A STUDY OF THE VARIATION OF THE ANTARCTIC CIRCUMPOLAR CURRENT DURING A ONE YEAR PERIOD

by

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Submitted to the Department of Meteorology on August 19, 1968, in partial fulfullment of the requirements for the degree of Master of Science.

ABSTRACT

During a one year period in 1938 and 1939, the R. R. S. Discovery made sixteen north-south hydrographic sections across the Antarctic Circumpolar Current south of the African continent. The distribution of temperature and salinity have been plotted for all of the sections. The geostrophic volume transport has been estimated for some of the sections. These sections show that the Antarctic Circumpolar Current is devoid of large scale fluctuations while nothing can be determined about the smaller scale ones.

Thesis Supervisor: Henry M. Stommel
Title: Professor of Oceanography

ACKNOWLEDGEMENTS

I would like to thank Professor Henry M. Stommel for suggesting this topic and for his helpful comments along the way. I would especially like to thank Dr. G. E. R. Deacon who allowed the data from the Discovery cruises to be used. I would also like to thank Mr. D. Halpern and Mr. A. Leetmaa who offered their suggestions. Lastly I thank my wife Deri who did the typing and helped on the preparation of the figures.

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INTRODUCTION

For many years oceanographers have been forced to piece together data from various cruises of various ships during various times of the year and to make the assumption of steady state in order to obtain some general understanding of the ocean. Even in the few areas of the world where large scale operations have been made, such as the Gulf Stream or the Kuroshio, the knowledge of the time variation remains minimal.

The Antarctic is one place in which the piecemeal study is quite evident because of its large area, distance from the northern hemisphere, and hostile environment. The cruises of the Discovery II, the Meteor, and other ships were only intended to be preliminary studies of the unknown Southern Ocean. Their data, however, remains in use today because of the sparceness of supplimentary data. Only in the recent surveys made by the Eltanin, Ob, and "Deepfreeze" icebreakers have the beginnings of a comprehensive study been made. But one or two ships are not able to repeat cruises fast enough to cover the entire Antarctic sufficiently well to determine its time variation. A large number of ships and other methods of data acquisition must be employed to spend a great amount of time studying the Antarctic in order just to know as much about it as is known about the Gulf Stream.

Before any large scale program is planned, however, it is necessary to review the old data to define better the problem that is faced and to possibly suggest what course of action is to be taken. One such block of old data which has not been reviewed is that taken by the Discovery II between April, 1938, and March, 1939, in which during the end of a circumpolar cruise and seven repeated cruises south and west of the Cape of Good Hope, the Antarctic Circumpolar Current was crossed completely or partially sixteen times. Half of the crossings were made along 0° longitude, the other half along 20°E longitude. While stations were neither taken at the same locations nor spaced very close together, these sections give information as to the general variability of the Circumpolar Current and the distribution of properties.

I. Descriptions of Sections

The two north-south sections (numbered 1 and 2) that were made in April, 1938, were the last part of a circumpolar cruise that the Discovery began in October, 1937. The first section begins near 50^{o}S, 0^{o} and runs due south to latitude 65^{o}S. After zig-zagging eastward along the ice pack to longitude 20^{o}E, the ship headed due north to the South African coast making a section crossing the Circumpolar Current.

After a two month stay in port the Discovery began in July the first of seven repeated cruises in which fourteen sections across the Current were made. The general pattern of each cruise consisted of two sections across the Circumpolar Current. The first section, called the 0^{o} longitude section, had four or five deep hydrographic stations between Capetown and a position 40^{o}S, 0^{o} and deep stations every 3^{o} or 4^{o} of latitude due south along 0^{o} longitude to either the ice pack or the Antarctic Continent. The second section, called the 20^{o}E longitude section, had deep stations every 3^{o} or 4^{o} of latitude due north along 20^{o}E from as far south as possible to Capetown. These fourteen sections (numbered 3 to 16) along with numbers 1 and 2 give sixteen north-south sections during a period of one year by which the Antarctic Circumpolar Current may be examined to determine whether or not there is a discernable variation.

Five of the sections, those of the summer months, covered the entire distance between Africa and the Antarctic Continent crossing the Circumpolar Current completely. Of the other sections all but number 1, which was mainly to the south, crossed the major portion of the Current. Also all of the sections except number 1 crossed the Antarctic Convergence as determined by Mackintosh (1946) to be between $49^{\circ}24'$S and $51^{\circ}36'$ for the 0° longitude sections and between $48^{\circ}24'$S and $50^{\circ}48'$S for the 20° longitude sections.

From the surface current chart of Schott (1942) it can be seen that sections are not exactly perpendicular to the Current. North of 40°S the 0° longitude sections are parallel to the Current. Another complication in this area is the Sub-tropical Convergence near the African coast. Between 40°S and 50°S these sections are nearly perpendicular to the Current while south of 50°S to the Antarctic Divergence near 65°S they again become more parallel to the Current. The 20°E longitude sections cross the Current perpendicularly except near the African continent where the Agulhas Current complicates the flow and south of the Antarctic Divergence near 60°S.

II. Distribution of Properties

The distributions of temperature and salinity given in Figures 7 to 38 for all the sections are remarkably similar. This similarity holds not only for the summer and winter sections but also for the 0° and 20° sections.

Below 1000 meters the temperature distribution has only a slight variation from one section to another. Figures 5 and 6 show the time and latitude of the temperature at 2000 meters for the 0° longitude sections and 20°E longitude sections respectively. The majority of the variation in latitude of the temperature is within one and a half degrees while the maximum variation is less than three degrees of latitude. There may be a strengthening of the horizontal temperature gradient in sections 5, 6, 9, and 10 which would indicate greater density gradients and greater currents at these times (sections 5 and 6 are in August, 9 is in the end of October, and 10 is in the beginning of November). It must be noted that these variations are less than the station spacing, and thus any small scale variations may not be significant due to aliasing. Large scale variations in the deep temperature field, however, are noticeably lacking.

Above 1000 meters more variation is seen to exist. As is to be expected the temperature of the surface layer is seasonal. Below this layer, while the sections are not all the same, they do have similarities. On all of the 0° longitude sections the isotherms between 3^{o}C and 9^{o}C are fairly flat north of about 43^{o}S at which point they quickly begin to slope upwards towards the south entering the level influenced by the surface variations within 1^{o} to 3^{o} of latitude. These sloping isotherms will give cause to a sloping density field and its ensuing current. The northern edge of this current remains at approximately the same position throughout the year. North of 40^{o}S the stations may appear to be more closely spaced than to the south. This is an illusion since the stations here have been projected from their true position onto the 0^{o} longitude line. On all of the 20^{o}E longitude sections except number 16, the isotherms between 3^{o}C and 9^{o}C have no area in which they are flat as they rise toward the south from the northernmost station. This may indicate that sections do not cross the current completely. But this is a complicated area; one in which the wide station spacing is unable to resolve.

All of the sections show a temperature maximum at a depth of between 750 and 1000 meters at its northernmost point, approximately 48^{o}S, and rising towards the south to a depth of about 250 meters at the southern end of the section. The actual end points are impossible to define from these sections.

All of the sections also show a temperature minimum at a depth of 600 meters near 48^{o}S rising towards the south to a depth of 100 meters. The winter minimums nearly disappear near the ice pack. The summer minimums do not have the very cold core extending as far north as the winter ones. The coldest temperature is found on the edge of the ice pack in the winter and both at about 60^{o}S and at the Antarctic continent in the summer.

As with the temperature distributions, the salinity distributions have similar characteristics for all of the sections. A salinity maximum extending completely across the sections begins at a depth of about 3000 meters and a salinity of 34.85 ‰ in the north and becomes shallower towards the south reaching a depth of between 500 and 900 meters at 55^{o}S and a salinity of 34.69 ‰ or greater. The winter stations do not extend far enough south to show the minimum depth of the maximum.

A salinity minimum of less than 34.00 ‰ is found at the surface of all sections from the southern extreme to as far north as between 45^{o}S and 50^{o}S. These minimums can be traced downward and northward to a depth of 1000 meters and a salinity of less than 34.50 ‰ at northern end of the section. Neither the thicknesses nor the penetrations of the minimum appear to be the same for each section. But the variations do not appear to be seasonal. Sections made with a more frequent period would be needed to resolve these fluctuations.

III. Geostrophic Volume Transport

In order to compute the vertically integrated volume transports perpendicular to a line connecting two stations, it is necessary to determine some lower reference level from which to integrate. If this reference level is one in which there is no horizontal motion, then the transport computed will be the absolute transport. One method of determining the level of no motion is to find a range of depths in which the differences in dynamic heights between two adjacent stations remains constant (Defant, 1961).

In the Discovery sections there does not appear to be a level of no motion above 3000 meters since the differences in the dynamics heights for two stations do not become constant. Below 3000 meters the National Oceanographic Data Center has only calculated the dynamic heights at 4000 meters; and, in fact, there are a great number of stations which do not extend down to 4000 meters. These sections are unable to determine whether or not a very deep level of no motion exists.

By the use of a deep isobaric surface as a reference, the level of no motion problem is circumvented, but only relative transports are then computed. As has been stated above many of the stations do not extend to 4000 meters. This is especially true at the southern end of the winter 0^{o} longitude sections near Bouvet Island and the Atlantic-Indian Ridge. In fact, all but one of the winter 0^{o} sections do not have an end station as deep at 3000 meters. It is thus impossible to determine any variation in the transport relative to 3000 meters or 4000 meters for the 0^{o} longitude sections.

The 20^{o}E sections are more suited to using a deep isobaric reference level since all but one (number 10) has a southern station with a maximum depth of at least 3000 meters. Again, however, the geostrophic transports do not yield reliable results. The dynamic heights at the northern ends of the sections are not level between any two stations except in number 16. These sections are unable to define the northern edge of the current. During the winter months the sections do not extend completely across the Circumpolar Current, but the transport missed is probably small since the dynamic heights are beginning to become level at the southern end of the sections.

Table 2 gives the transports across those sections which have deep stations on the edges. The transport has been computed using only the two extreme stations and on average Coriolis parameter. Since the Coriolis parameter varies along the sections, these transports will be less than more exact analysis which computes the transport between each station. Since the Antarctic Circumpolar Current remains at approximately the same latitude, a comparison may be made between the transports to determine whether or not there is any variation in the Current.

Sections 8 and 16, which have level dynamic heights at the northern edge, give a much lower transport. The other sections have nearly the same transport. It appears as though the geostrophic transport of the Antarctic Circumpolar Current remains fairly constant throughout the year.

In order to obtain a better understanding of the transport in this area the northern edge of the Current has to be defined better by closer station spacing, the two dimensional velocity field has to be determined by east-west sections, and stations have to be made as deep as possible with samples taken closer together.

IV. Conclusions

The study of these sections made by the Discovery II in 1938 and 1939 shows that the Antarctic Circumpolar Current tends to remain in a quite stable configuration throughout the year. The temperature and salinity fields retain their same characteristics in all of the sections with large scale fluctuations being notably absent. The deep isotherms slope up towards the south in the same manner and in the same general area in all of the sections. Temperature maximums and minimums are present in approximately the same positions with some seasonal variation in the minimum. Salinity maximums and minimums are always present. Throughout the sections the minimum does show a marked variation in its thickness which cannot be resolved.

Since the station spacing is of the order of 3^o to 4^o of latitude, the variations that are on a smaller scale than this cannot be seen (about a fifth of the total width of the eastward moving current). To determine how much the small scale variations affect the Antarctic Circumpolar Current, it is necessary to have stations spaced closer together in the areas where changes occur within a small distance. One of these areas is the northern edge of the Current, especially just south of the African continent. Another area is where the deep isotherms pass through the temperature maximum and mimimum. Deeper stations would also help determine the geostrophic transport and the distribution of properties more accurately. More sections throughout the year would give a better understanding of the variation in the distributions, especially in the salinity minimum.

SECTION	STATIONS	DATES	LATITUDE - South
1	2311 - 2323	11 iv - 18 iv 1938	50°05' - 65°04'
2	2335 - 2350	22 iv - 2 v 1938	67°10' - 39°11'
3	2351 - 2362	2 vii - 12 vii 1938	35°31' - 54°59'
4	2374 - 2380	19 vii - 25 vii 1938	55°42' - 39°51'
5	2381 - 2394	6 viii - 18 viii 1938	35°30' - 57°18'
6	2411 - 2419	23 viii - 30 viii 1938	56°25' - 38°46'
7	2420 - 2432	15 ix - 25 ix 1938	35°11' - 56°37'
8	2447 - 2453	1 x - 6 x 1938	54°47' - 37°51'
9	2454 - 2465	18 x - 27 x 1938	35°36' - 55°17'
10	2478 - 2486	2 xi - 9 xi 1938	54°17' - 34°38'
11	2487 - 2501	23 xi - 5 xii 1938	34°40' - 55°30'
12	2517 - 2525	12 xii - 18 xii 1938	56°57' - 34°29'
13	2526 - 2547	7 i - 22 i 1939	34°20' - 69°30'
14	2559 - 2576	27 i - 5 ii 1939	68°50' - 40°12'
15	2578 - 2601	16 ii - 4 iii 1939	35°08' - 69°44'
16	2606 - 2626	5 iii - 18 iii 1939	69°40' - 37°47'

Summarized List of Stations

Table 1

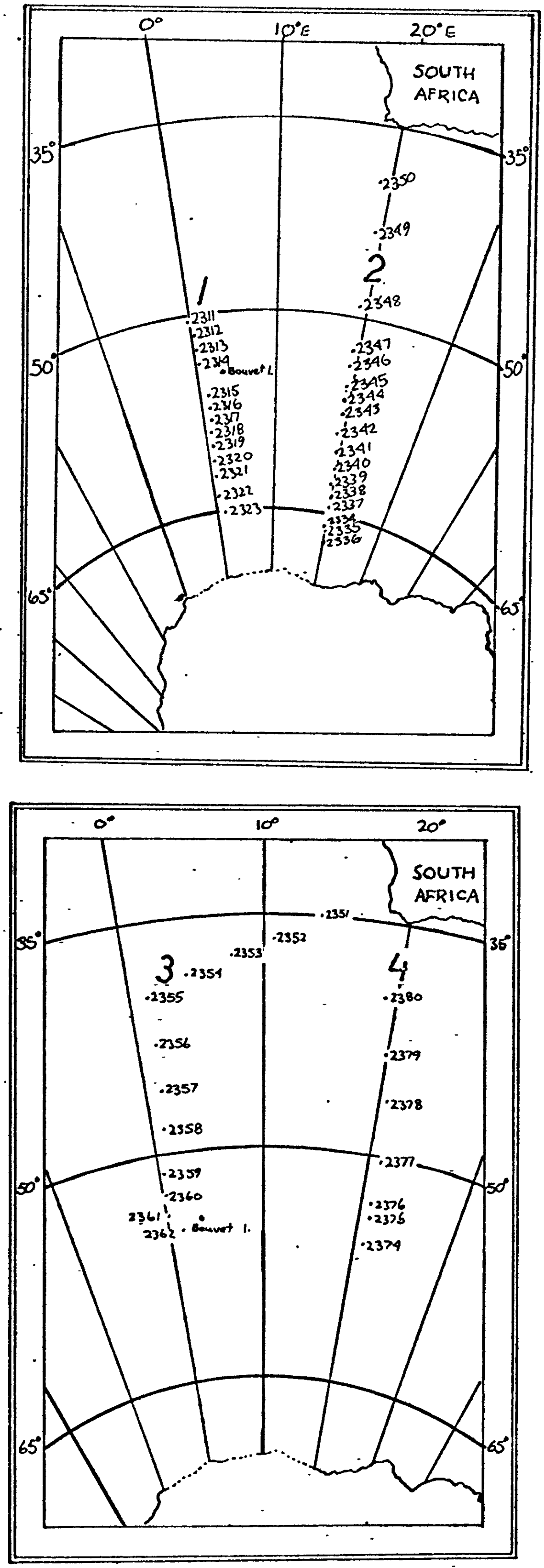

Figure 1. Positions of stations on sections 1, 2, 3, and 4.

