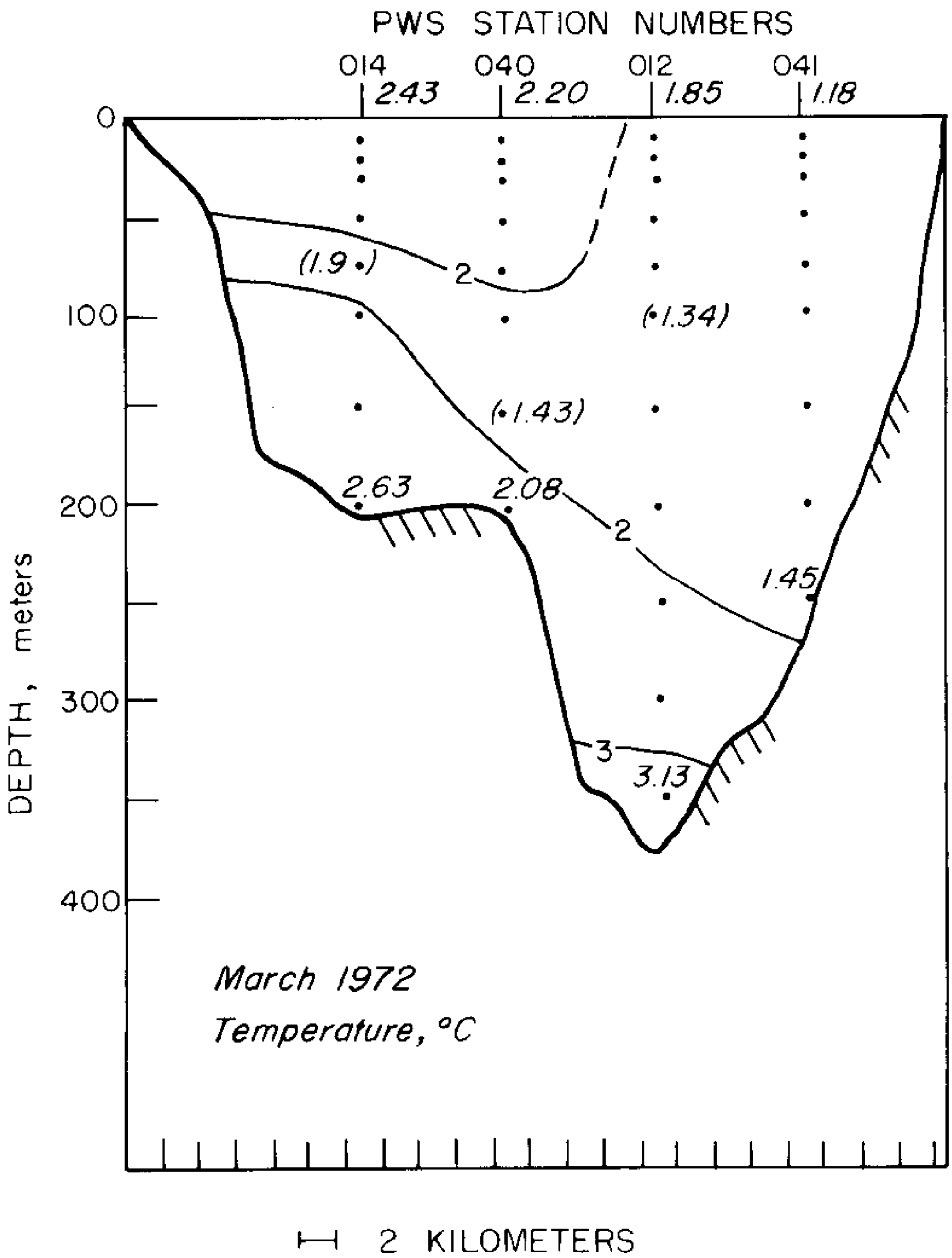

Figure 6. Vertical distribution of temperature in cross-section II, March 1972.

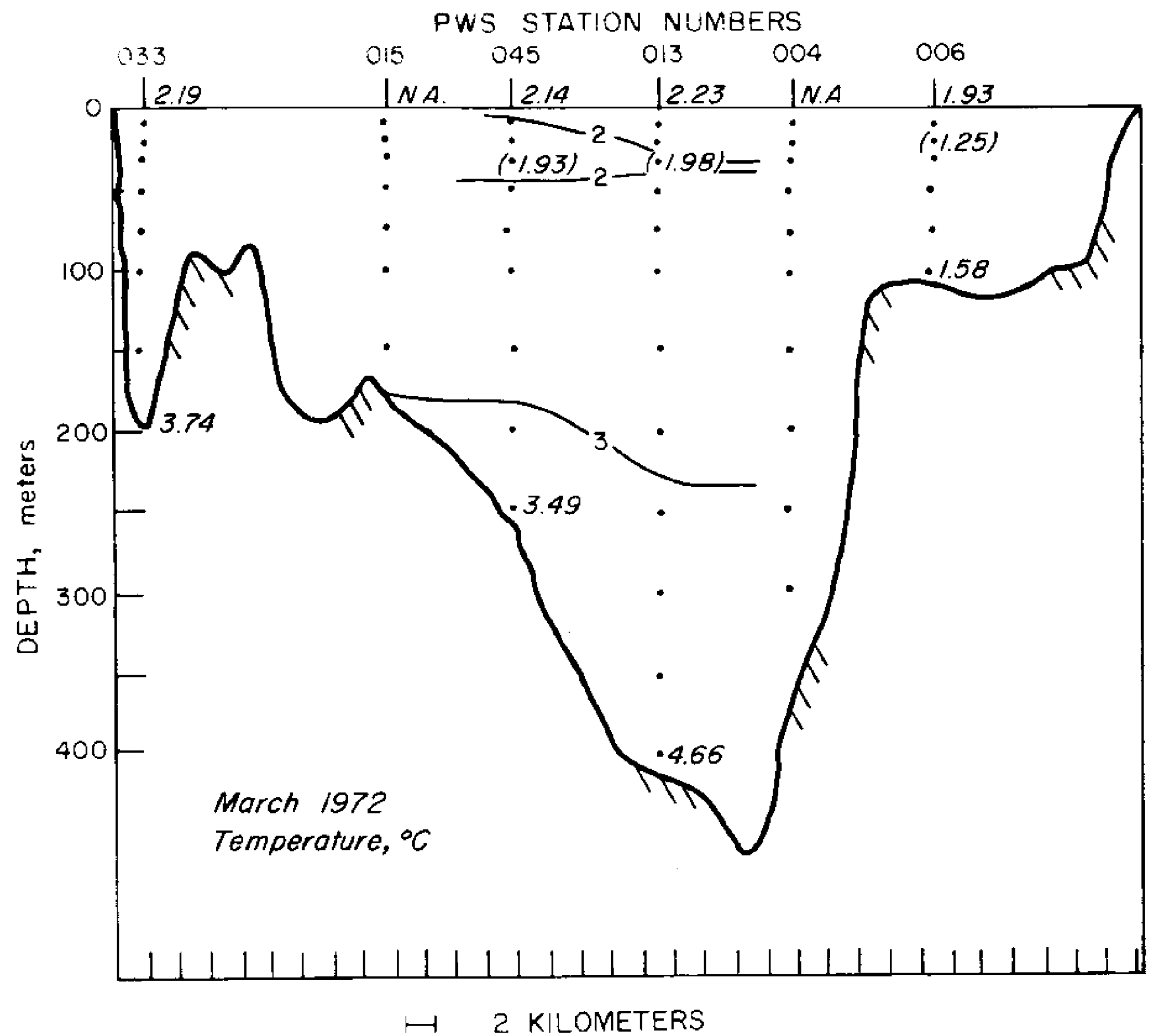

Figure 7. Vertical distribution of temperature in cross-section III, March 1972.

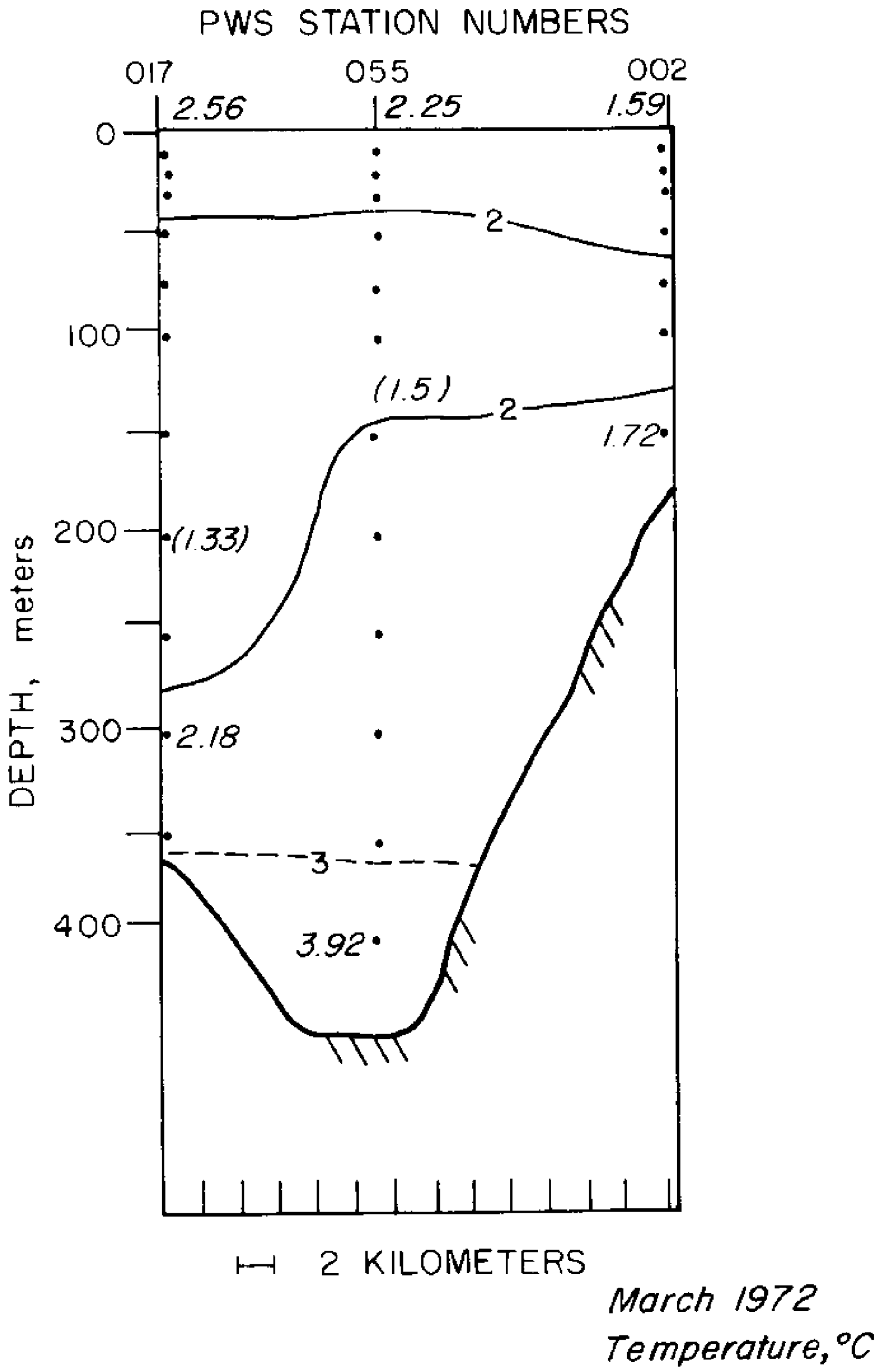

Figure 8. Vertical distribution of temperature in cross-section V, March 1972.

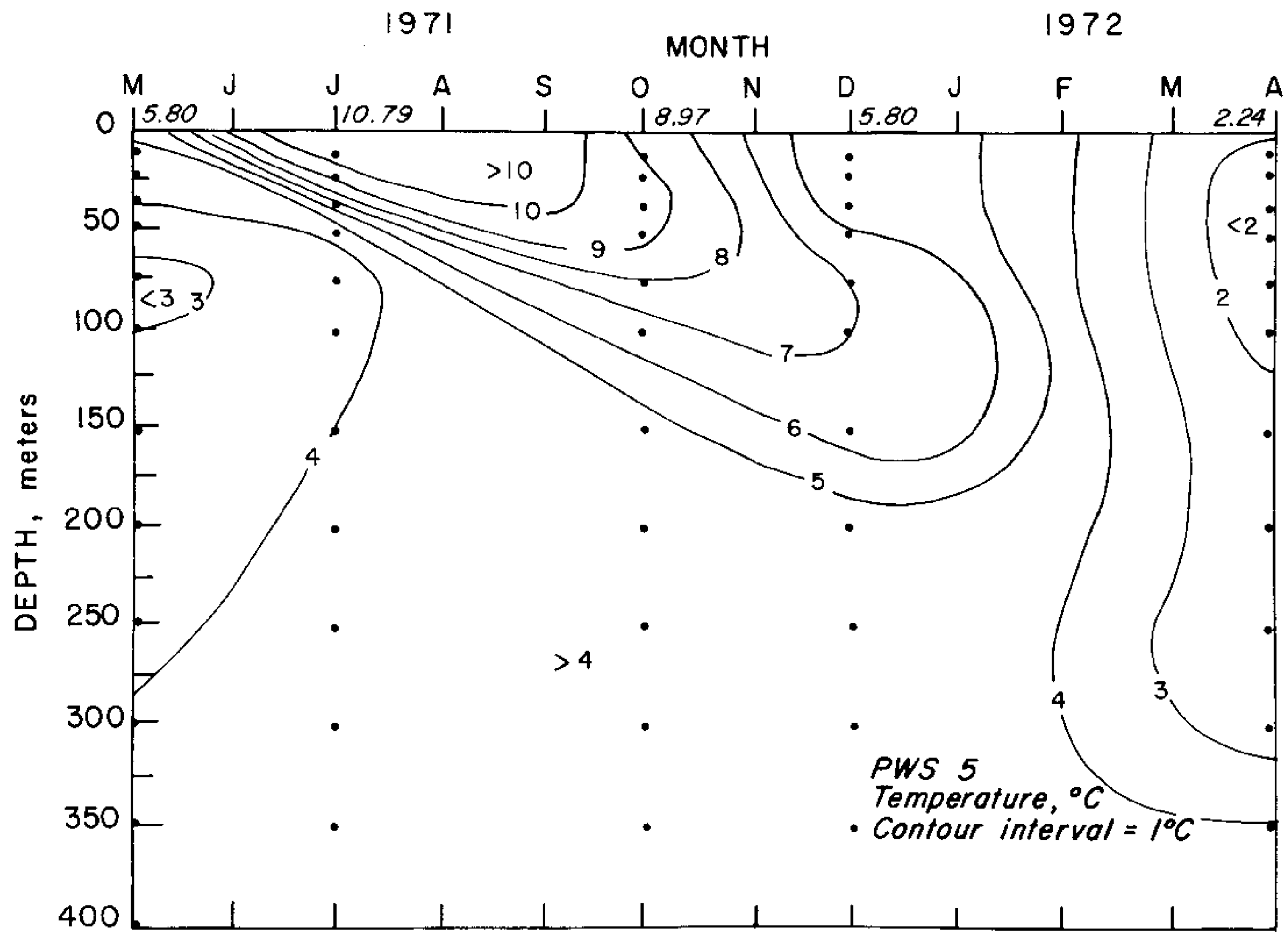

Figure 9. Time series of temperature at PWS 5 from May 1971 to April 1972.

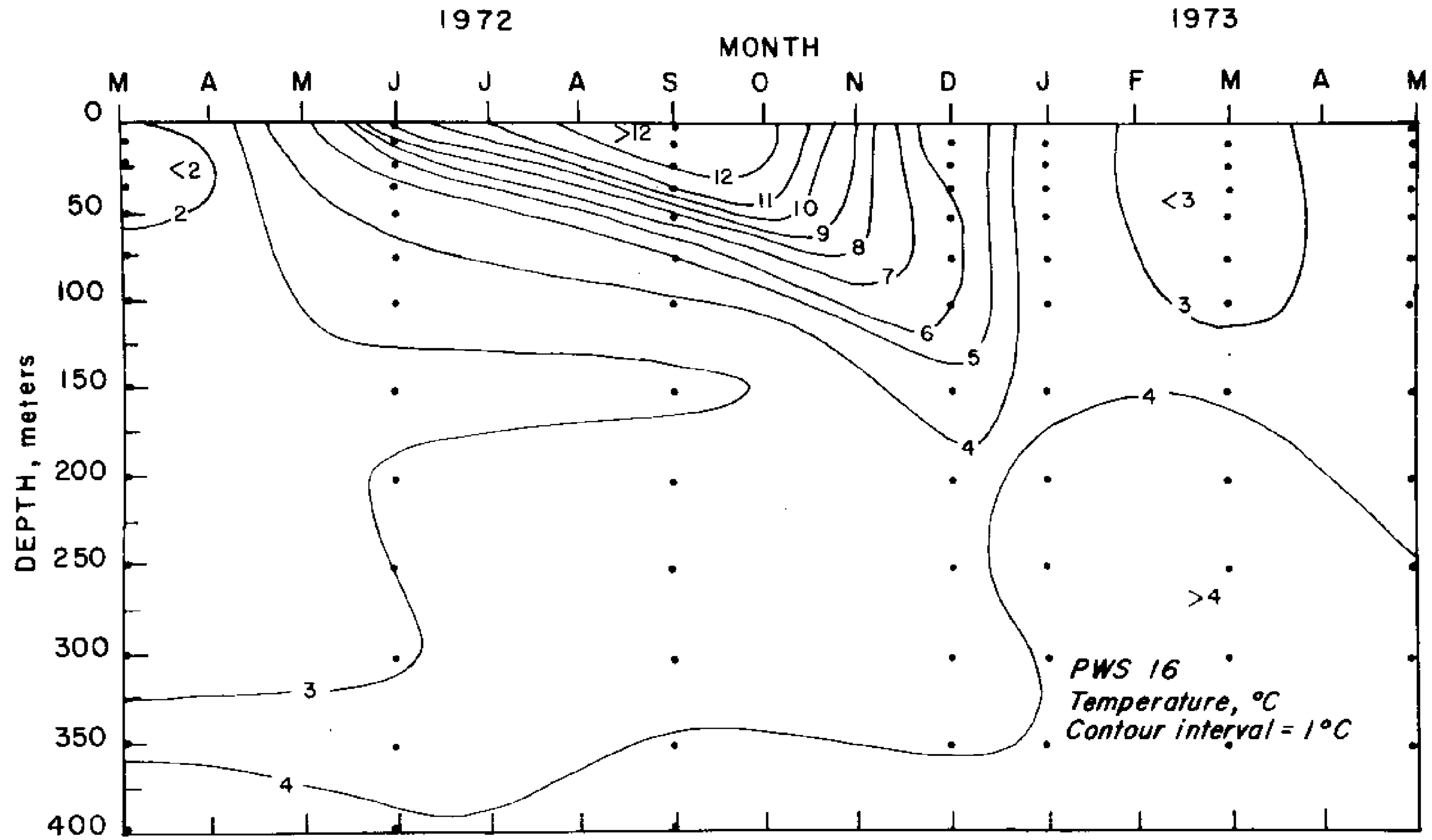

Figure 10. Time series of temperature at PWS 016 from May 1972 to May 1973.

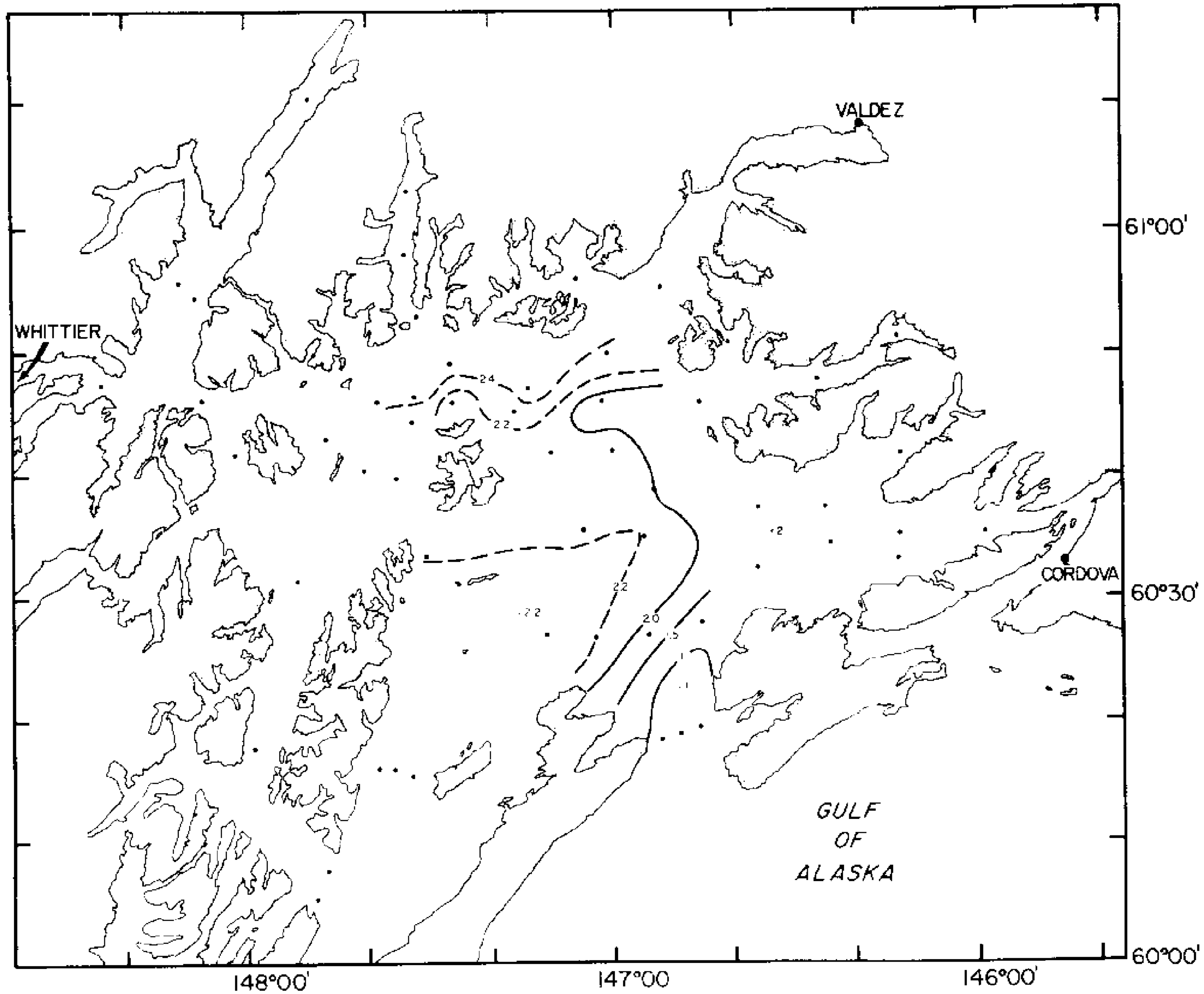

Figure 11. Surface distribution of temperature, March 1972.

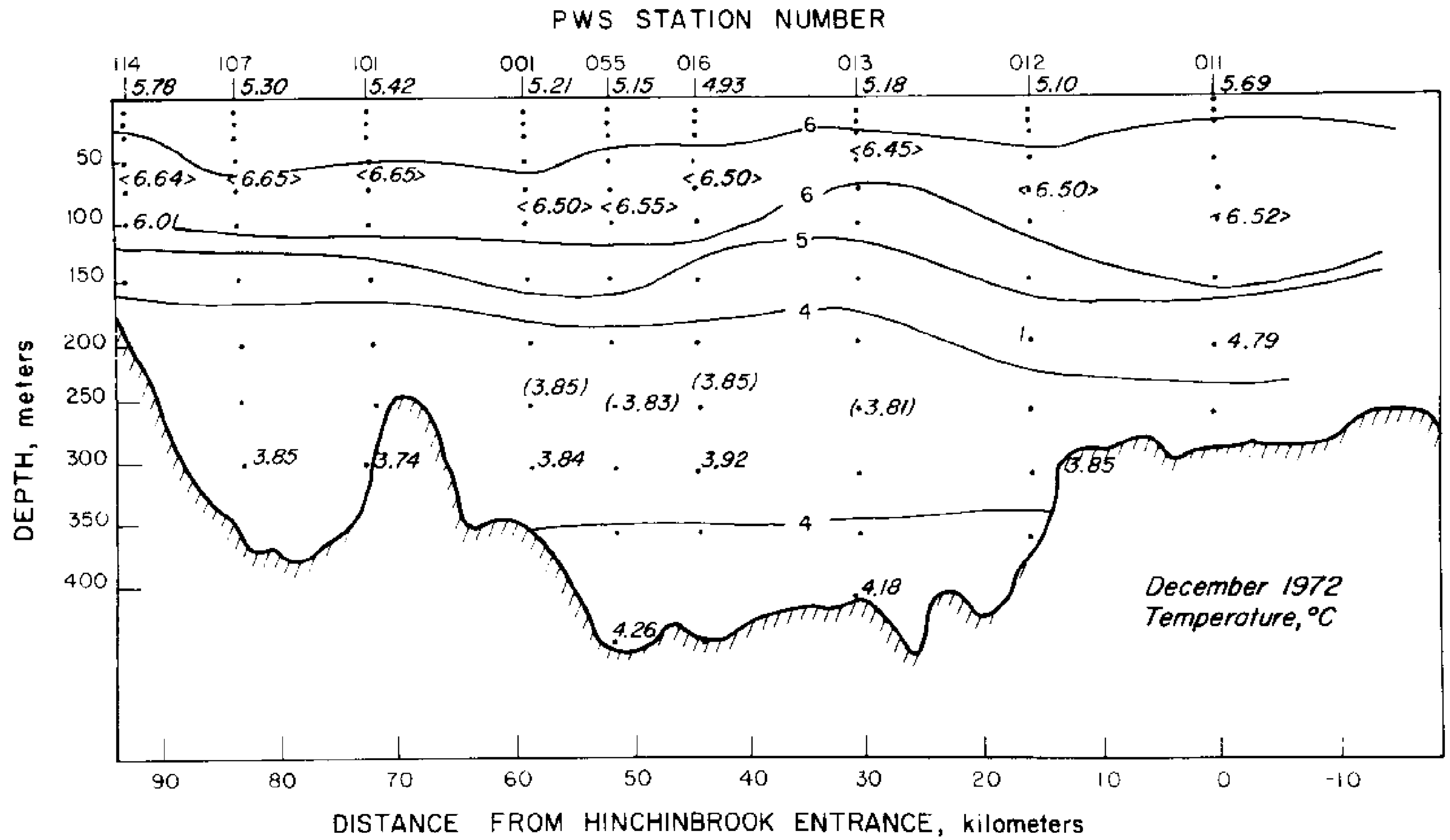

Figure 12. Vertical distribution of temperature in the longitudinal section, December 1972.

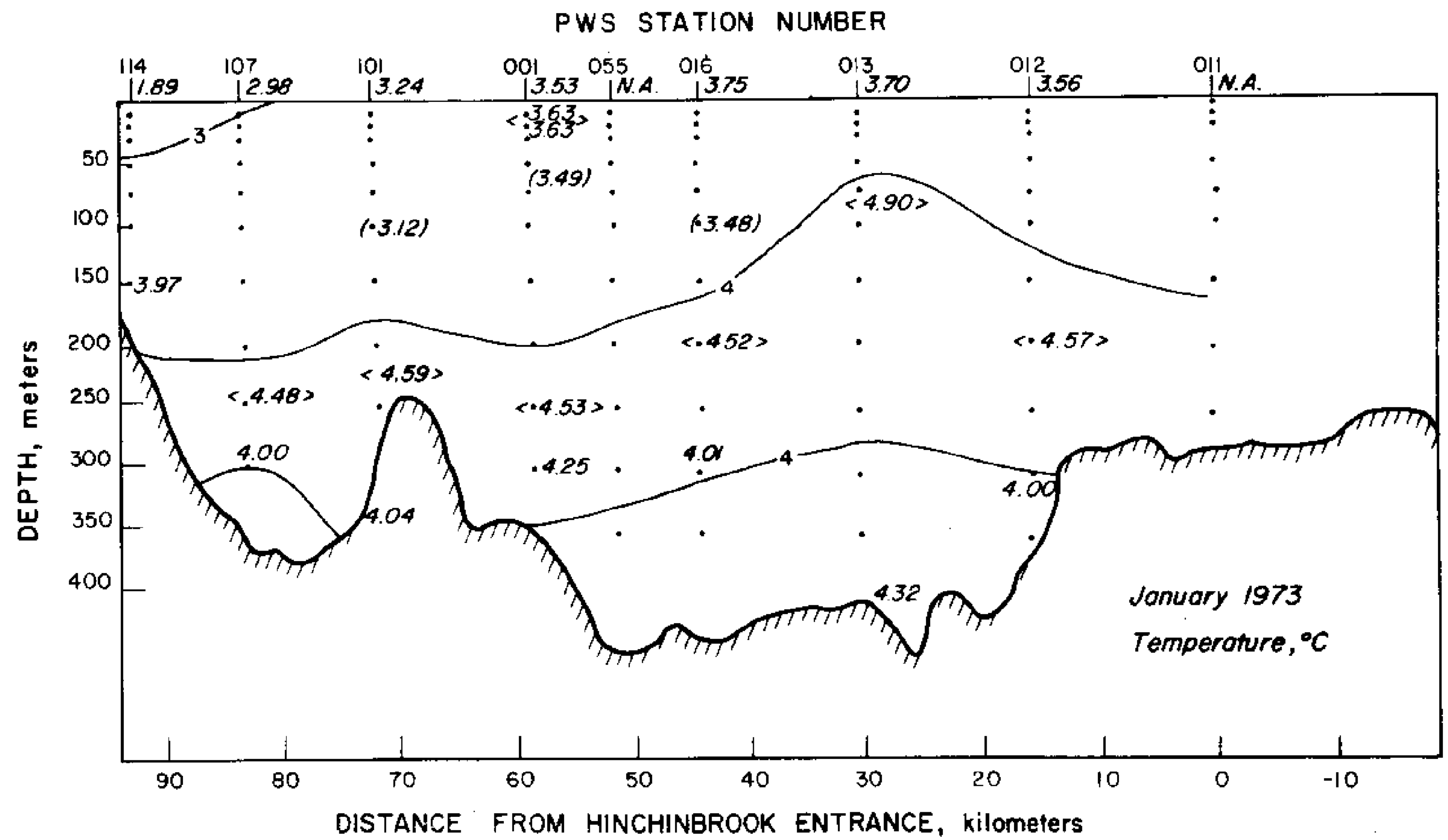

Figure 13. Vertical distribution of temperature in the longitudinal section, January 1973.

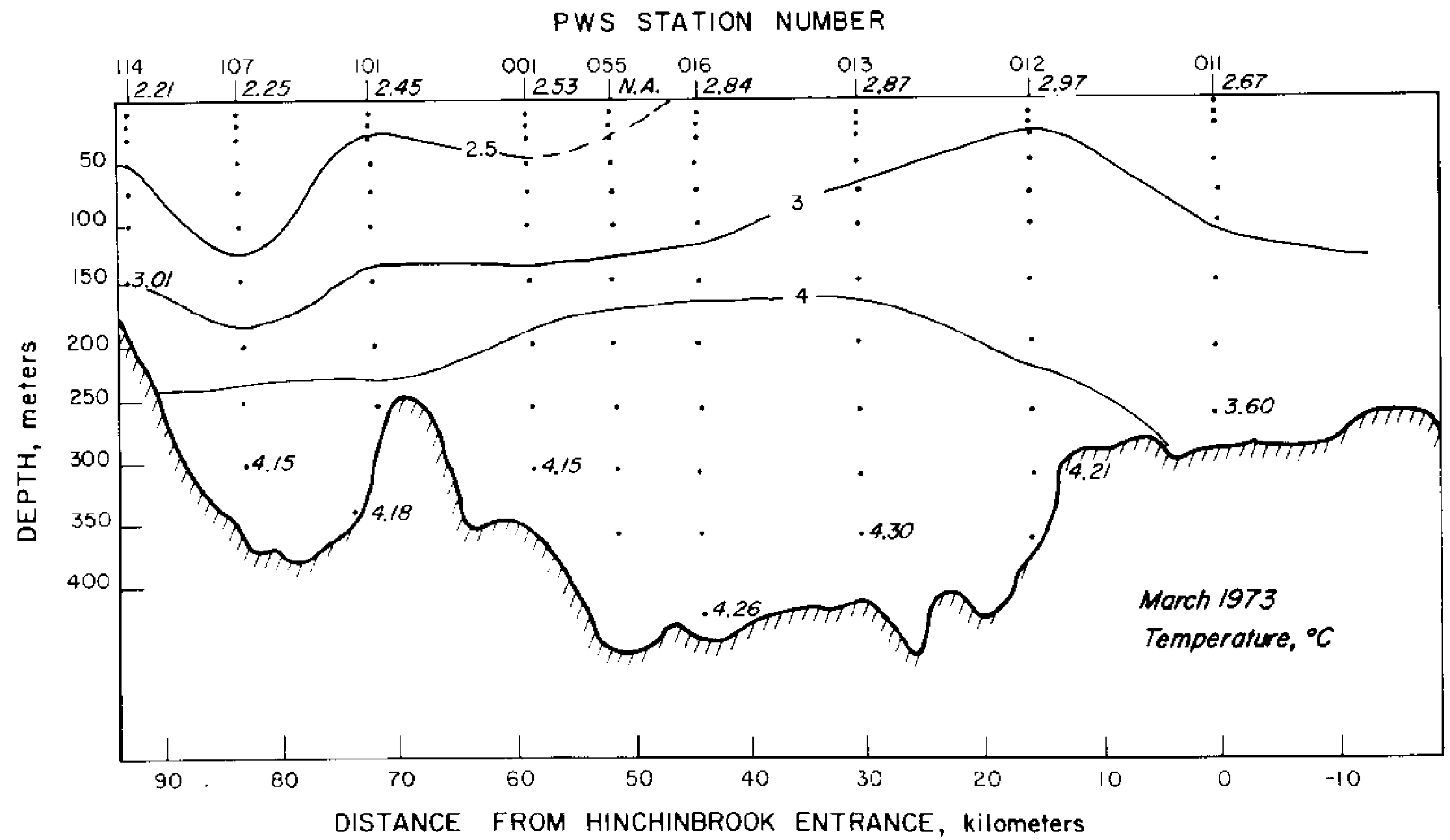

Figure 14. Vertical distribution of temperature in the longitudinal section, March 1973.