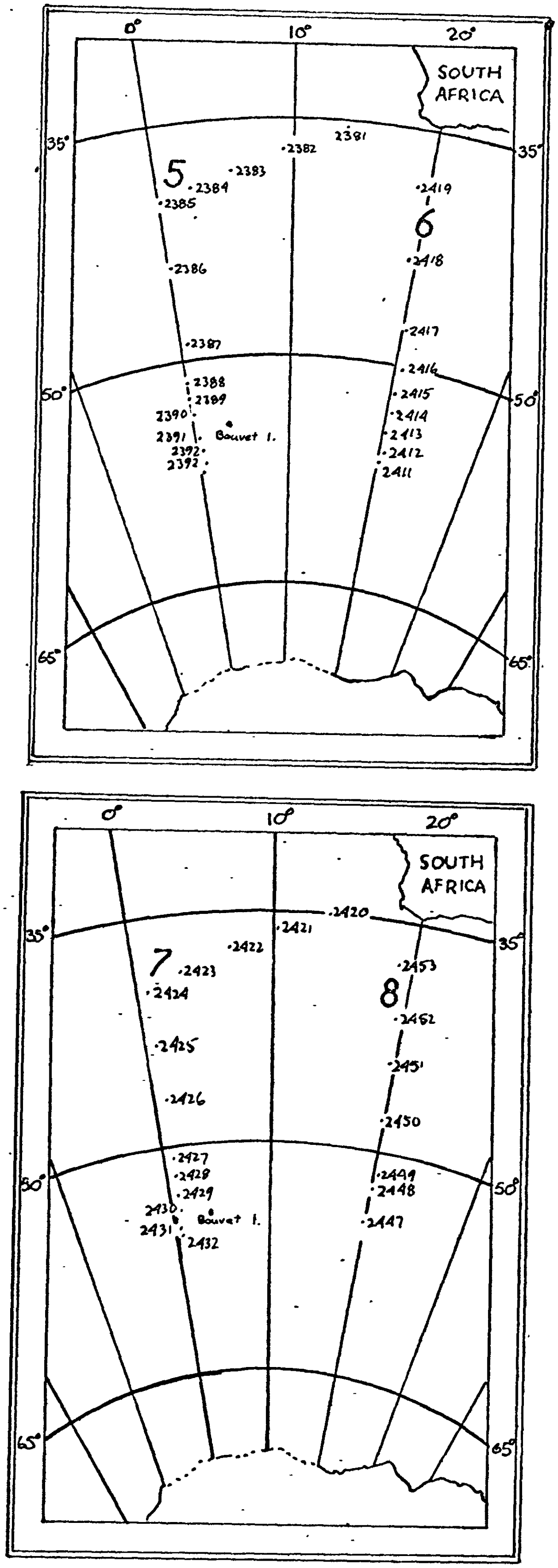

Figure 2. Positions of stations on sections 5, 6, 7, and 8.

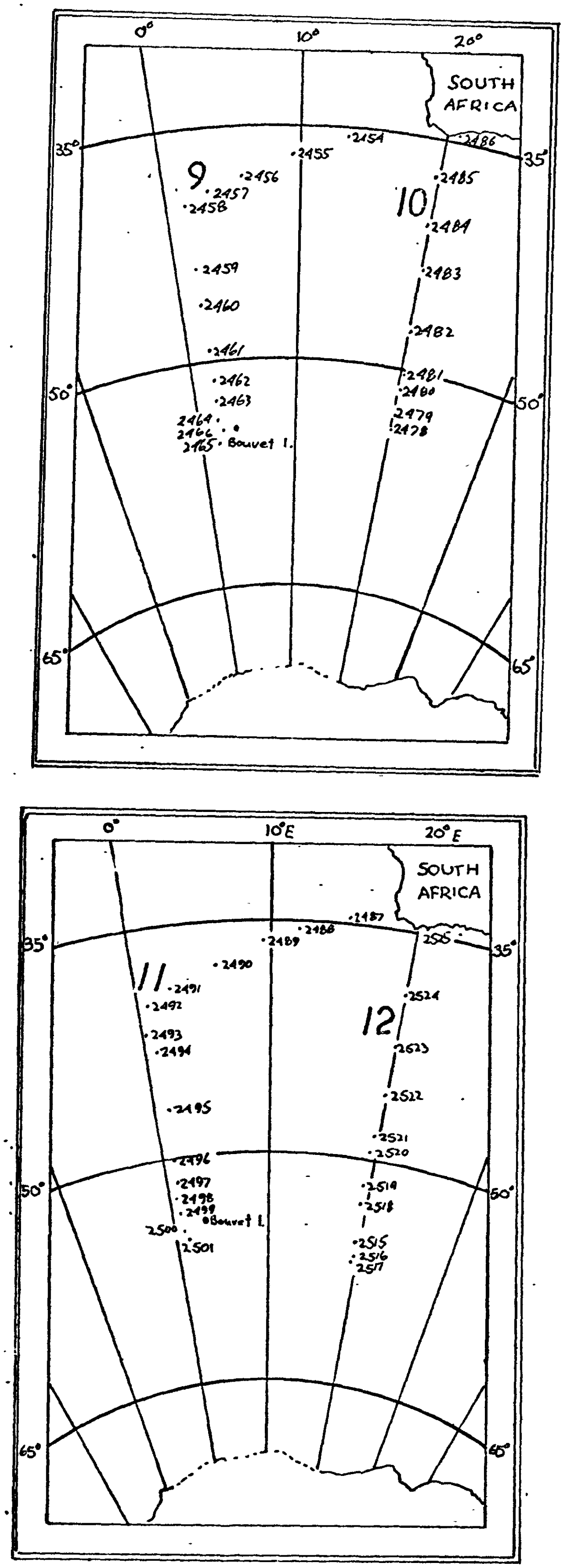

Figure 3. Positions of stations on sections 9, 10, 11, and 12.

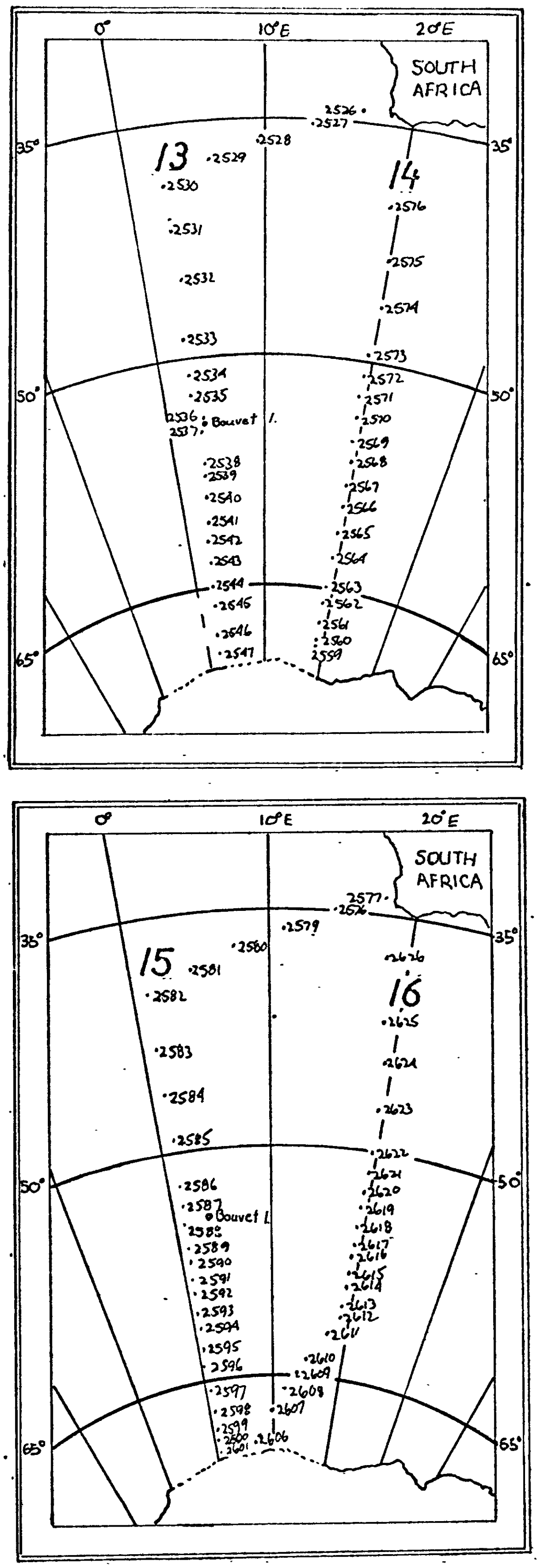

Figure 4. Positions of stations on sections 13, 14, 15, and 16.

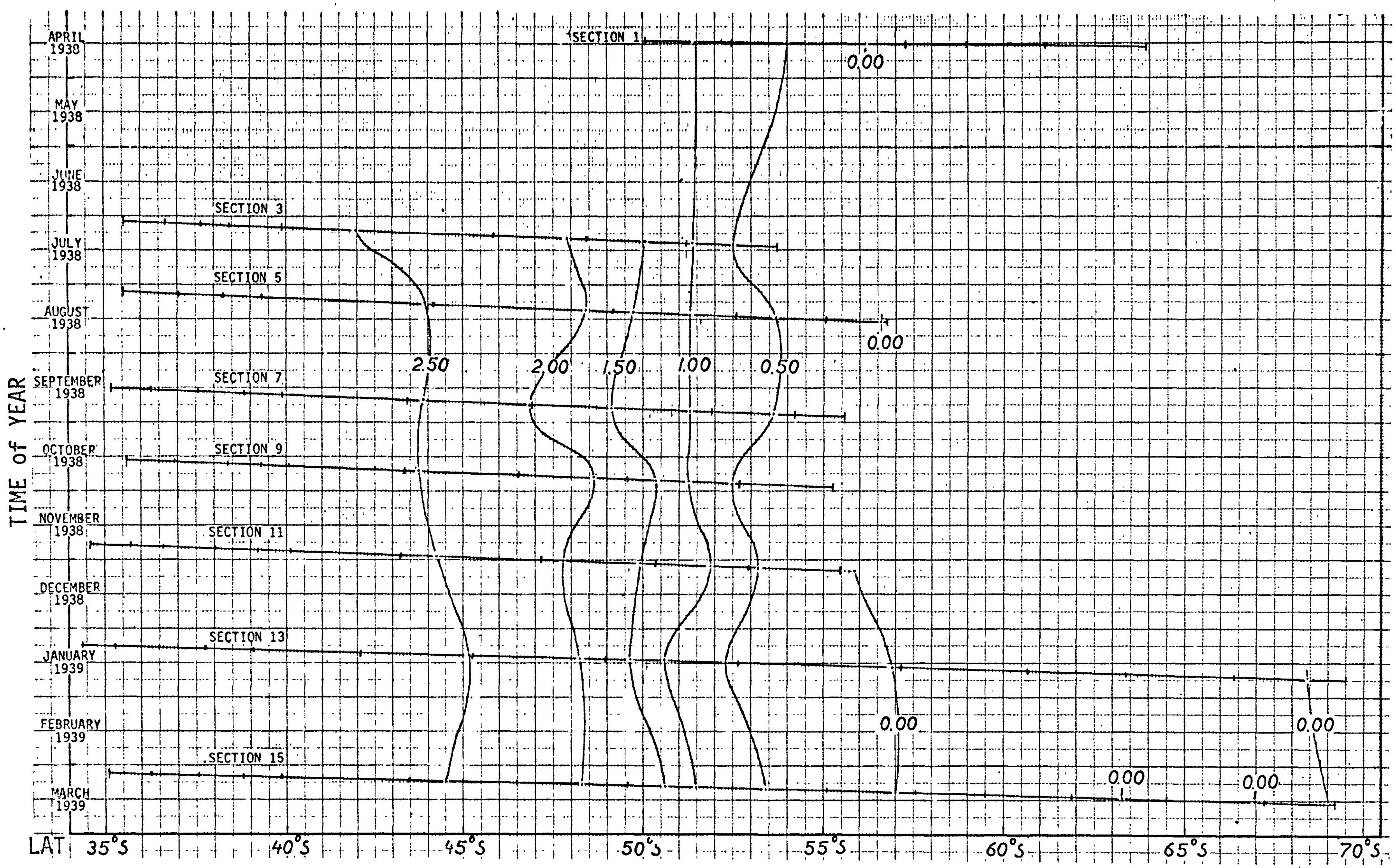

Figure 5. Temperature at 2000 meters for 0° longitude sections showing variation in latitude and time of year. Straight lines give sections in latitude and time; tick marks designate deep stations.

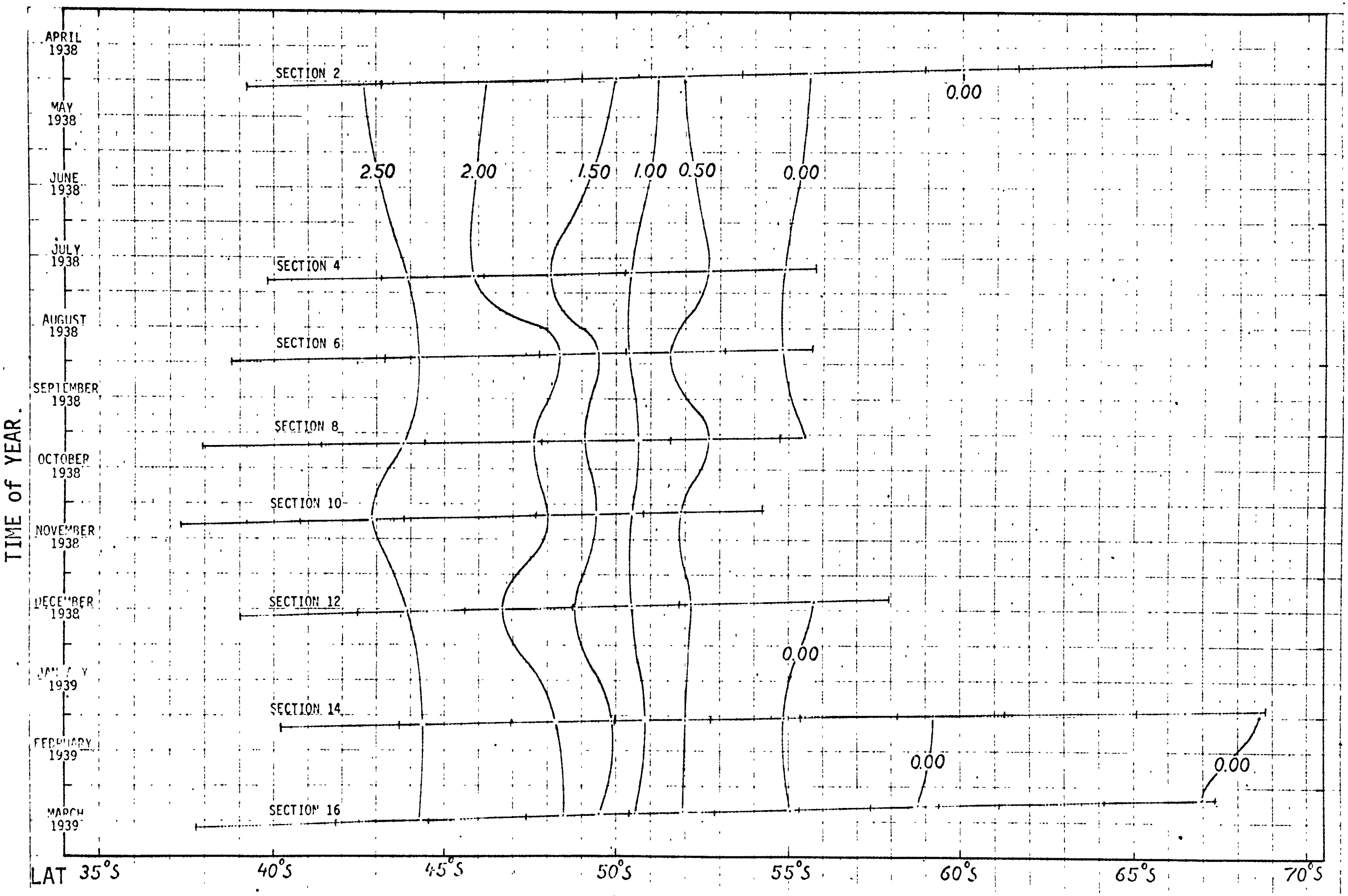

Figure 6. Temperature at 2000 meters for 20°E longitude sections showing variation in latitude and time of year. Straight lines give sections in latitude and time; tick marks designate deep stations.

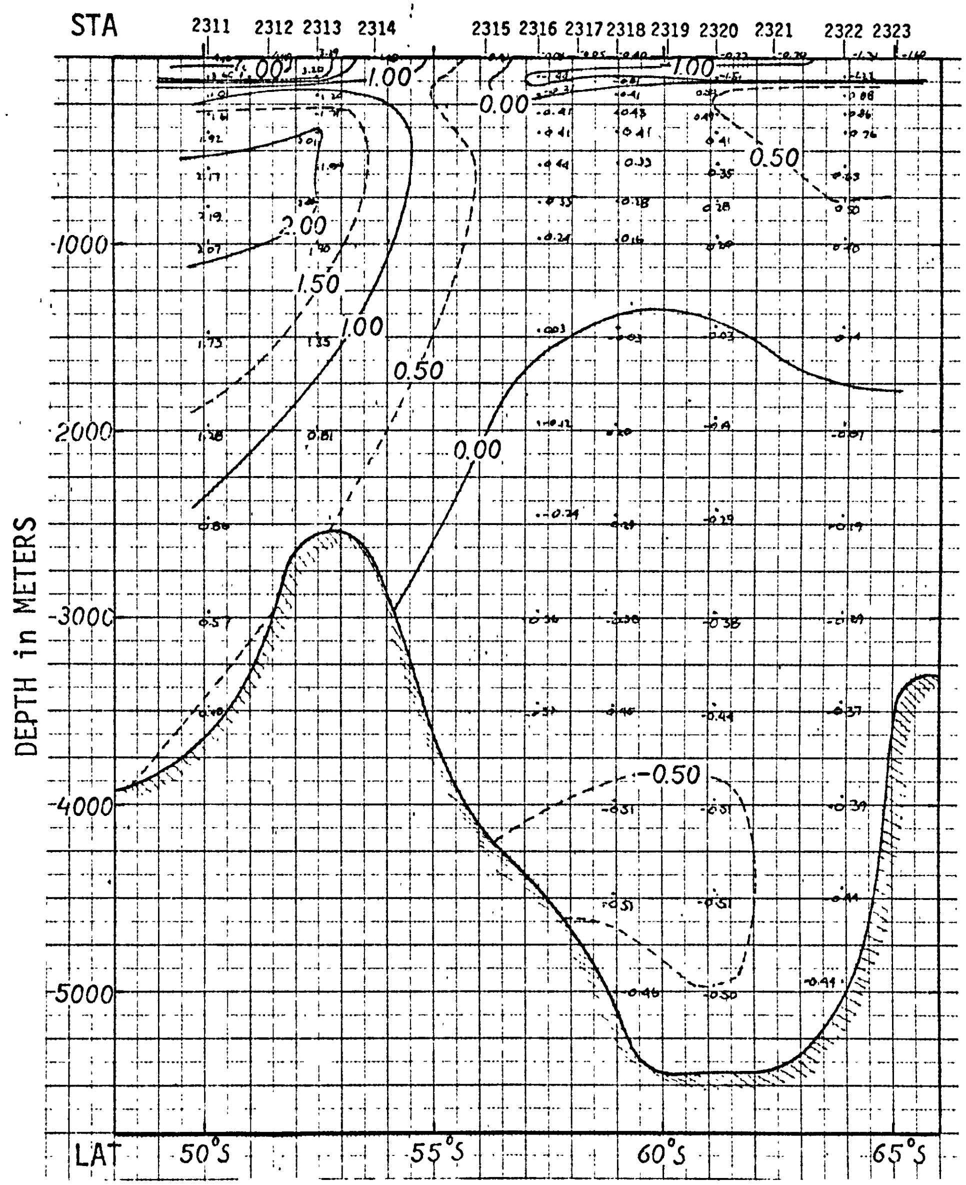

Figure 7. The distribution of temperature along section 1. A 0° longitude section from 50°05'S to 65°04'S. 11 April to 18 April 1938.

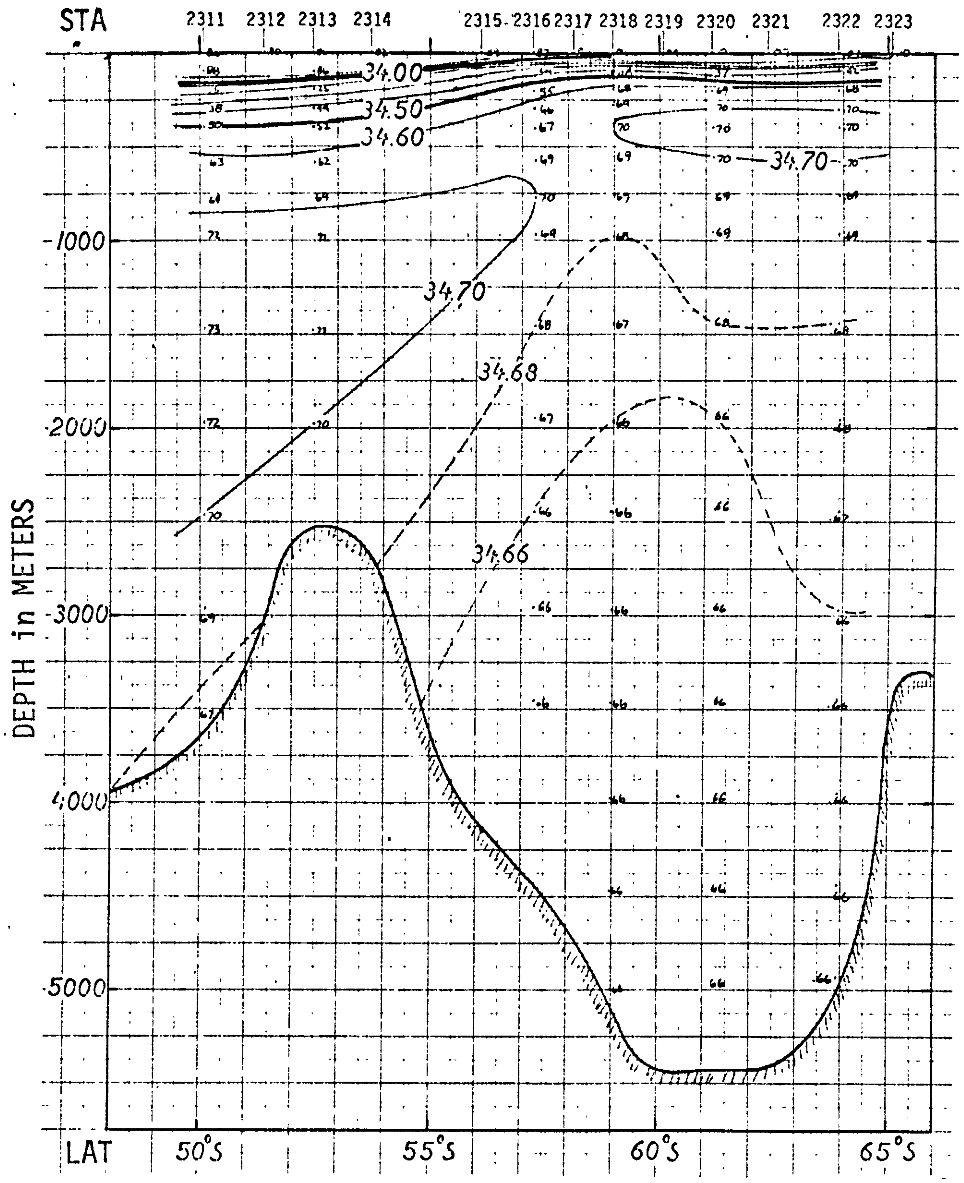

Figure 8. The distribution of salinity along section 1. A 0° longitude section from 50°05' S to 65°04' S. 11 April to 18 April 1938.

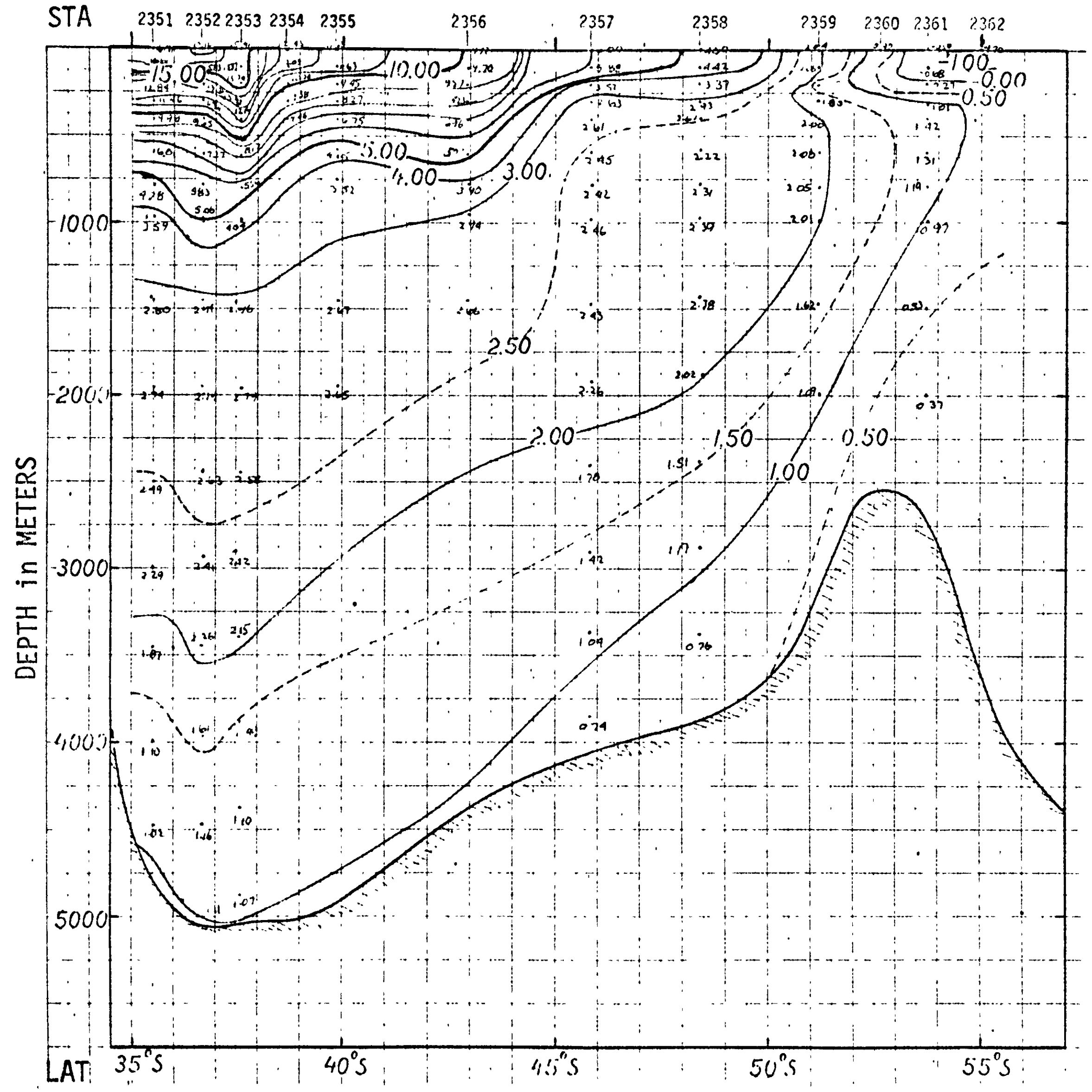

Figure 9. The distribution of temperature along section 3. A 0° longitude section from 35°31'S to 54°59'S. 2 July to 12 July 1938.

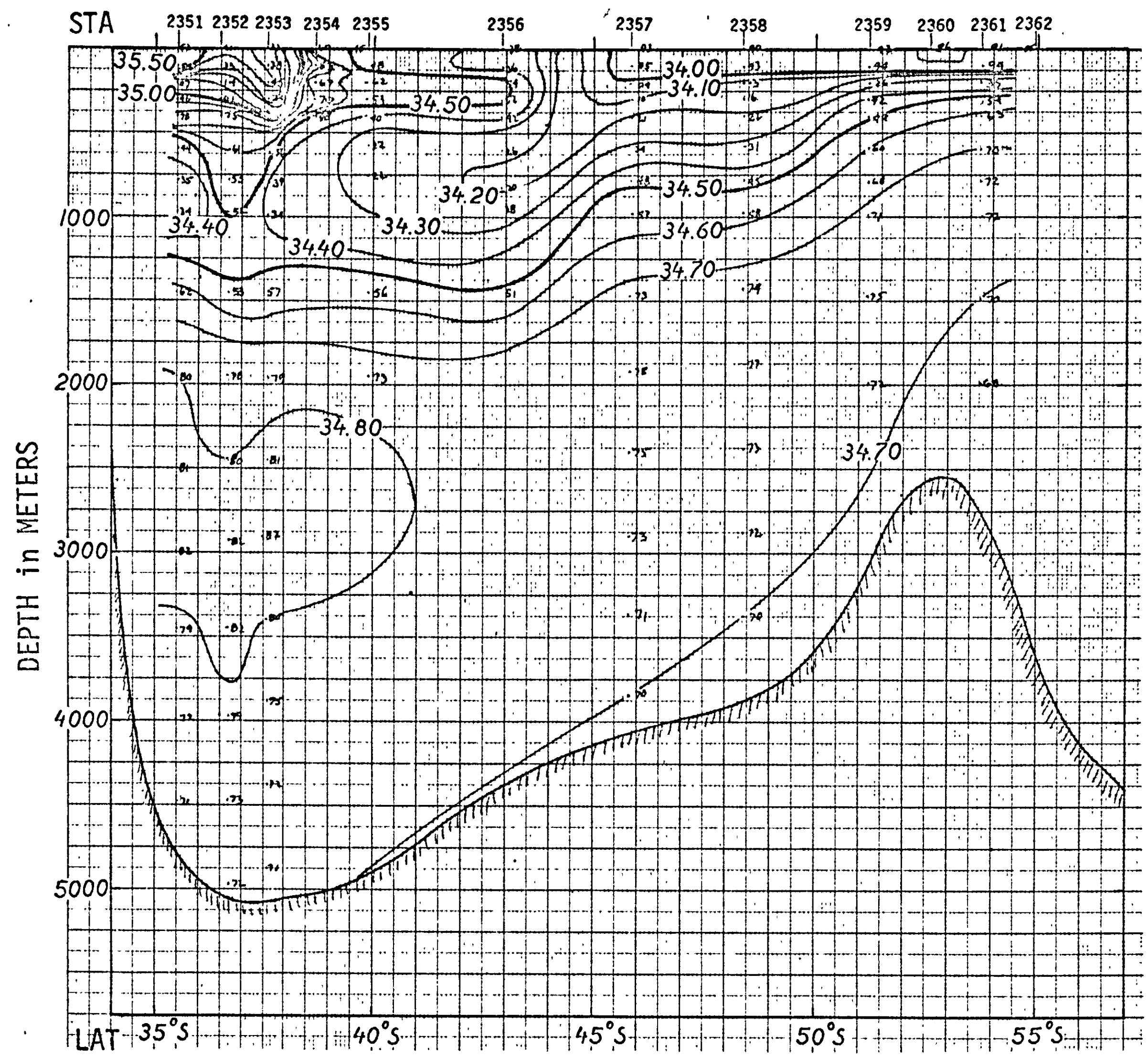

Figure 10. The distribution of salinity along section 3. A 0° longitude section from 35°31'S to 54°59'S. 2 July to 12 July 1938.

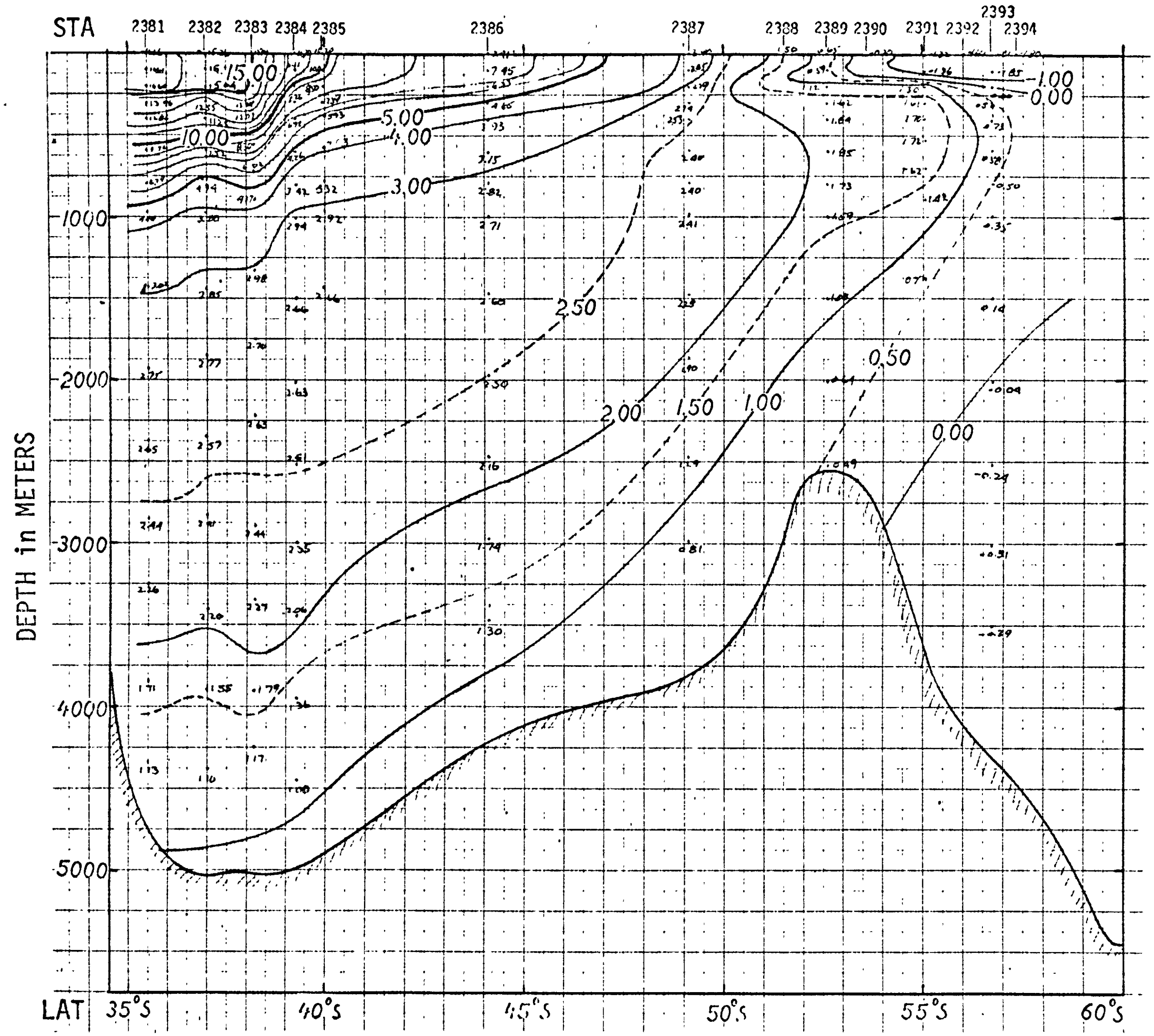

Figure 11. The distribution of temperature along section 5. A 0° longitude section from 35°30' S to 57°18' S. 6 August to 18 August 1938.