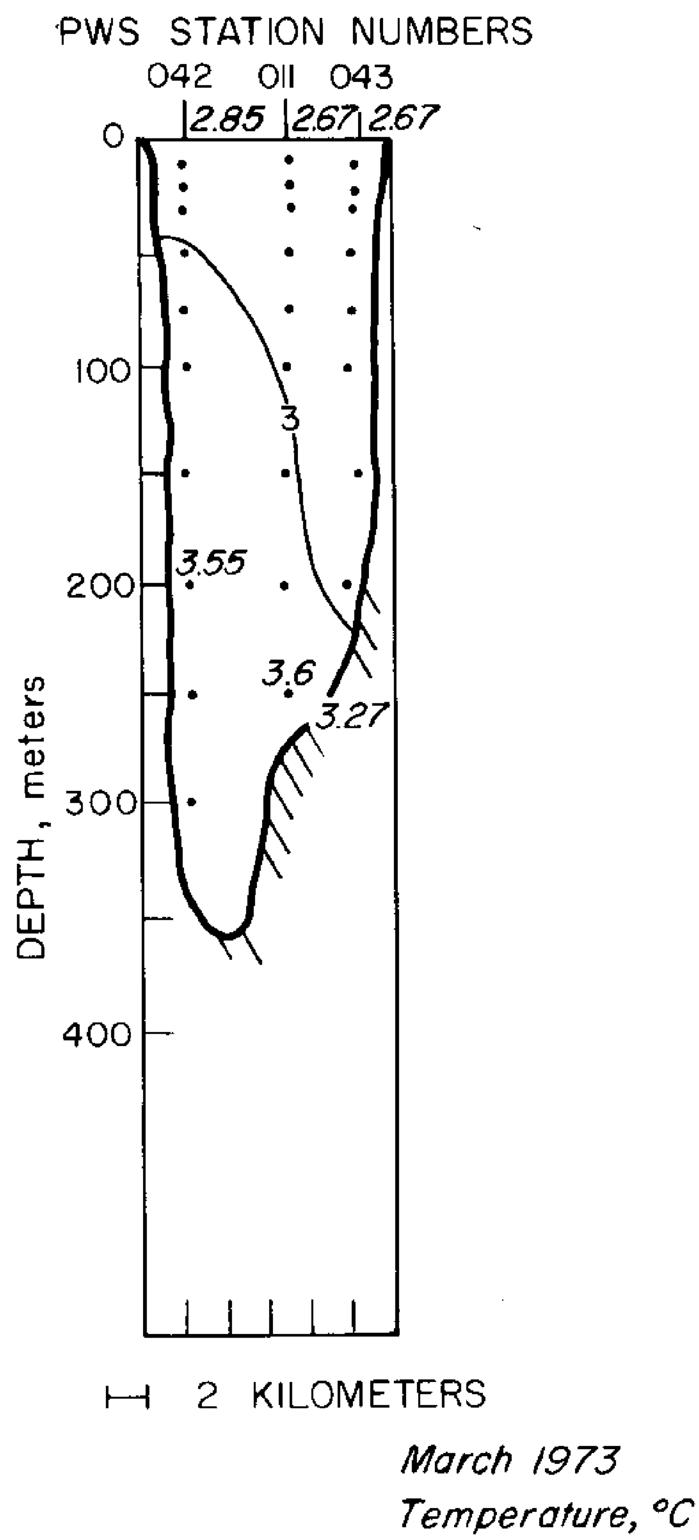

Figure 15. Vertical distribution of temperature in cross-section I, March 1973.

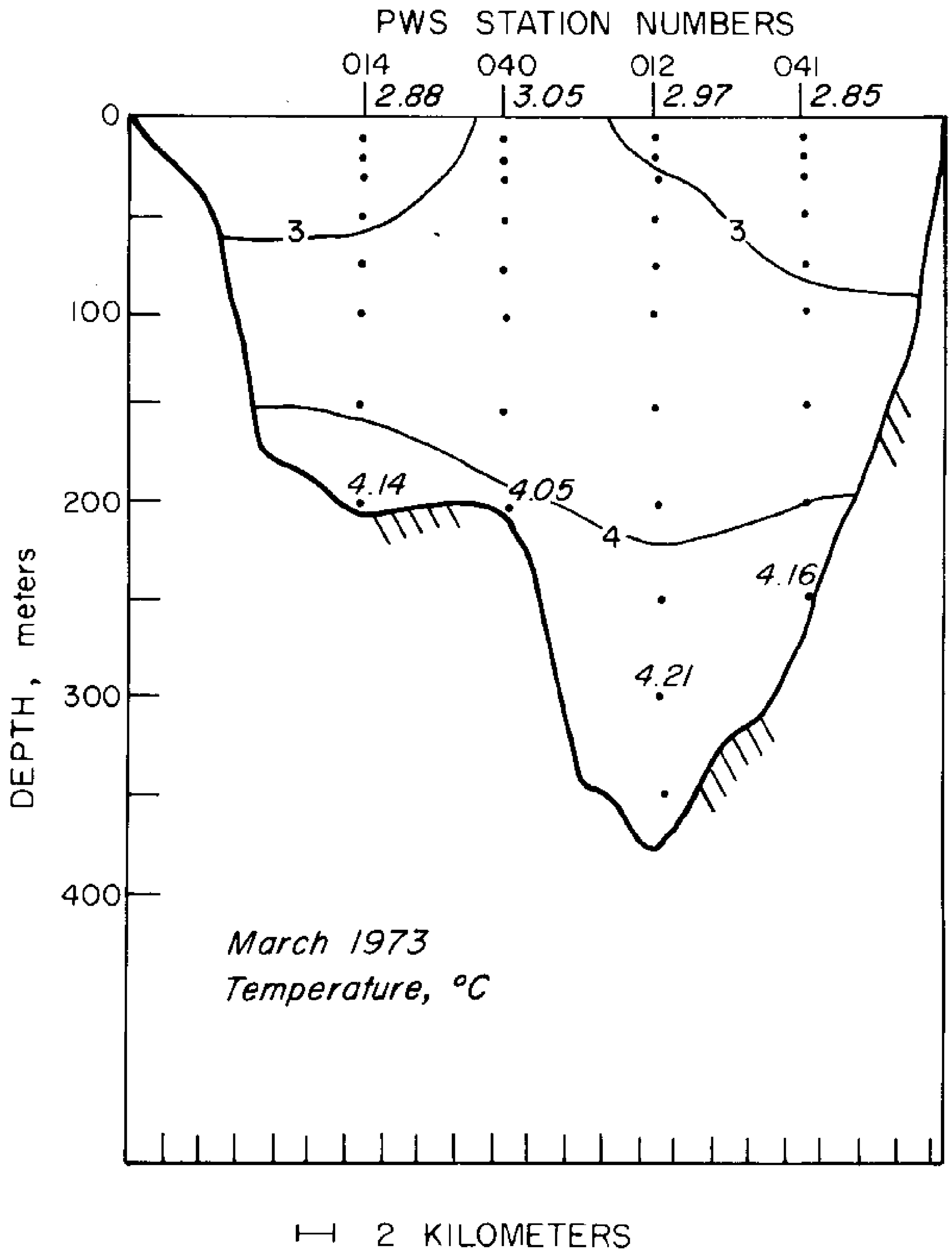

Figure 16. Vertical distribution of temperature in cross-section II. March 1973.

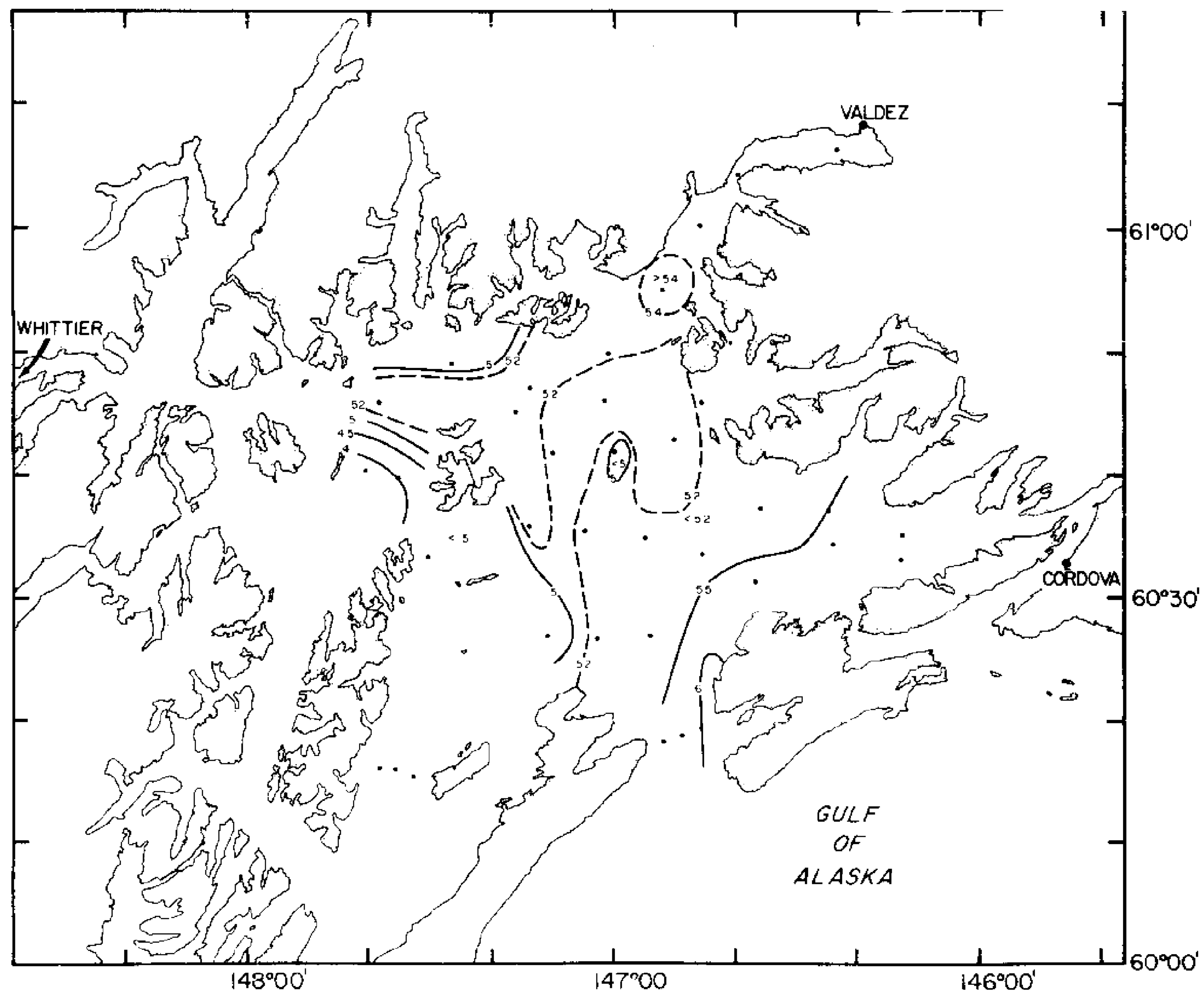

Figure 17. Surface distribution of temperature December 1972

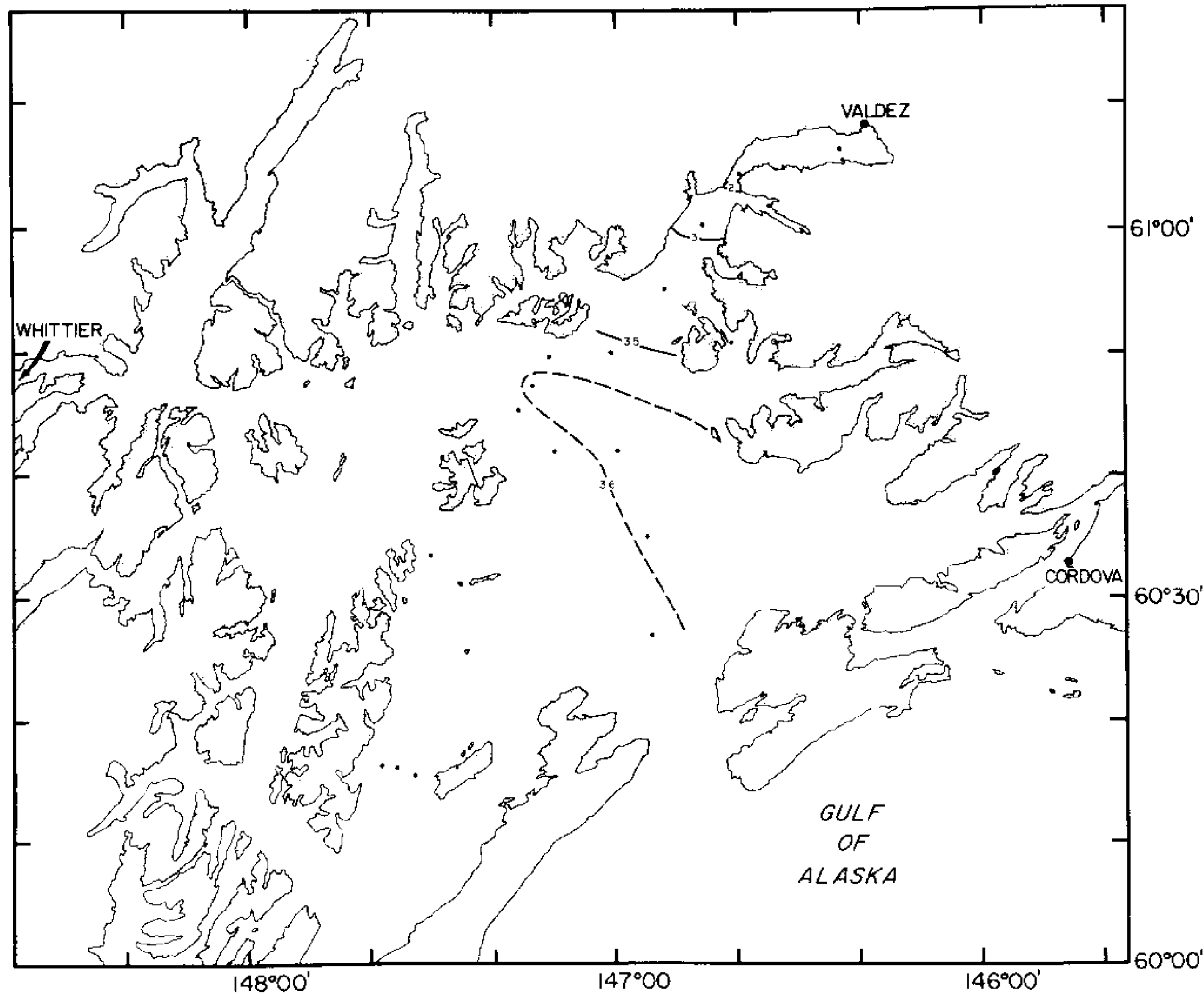

Figure 18. Surface distribution of temperature, January 1973.

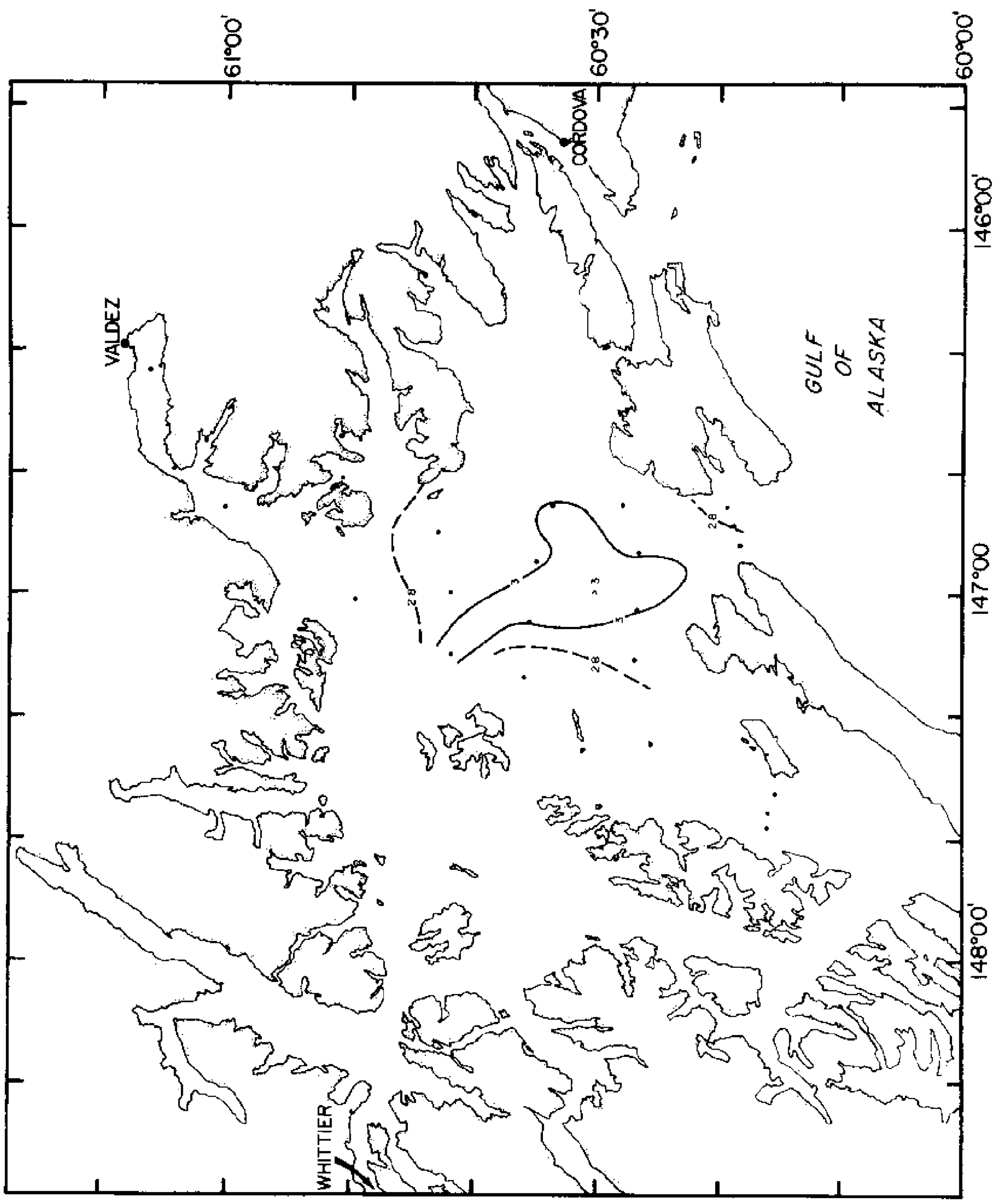

Figure 19. Surface distribution of temperature. March 1973.

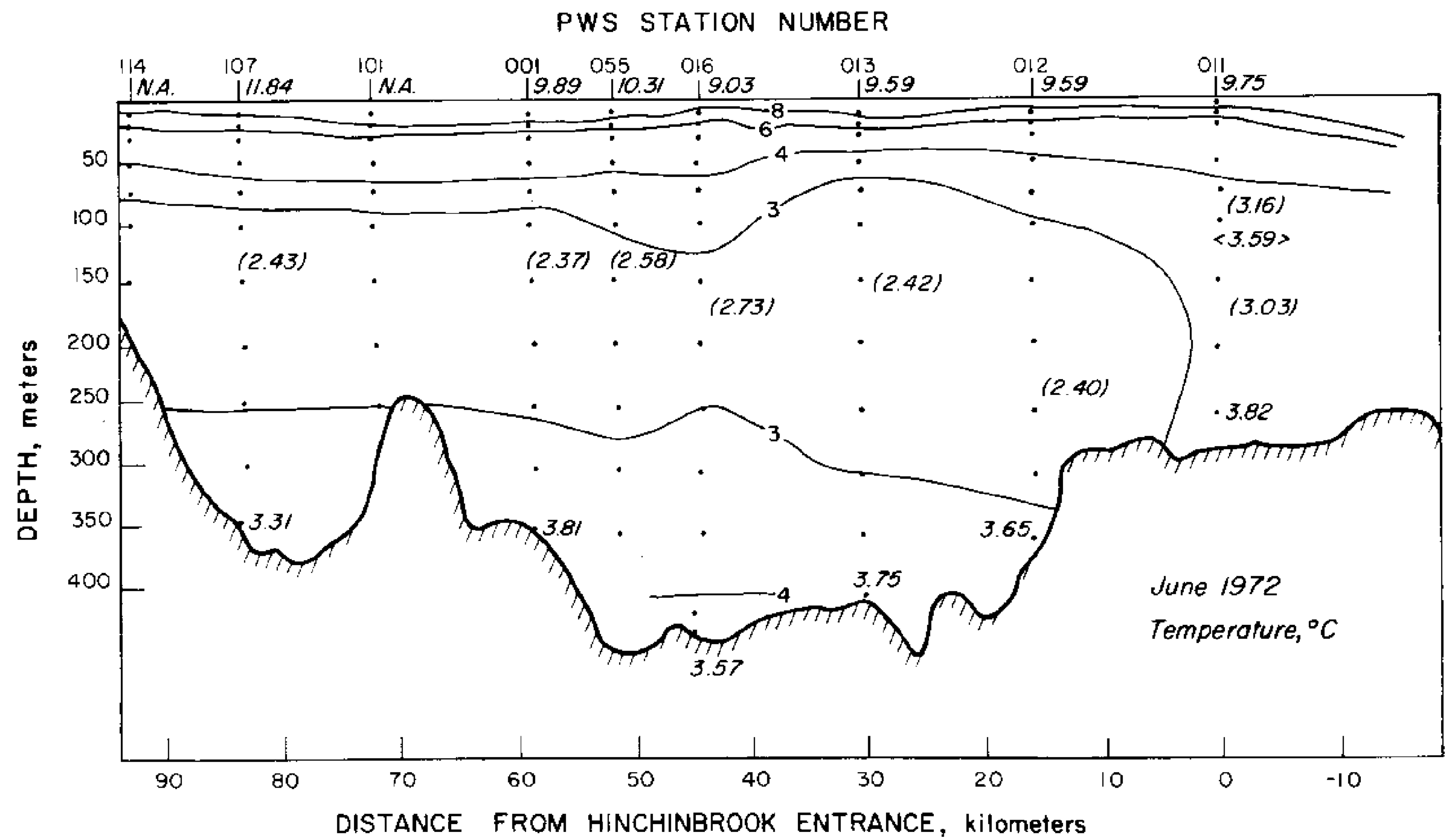

Figure 20. Vertical distribution of temperature in the longitudinal section, June 1972.

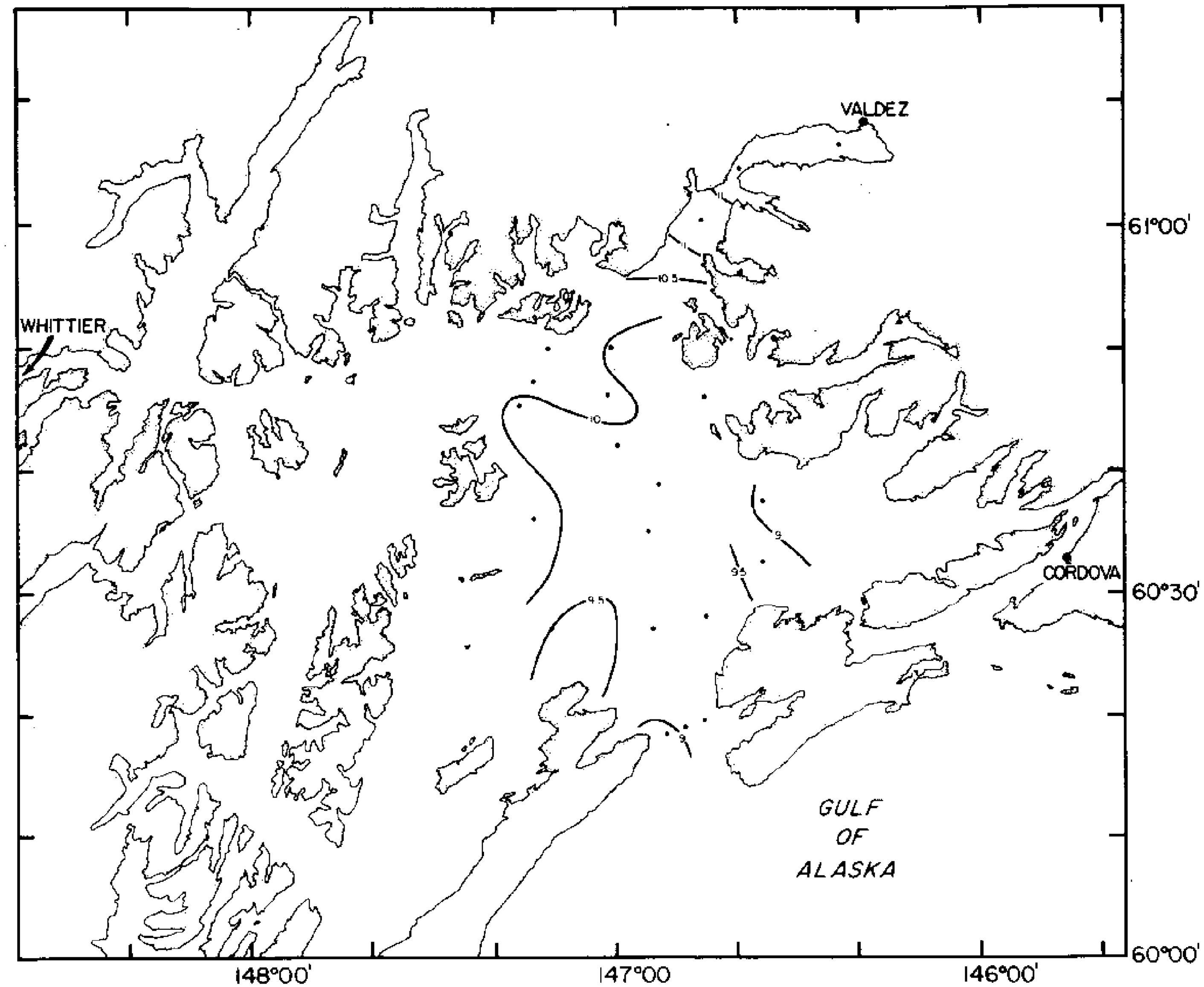

Figure 21. Surface distribution of temperature, June 1972.

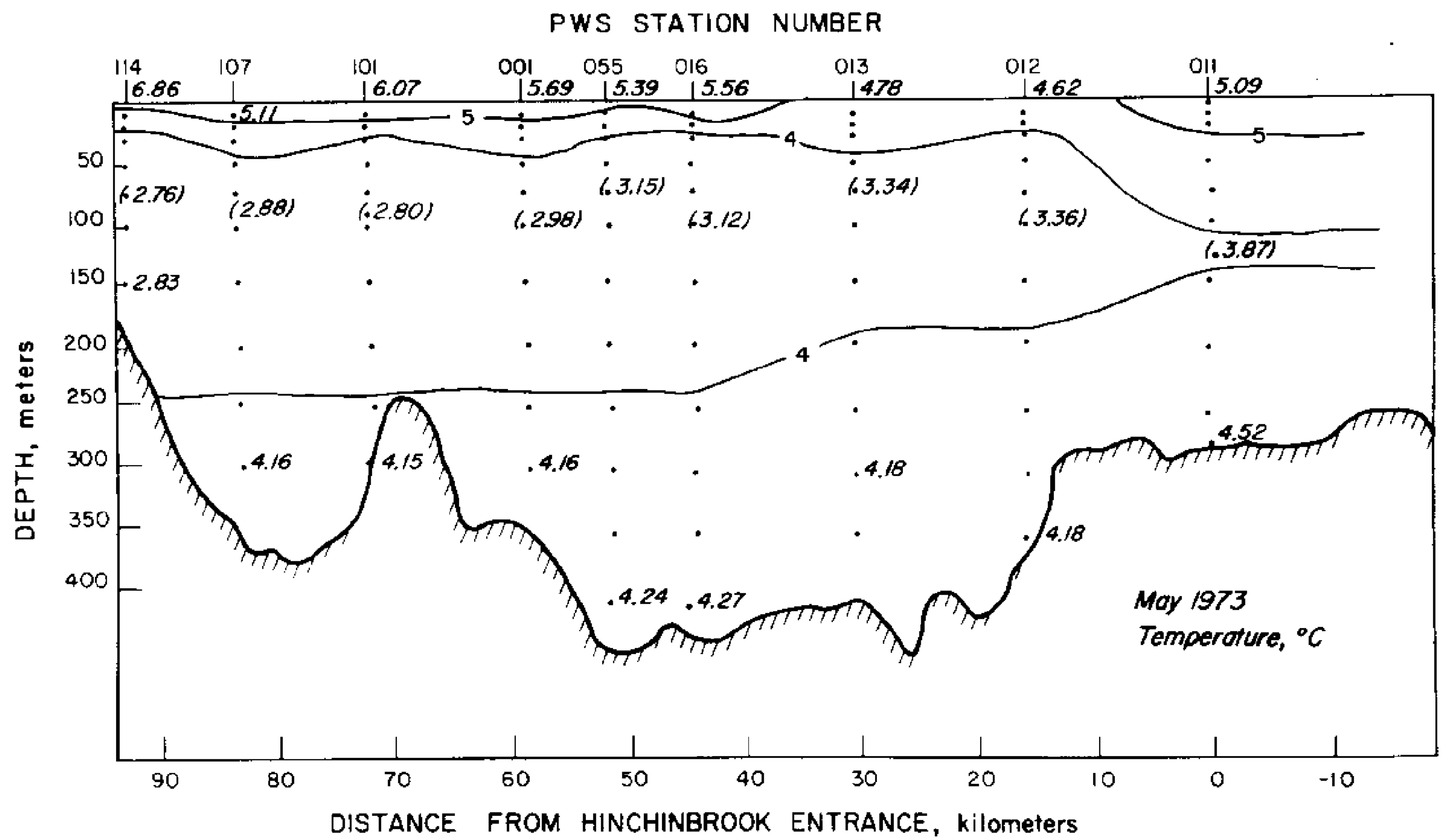

Figure 22. Vertical distribution of temperature in the longitudinal section, June 1972.

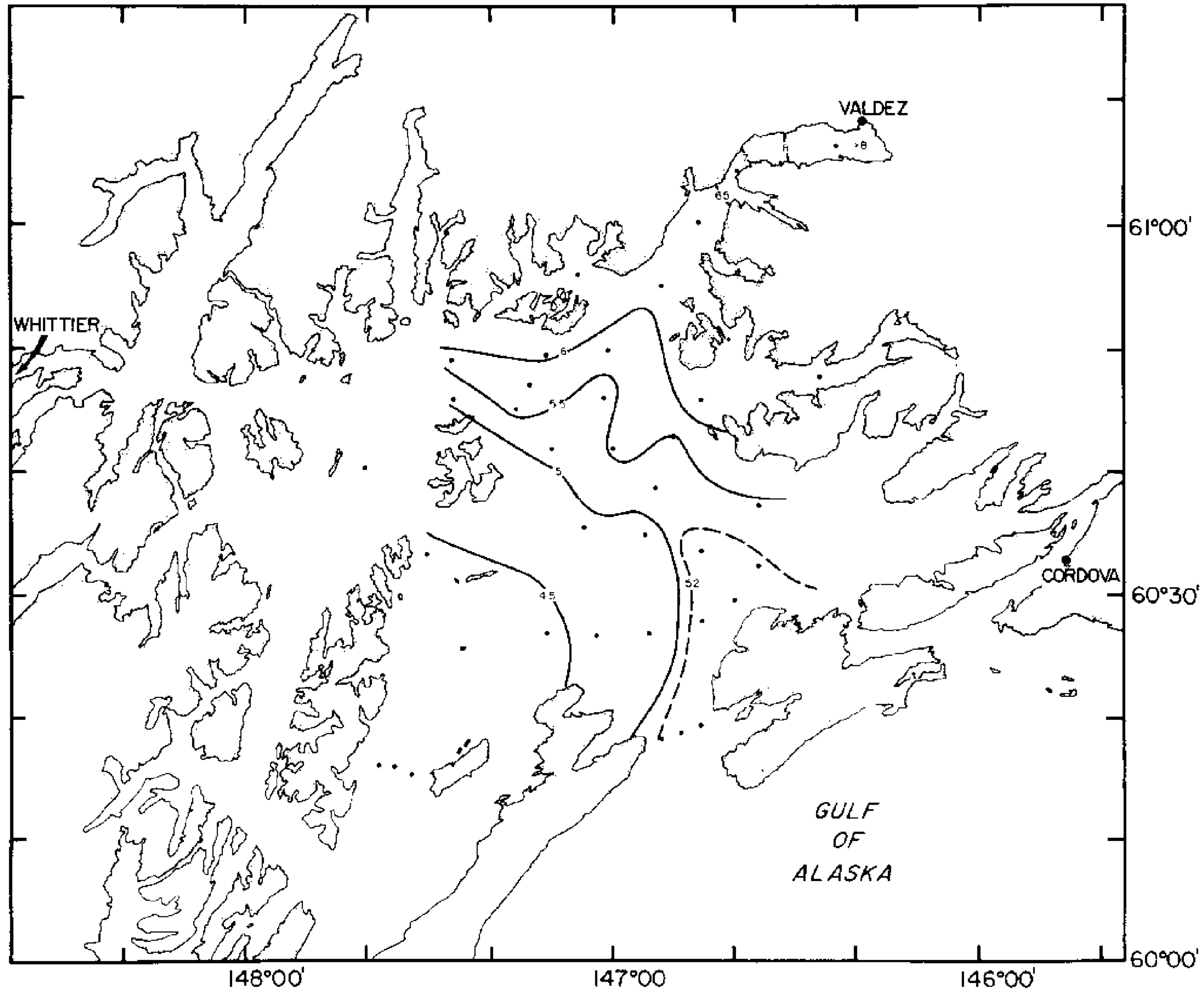

Figure 23. Surface distribution of temperature, May 1973.