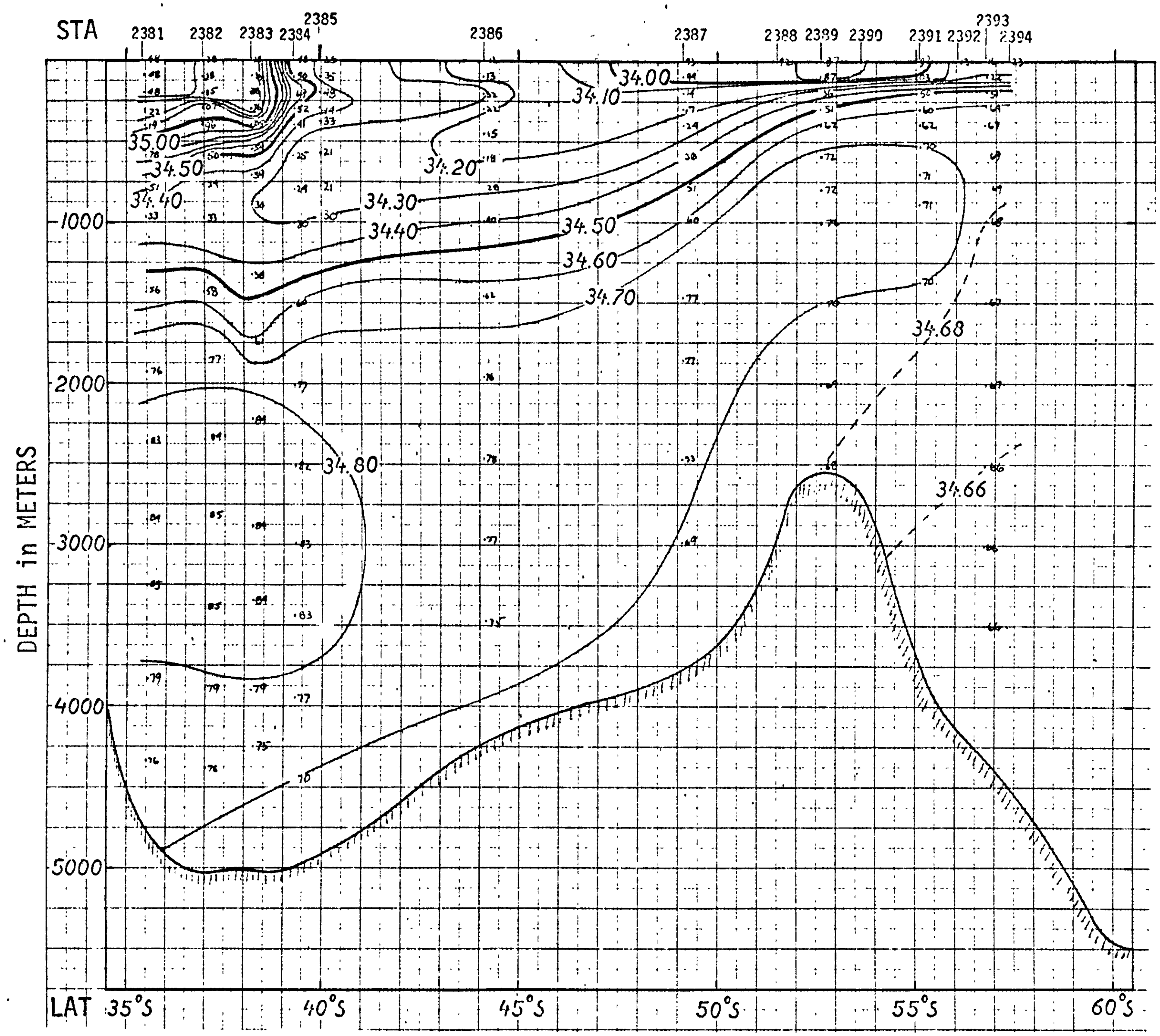

Figure 12. The distribution of salinity along section 5. A 0° longitude section from 35°30' S to 57°18' S. 6 August to 18 August 1938.

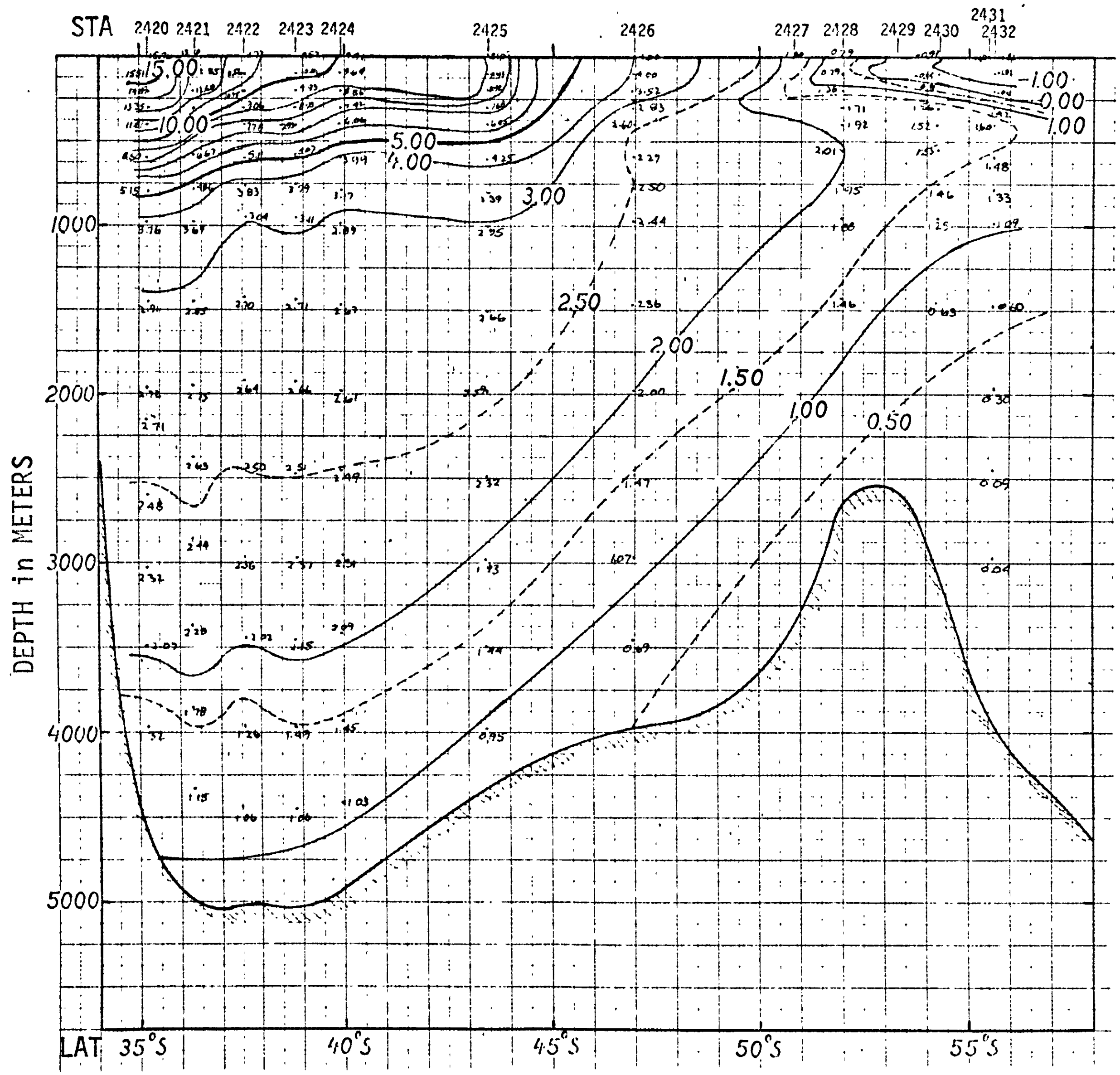

Figure 13. The distribution of temperature along section 7. A 0° longitude section from 35°11'S to 56°37'S. 15 September to 25 September 1938.

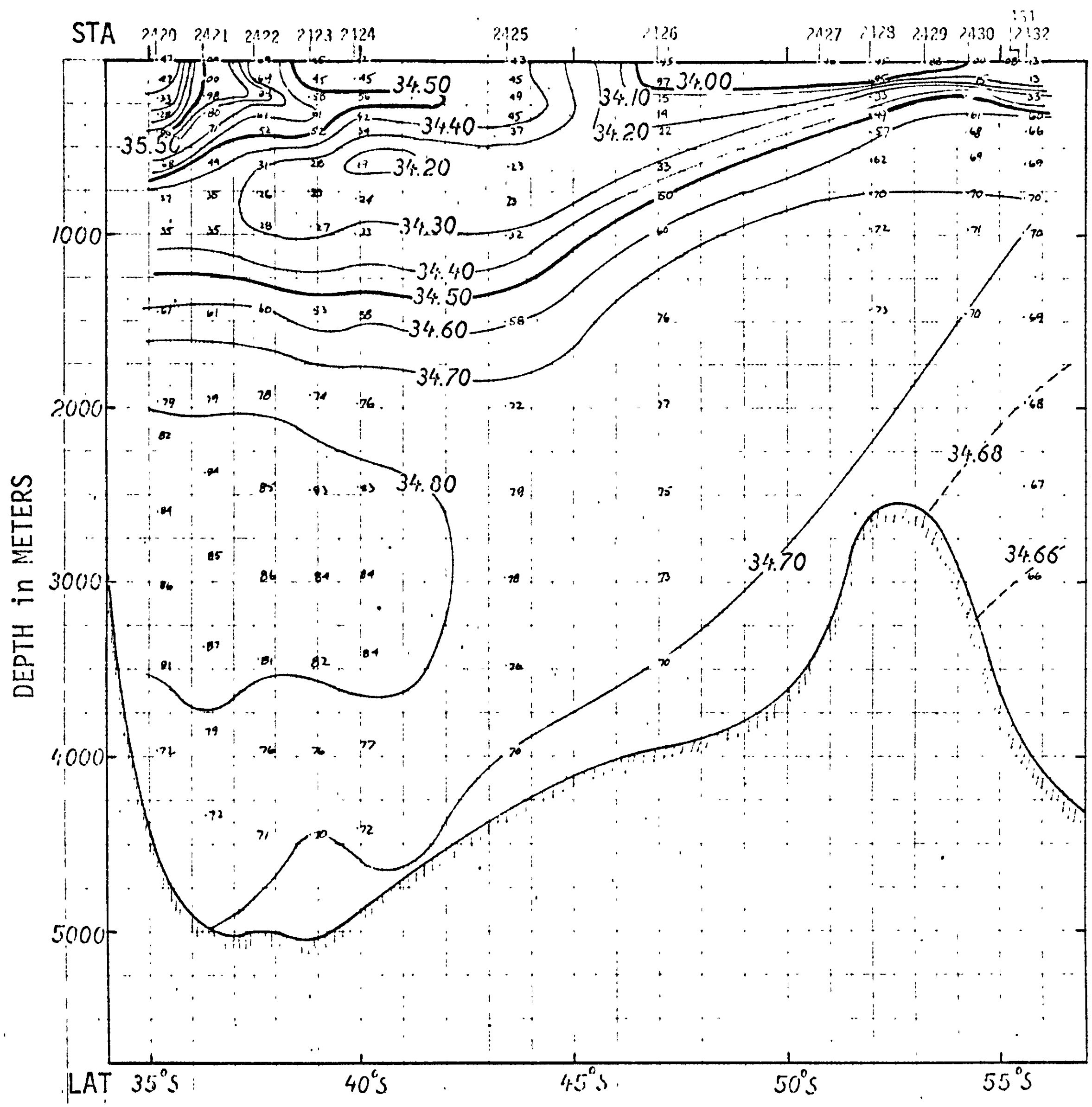

Figure 14. The distribution of salinity along section 7. A 0° longitude section from 35°11'S to 56°37'S. 15 September to 25 September 1938.

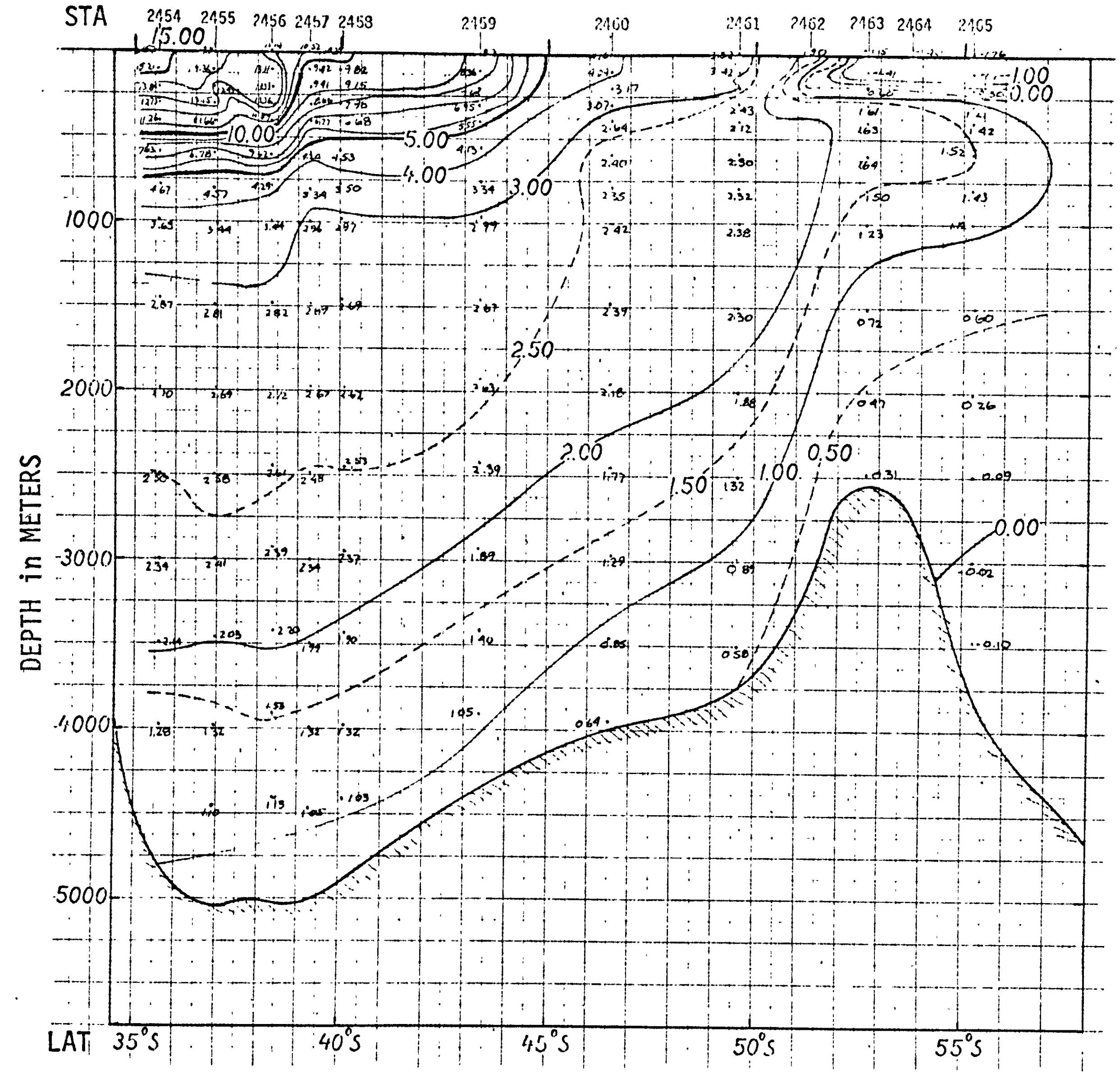

Figure 15. The distribution of temperature along section 9. A 0° longitude section from 35°36'S to 55°17'S. 18 October to 27 October 1938.