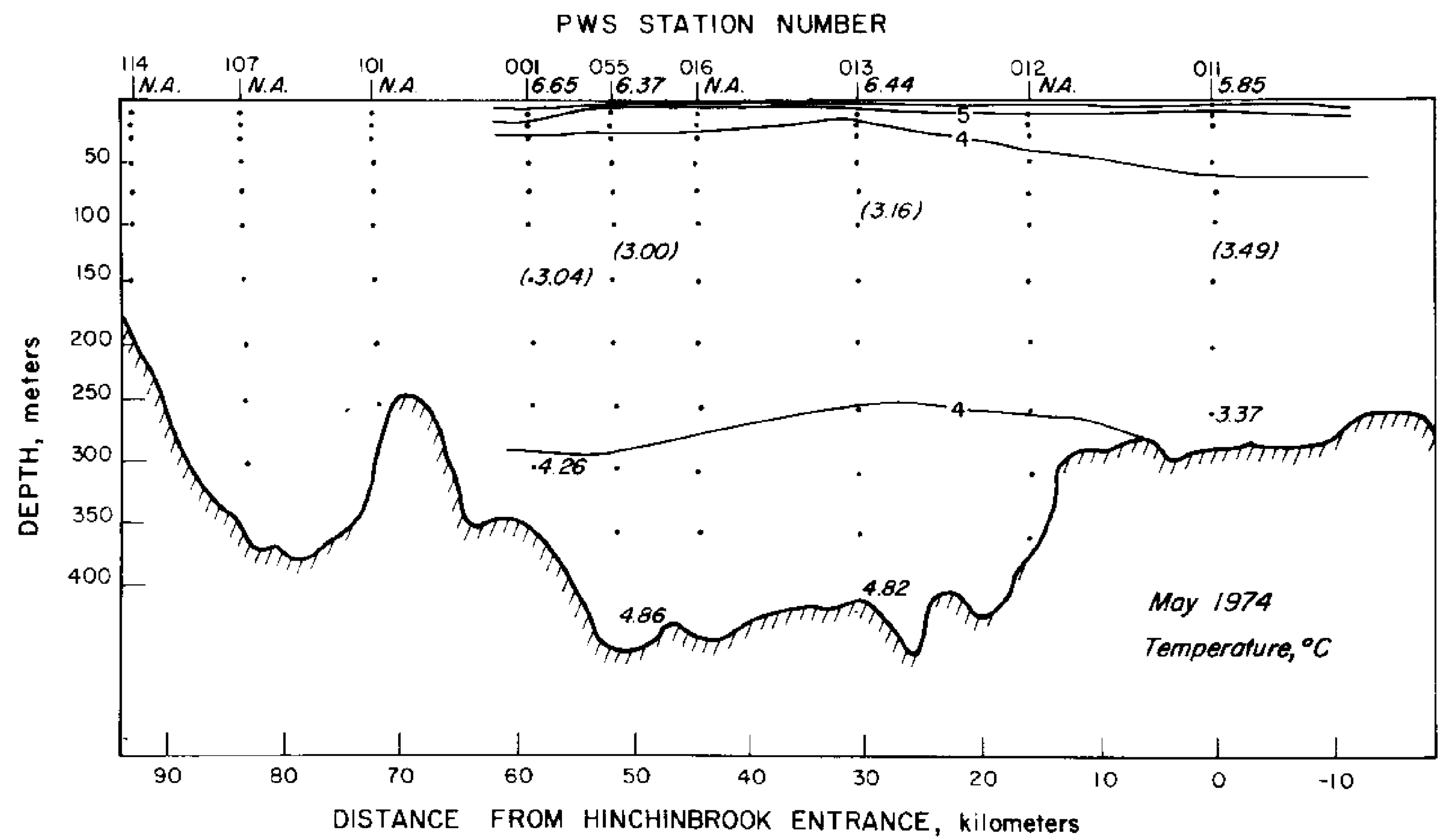

Figure 24. Vertical distribution of temperature in the longitudinal section, May 1974.

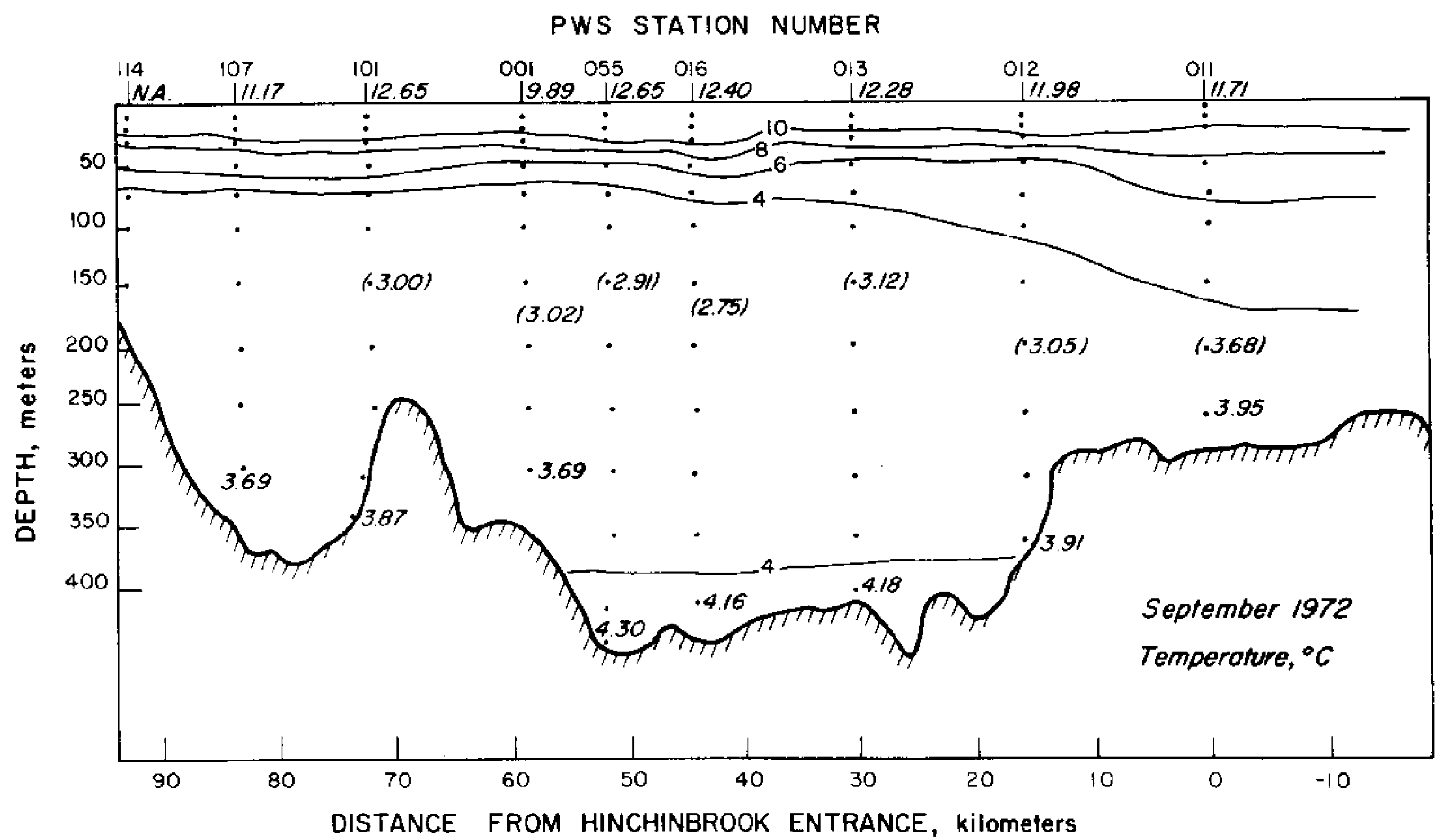

Figure 25. Vertical distribution of temperature in the longitudinal section, September 1972.

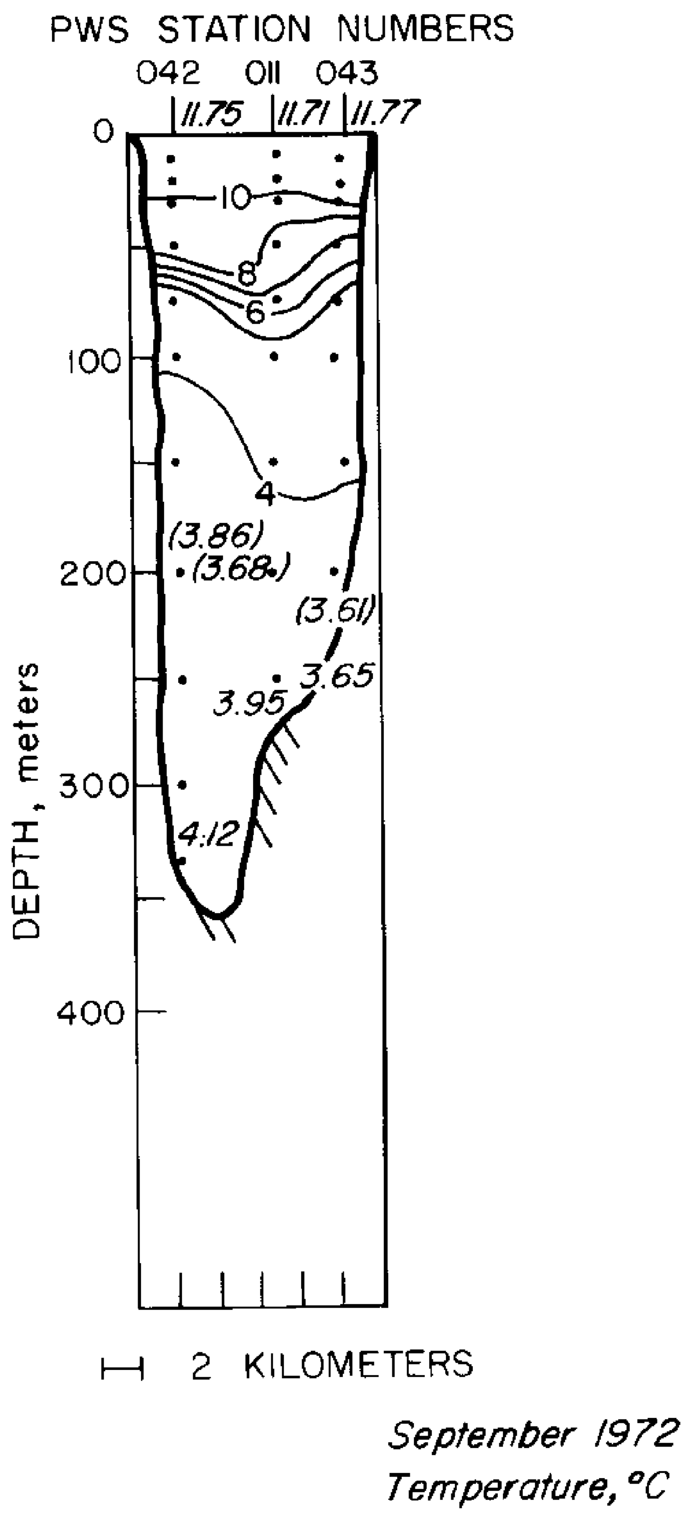

Figure 26. Vertical distribution of temperature in cross-section I, September 1972.

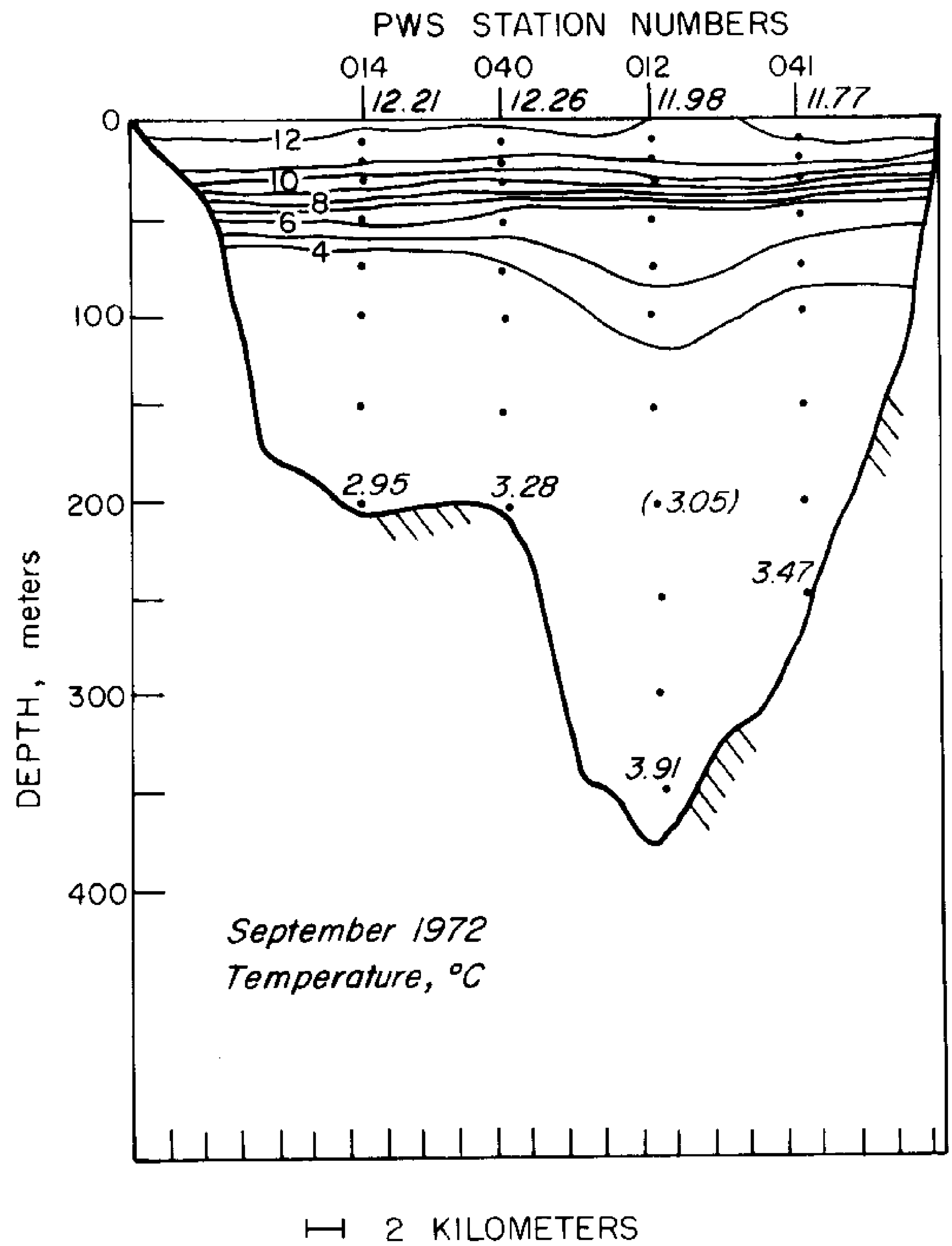

Figure 27. Vertical distribution of temperature in cross-section II, September 1972.

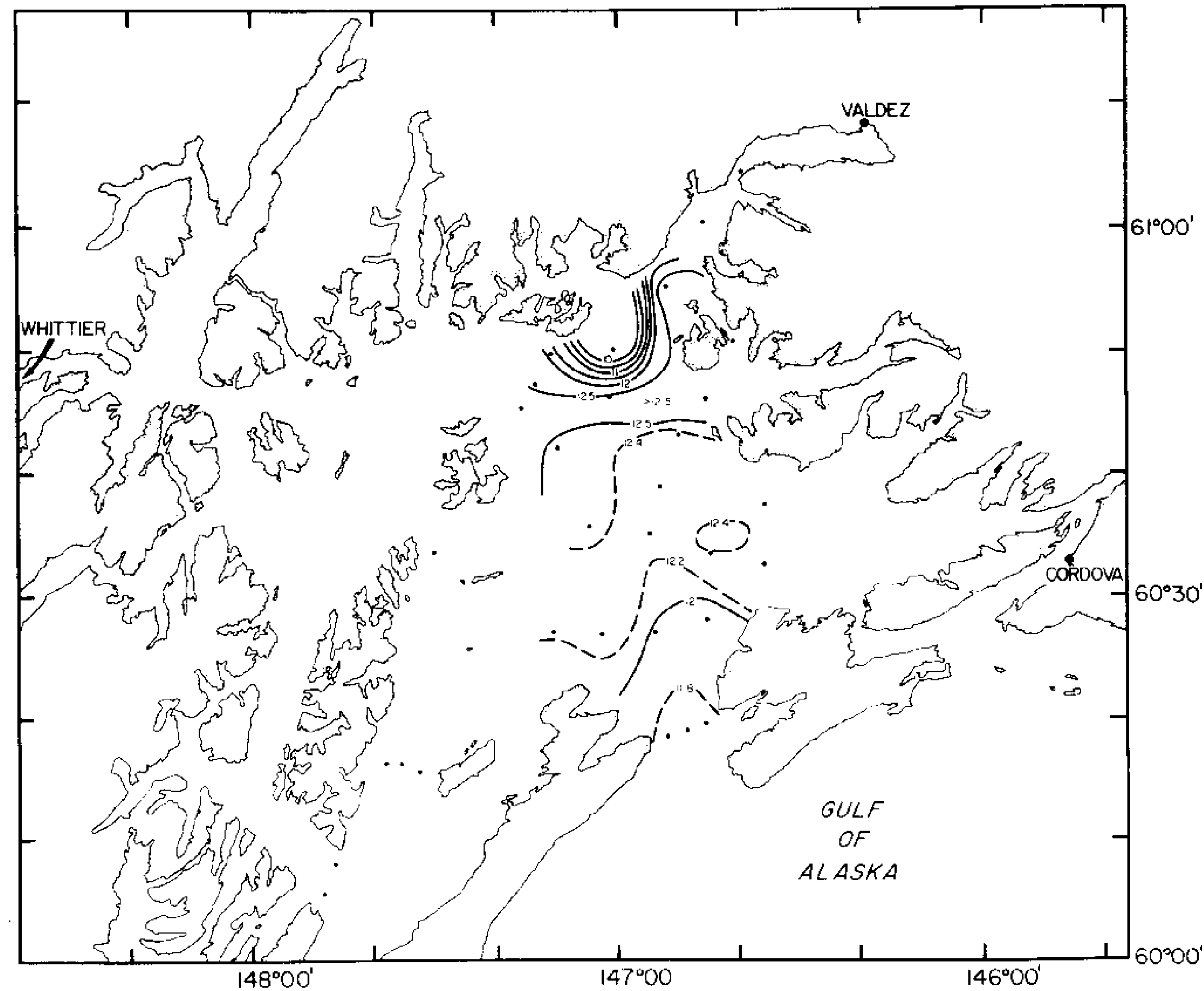

Figure 28. Surface distribution of temperature. September 1972.

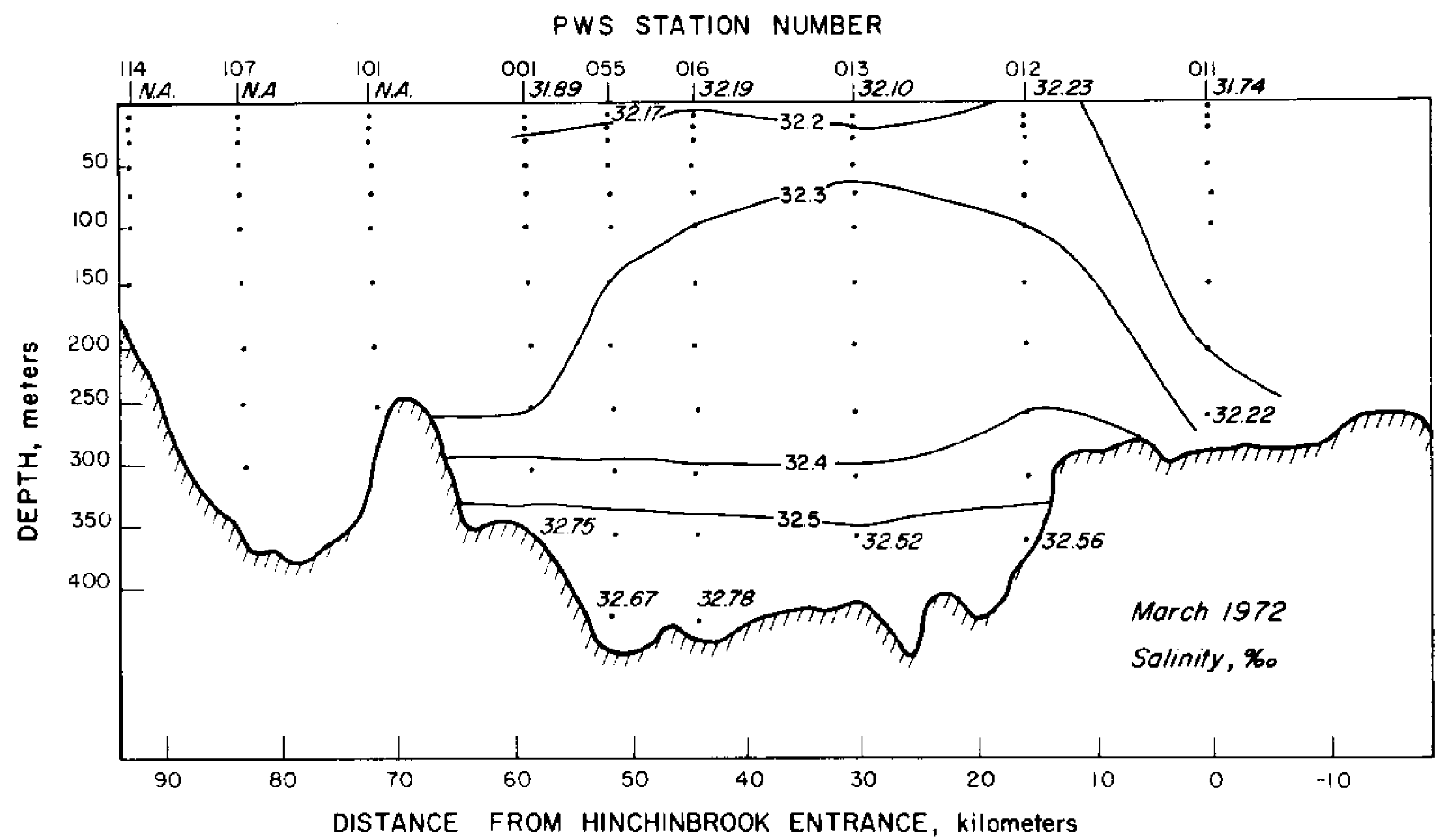

Figure 29. Vertical distribution of salinity in the longitudinal section, March 1972.

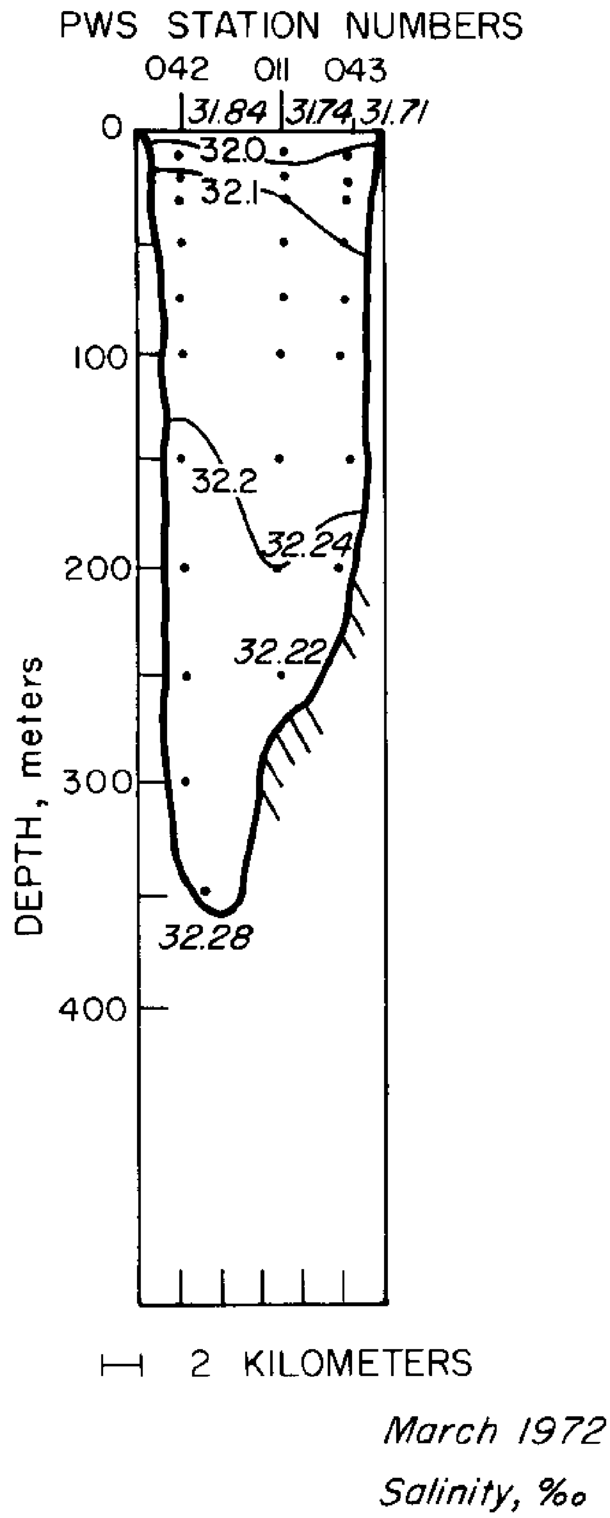

Figure 30. Vertical distribution of salinity in cross-section I, March 1972.

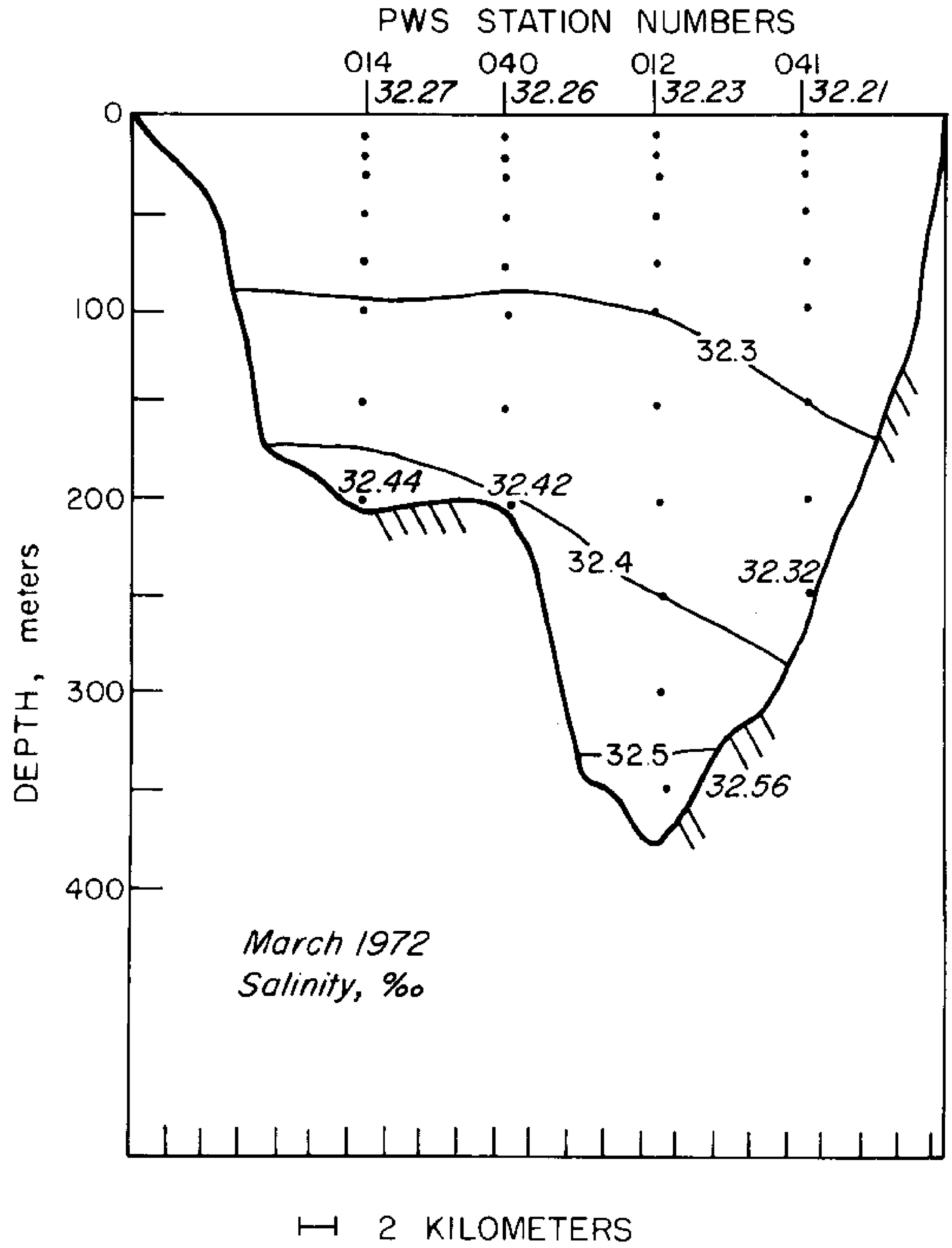

Figure 31. Vertical distribution of salinity in cross-section II, March 1972.

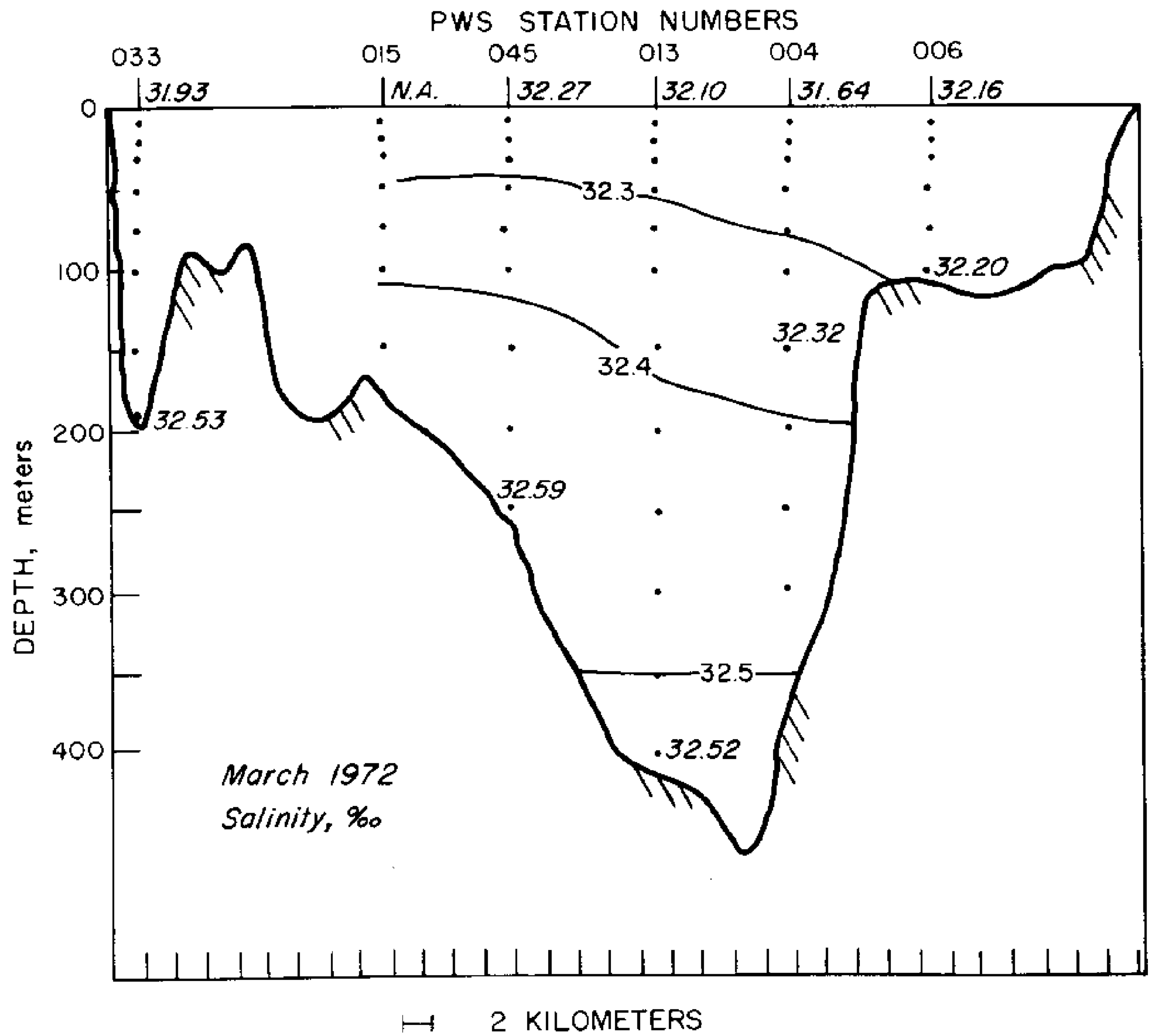

Figure 32. Vertical distribution of salinity in cross-section III. March 1972.

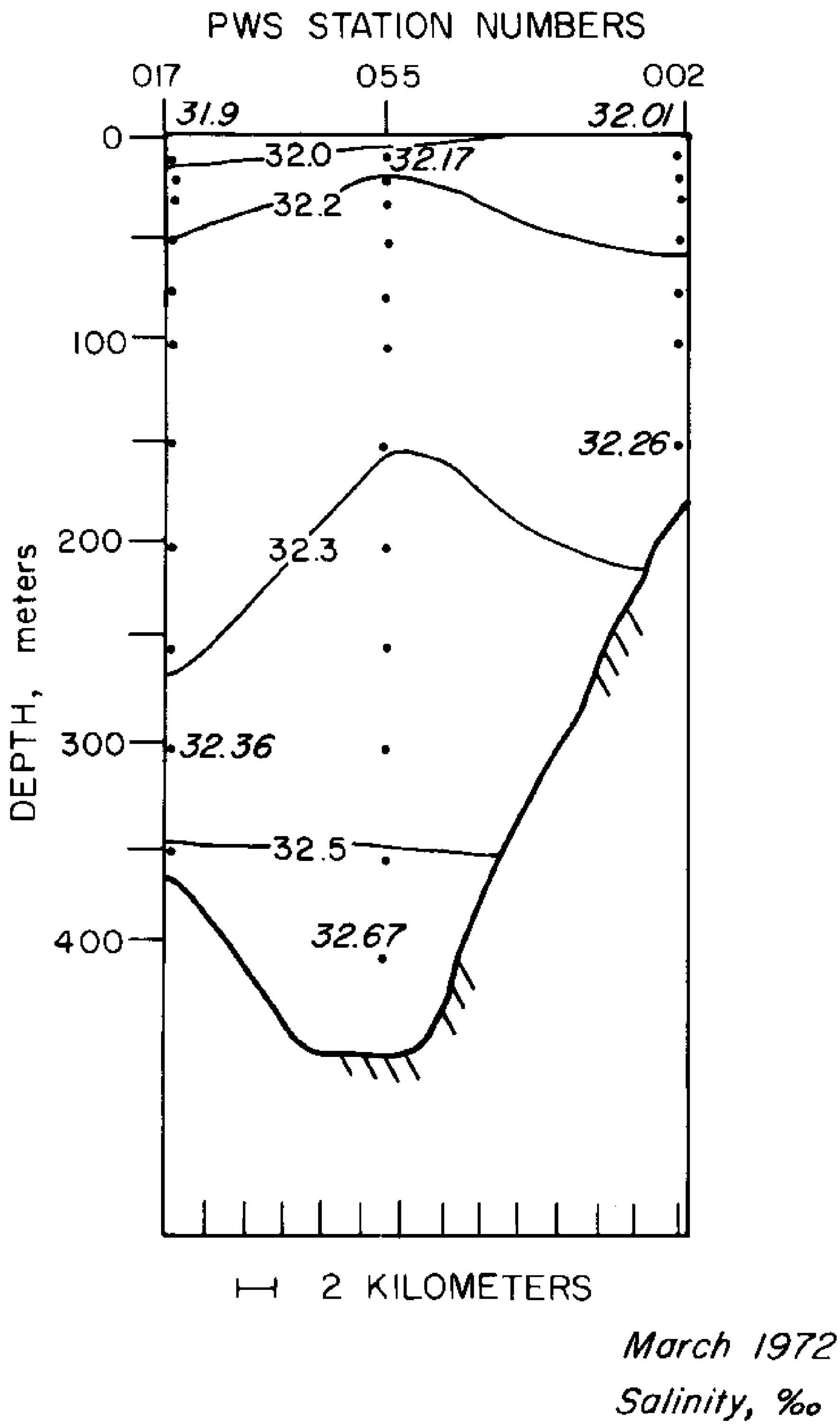

Figure 33. Vertical distribution of salinity in cross-section V, March 1972.

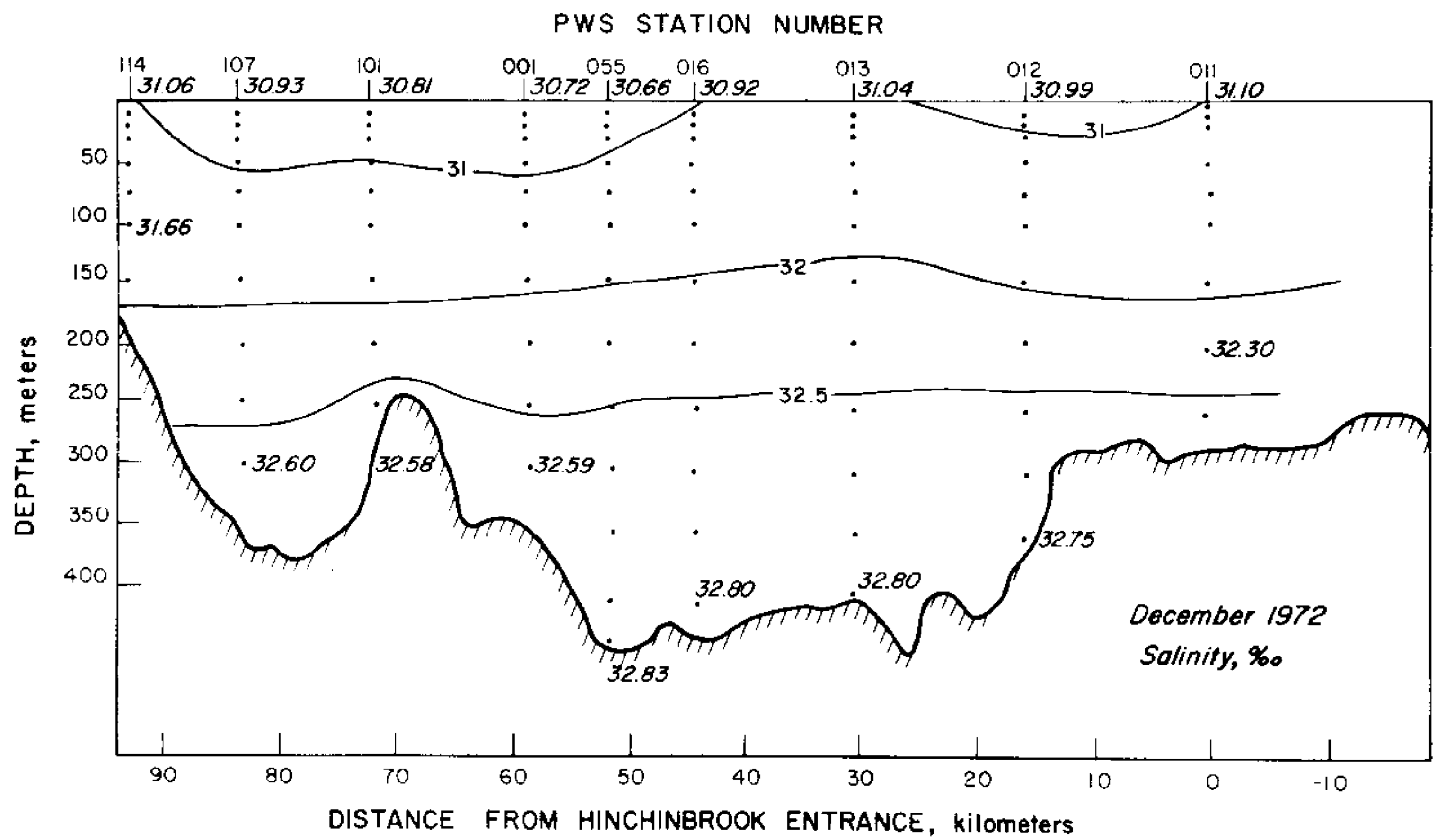

Figure 34. Vertical distribution of salinity in the longitudinal section. December 1972.

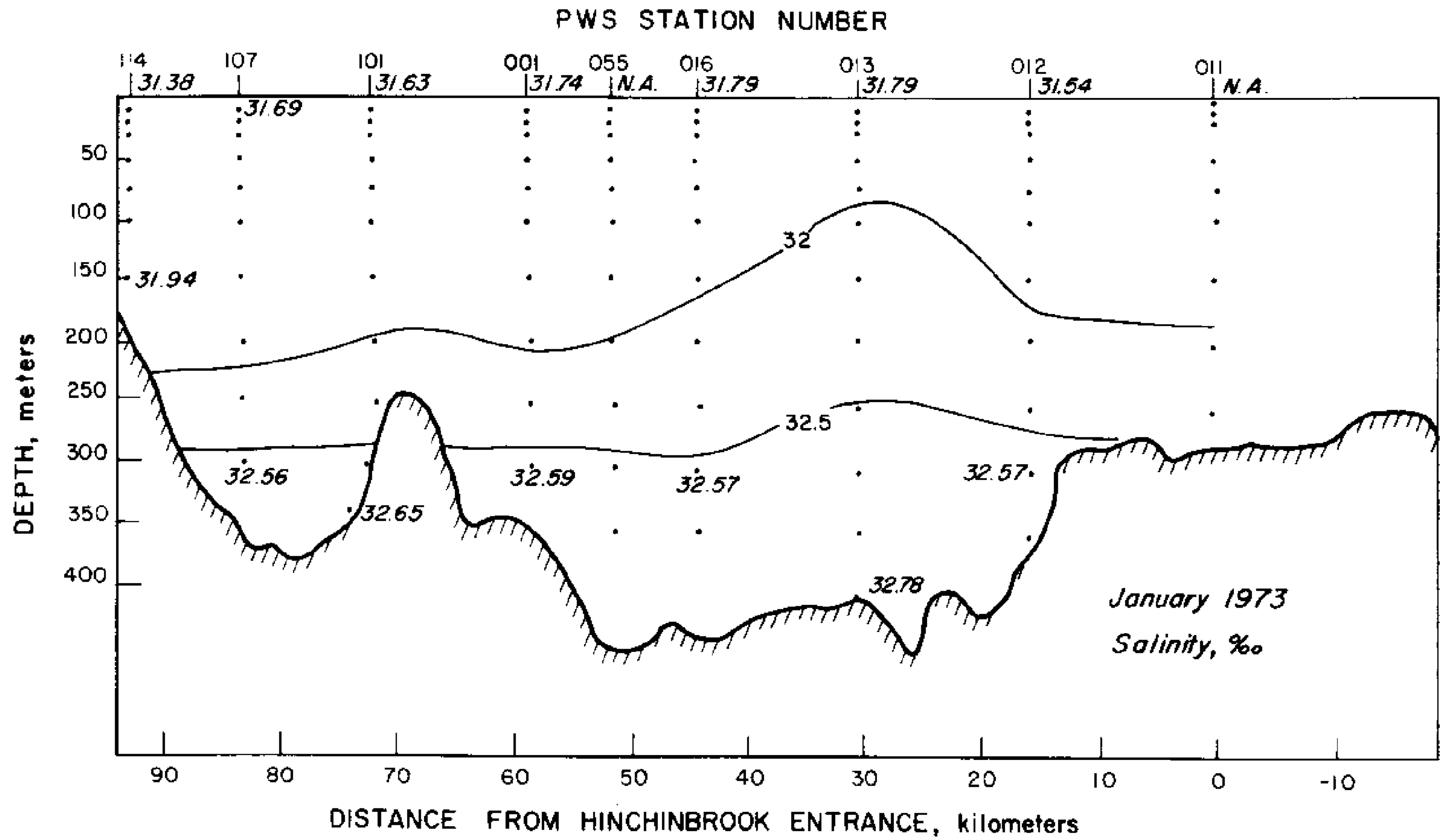

Figure 35. Vertical distribution of salinity in the longitudinal section, January 1973.

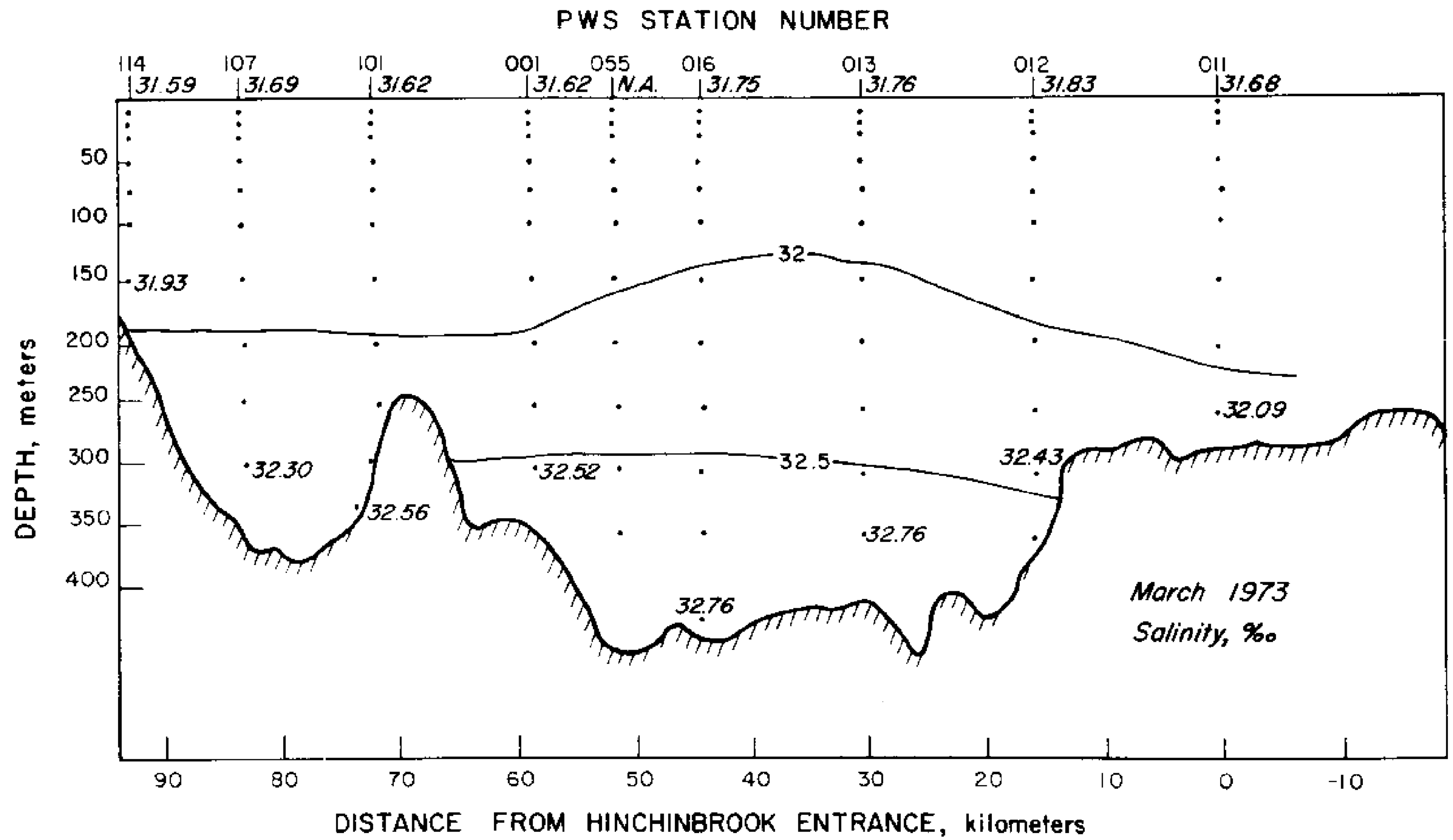

Figure 36. Vertical distribution of salinity in the longitudinal section, March 1973.

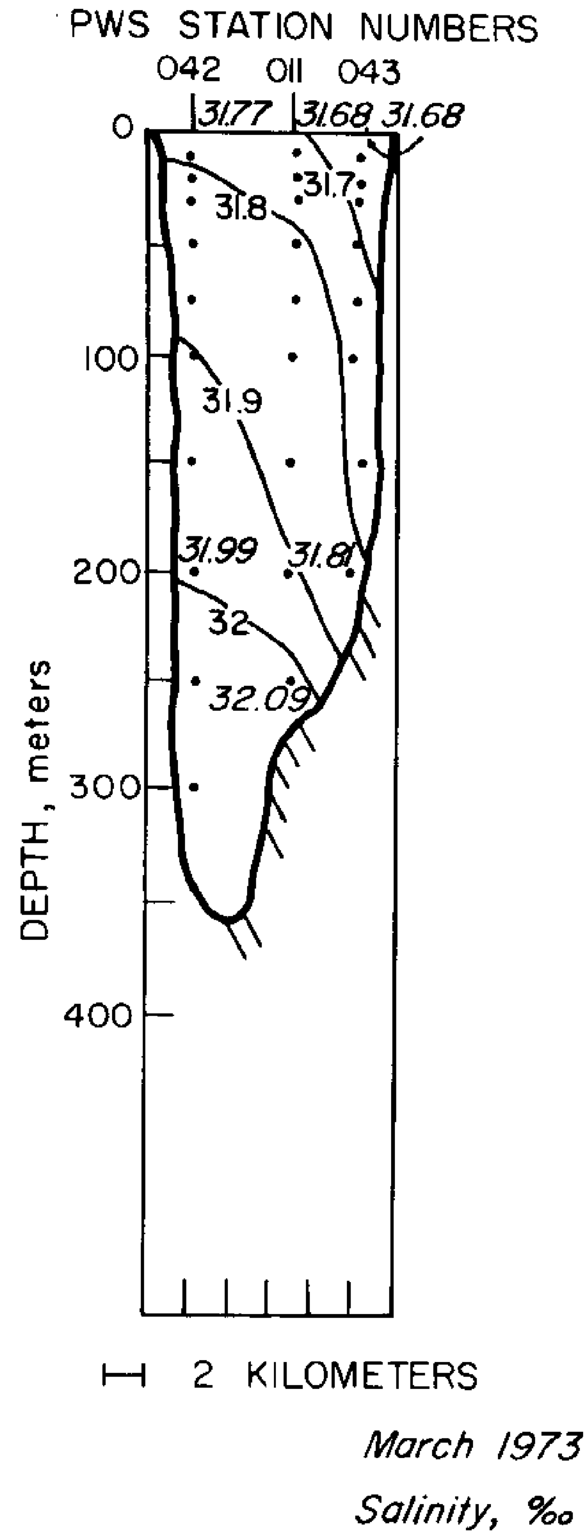

Figure 37. Vertical distribution of salinity in cross-section I, March 1973.

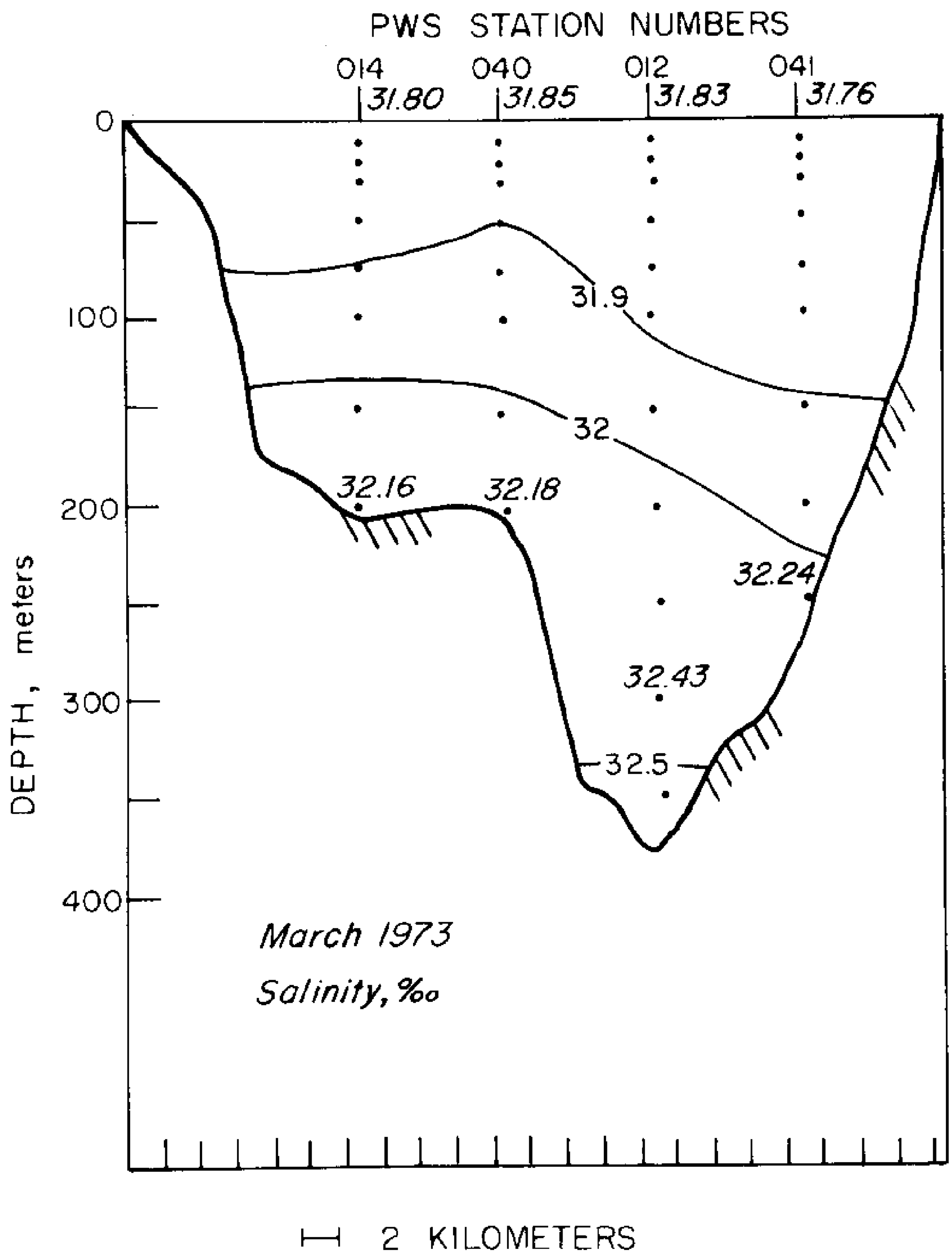

Figure 38. Vertical distribution of salinity in cross-section II. March 1973.

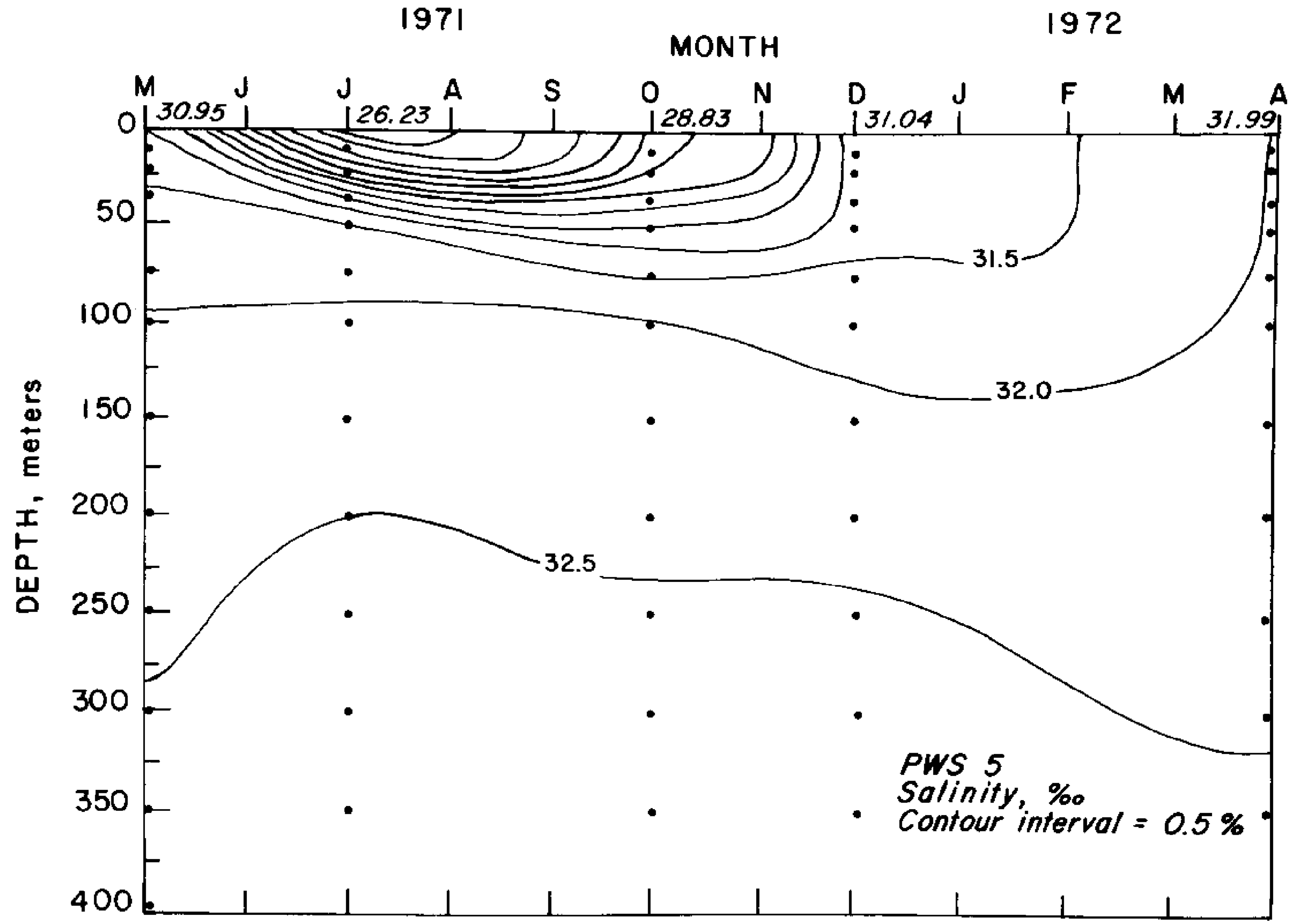

Figure 39. Time series of salinity at PWS 5 from May 1971 to April 1972.

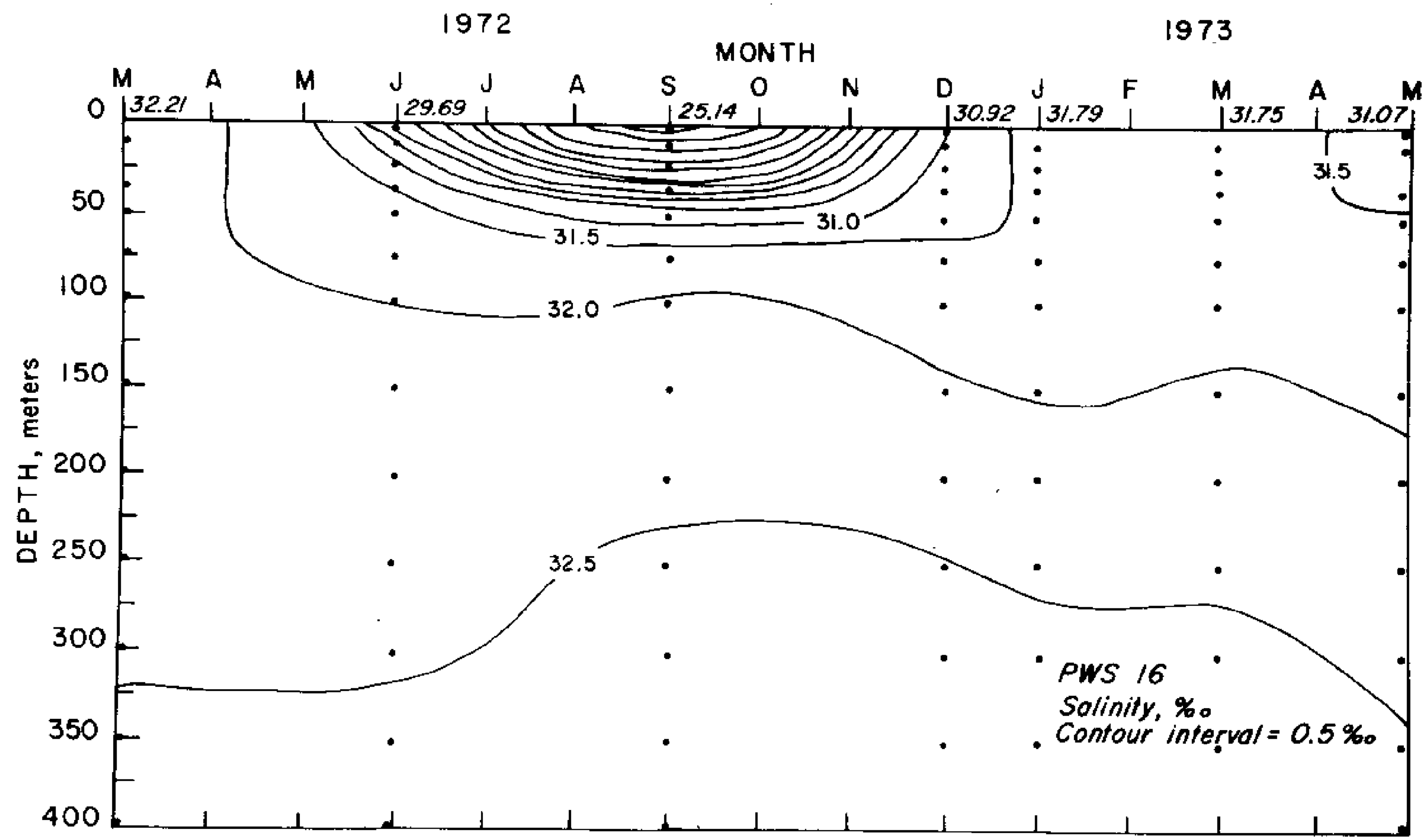

Figure 40. Time series of salinity at PWS 016 from May 1972 to May 1973.

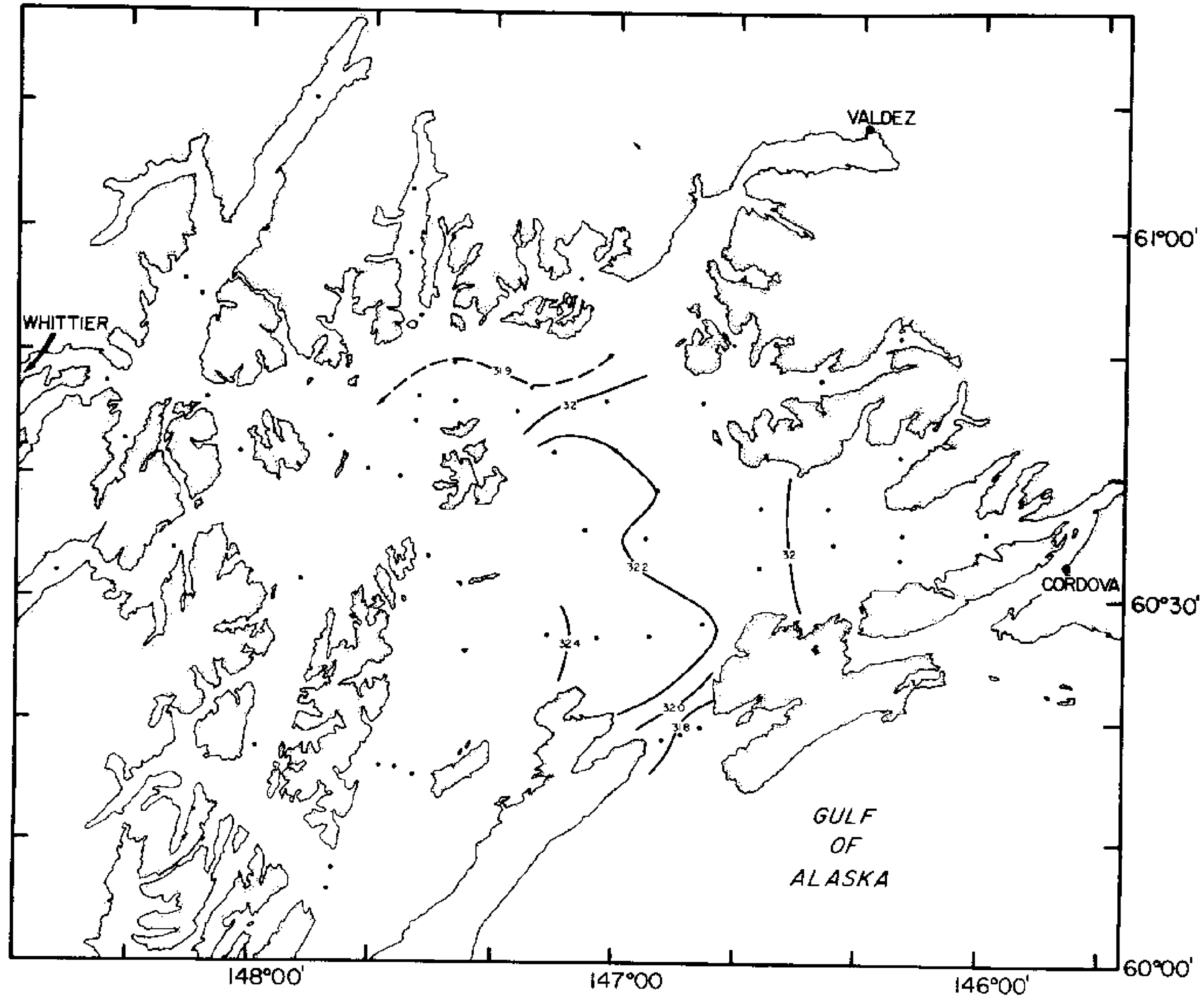

Figure 41. Surface distribution of salinity, March 1972.