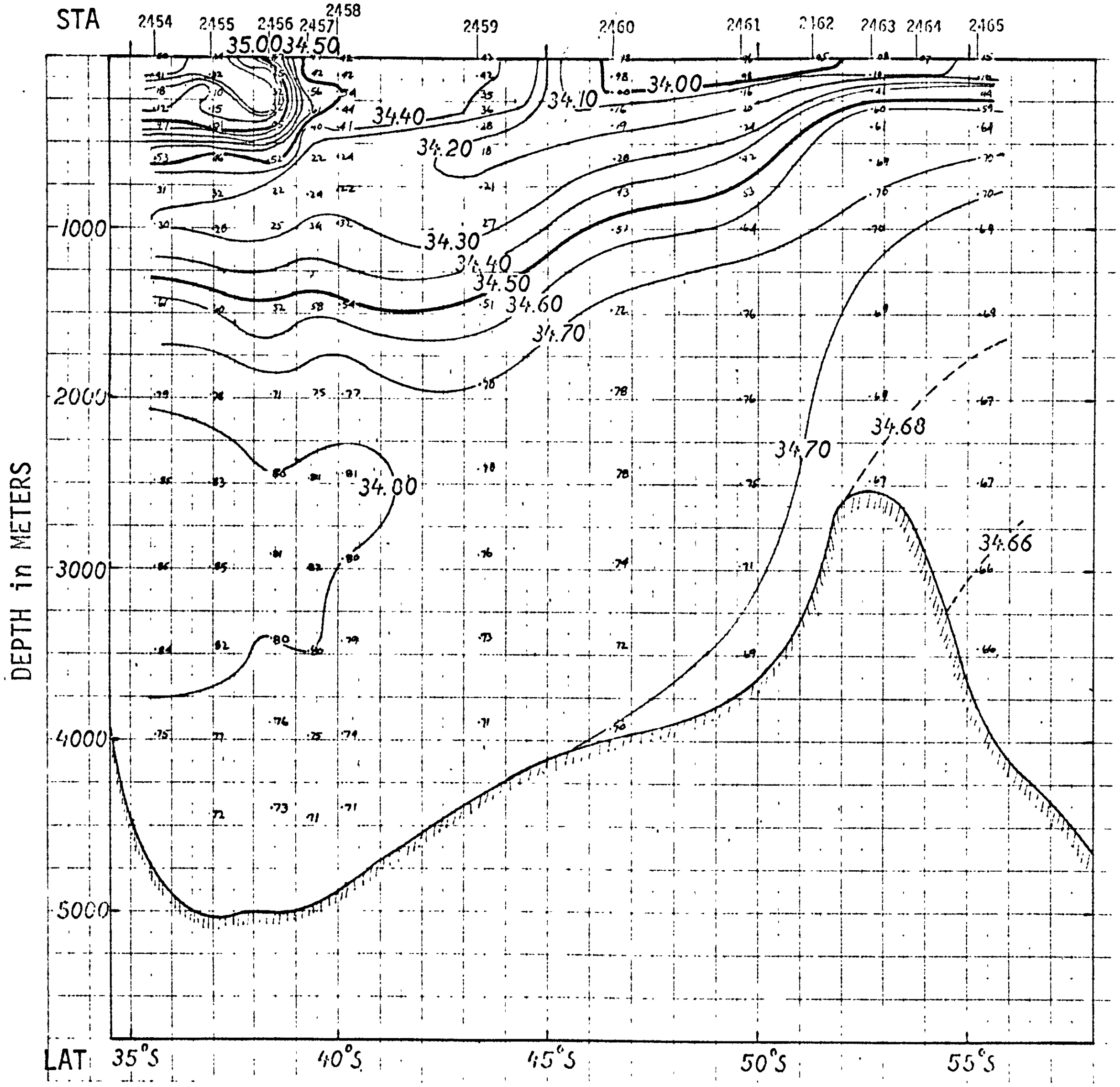

Figure 16. The distribution of salinity along section 9. A 0° longitude section from 35°36' S to 55°17' S. 18 October to 27 October 1938.

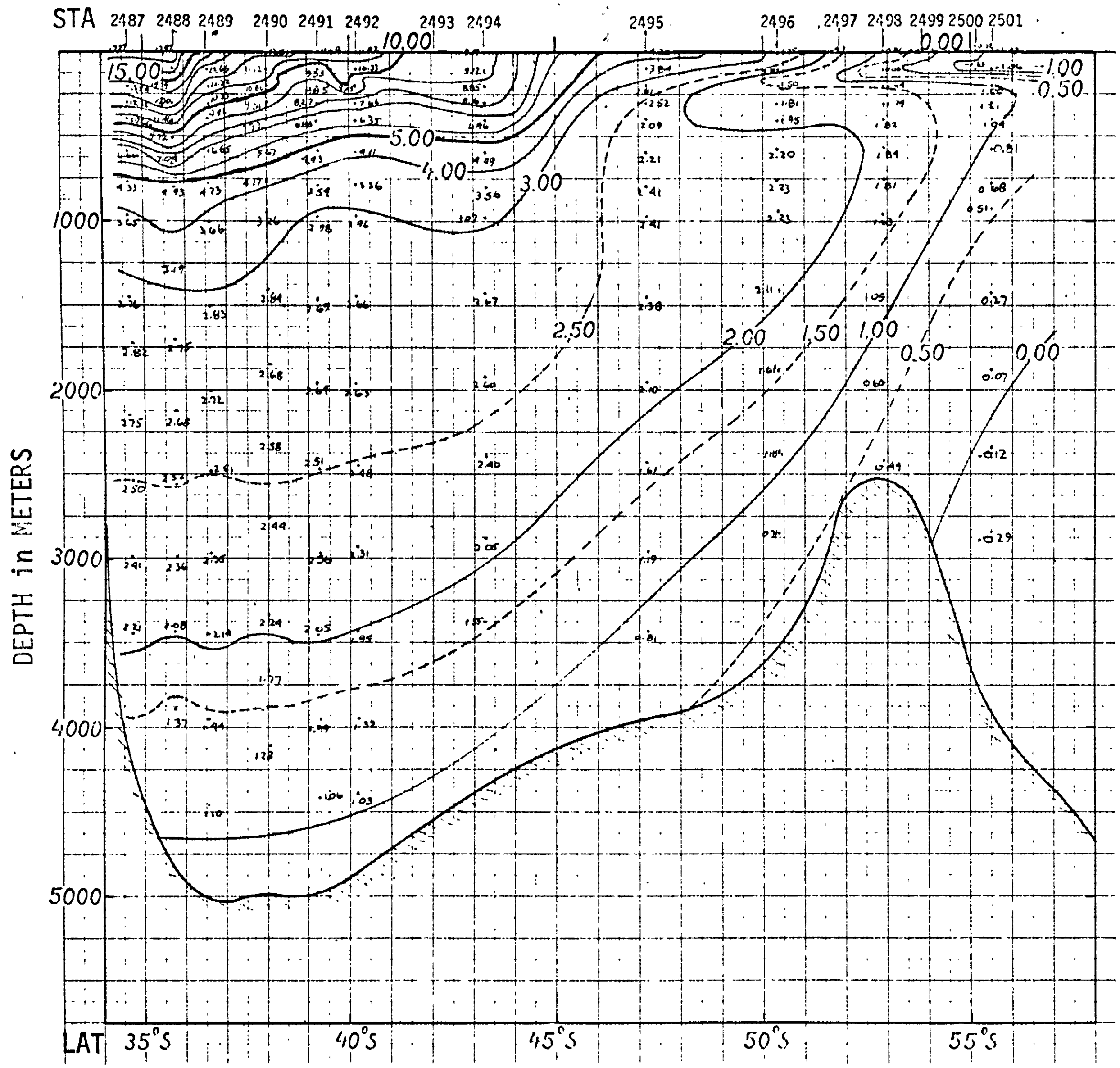

Figure 17. The distributuin of temperature along section 11. A 0° longitude section from 34°40' S to 55°30' S. 23 November to 5 December 1938.

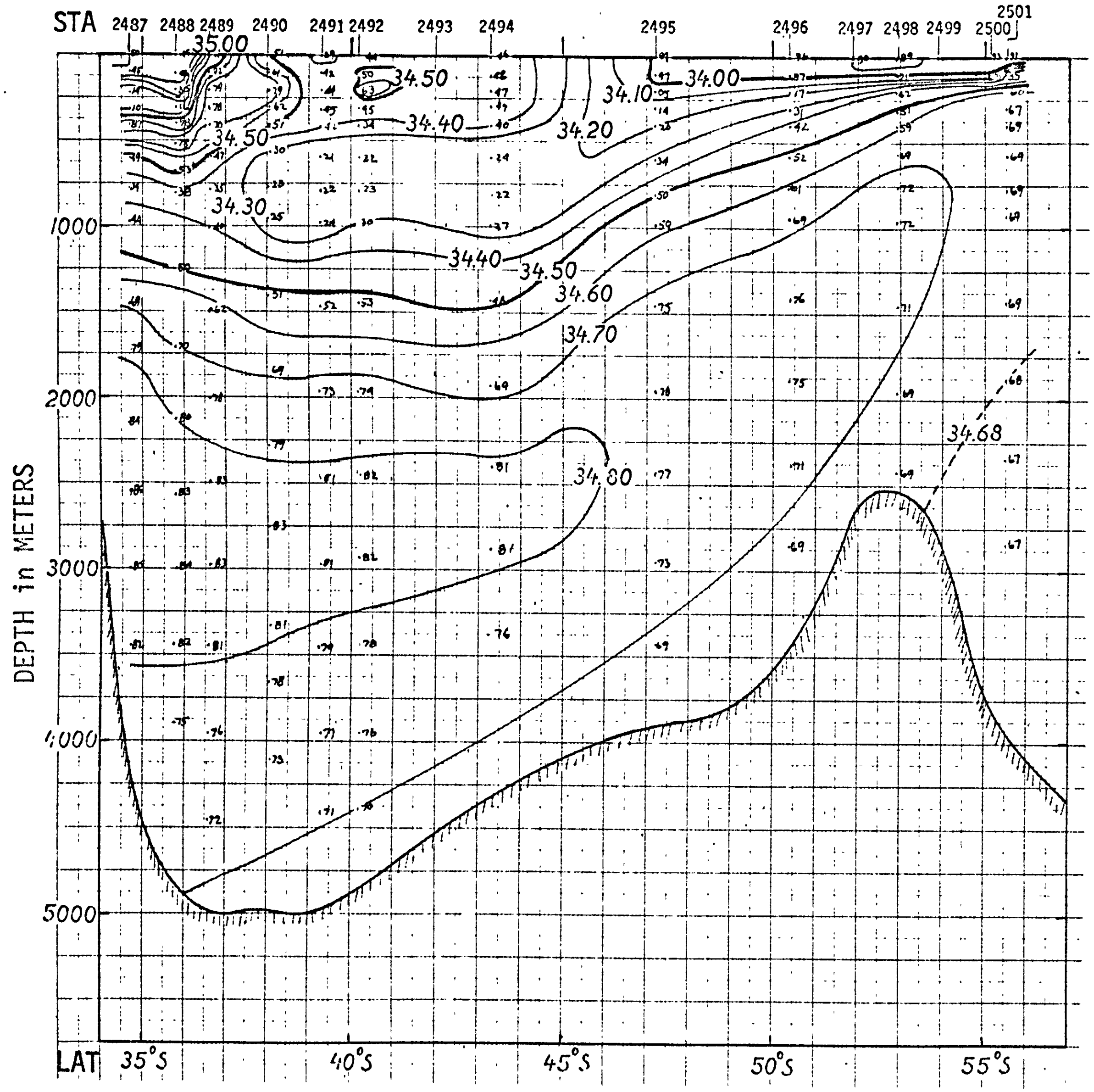

Figure 18. The distribution of salinity along section 11. A 0° longitude section from 34°40' S to 55°30' S. 23 November to 5 December 1938.

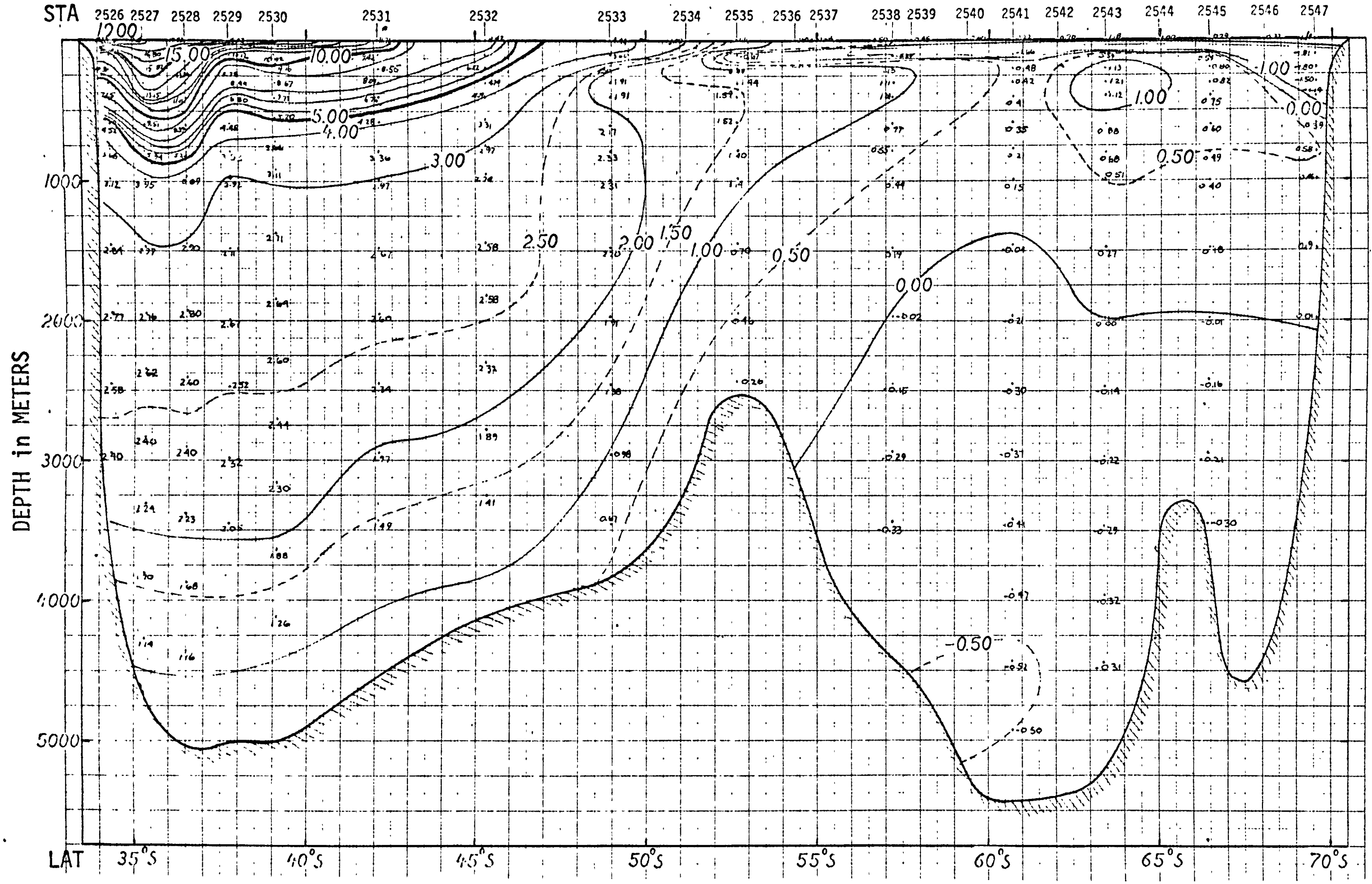

Figure 19. The distribution of temperature along section 13. A 0° longitude section from 34°20'S to 69°30'S. 7 January to 22 January 1939.

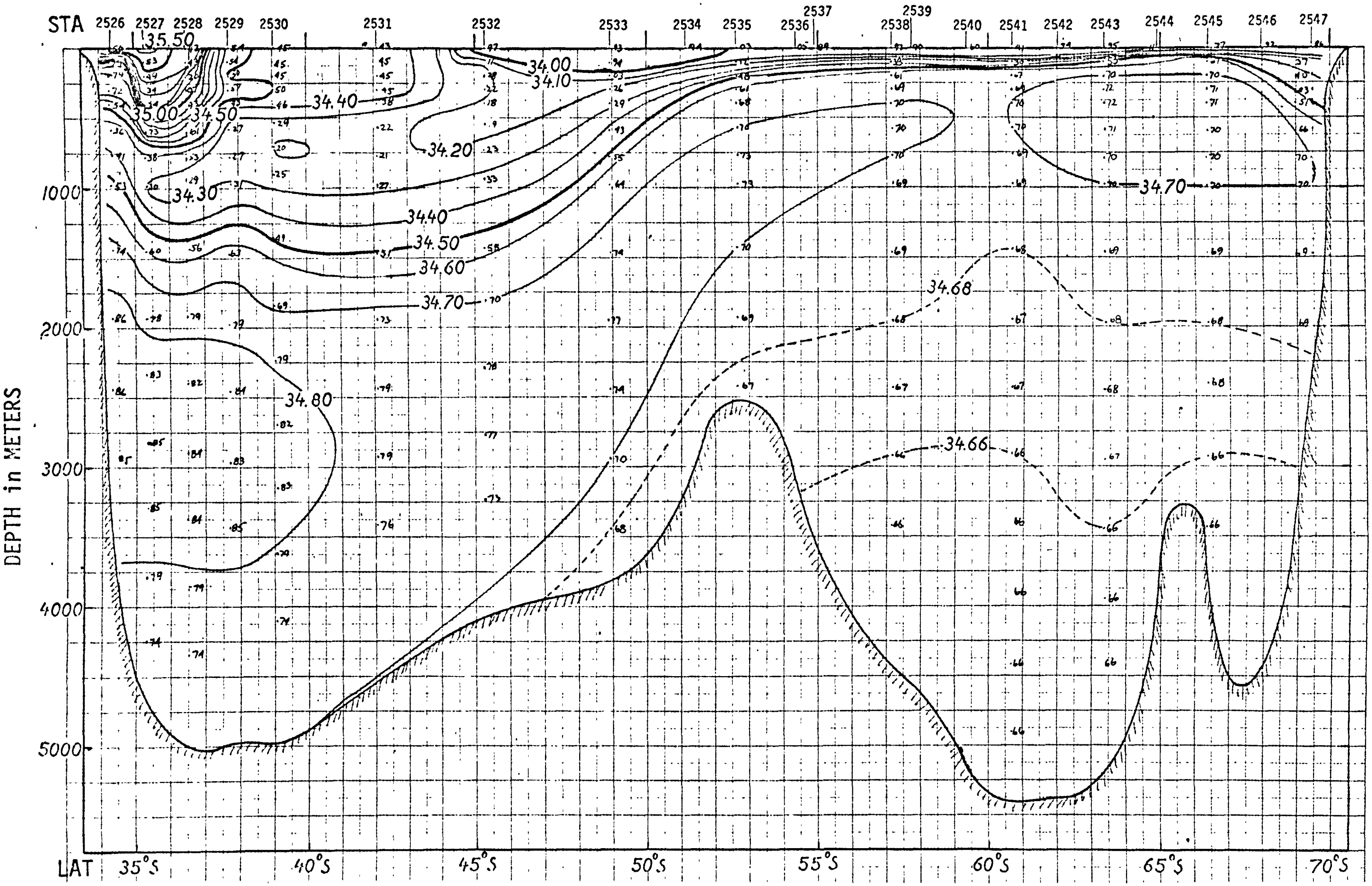

Figure 20. The distribution of salinity along section 13. A 0° longitude section from 34°20' S to 69°30' S. 7 January to 22 January 1939.