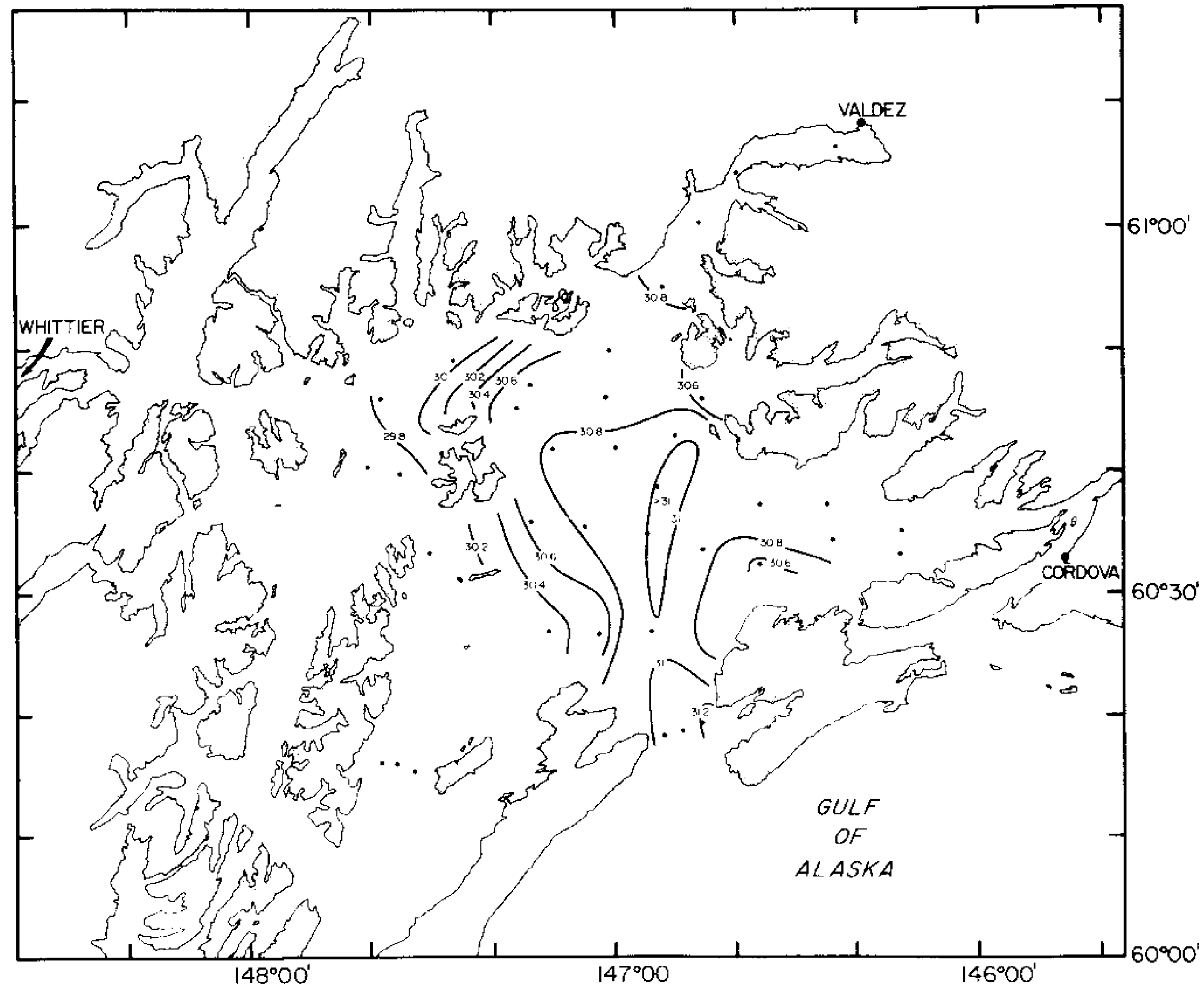

Figure 42. Surface distribution of salinity, December 1972.

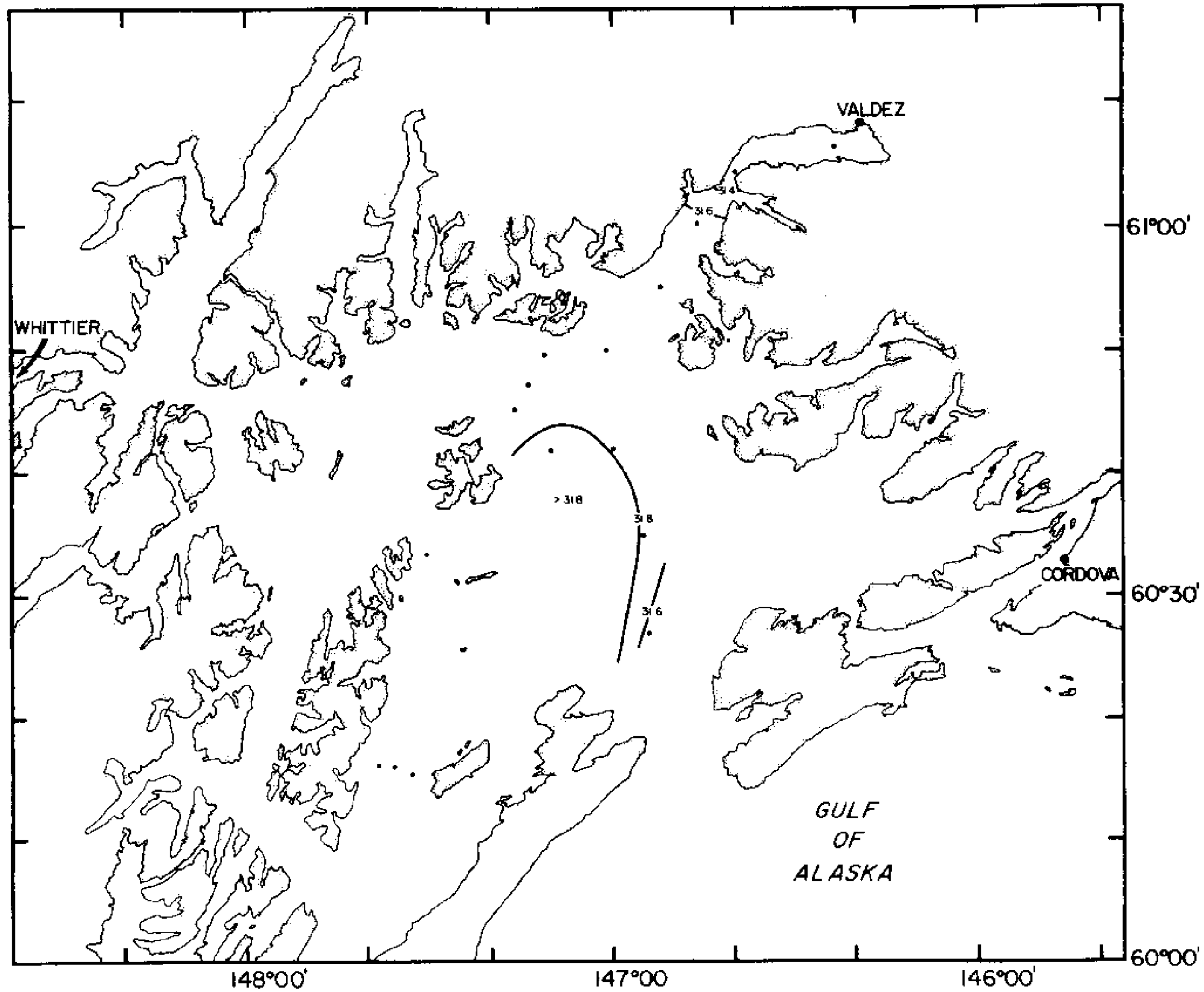

Figure 43. Surface distribtuion of salinity, January 1973.

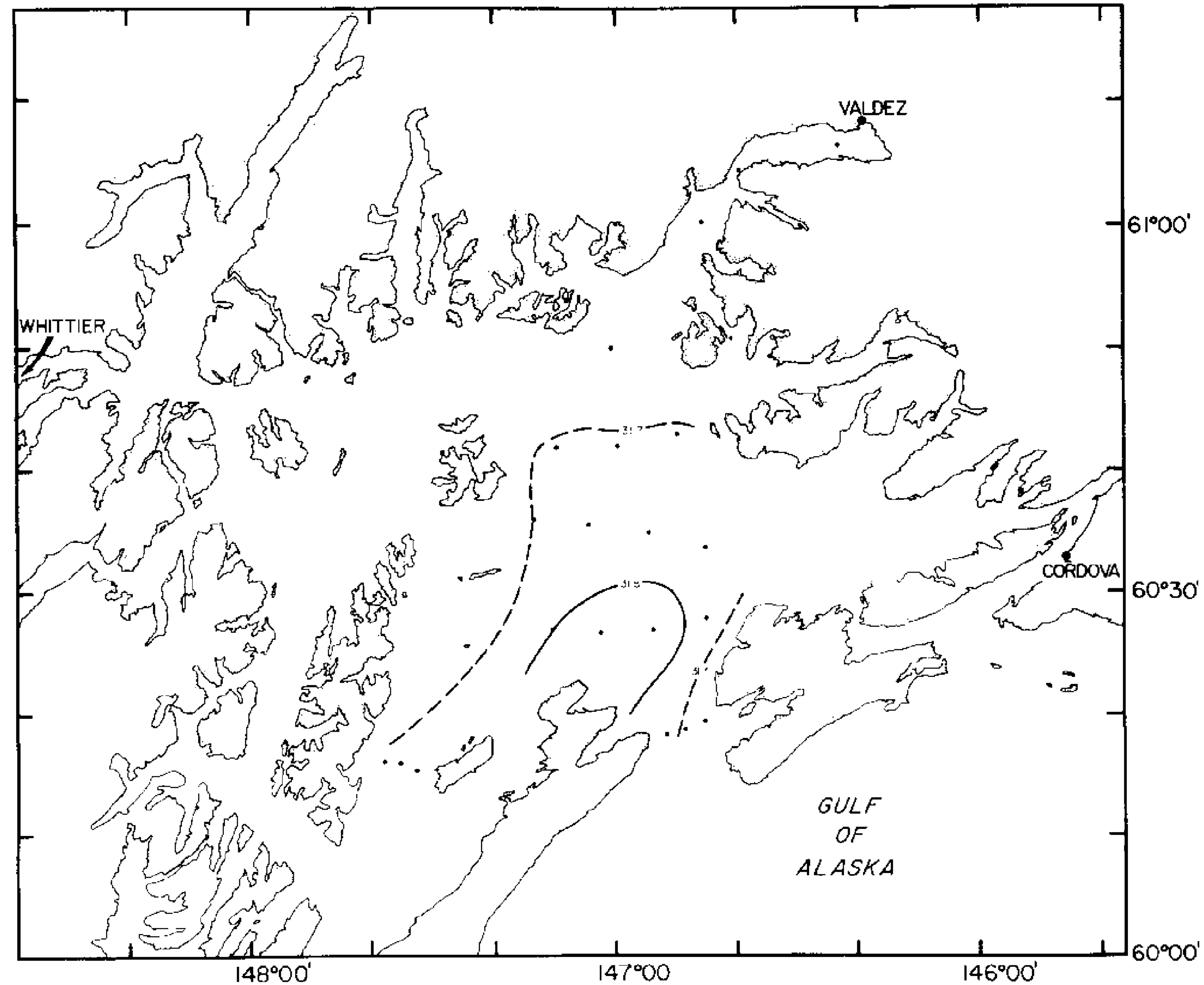

Figure 44. Surface distribution of salinity, March 1973.

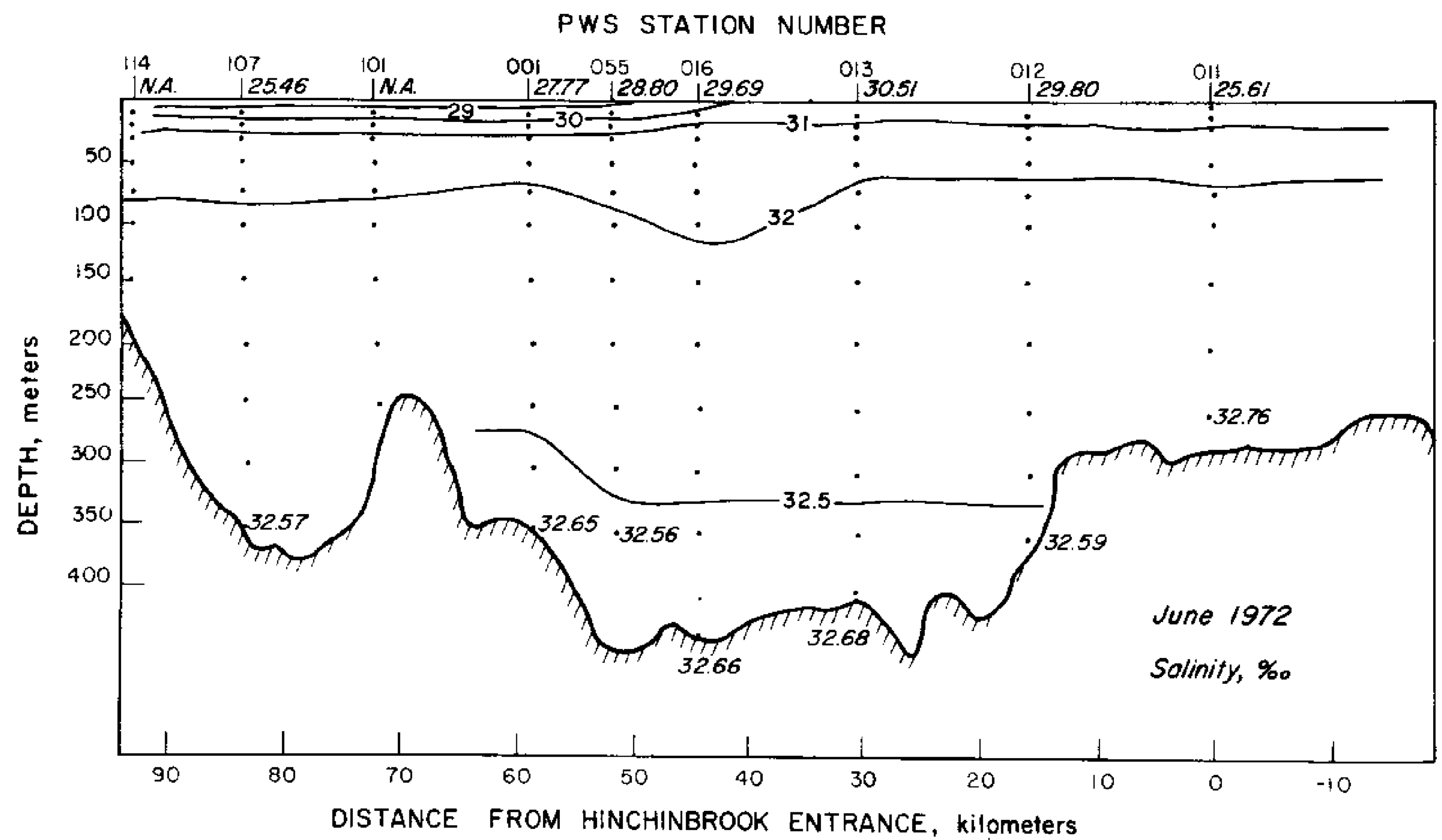

Figure 45. Vertical distribution of salinity in the longitudinal section, June 1972.

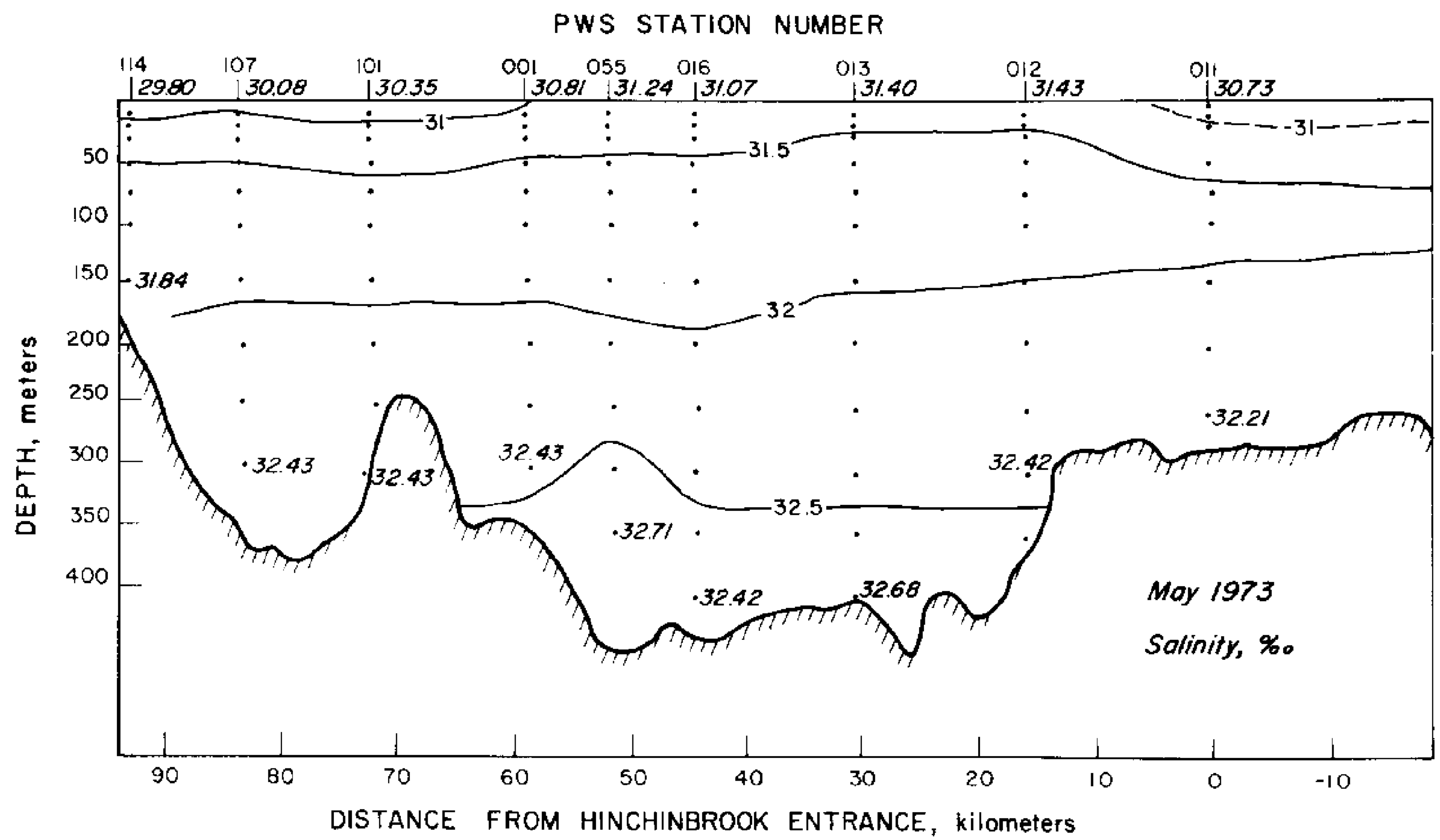

Figure 46. Vertical distribution of salinity in the longitudinal section, May 1973.

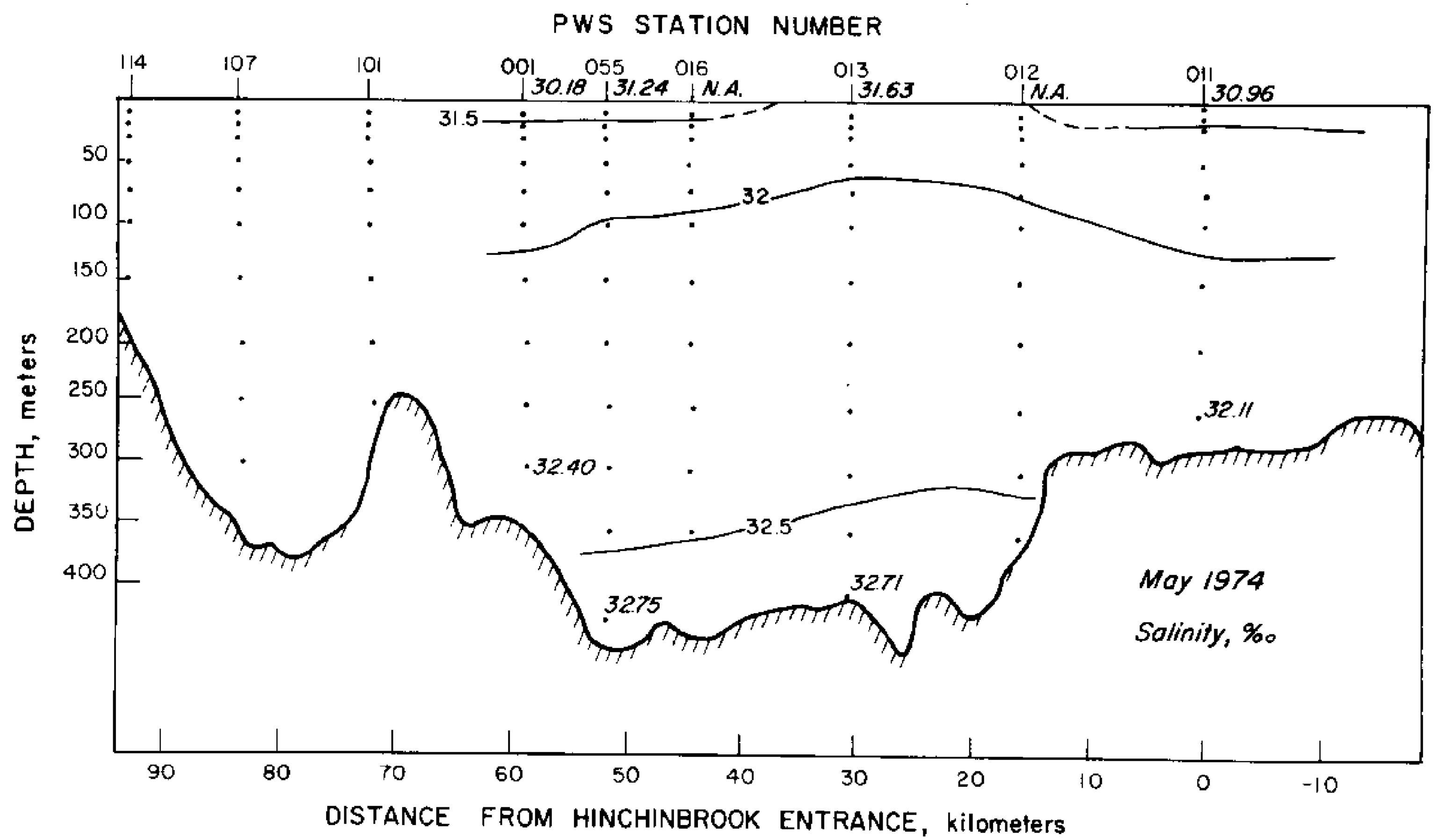

Figure 47. Vertical distribution of salinity in the longitudinal section. May 1974.

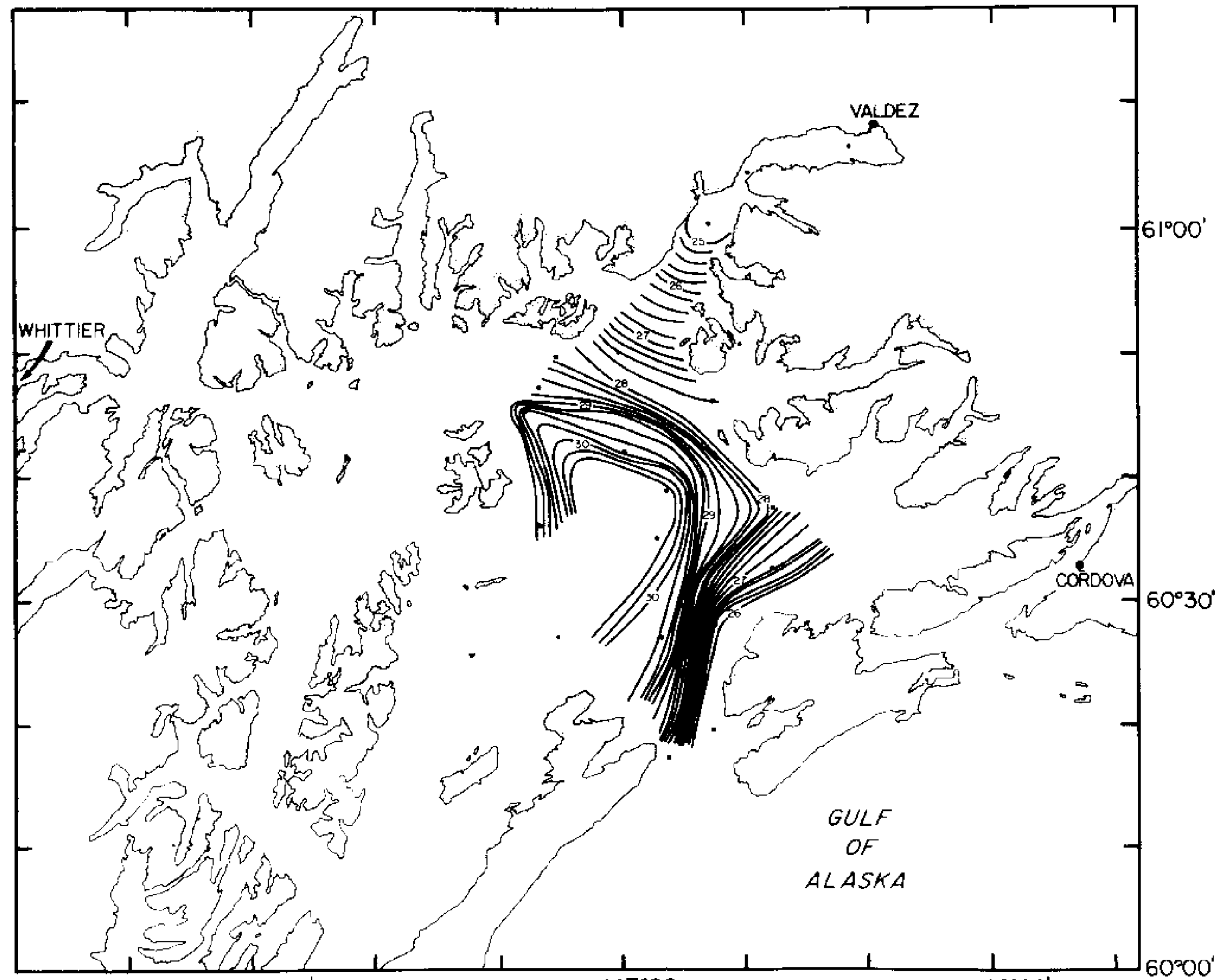

Figure 48. Surface distribution of salinity, June 1972.

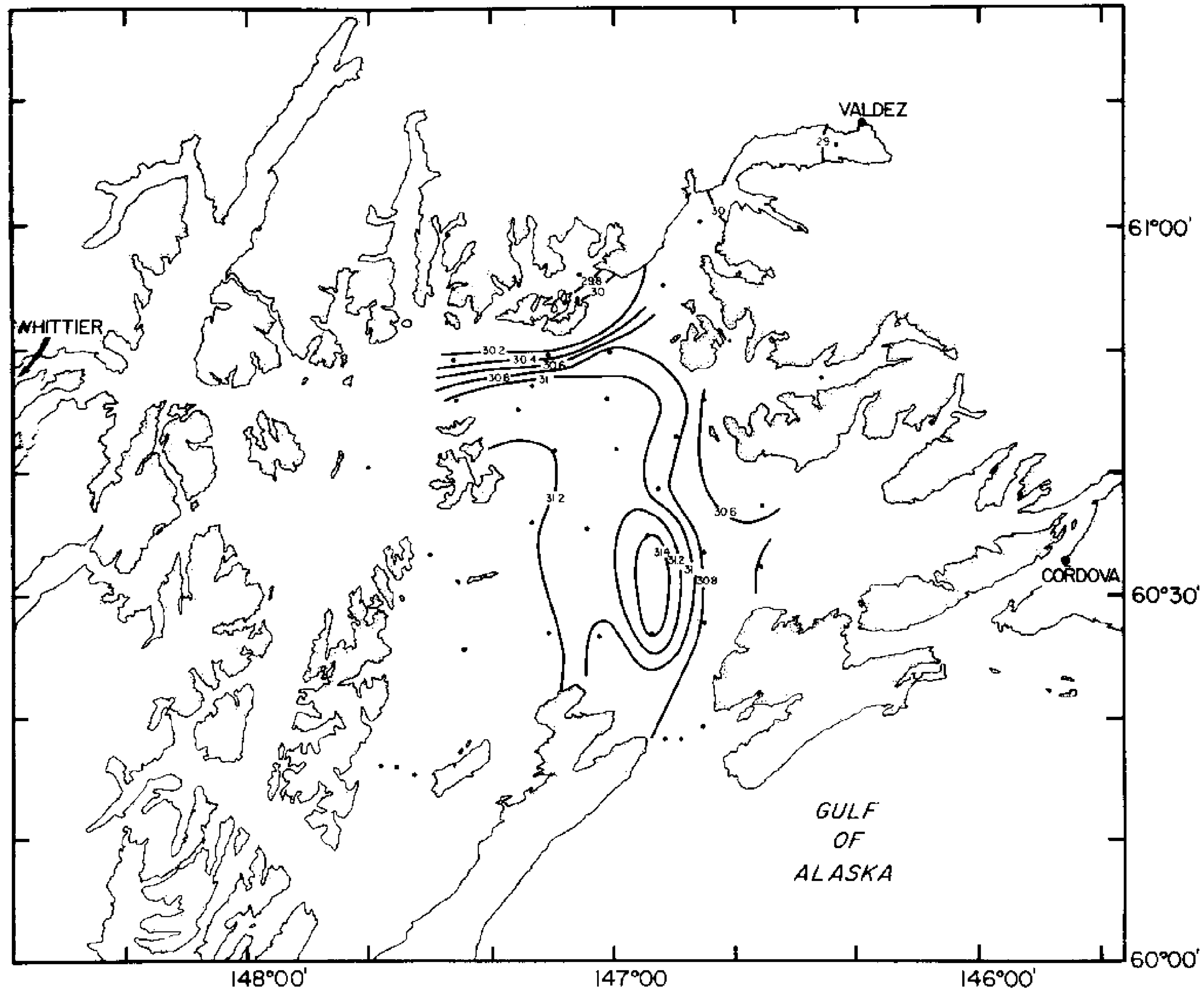

Figure 49. Surface distribution of salinity, May 1973.

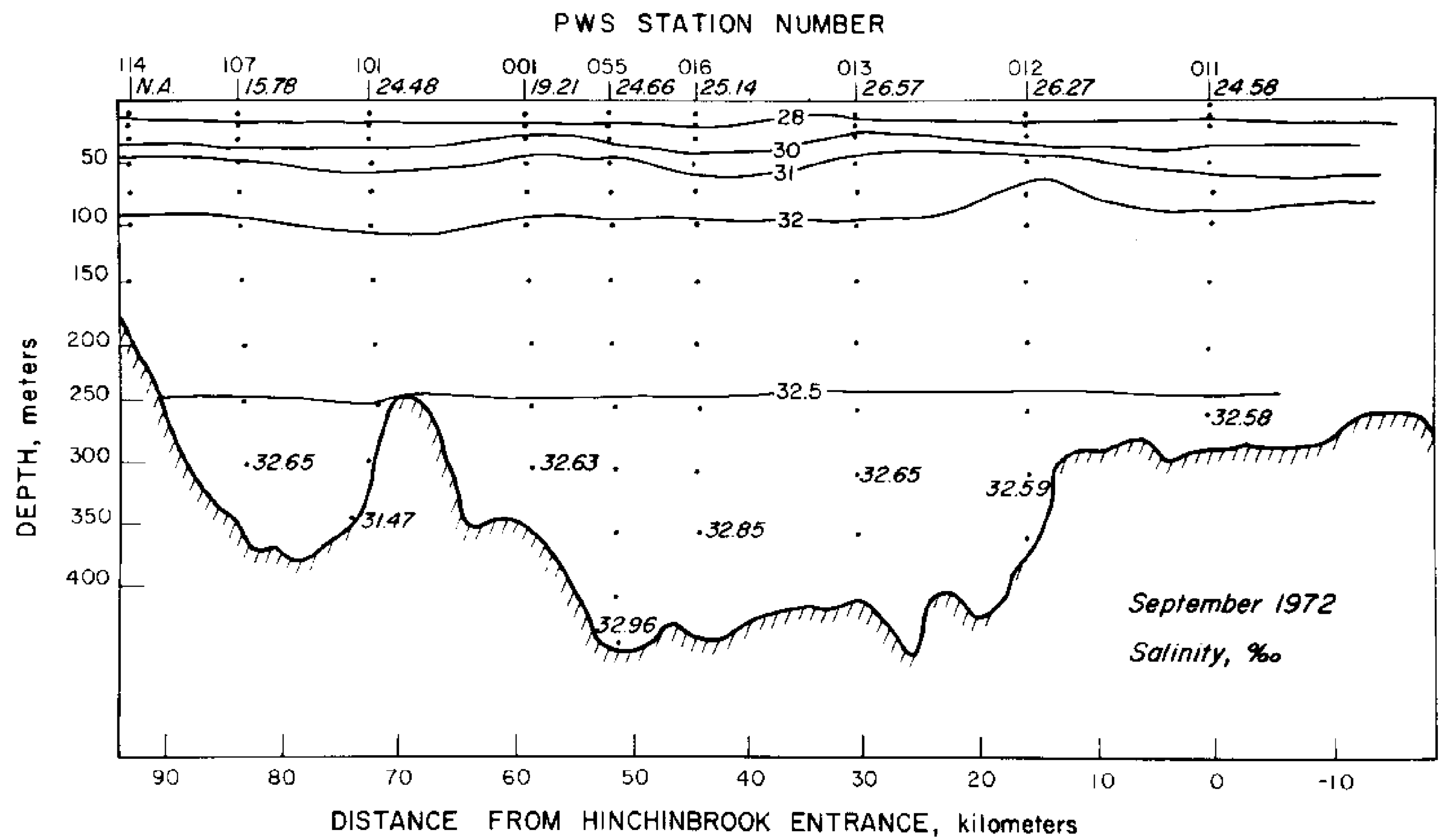

Figure 50. Vertical distribution of salinity in the longitudinal section, September 1972.