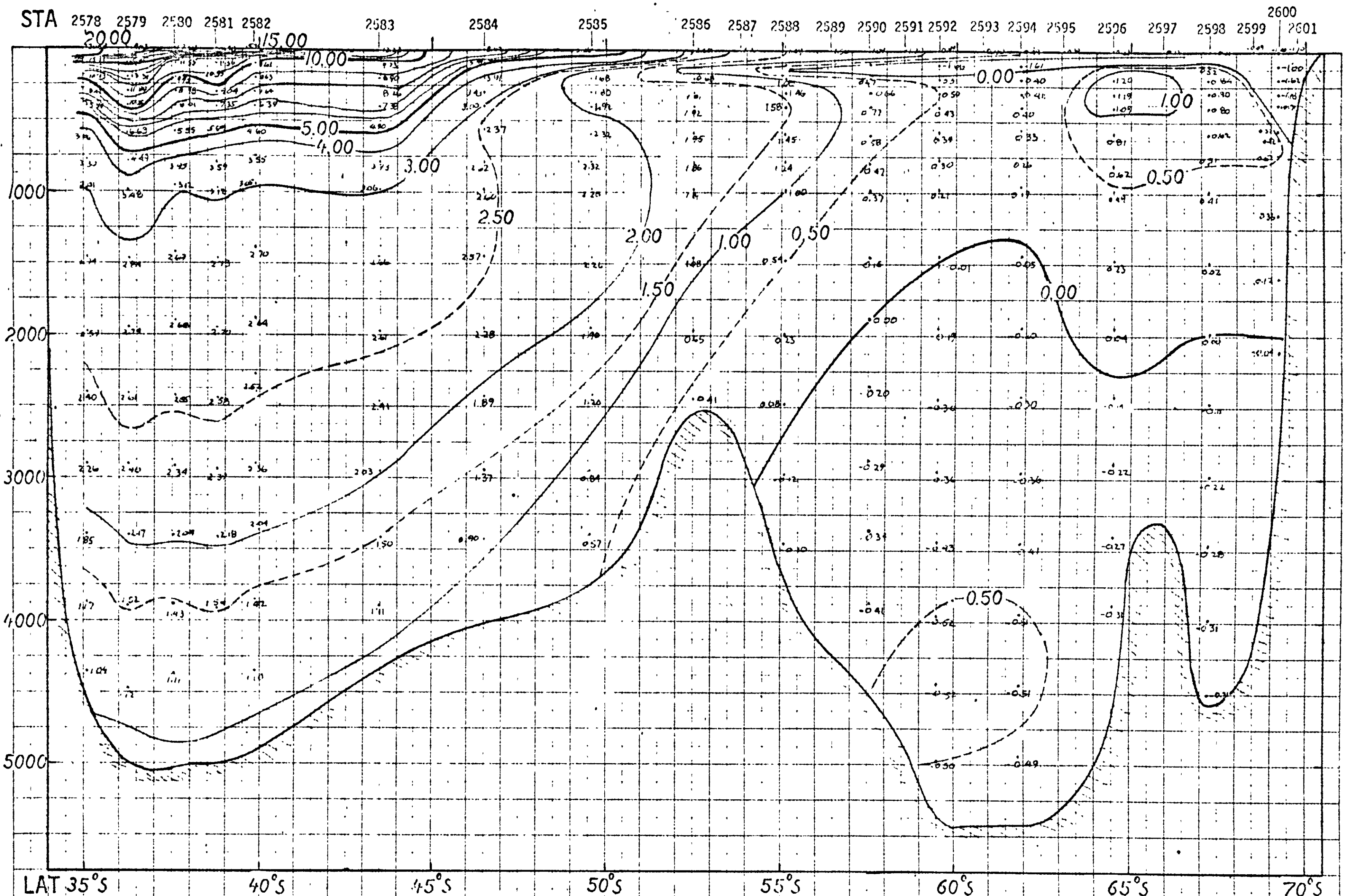

Figure 21. The distribution of temperature along section 15. A 0° longitude section from 35°08'S to 69°44'S. 16 February to 4 March 1939.

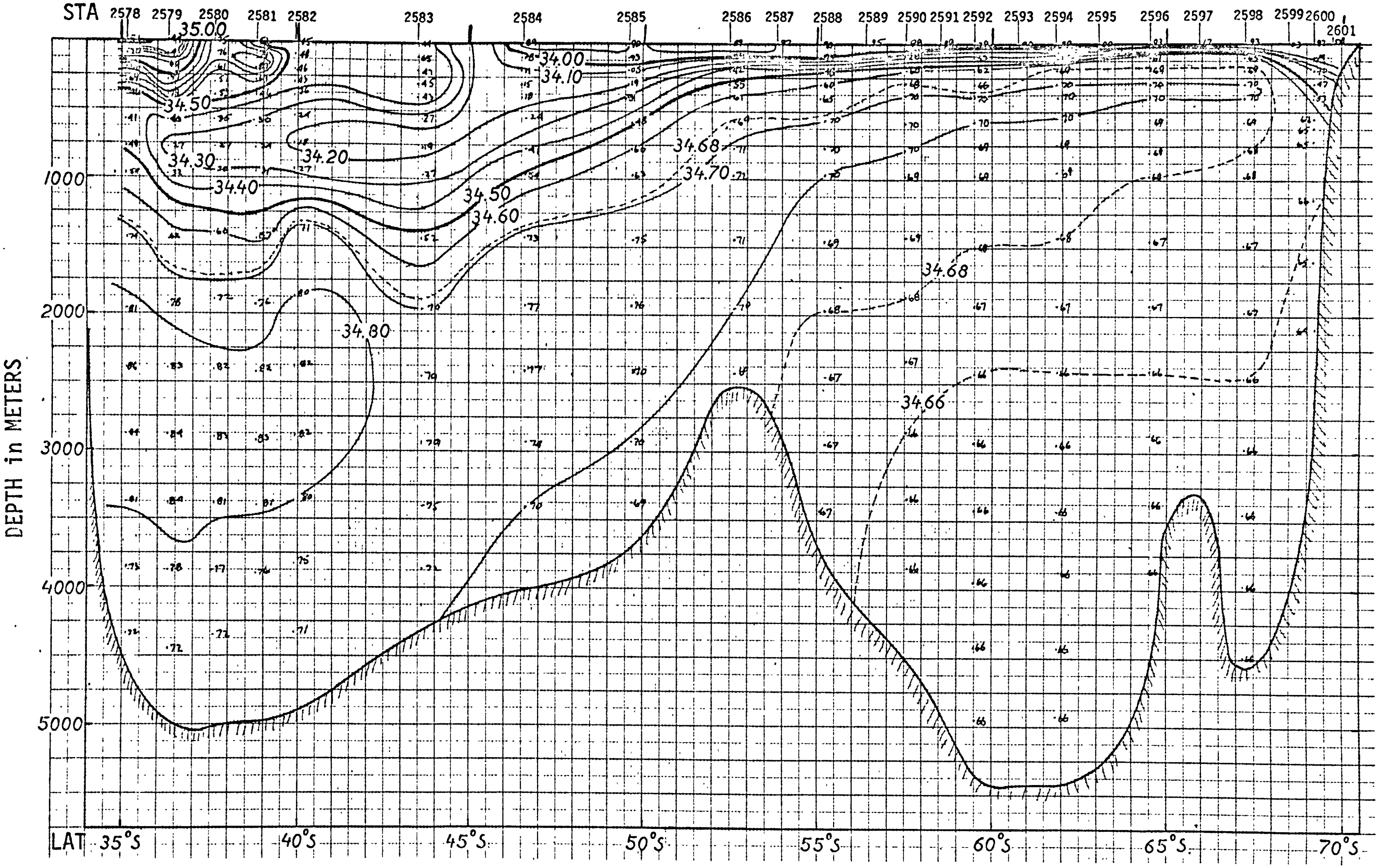

Figure 22. The distribution of salinity along section 15. A 0° longitude section from 35°08'S to 69°44'S. 16 February to 4 March 1939.

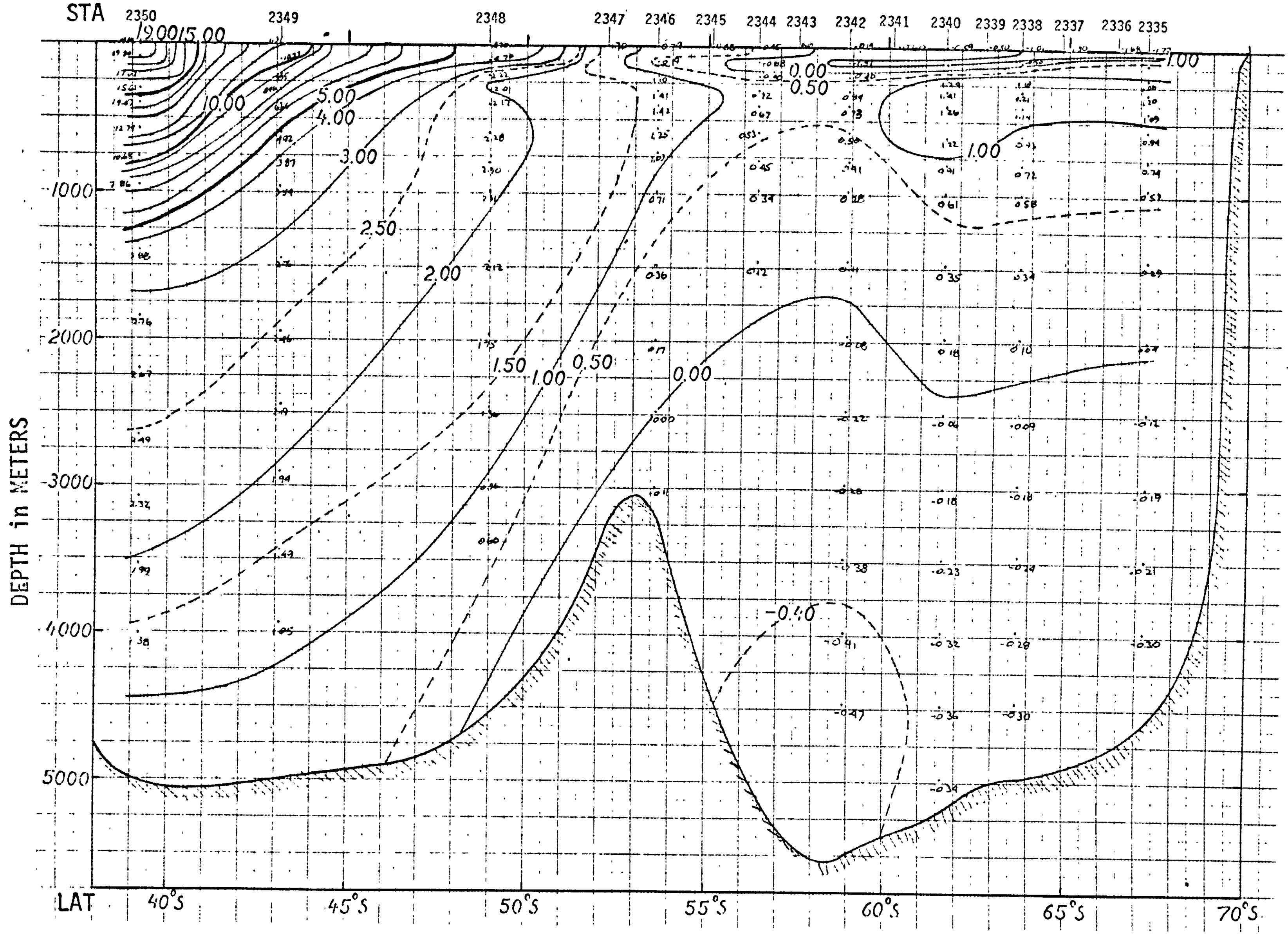

Figure 23. The distribution of temperature along section 2. A 20° E longitude section from 67°10'S to 39°11'S. 22 April to 2 May 1938.

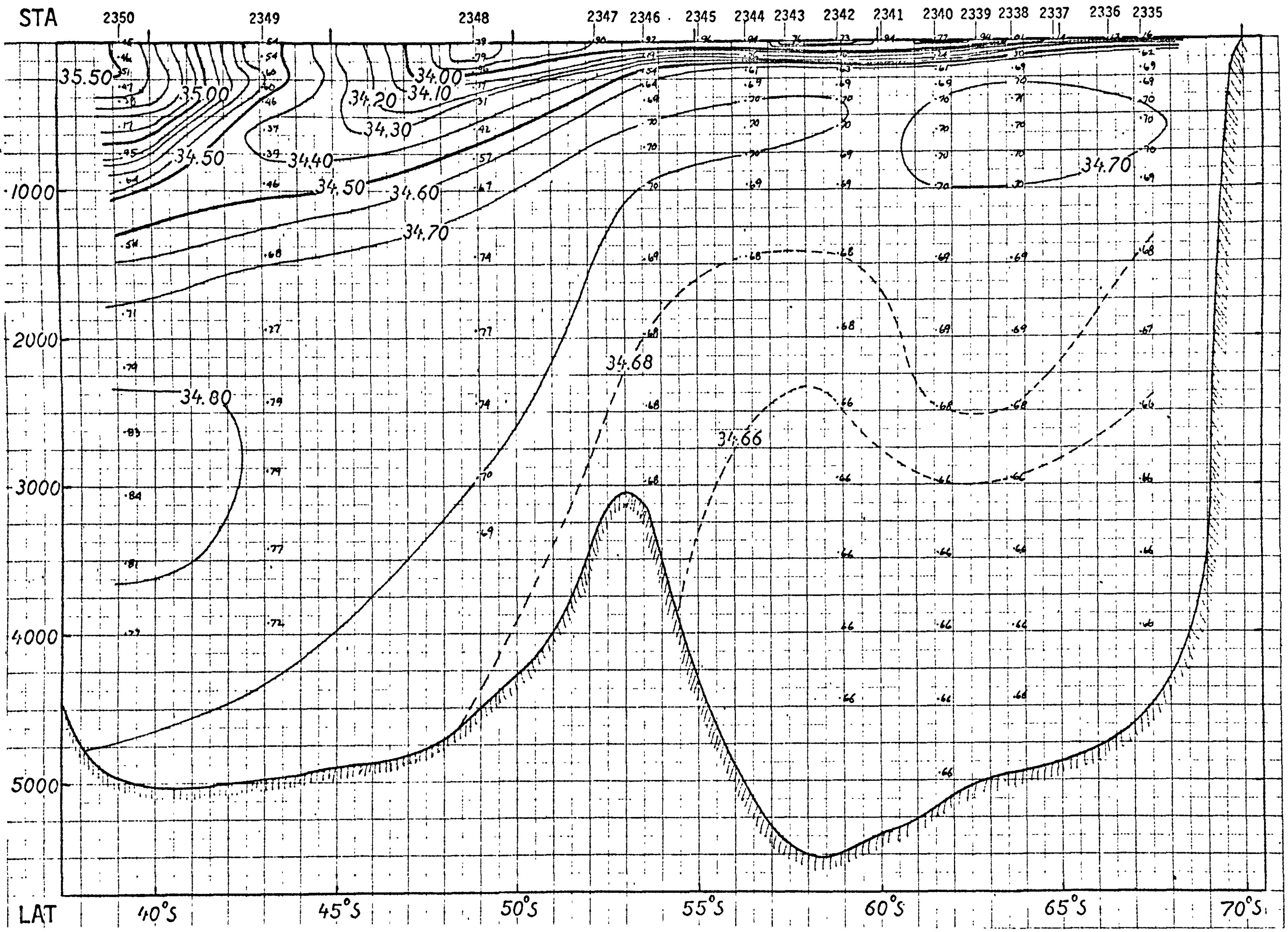

Figure 24. The distribution of salinity along section 2. A 20° E longitude section from 67°10'S to 39°11'S. 22 April to 2 May 1938.