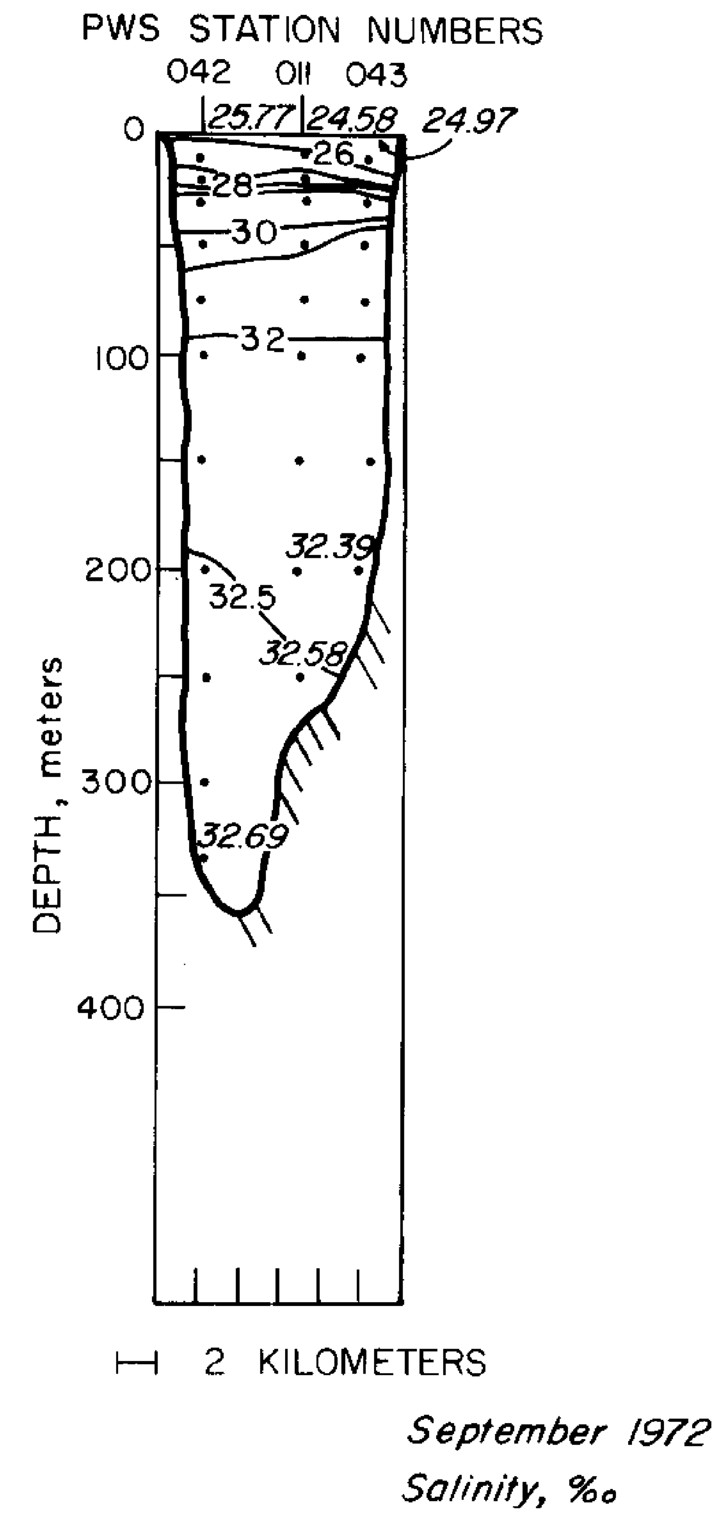

Figure 51. Vertical distribution of salinity in cross-section I, September 1972.

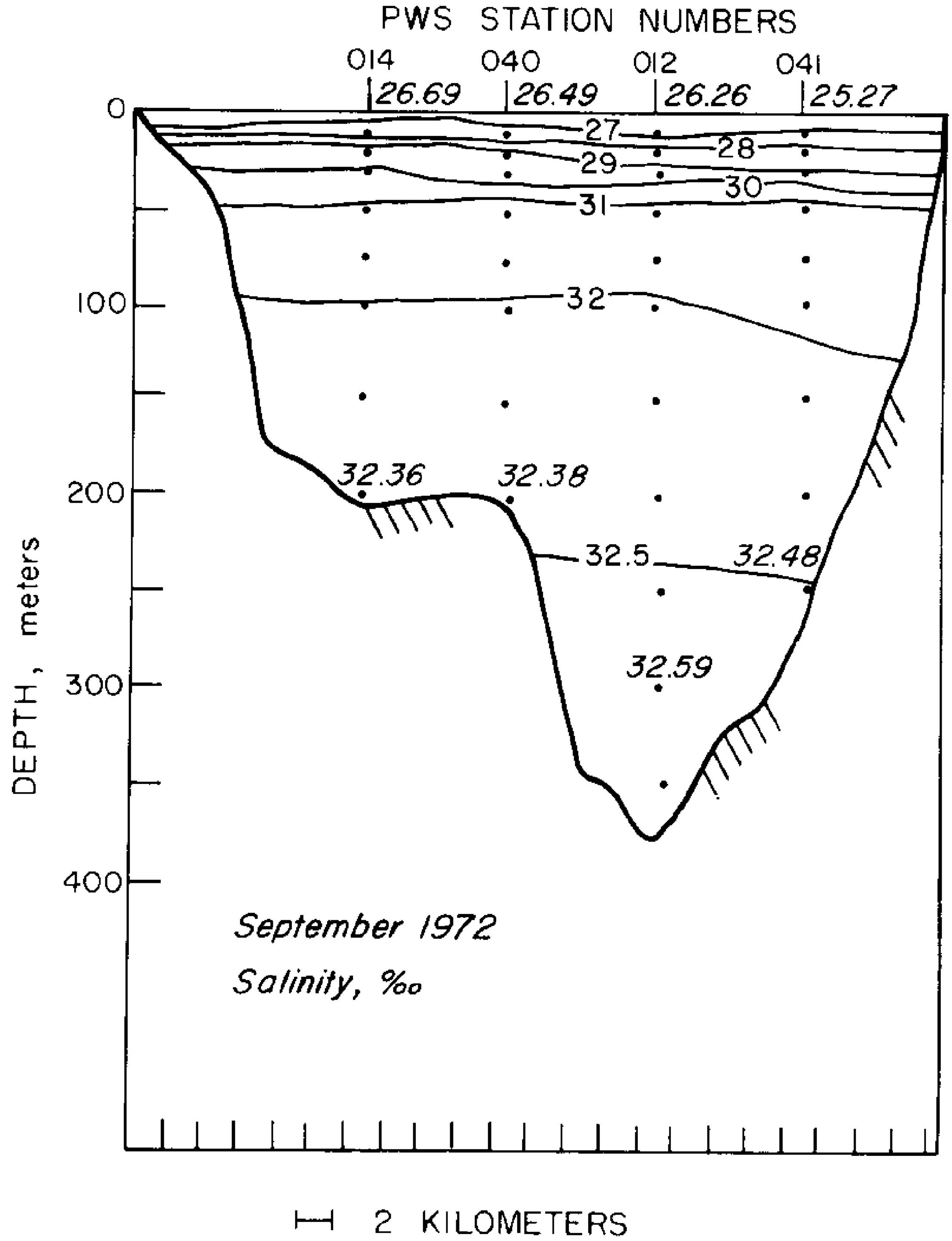

Figure 52. Vertical distribution of salinity in cross-section II, September 1972.

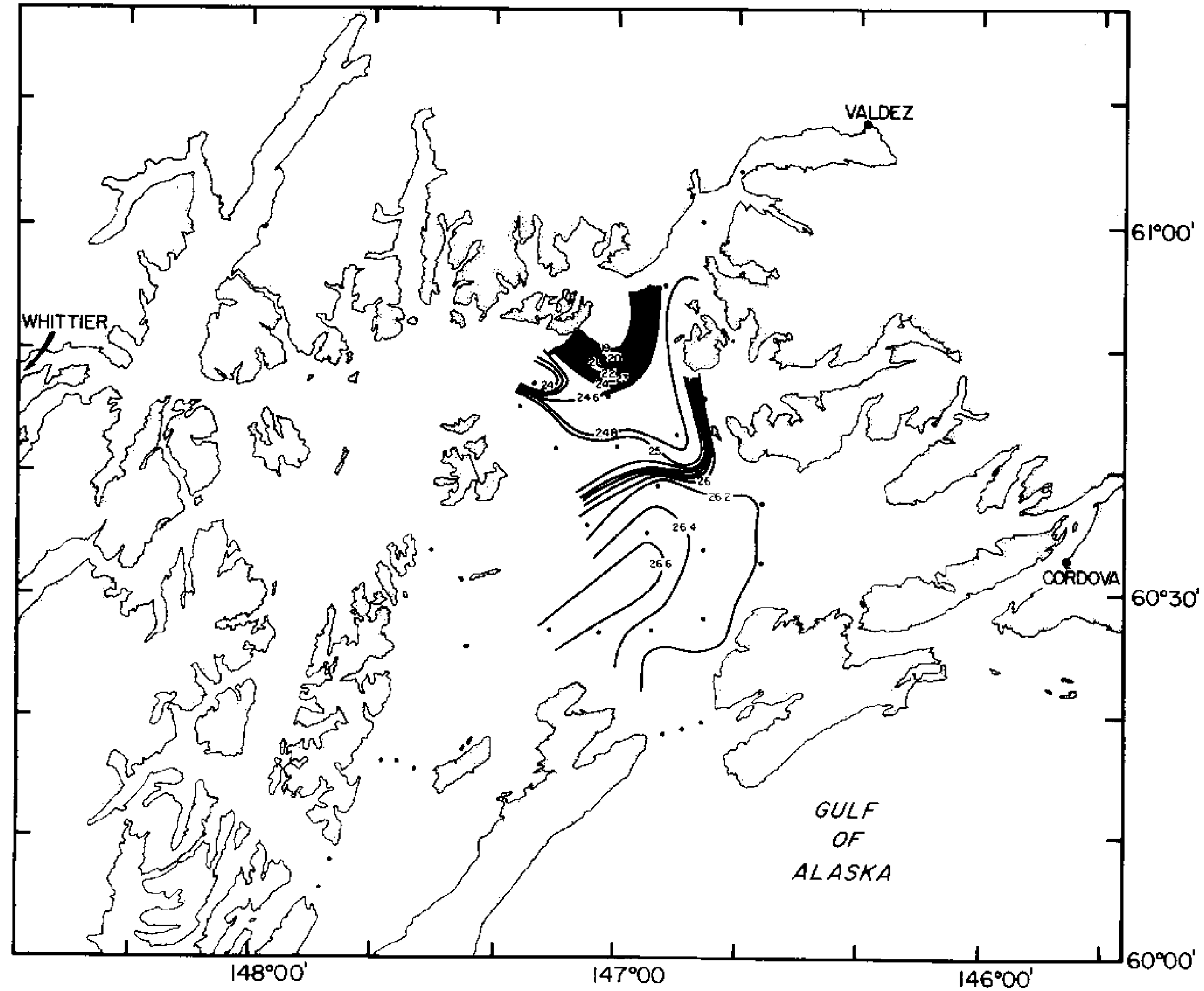

Figure 53. Surface distribution of salinity, September 1972.

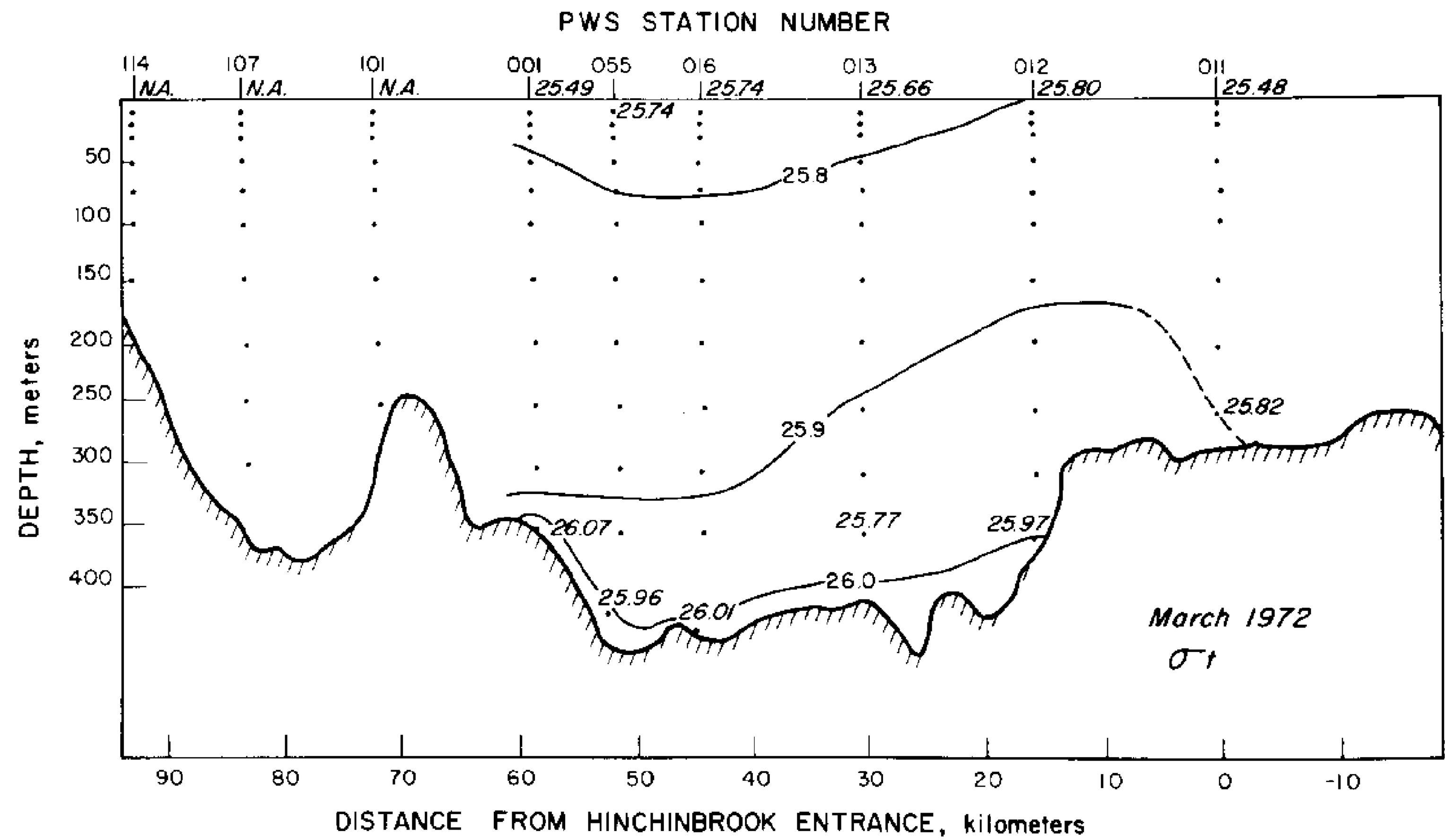

Figure 54. Vertical distribution of density in the longitudinal section, March 1972.

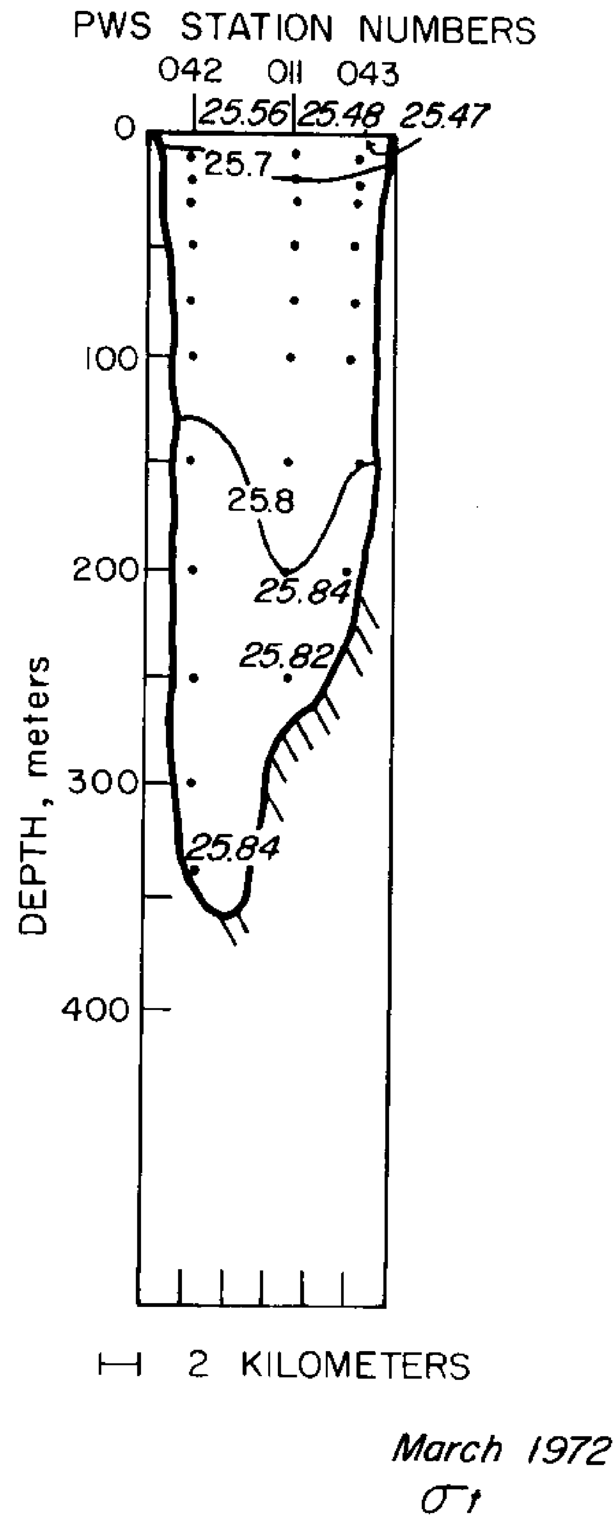

Figure 55. Vertical distribution of density
in cross-section I, March 1972.

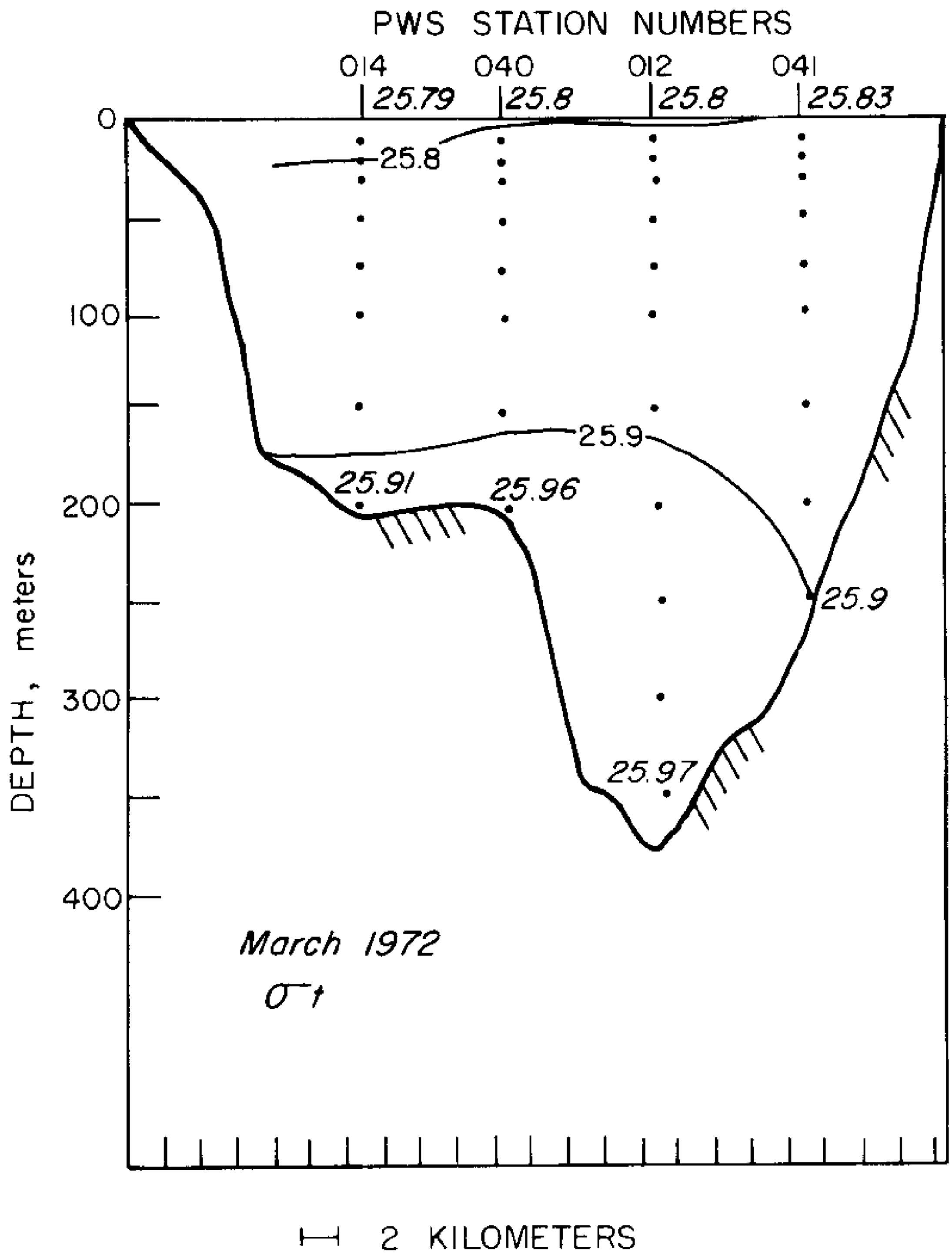

Figure 56. Vertical distribution of density in cross-section II, March 1972.

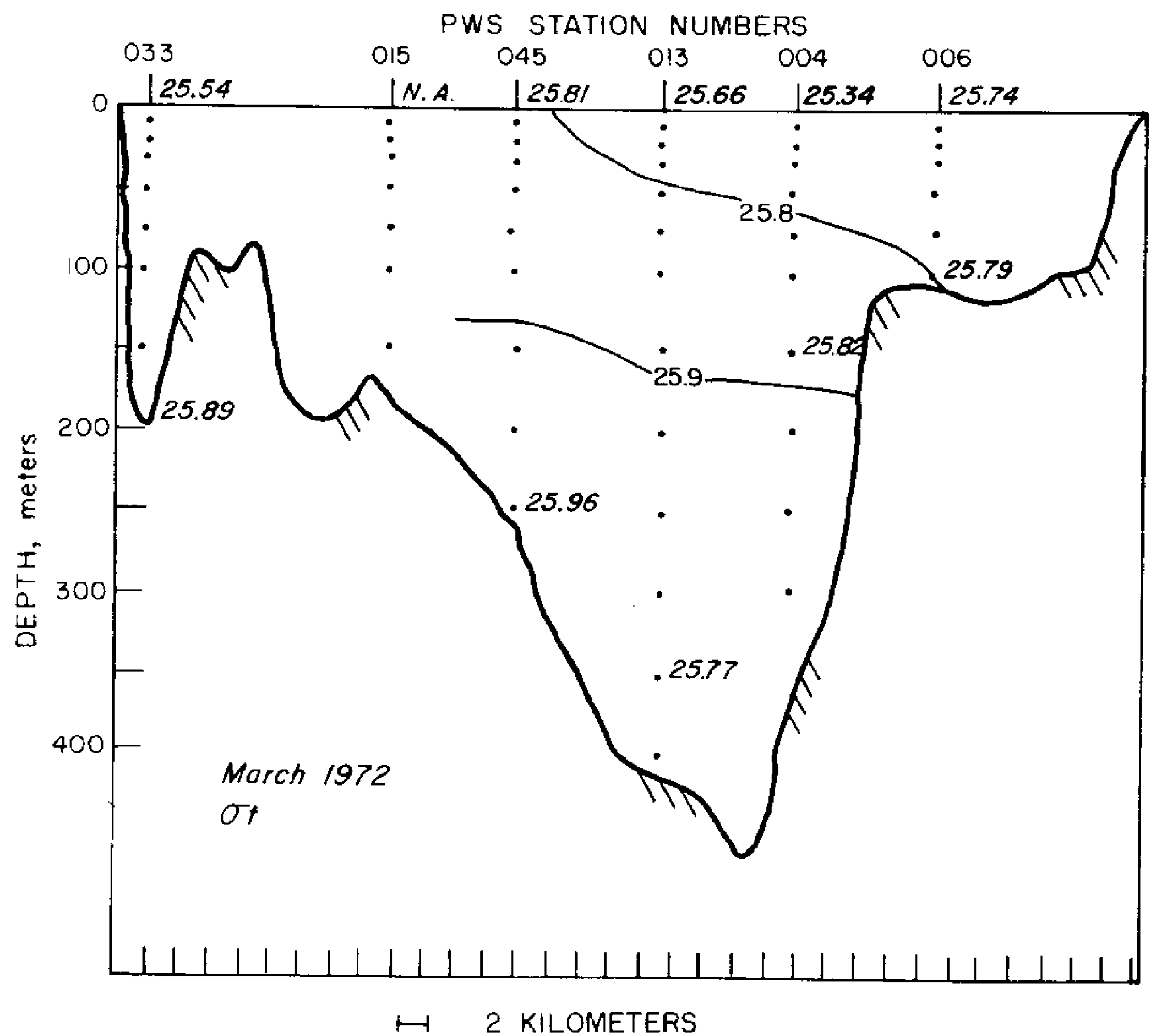

Figure 57. Vertical distribution of density in cross-section III. March 1972.

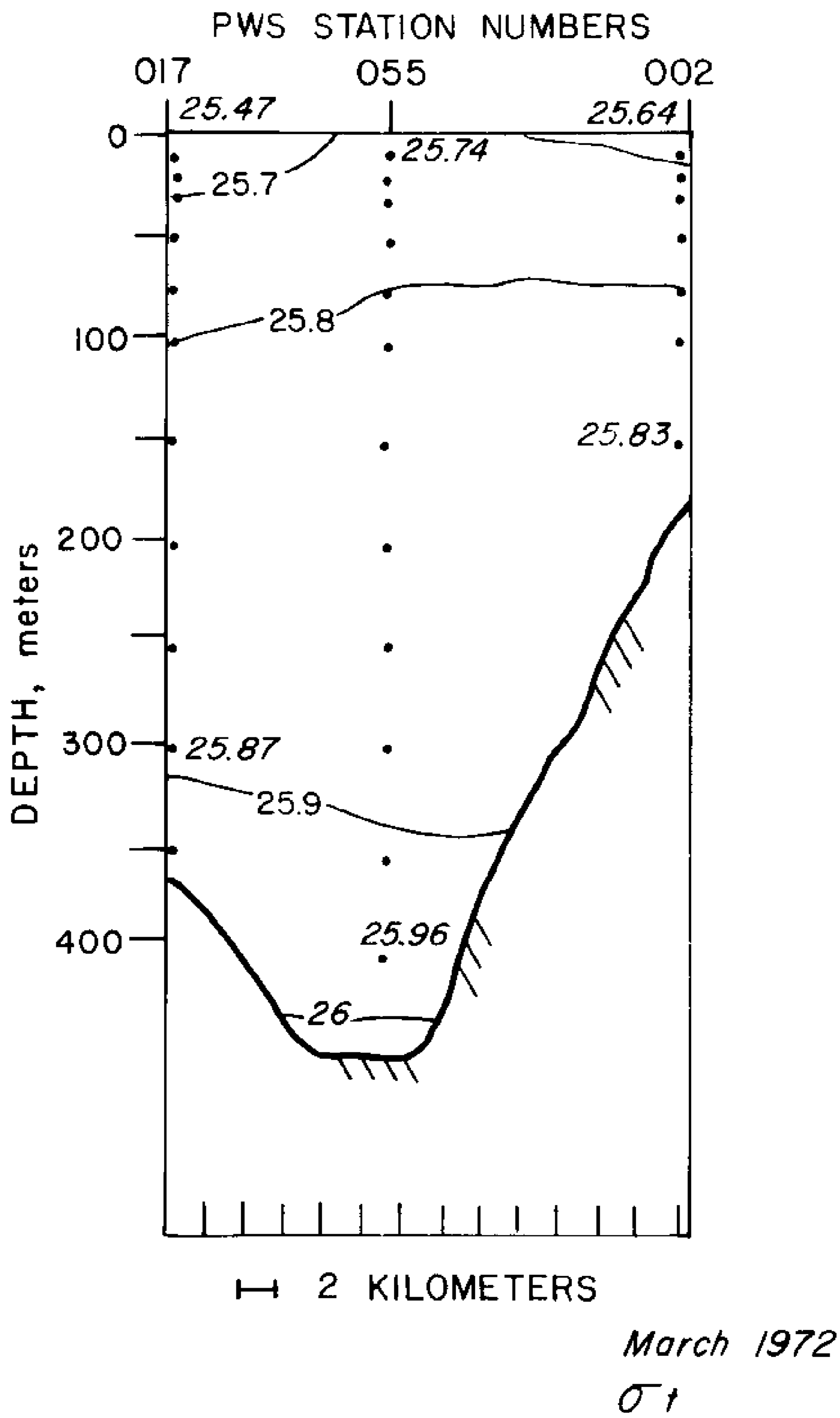

Figure 58. Vertical distribution of density in cross-section V, March 1972.

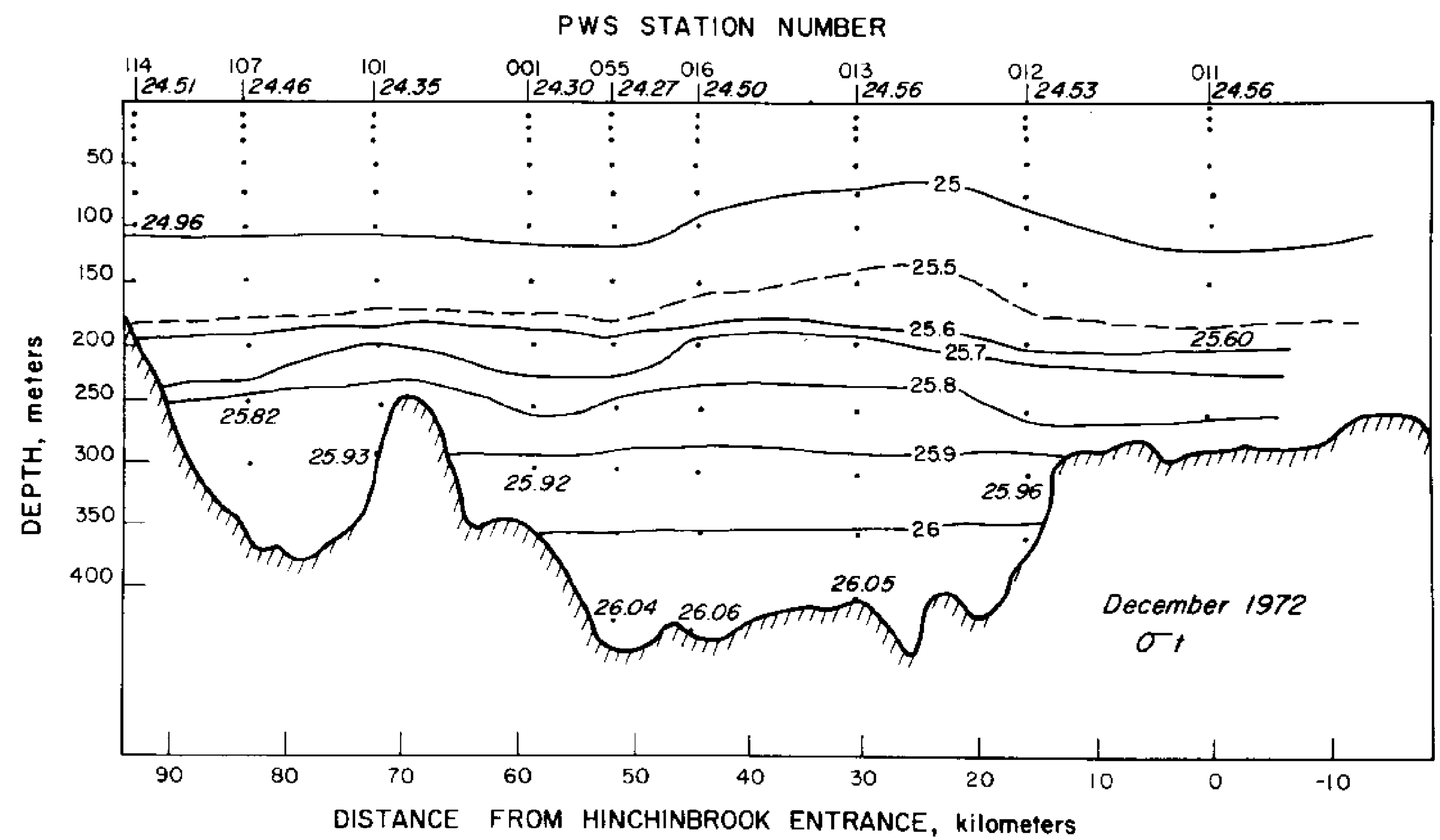

Figure 59. Vertical distribution of density in longitudinal section, December 1972.

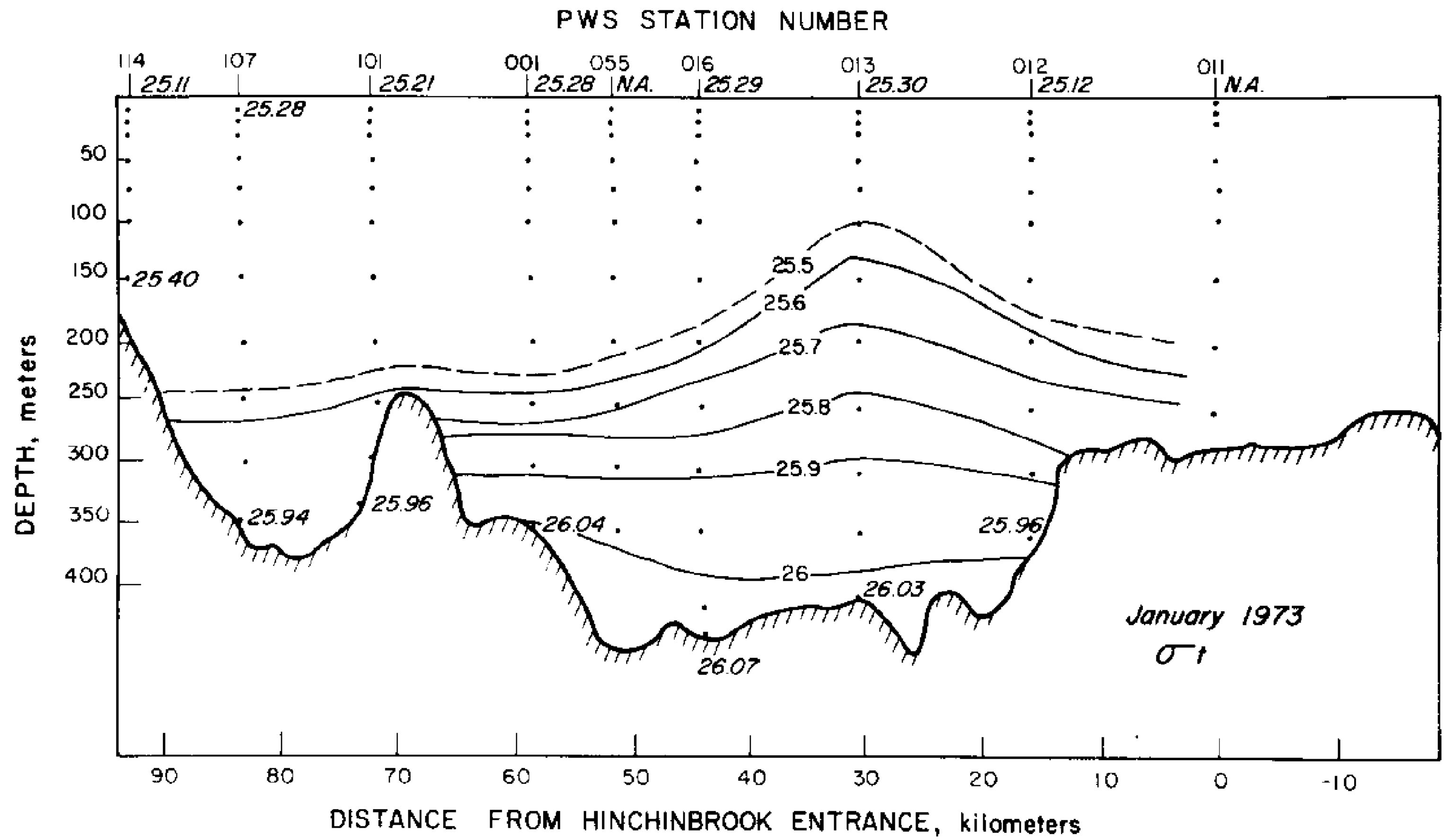

Figure 60. Vertical distribution of density in the longitudinal section, January 1973.

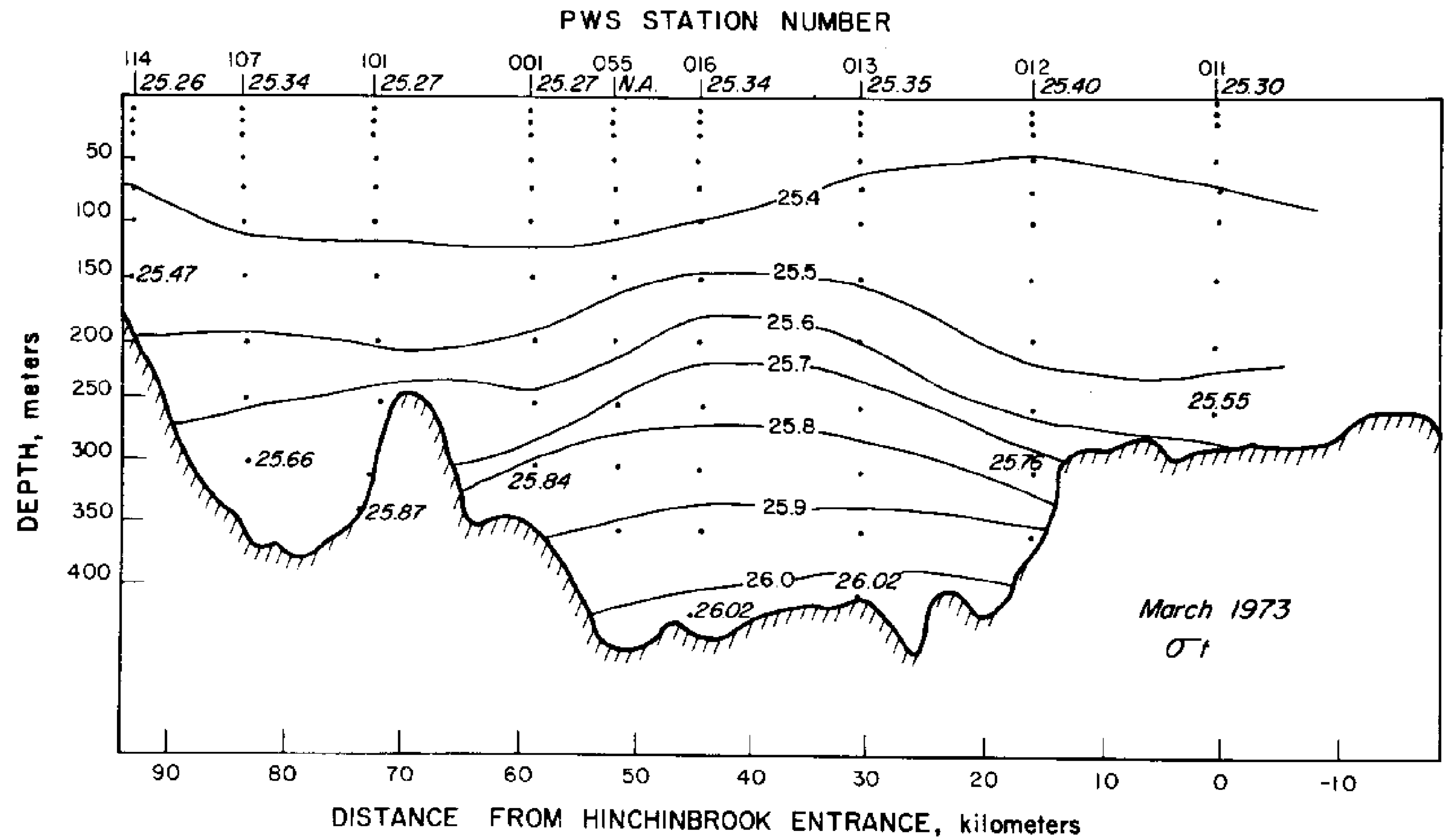

Figure 61. Vertical distribution of density in the longitudinal section, March 1973.

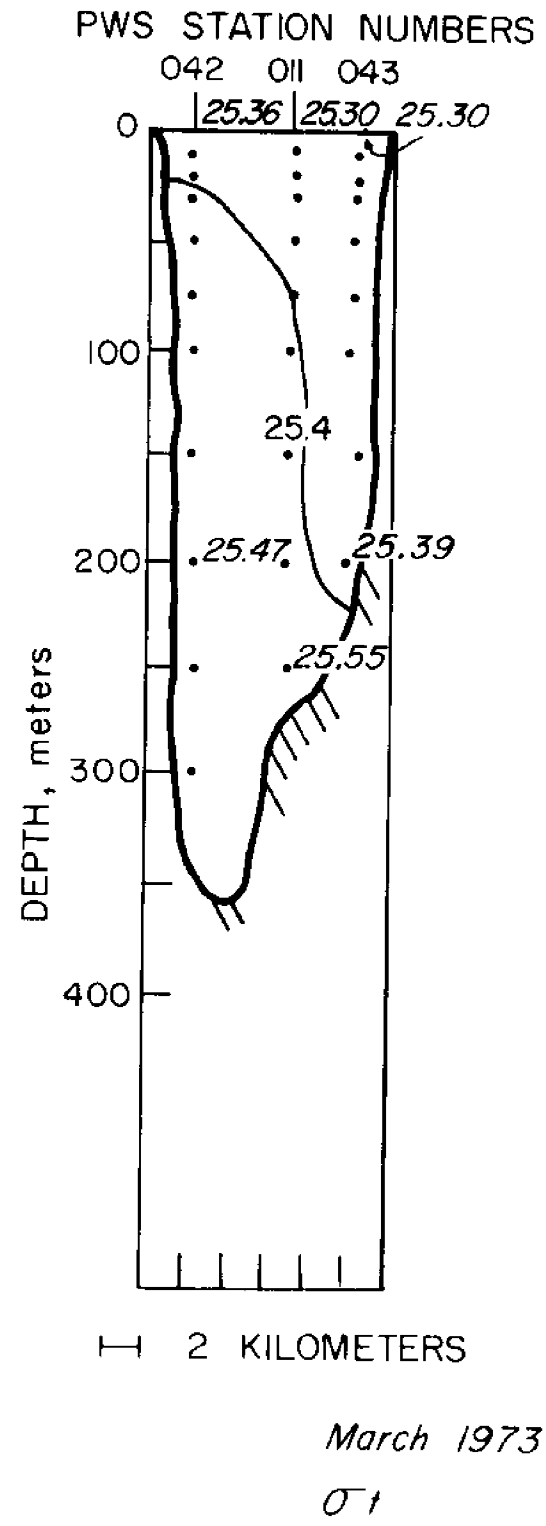

Figure 62. Vertical distribution of density in cross-section I, March 1973.

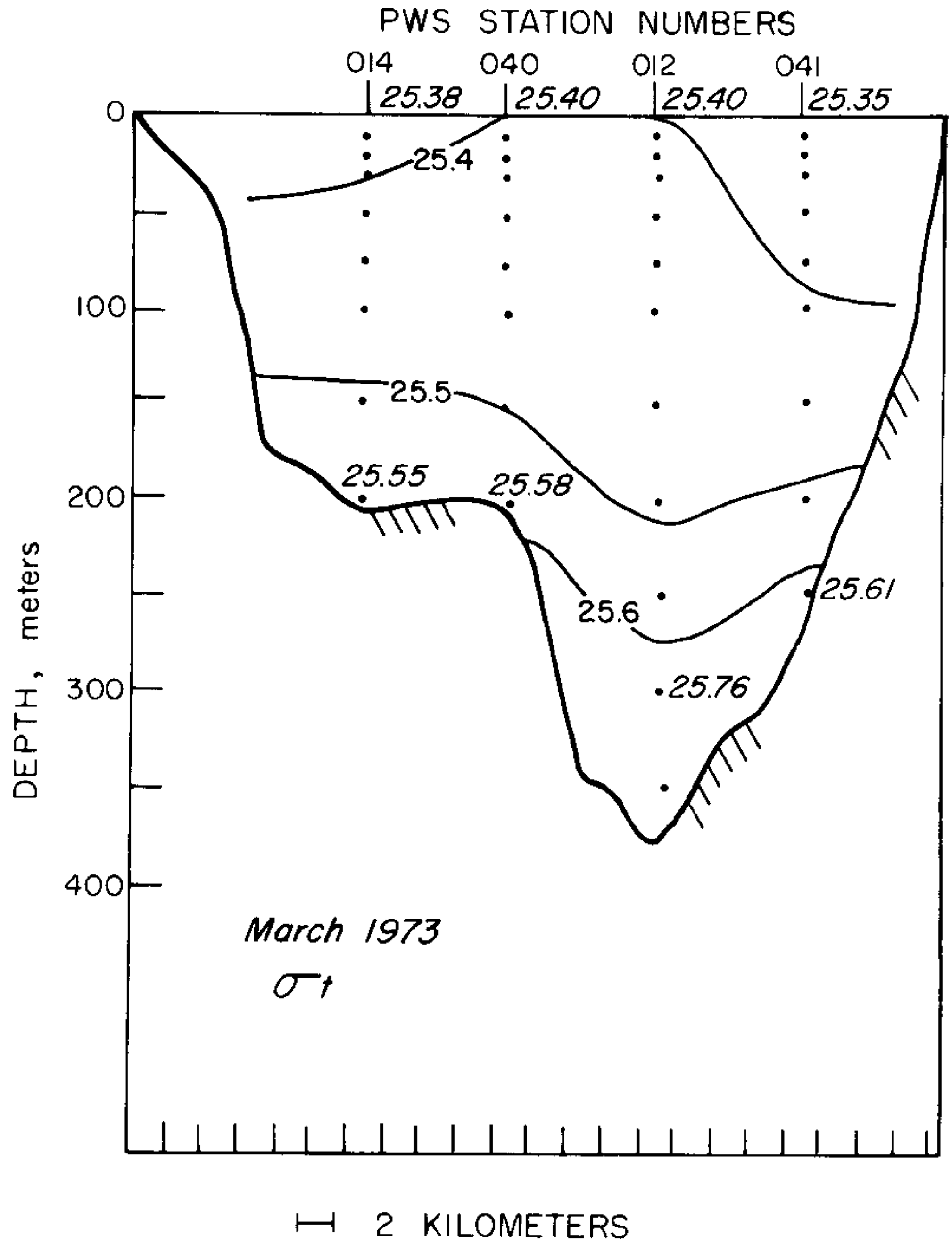

Figure 63. Vertical distribution of density in cross-section II, March 1973.

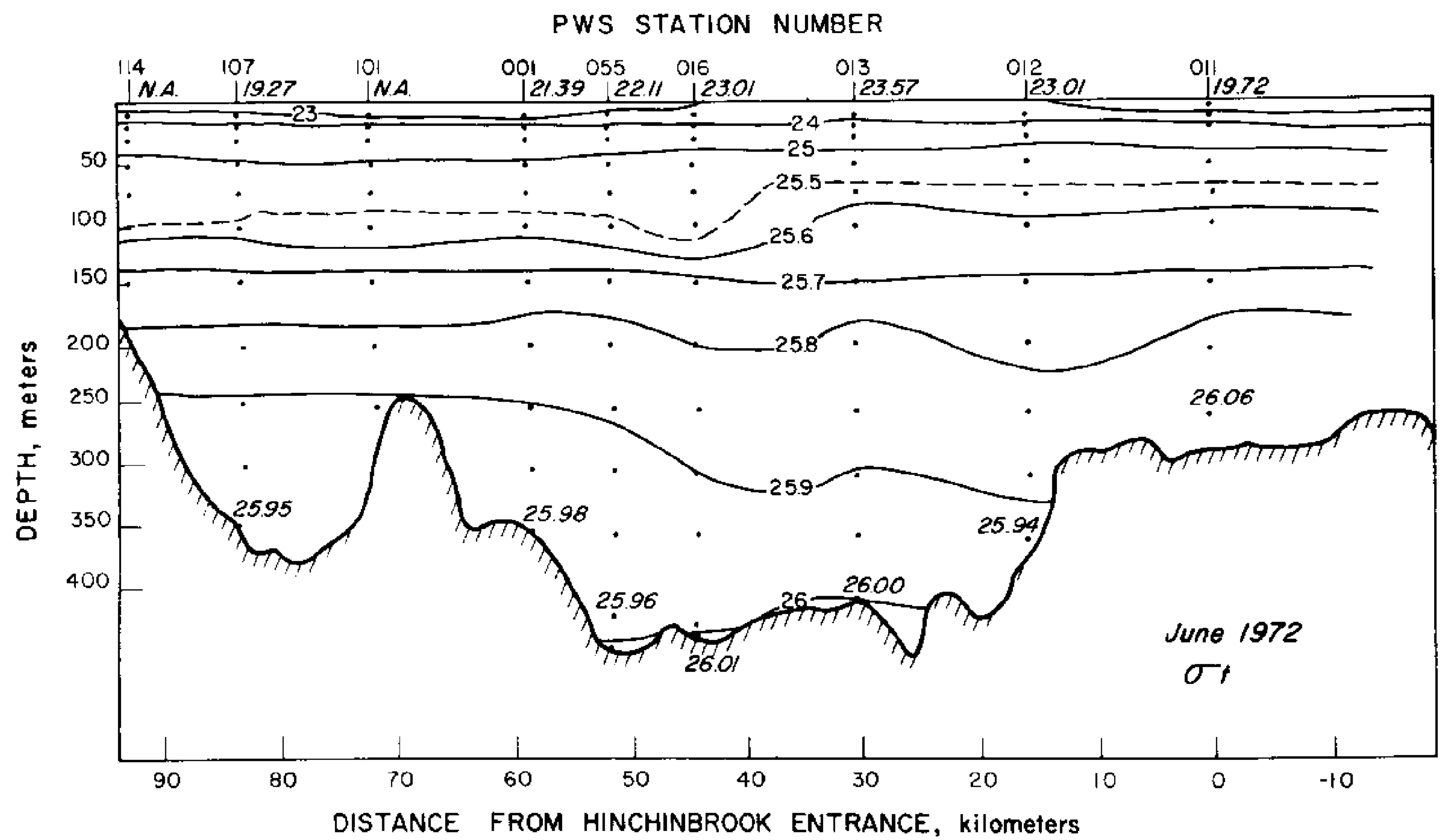

Figure 64. Vertical distribution of density in the longitudinal section, June 1972.

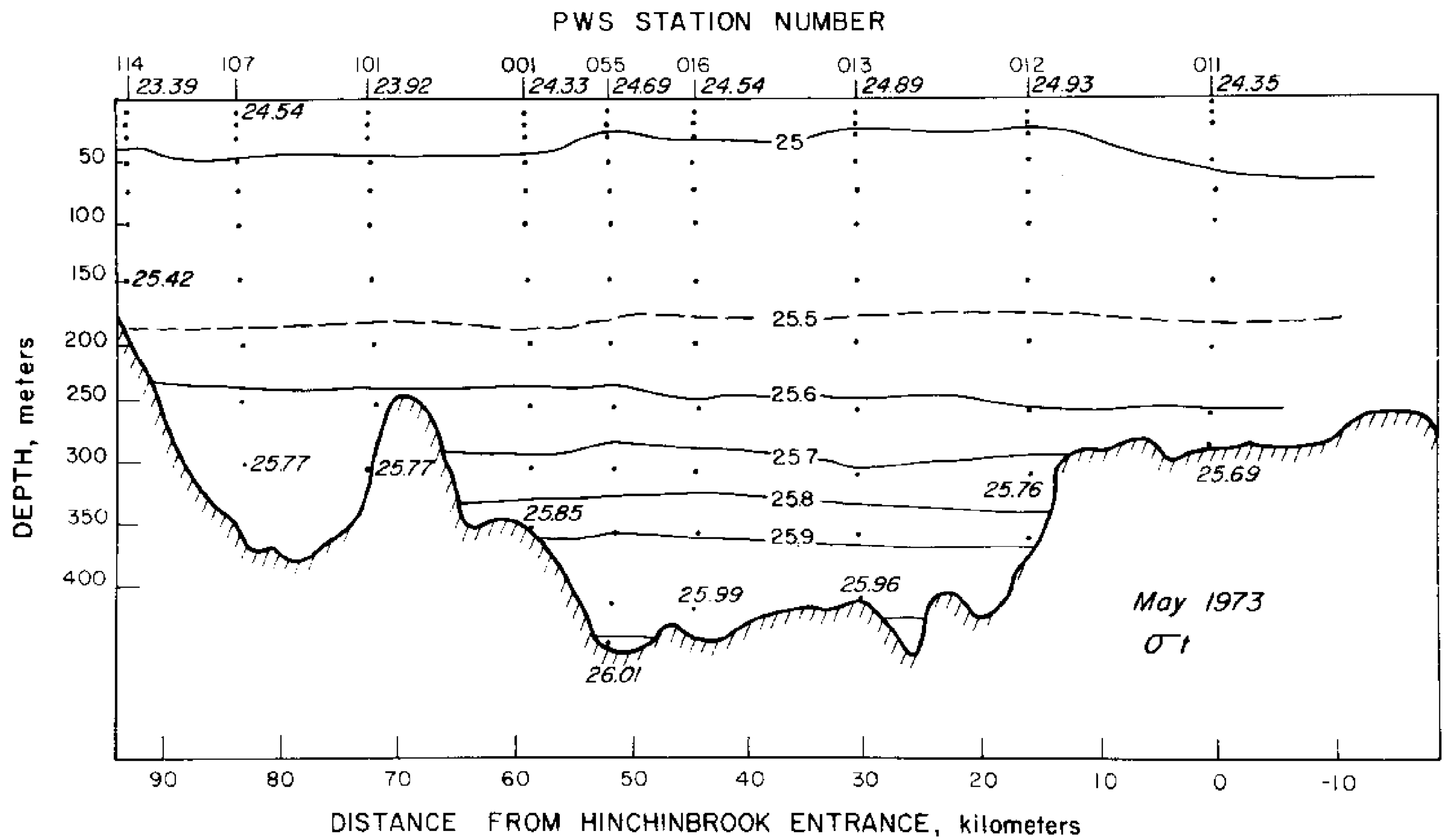

Figure 65. Vertical distribution of density in the longitudinal section, May 1973.

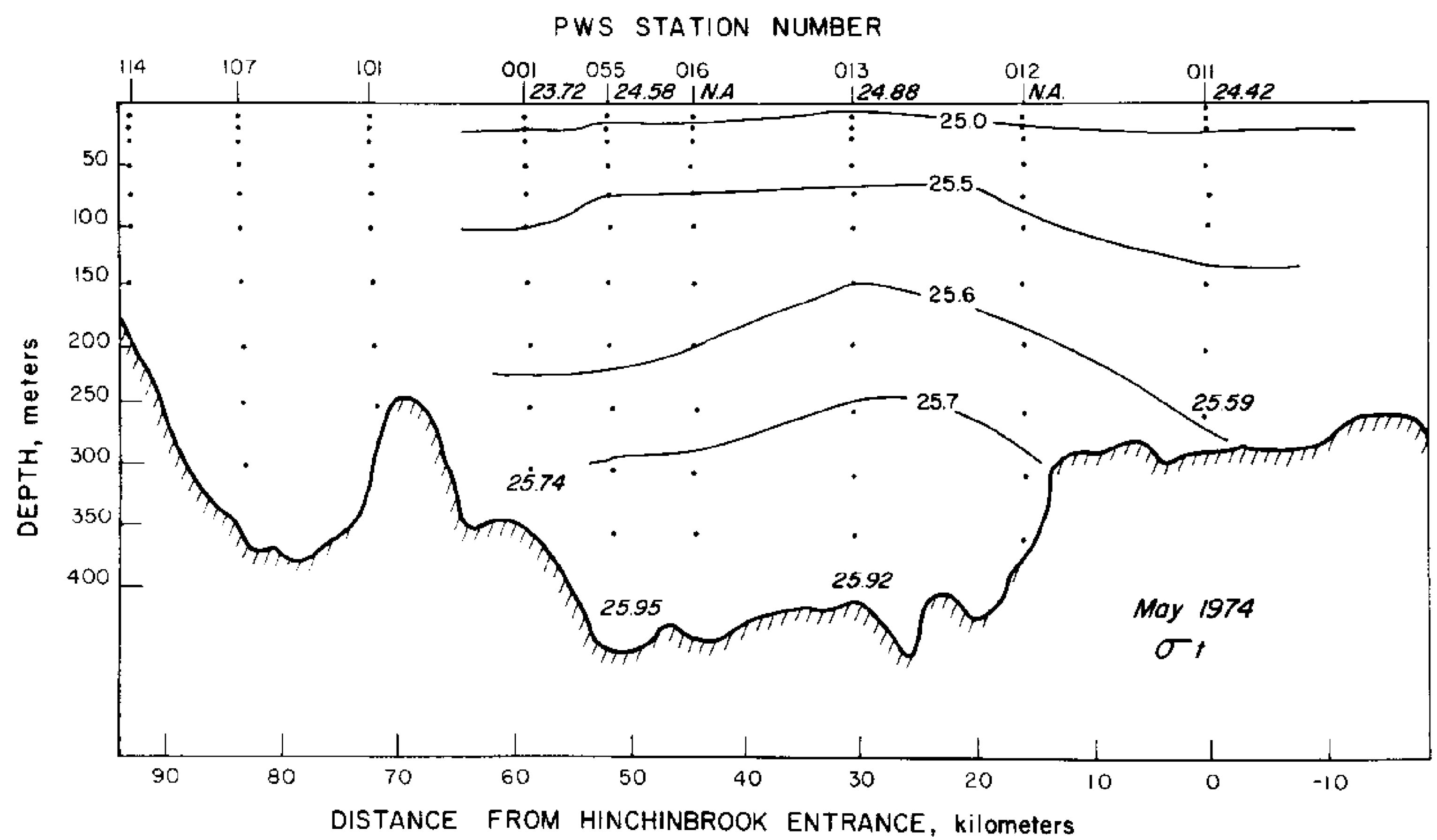

Figure 66. Vertical distribution of density in the longitudinal section, May 1974.

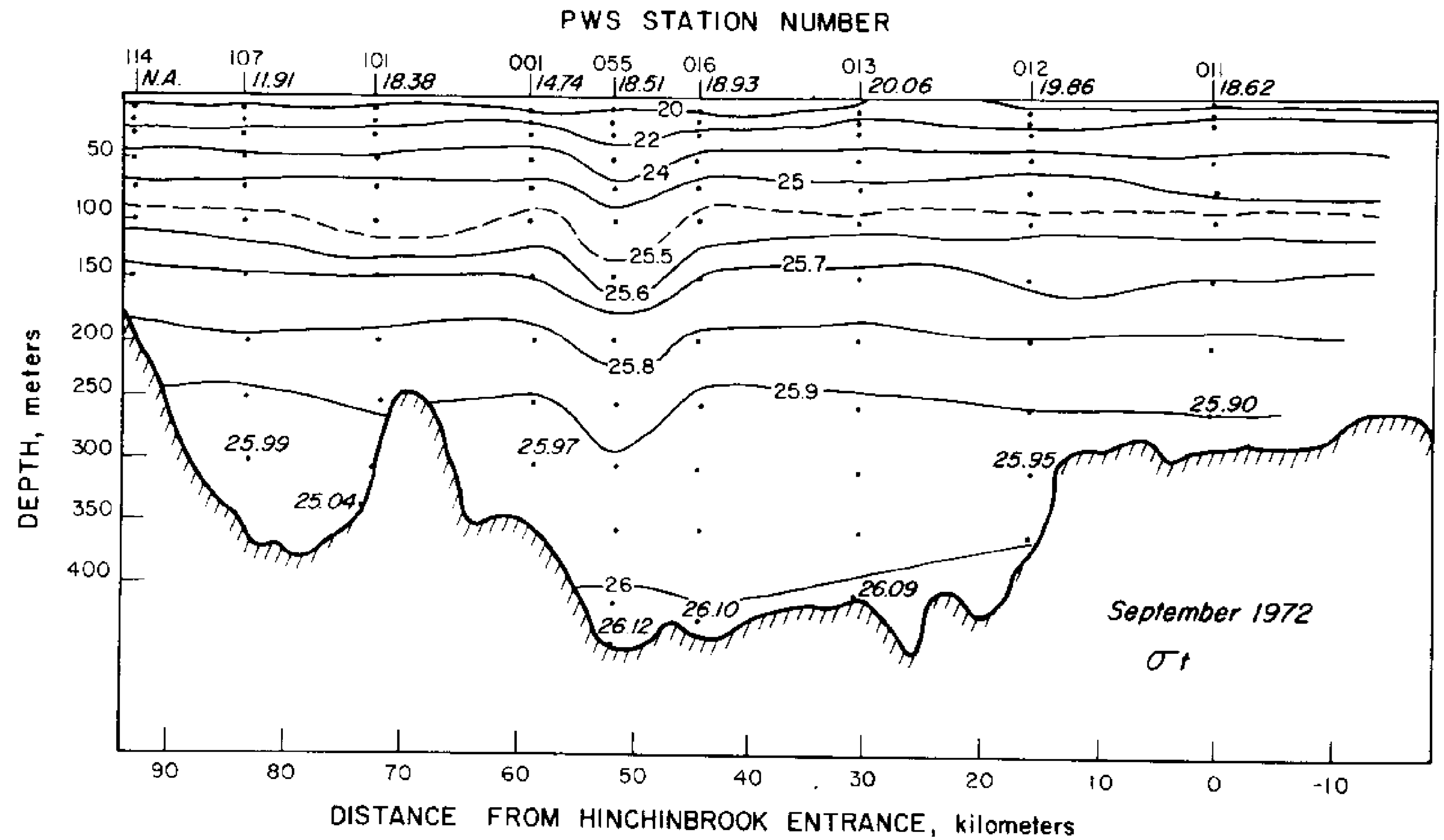

Figure 67. Vertical distribution of density in the longitudinal section. September 1972.

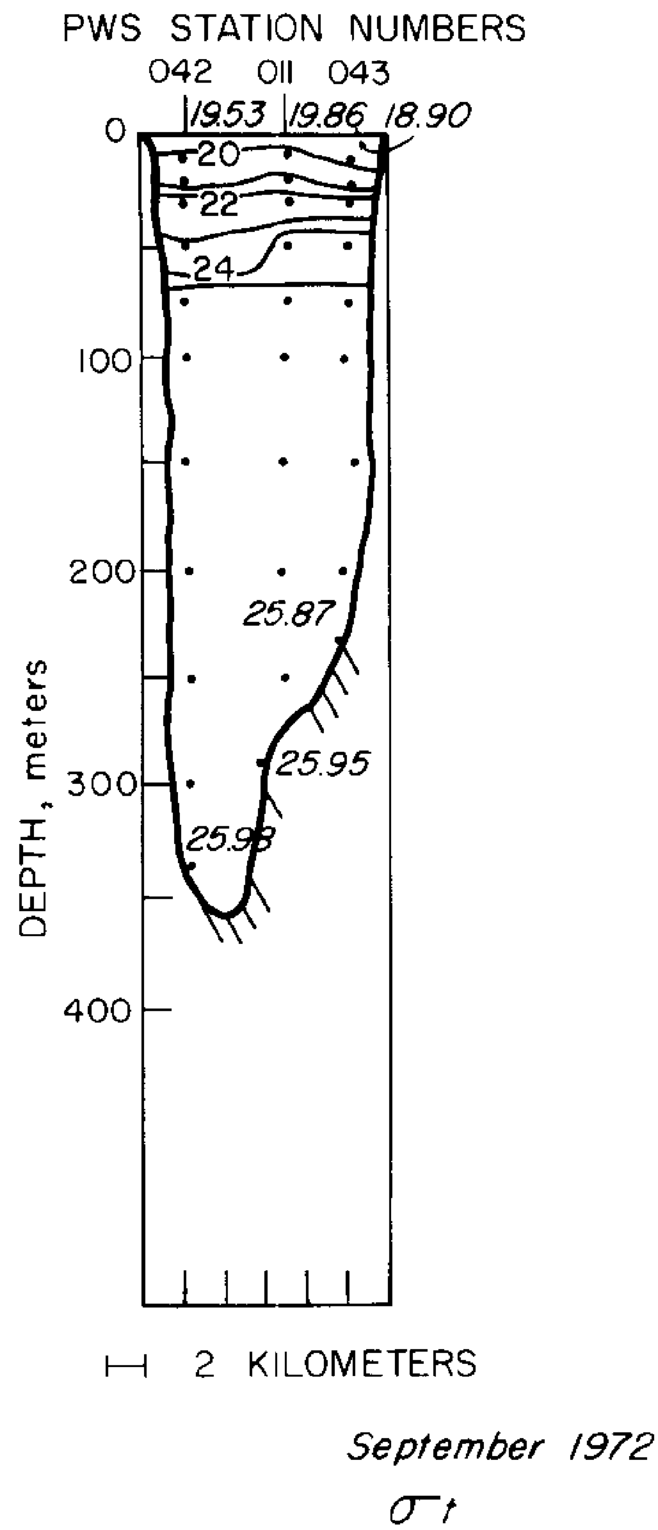

Figure 68. Vertical distribution of density in cross-section 1. September 1972.