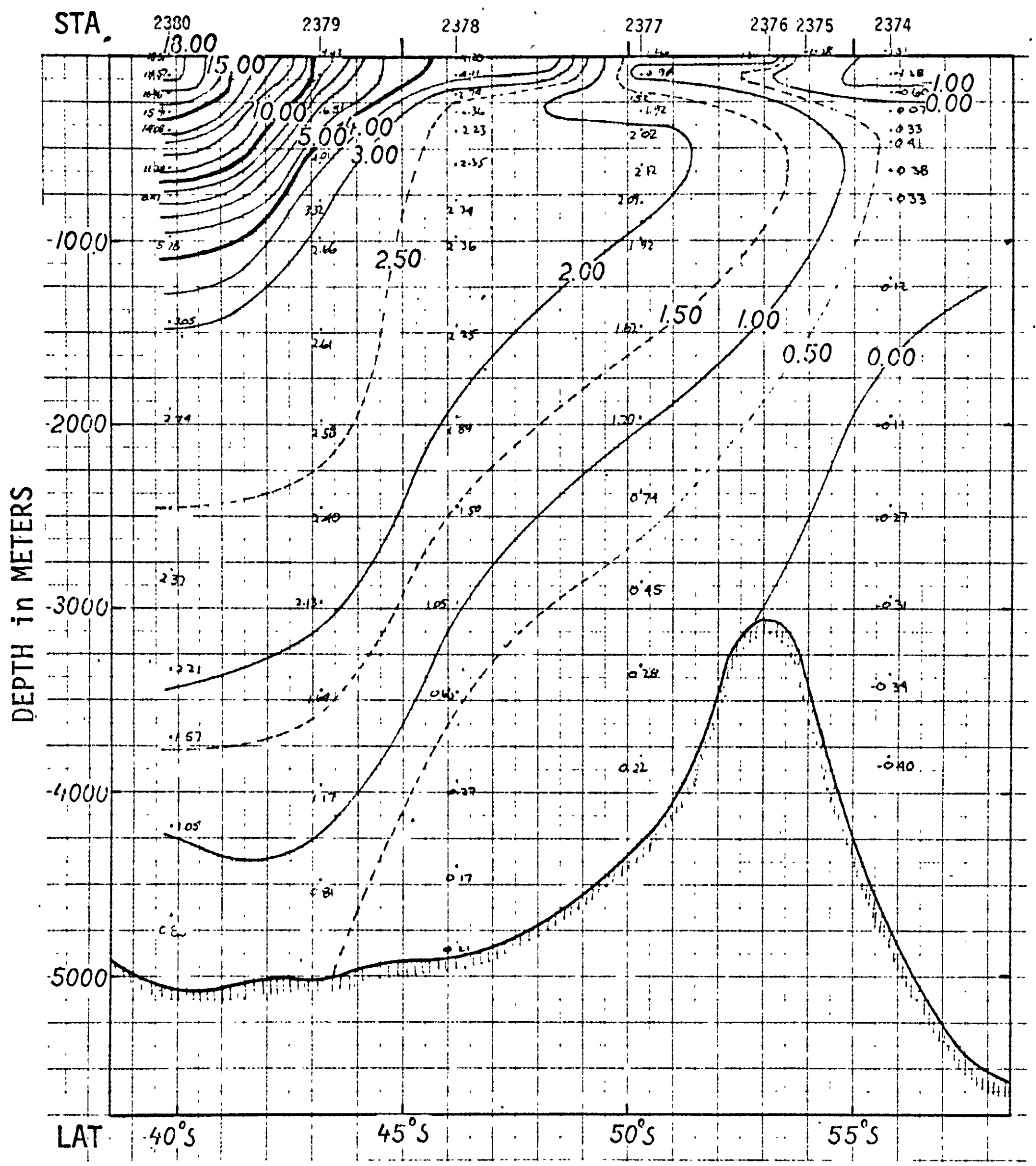

Figure 25. The distribution of temperature along section 4. A 20° E longitude section from 55°42' S to 39°51' S. 19 July to 25 July 1938.

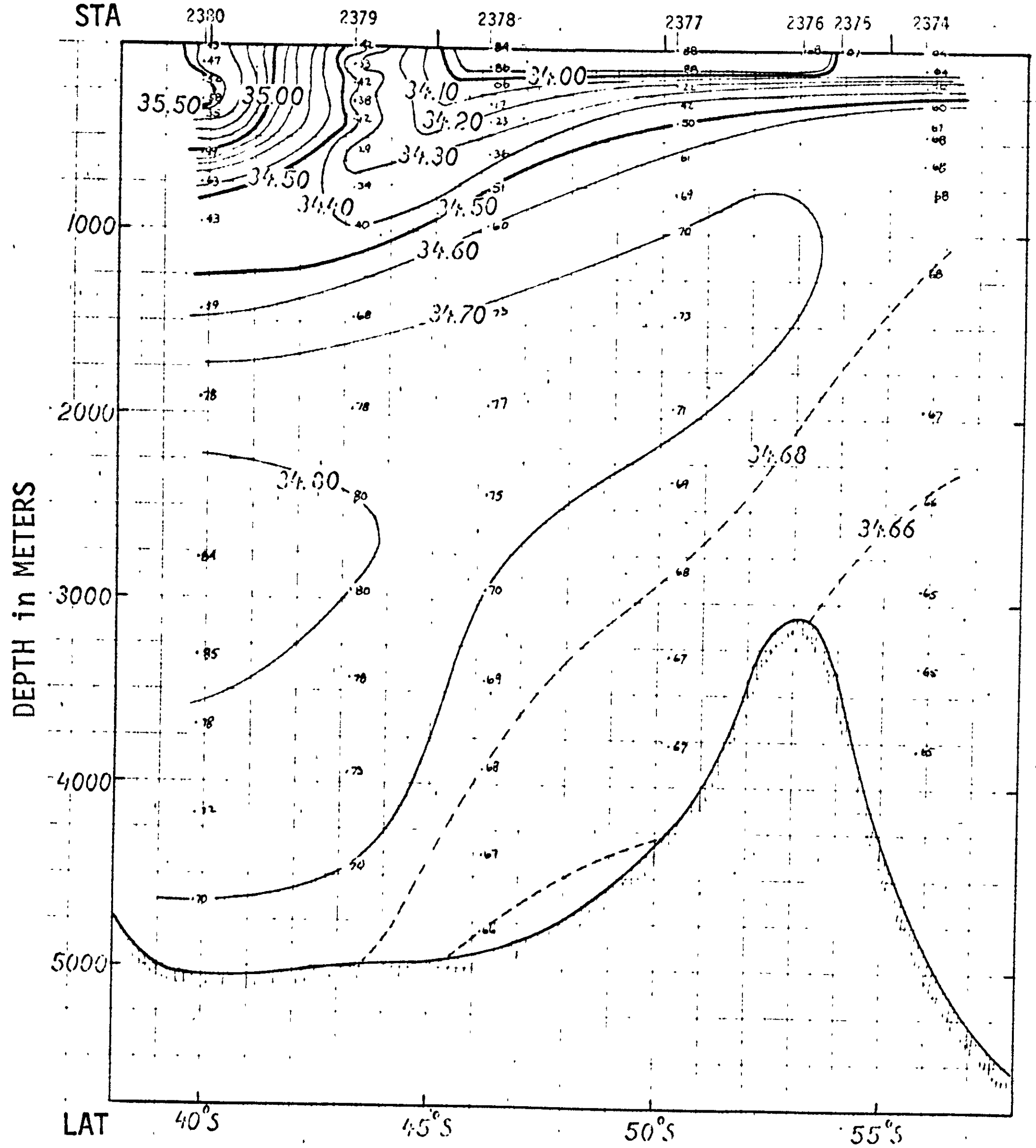

Figure 26. The distribution of salinity along section 4. A 20°E longitude section from 55°42'S to 39°51'S. 19 July to 25 July 1938.

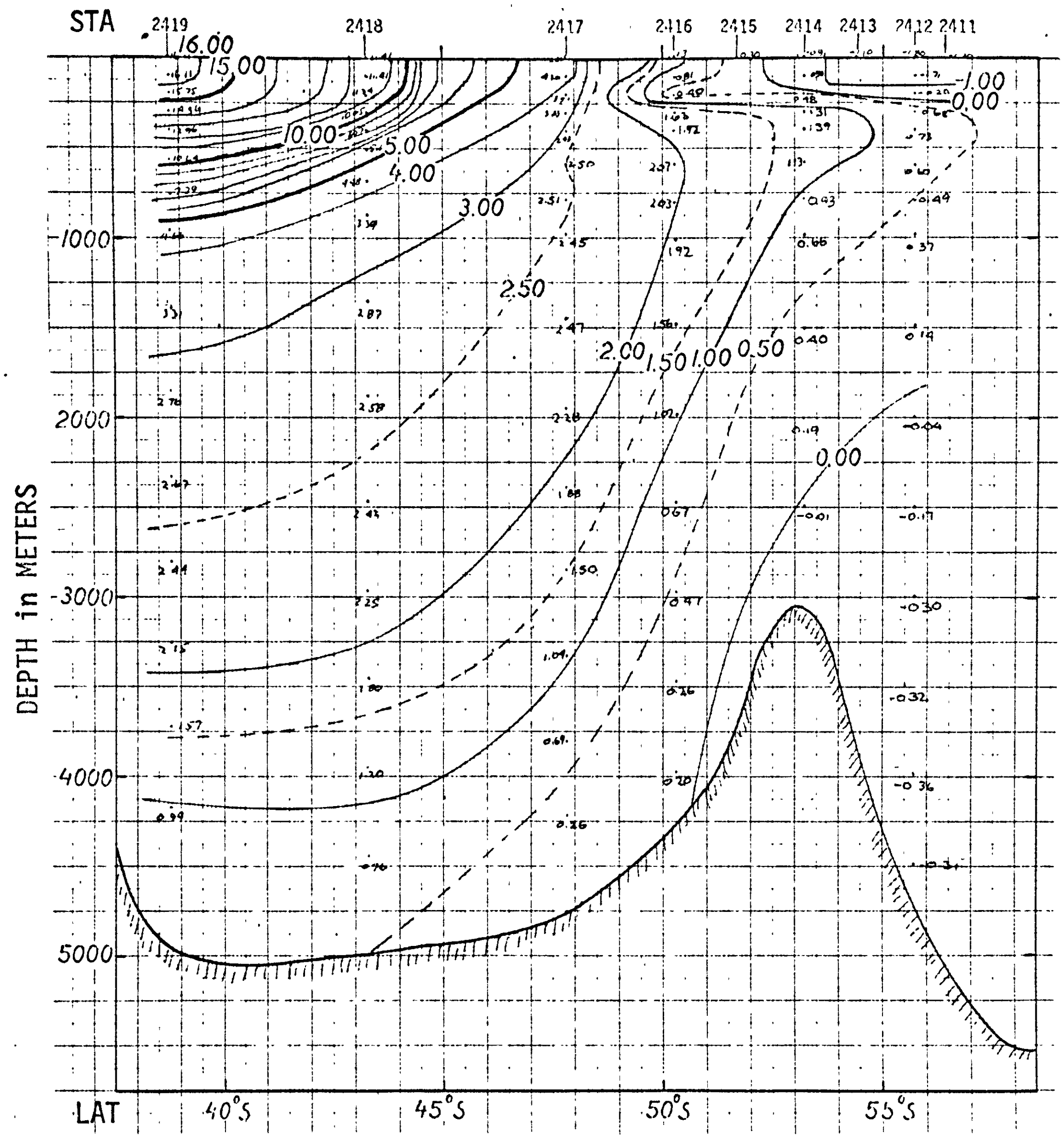

Figure 27. The distribution of temperature along section 6. A 20°E longitude section from 56°25' S to 38°46' S. 23 August to 30 August 1938.

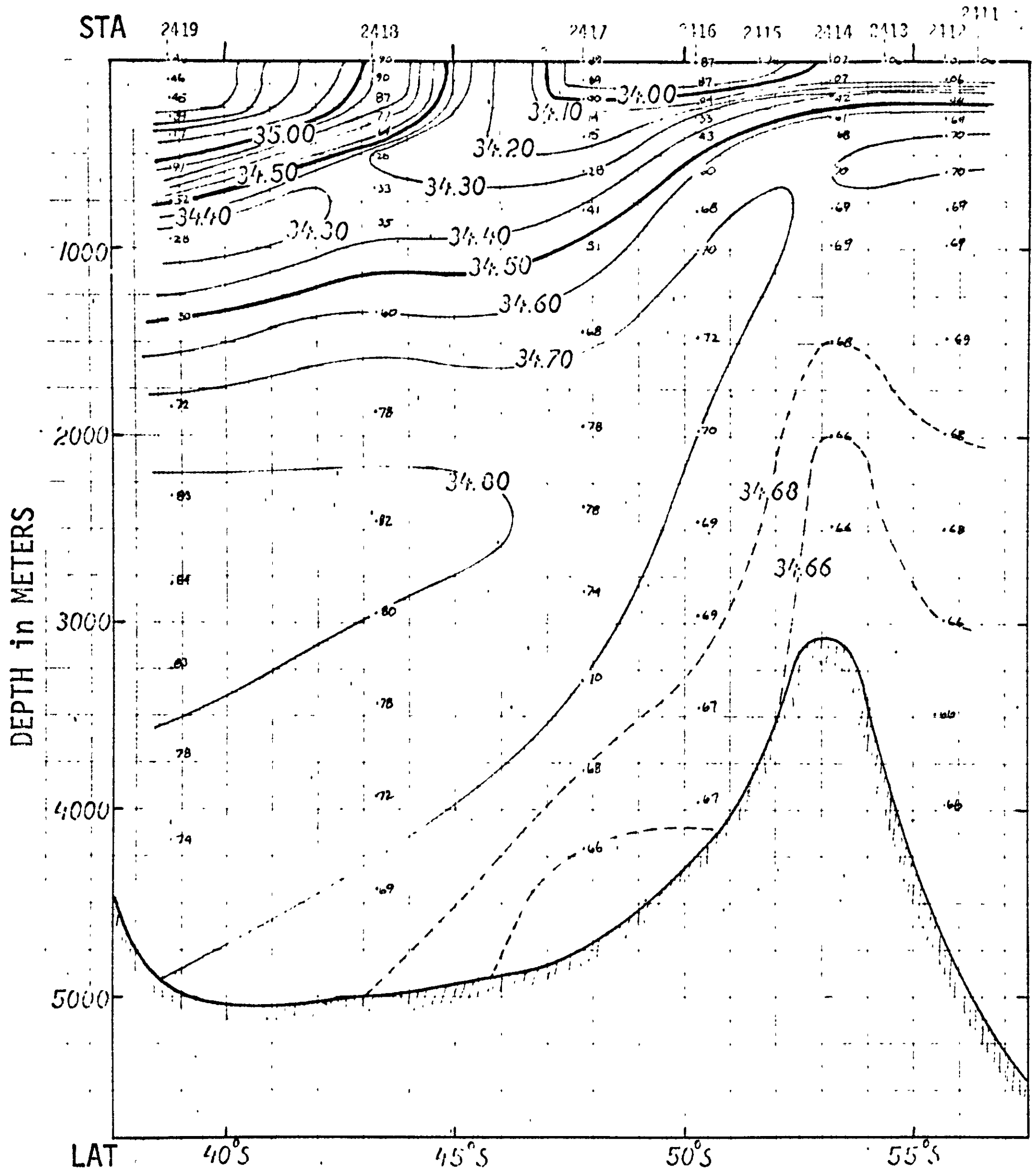

Figure 28. The distribution of salinity along section 6. A 20°E longitude section from 56°25' S to 38°46' S. 23 August to 30 August 1938.

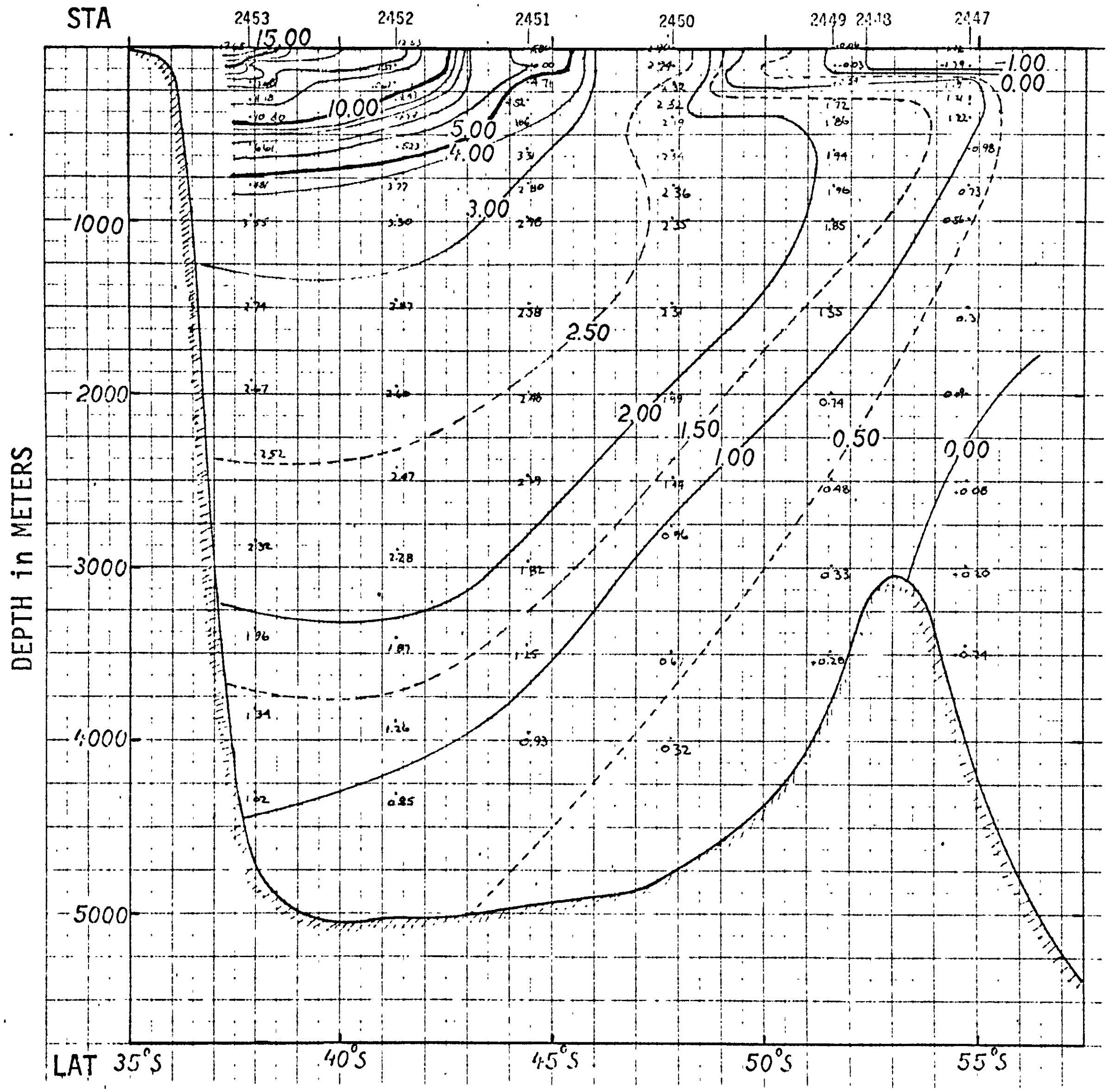

Figure 29. The distribution of temperature along section 8. A 20°E longitude section from 54°47'S to 37°51'S. 1 October to 6 October 1938.