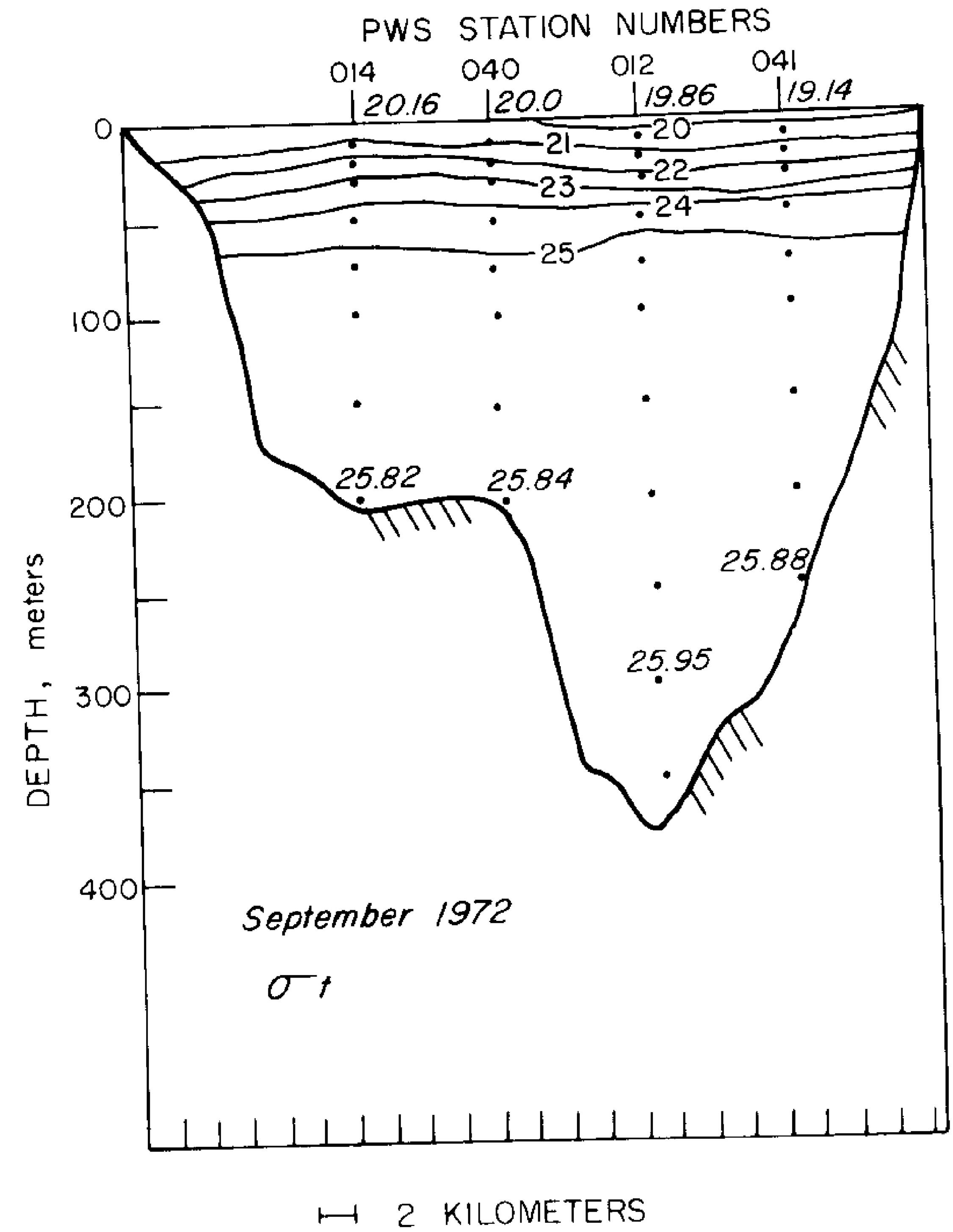

Figure 69. Vertical distribution of density in cross-section II, September 1972.

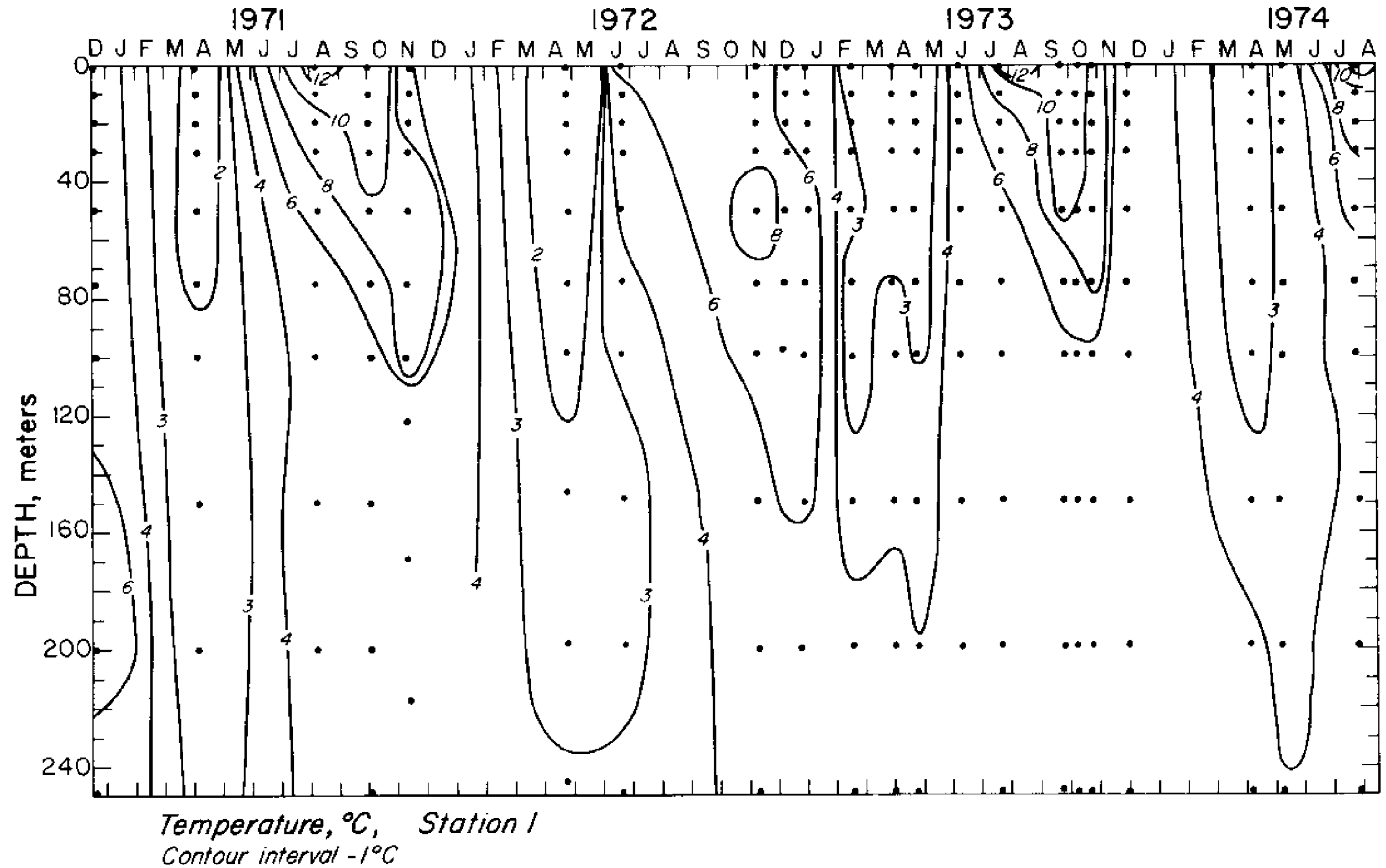

Figure 70. Time series of temperature at GAK 1 from December 1971 to April 1974.

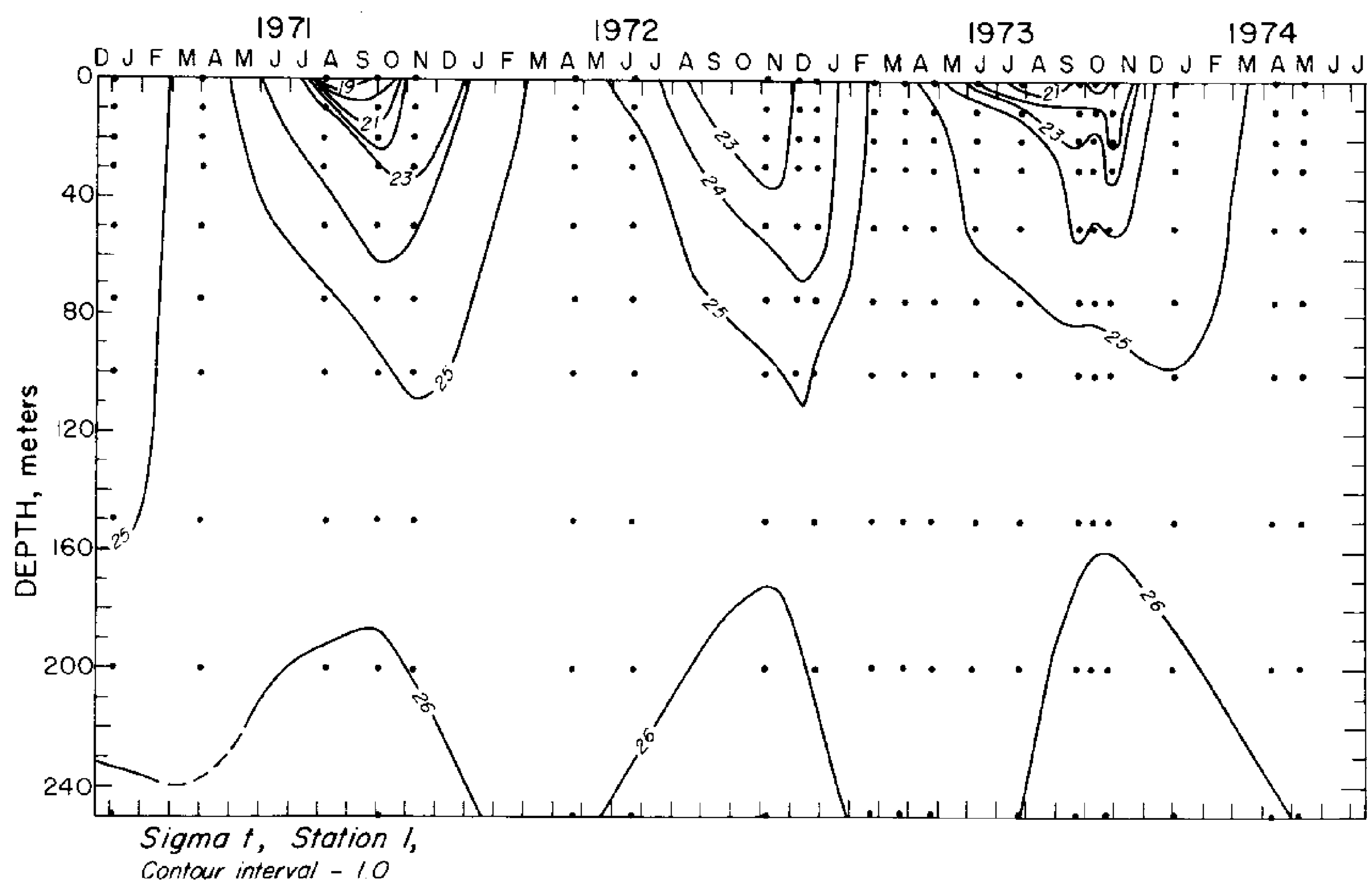

Figure 71. Time series of sigma t at GAK 1 from December 1971 to April 1974.

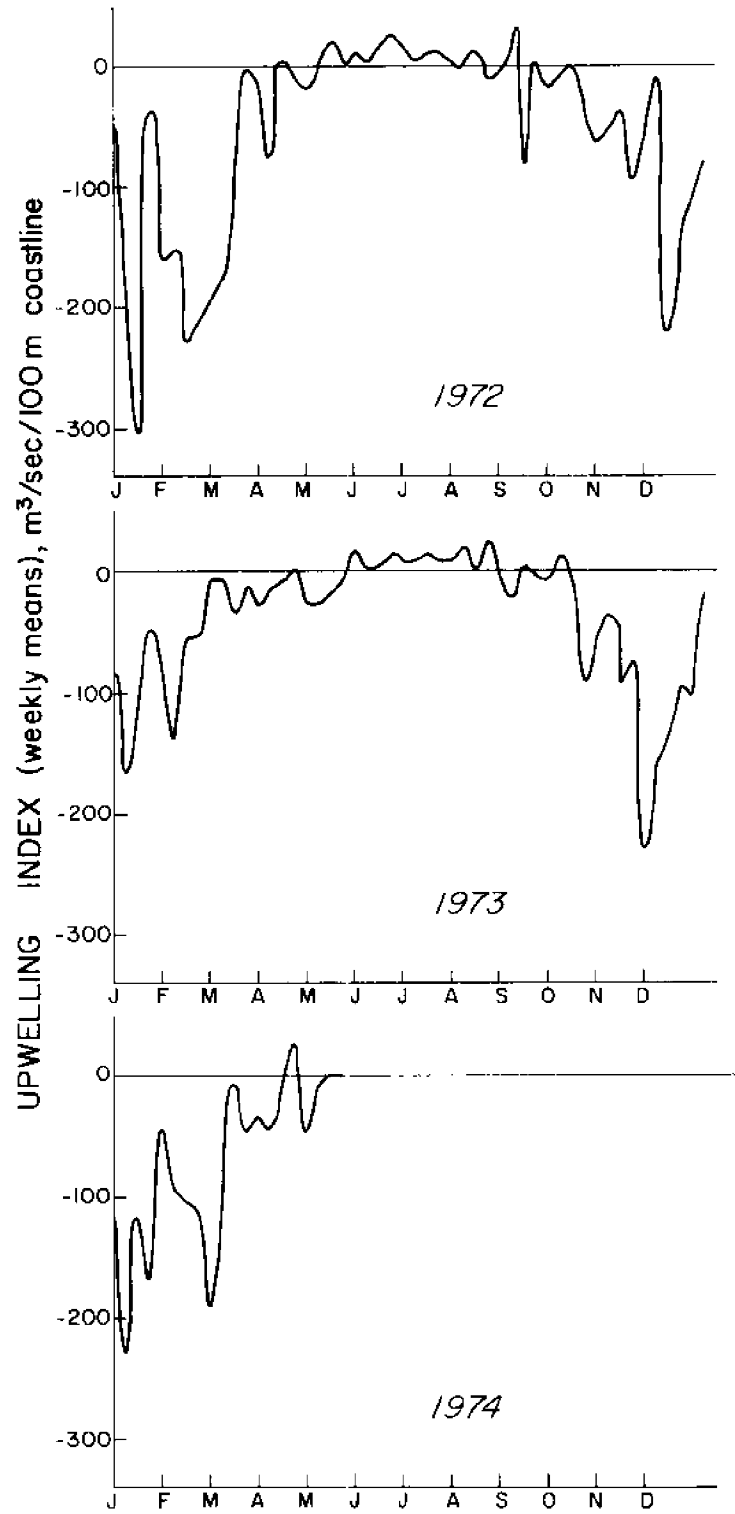

Figure 72. Upwelling indices at 60°N, 146°W (from Bakum 1973).

APPENDIX 1

Prince William Sound

Historical Weather Summary

(Period of record in years)

CLIMATOLOGICAL DATA FOR CAPE HINCHINBROOK

TABLE 1

Month	(26) Temp. °F	(26) Precip. (inches)	(20) Snow and Sleet (inches)	Wind Speed (mph)	Wind Direction
January	30.9	6.71	18.7	(Only 3 years available)	
February	32.4	6.58	19.8		
March	32.9	5.89	17.9		
April	37.8	5.42	6.9		
May	43.9	6.37	0.7		
June	50.6	4.69	0.0		
July	54.5	7.36	0.0		
August	55.0	9.23	0.0		
September	50.4	12.88	0.0		
October	42.4	12.28	4.0		
November	36.3	8.16	9.5		
December	32.0	8.76	17.2		
Annual	41.6	94.33	94.7		

CLIMATOLOGICAL DATA FOR CORDOVA AIRPORT

TABLE 2

Month	(29) Temp. °F	(29) Precip. (inches)	(20) Snow and Sleet (inches)	(14) Wind Speed (mph)	(19) Wind Direction
January	23.1	6.10	25.0	4.6	E
February	26.2	4.64	22.5	4.8	E
March	29.1	3.84	24.5	5.0	E
April	36.2	4.32	11.2	5.4	ESE
May	43.7	5.06	1.4	5.3	ESE
June	50.2	3.48	0.0	4.7	SW
July	53.2	6.27	0.0	4.1	E
August	52.4	8.06	0.0	3.8	E
September	47.6	12.51		5.1	E
October	39.8	11.90	2.6	5.6	E
November	31.1	8.02	10.3	5.3	E
December	25.6	6.78	27.2	5.1	E
Annual	38.2	80.98	124.7	4.9	E

CLIMATOLOGICAL DATA FOR LATOUCHE

TABLE 3

Month	(20) Temp. °F	(20) Precip. (inches)	(16) Snow and Sleet (inches)	Wind Speed (mph)	Wind Direction
January	30.5	16.23	30.0	(Wind data not available)	
February	32.1	15.68	24.2		
March	33.3	16.37	33.2		
April	37.0	14.97	11.3		
May	43.5	12.08	0.9		
June	50.6	6.28	0.0		
July	55.1	7.00	0.0		
August	55.4	12.39	0.0		
September	50.2	17.44			
October	42.6	24.02	1.4		
November	35.7	19.06	9.6		
December	31.7	19.44	27.9		
Annual	41.5	180.96	138.5		

CLIMATOLOGICAL DATA FOR VALDEZ

TABLE 4

Month	(29) Temp. °F	(29) Precip. (inches)	(48) Snow and Sleet (inches)	Wind Speed (mph)	(3) Wind Direction
January	18.2	5.79	56.3	Monthly Mean not Available	ENE
February	21.8	4.88	47.2		ENE
March	26.2	3.70	36.7		ENE
April	34.9	2.96	13.1		SW
May	43.1	3.48	2.1		SW
June	56.4	2.61	0.0		SW
July	52.7	4.72			SW
August	51.6	6.48	0.0		SW
September	46.0	8.38	0.1		SW
October	37.2	7.95	8.4		E
November	26.2	6.27	31.0		ENE
December	19.7	5.15	49.6		NE
Annual	35.7	62.37	244.5		SW

CLIMATOLOGICAL DATA FOR WHITTIER

TABLE 5

Month	(20) Temp. °F	(20) Precip. (inches)	(14) Snow and Sleet (inches)	Wind Speed (mph)	(5) Wind Direction
January	25.5	14.67	57.2	Monthly Mean not Available	SW
February	26.9	10.69	50.8		SW
March	27.7	10.50	37.4		SW
April	36.0	10.98	24.9		NE
May	43.8	15.52	1.2		NE
June	51.9	10.13	0.0		SW
July	56.0	12.21	0.0		NE
August	54.9	14.39			NE
September	48.3	18.21			NE
October	38.3	20.82	7.1		SW
November	29.5	16.88	19.2		SW
December	25.4	20.37	66.0		SW
Annual	38.7	175.28	263.8		SW

APPENDIX 2

Monthly Weather Summaries

1971 to 1973

Cape Hinchinbrook

1. Wind speed - mph
2. Surface air temperature (^{o}F)
3. Relative humidity - (Averages %)

CAPE HINCHINBROOK

Wind Speed-MPH

1971

Month	Res. Dir.	Ave. Speed	Max. Speed	Date Max.	Dir. Max.
January	4.5	4.7	40.0	3	40.0
February	62.0	9.5	48.0	7	80.0
March	44.7	3.8	48.0	16	80.0
April	68.9	11.5	56.0	14	100.0
May	79.4	16.4	56.0	20	80.0
June	85.8	5.0	44.0	1	120.0
July	77.6	6.8	36.0	24	80.0
August	62.4	7.2	28.0	29	80.0
September	66.2	4.6	42.0	15	80.0
October	79.0	5.5	60.0	9	60.0
November	67.1	4.1	72.0	17	100.0
December	33.3	5.7	44.0	29	100.0

CAPE HINCHINBROOK

Wind Speed-MPH

1972

Month	Res. Dir.	Ave. Speed	Max. Speed	Date Max.	Dir. Max.
January	328.4	3.5	36.0	17	280.0
February	44.6	5.3	40.0	8	60.0
March	51.0	1.9	80.0	10	60.0
April	48.8	2.4	36.0	17	80.0
May	69.1	7.1	36.0	18	60.0
June	78.1	5.1	28.0	23	60.0
July	171.2	0.5	32.0	14	120.0
August					
September	79.1	3.3	32.0	28	40.0
October	60.5	6.3	40.0	15	30.0
November	98.3	5.9	44.0	21	120.0
December	45.3	2.9	35.0	16	40.0

CAPE HINCHINBROOK

Wind Speed-MPH

1973

Month	Res. Dir.	Ave. Speed	Max. Speed	Date Max.	Dir. Max.
January	76.9	3.0	32.0	22	40.0
February	71.2	4.7	38.0	2	120.0
March	98.3	8.3	34.0	28	100.0
April	100.3	9.2	33.0	8	180.0
May	102.4	9.9	35.0	25	120.0
June	111.7	2.5	30.0	5	120.0
July	123.5	4.4	25.0	28	120.0
August	110.8	4.2	30.0	22	130.0
September	89.8	5.9	29.0	7	120.0
October	82.5	5.6	39.0	10	120.0
November	30.7	4.5	35.0	24	120.0
December	90.3	9.5	38.0	27	100.0

CAPE HINCHINBROOK

Surface Air Temperature (°F)

1971

Month	Ave. Max.	Ave. Min.	Ave.	Dif. Norm.	Max.	Date Max.	Min.	Date Min.	Degree Days
January	25.7	18.7	22.8	-10.5	40.0	5	2.0	25	1307.5
February	32.4	27.2	30.1	-3.6	38.0	14	6.0	28	997.6
March	32.5	24.3	28.8	-5.6	42.0	20	4.0	5	1122.6
April	36.8	31.3	34.6	-3.2	43.0	23	8.8	30	910.6
May	41.1	34.9	38.7	-4.0	49.0	12	9.5	31	816.8
June	50.5	41.4	47.0	-0.9	64.0	23	0.0	5	538.8
July	55.0	47.7	52.4	-0.1	75.0	10	13.0	31	391.4
August	56.6	49.2	53.6	-0.4	66.0	3	13.0	31	354.3
September	52.3	43.9	48.8	-1.8	58.0	25	11.0	30	487.4
October	42.9	35.7	40.1	-4.5	50.0	16	7.6	31	773.3
November	37.8	31.7	35.1	-3.9	44.0	17	5.8	30	896.9
December	32.9	26.0	30.0	-4.9	39.0	7	5.6	31	1084.2

CAPE HINCHINBROOK

Surface Air Temperature (°F)

1972

Month	Ave. Max.	Ave. Min.	Ave.	Dif. Norm.	Max.	Date Max.	Min.	Date Min.	Degree Days
January	28.3	19.4	24.8	-8.5	37.0	29	0.0	3	1246.6
February	32.3	21.0	28.2	-5.5	38.0	22	0.0	27	1066.9
March	31.1	22.6	27.5	-6.9	40.0	22	0.0	10	1163.5
April	36.1	25.2	32.2	-5.6	43.0	27	0.0	18	982.9
May	44.5	35.8	40.9	-1.8	56.0	8	11.0	31	748.1
June	49.3	41.4	46.3	-1.6	61.0	11	11.8	30	561.0
July	60.9	51.4	57.0	4.7	75.0	6	16.7	1	248.8
August									
September	51.8	42.5	48.0	-2.6	57.0	19	8.2	30	510.6
October	43.6	37.2	40.9	-3.7	50.0	12	4.0	31	746.6
November	39.1	33.6	36.8	-2.2	46.0	8	12.3	1	846.6
December	35.1	29.1	32.4	-2.5	40.0	25	10.3	1	1010.9

CAPE HINCHINBROOK

Surface Air Temperature (°F)

1973

Month	Ave. Max.	Ave. Min.	Ave.	Dif. Norm.	Max.	Date Max.	Min.	Date Min.	Degree Days
January	28.3	21.6	25.5	-7.8	37.0	8	0.0	2	1224.8
February	33.5	25.2	30.3	-3.4	38.0	25	0.0	13	971.1
March	34.8	27.1	32.1	-2.3	41.0	24	0.0	29	1019.5
April	39.4	31.6	36.2	-1.6	48.0	22	6.8	30	865.4
May	44.5	37.8	41.3	-1.4	53.0	14	12.0	1	733.4
June	52.3	43.4	48.3	0.4	64.0	12	15.0	1	500.0
July	55.1	45.5	51.8	-0.5	60.0	24	0.0	13	410.6
August	56.0	46.4	52.3	-1.7	64.0	17	0.0	1	392.1
September	51.3	41.7	47.7	-2.9	57.0	3	0.0	9	519.8
October	43.7	36.9	40.9	-3.7	51.0	1	15.7	1	148.4
November	33.5	26.4	30.5	-8.5	43.0	1	0.0	25	1034.9
December	35.7	29.3	33.3	-1.6	41.0	27	0.0	30	983.6

CAPE HINCHINBROOK

Relative Humidity - (Averages %)

Standard of Time
150th Meridian

1971

Month	02	08	14	20
January	93.5	93.3	93.4	93.9
February	96.8	95.2	96.8	97.6
March	95.4	93.2	90.5	94.9
April	96.2	92.1	91.0	94.8
May	95.3	93.6	91.6	93.8
June	95.5	94.9	95.1	97.9
July	92.3	90.3	89.0	90.0
August	94.1	90.3	89.2	92.8
September	89.1	88.0	83.9	85.1
October	85.8	86.4	82.6	82.3
November	83.2	82.8	76.2	83.1
December	78.1	77.9	80.1	77.5

CAPE HINCHINBROOK

Relative Humidity - (Averages %)

Standard of Time
150th Meridian

1973

Month	02	08	14	20
January	88.4	83.9	85.2	89.2
February	92.2	86.0	87.2	87.6
March	93.5	90.1	93.4	93.2
April	95.1	97.8	94.8	93.7
May	95.3	97.9	97.3	94.1
June	86.6	92.2	87.1	82.5
July	90.0	91.5	87.1	-2.0
August	91.5	90.4	86.3	86.0
September	91.5	92.1	88.8	85.8
October	91.1	85.8	84.5	84.8
November	80.9	79.8	79.5	81.4
December	89.1	90.8	88.0	85.9

CAPE HINCHINBROOK

Relative Humidity - (Averages %)

Standard of Time
150th Meridian

1972

Month	02	08	14	20
January	94.9	92.3	93.5	93.5
February	100.0	102.9	99.4	100.0
March	82.7	80.8	85.9	82.2
April	79.3	81.1	84.0	80.2
May	89.6	89.9	90.8	88.5
June	91.1	90.2	86.9	88.1
July	88.7	85.4	82.6	85.5
August				
September	80.0	80.5	80.5	82.5
October	88.4	87.8	82.7	89.3
November	83.0	85.6	80.8	81.1
December	86.4	84.8	79.4	81.1

APPENDIX 3

Prince William Sound

Station Locations

PRINCE WILLIAM SOUND

STATION NAMES

VAA	Valdez Arms	COF	College Fjord
PFI	Port Fidalgo	PWE	Port Wells
PGR	Port Gravina	WEP	Wells Passage
ORB	Orca Bay	PNJ	Port Nellie Juan
HIE	Hinchinbrook Entrance	KIP	Knight Island Passage
COL	Columbia Bay	MOS	Montague Strait
UNI	Unakwik Inlet	PEP	Perry Passage

PRINCE WILLIAM SOUND

STATION LOCATION

PWS -	Station	Latitude °N	Longitude °W
VAA	001	60 50.0	147 01.0
PFI	002	60 46.0	146 45.5
PFI	003	60 47.8	146 26.0
PFI	004	60 51.3	146 13.0
PGR	005	60 37.4	146 36.0
	006	60 32.5	146 36.0
PGR	007	60 41.7	146 13.0
PGR	008	60 37.4	146 24.8
ORB	009	60 33.3	146 12.8
ORB	010	60 35.4	145 58.7
HIE	011	60 19.0	146 49.0
	012	60 27.0	146 54.0
	013	60 35.0	146 55.0
	014	60 27.0	147 11.0
	015	60 36.0	147 14.0
	016	60 42.0	147 00.0
	017	60 47.0	147 13.8
COL	018	60 56.0	147 06.0
UNI	019	60 53.0	147 32.0
UNI	020	60 58.0	147 34.0
UNI	021	61 03.2	147 33.4

	022	60 46.5	147 32.5
	023	60 43.2	147 47.0
COF	024	61 10.5	147 49.5
PWE	025	60 55.8	148 11.2
PWE	026	60 47.5	148 24.0
WEP	027	60 46.3	148 07.5
	028	60 40.5	147 41.0
PWE	029	60 42.8	148 21.0
PNJ	030	60 34.2	148 12.9
PNJ	031	60 32.2	148 32.1
	032	60 31.1	147 47.2
	033	60 33.4	147 30.6
KIP	034	60 18.0	147 59.0
	035	60 16.3	147 36.0
KIP	036	60 05.6	147 48.8
MOS	037	59 58.8	147 50.5
	038	60 16.2	147 38.6
	039	60 15.5	147 33.0
	040	60 26.8	147 02.8
	041	60 28.0	146 45.4
HIE	042	60 18.5	146 51.9
HIE	043	60 19.7	146 45.7
	044	60 33.7	146 45.6
	045	60 35.6	147 04.8
	046	60 41.8	147 10.0

	047	60 43.0	146 50.0
	048	60 49.6	147 11.0
	049	60 45.2	147 16.2
	050	60 46.0	147 26.2
	051	60 49.2	147 26.5
PGR	052	60 34.5	146 24.0
ORB	053	60 35.3	146 12.8
	054	60 38.8	146 52.8
	055	60 46.1	147 01.6
	056	60 46.0	147 38.6
	057	60 44.4	147 33.3
	058	60 39.9	147 35.5
PWE	059	60 54.6	148 8.5
	060	61 04.4	147 58.0
PEP	061	60 40.2	148 02.0
	062	60 31.5	147 51.8
KIP	063	60 07.8	147 47.0
MOS	064	59 57.1	147 47.6

Port Valdez Region

VAA	101	60 55.1	146 52.8
VAA	107	61 00.3	146 45.9
PVN	114	61 04.4	146 39.7
PVA	139	61 06.4	146 23.1

PRINCE WILLIAM SOUND

OLD STATION LOCATION

PWS - Station	Latitude °N	Longitude °W
1	60 30.0	147 10.9
2	60 34.8	146 55.0
5	60 50.0	147 00.8
6	60 48.5	147 16.2
155	60 44.6	147 02.7
156	60 40.0	146 45.0

The following cruises occupied these stations as part of 1971 Port Valdez environmental study.

Cruise 113	May 1971
Cruise 117	July 1971
Cruise 123	October 1971
Cruise 125	December 1971
Cruise 131	April 1972

APPENDIX 4

Prince William Sound

Cruise Summary

PRINCE WILLIAM SOUND

CRUISE SUMMARY

Cruise							
Date	March 1972	June 1972	Sept. 1972	Dec. 1972	Jan. 1973	March 1973	May 1973
No.	129	137	141	147	153	159	164
Station							
001	x	x	x	x	x	x	x
002	x	x	x	x			x
003	x						x
004	x						
005	x	x	x	x			x
006	x	x	x	x			x
007	x						
008	x			x			
009	x			x			
010	x						
011	x	x	x	x		x	x
012	x	x	x	x	x	x	x
013	x	x	x	x	x	x	x
014	x	x	x	x		x	x
015	x	x	x	x		x	x
016	x	x	x	x	x	x	x
017	x	x	x	x	x		x
018	x						x
019	x						
020	x						
021	x						
022	x						
023	x						
024	x						
025	x						
026	x						
027	x						
028	x			x			x
029	x						
030	x						

031	x						
032	x						
033	x		x	x	x		x
034	x						
035	x		x	x	x	x	x
036	x		x				
037	x		x	x		x	x
038	x		x	x	x	x	x
039	x		x	x	x	x	x
040	x		x	x		x	x
041	x	x	x			x	x
042	x	x	x	x		x	x
043	x	x	x	x		x	x
044	x		x	x		x	x
045	x		x	x		x	x
046	x		x	x	x	x	x
047			x	x		x	x
048	x	x	x		x		x
049	x	x	x	x	x		x
050	x						x
051	x			x			x
052	x			x			x
053	x			x			
054	x	x	x	x			x
055	x	x	x	x			x
056	x			x			
057	x						
058	x			x			
059	x						
060							
061	x						
062	x						
063	x		x				
064	x		x	x		x	x

VAA	101		x	x	x	x	x
VAA	107	x	x	x	x	x	x
VAN	113	x	x				
PVN	114			x	x	x	x
PVA	139	x		x	x	x	x
PVA	172	x					

PRINCE WILLIAM SOUND

CRUISE SUMMARY

Cruise Date No.		May 1971 113	July 1971 117	October 1971 123	December 1971 125	April 1972 131
Station						
PWS	1	x	x	x	x	
PWS	2	x	x	x	x	x
PWS	5	x	x	x	x	x
PWS	6	x	x	x		x
PWS	155	x	x	x		x
PWS	156	x	x	x	x	x
KIP	6			x		
PWS	001					x