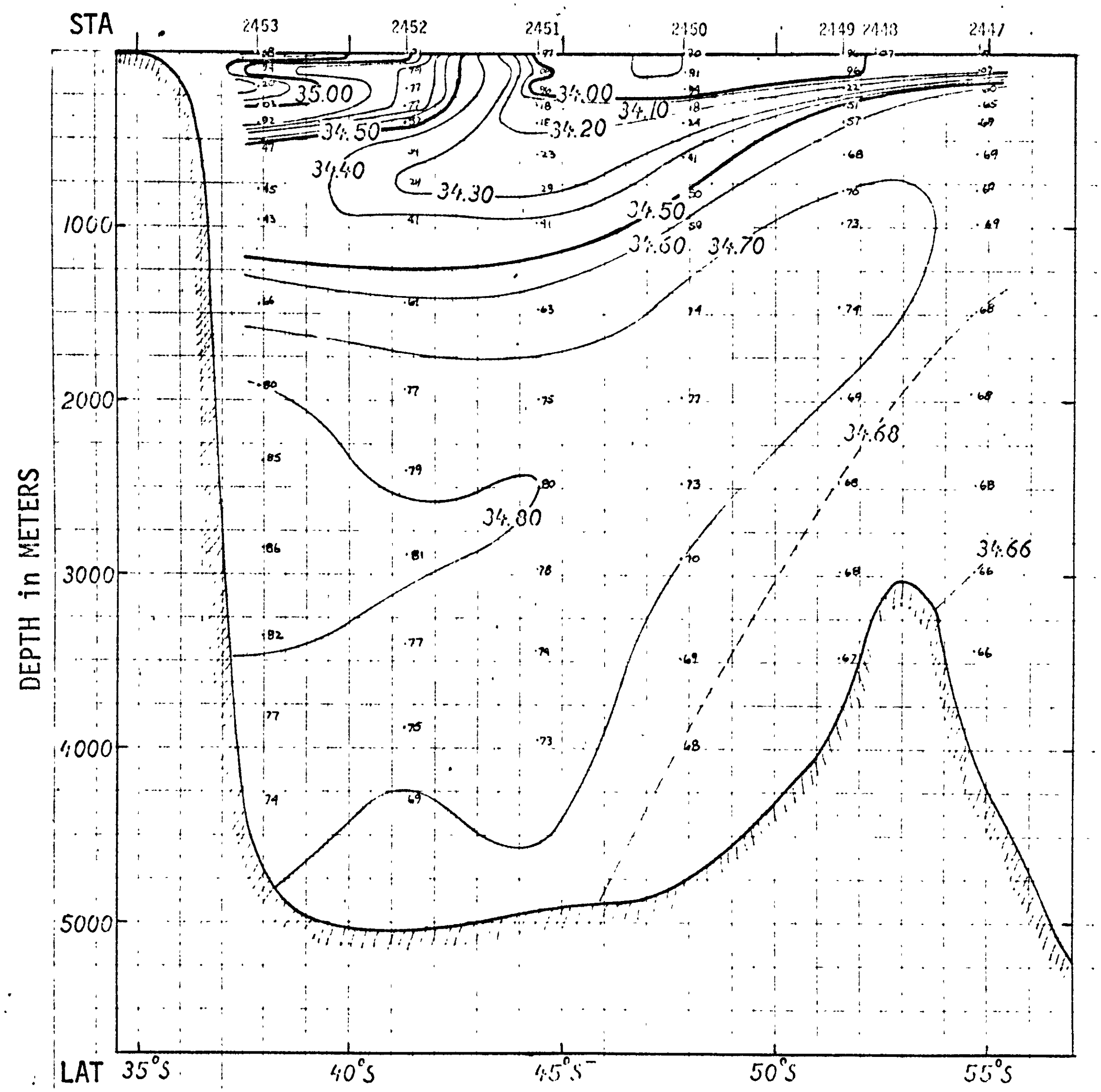

Figure 30. The distribution of salinity along section 8. A 20°E longitude section from 54°47' S to 37°51' S. 1 October to 6 October 1938.

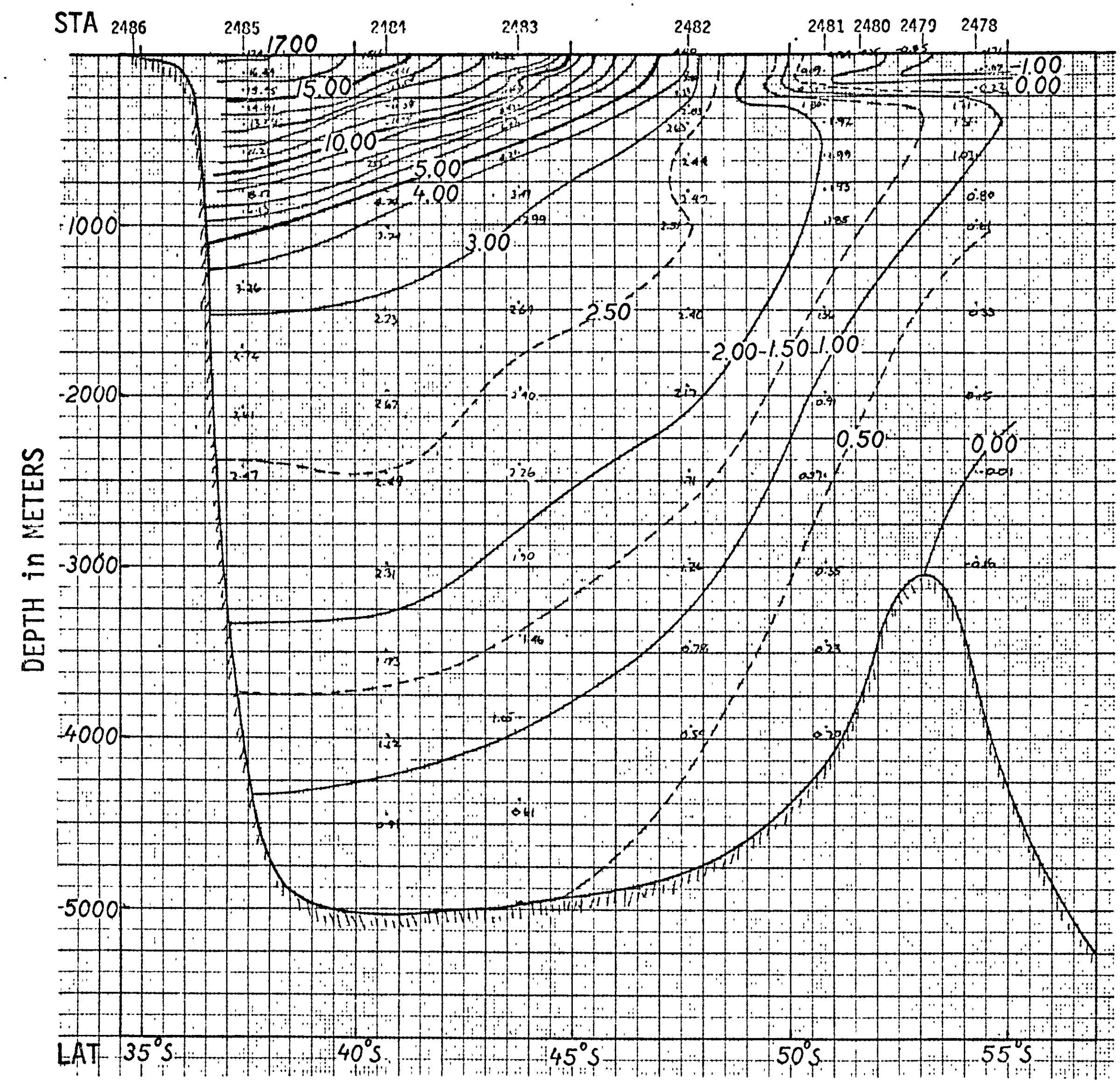

Figure 31. The distribution of temperature along section 10. A 20°E longitude section from 54°17' S to 34°38' S. 2 November to 9 November 1938.

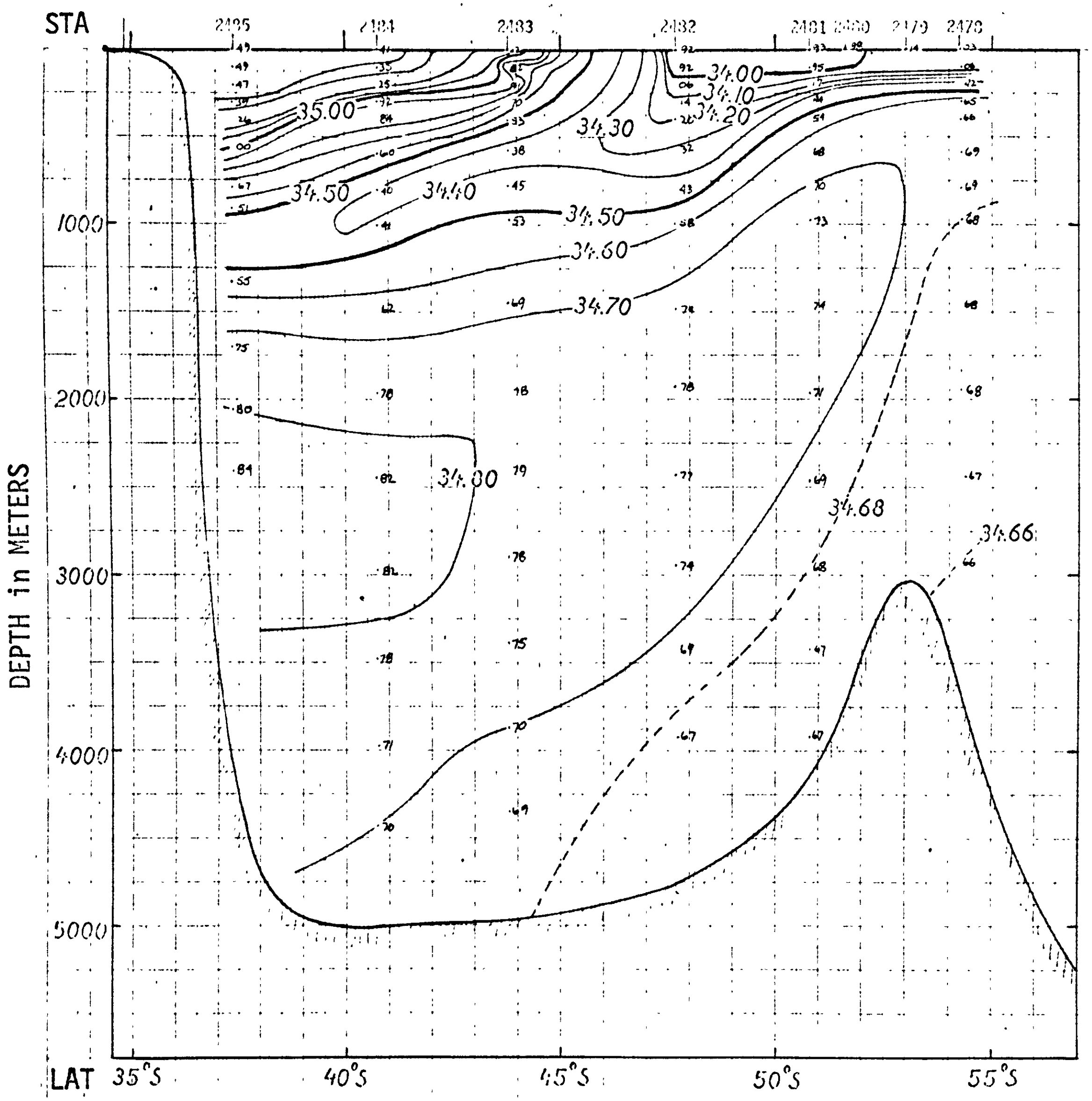

Figure 32. The distribution of salinity along section 10. A 20°E longitude section from 54°17'S to 34°38'S. 2 November to 9 November 1938.

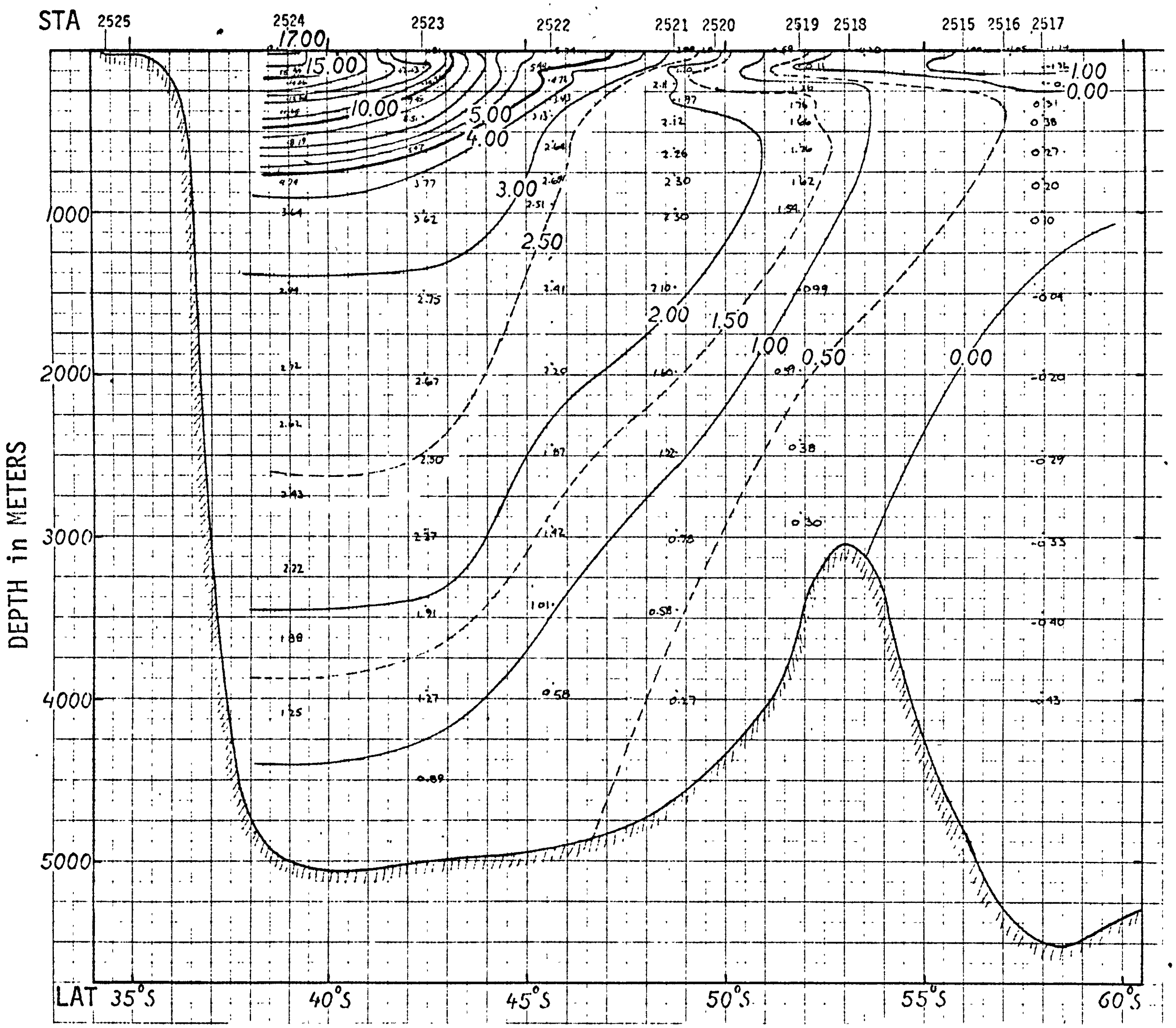

Figure 33. The distribution of temperature along section 12. A 20°E longitude section from 56°57' S to 34°29' S. 12 December to 18 December 1938

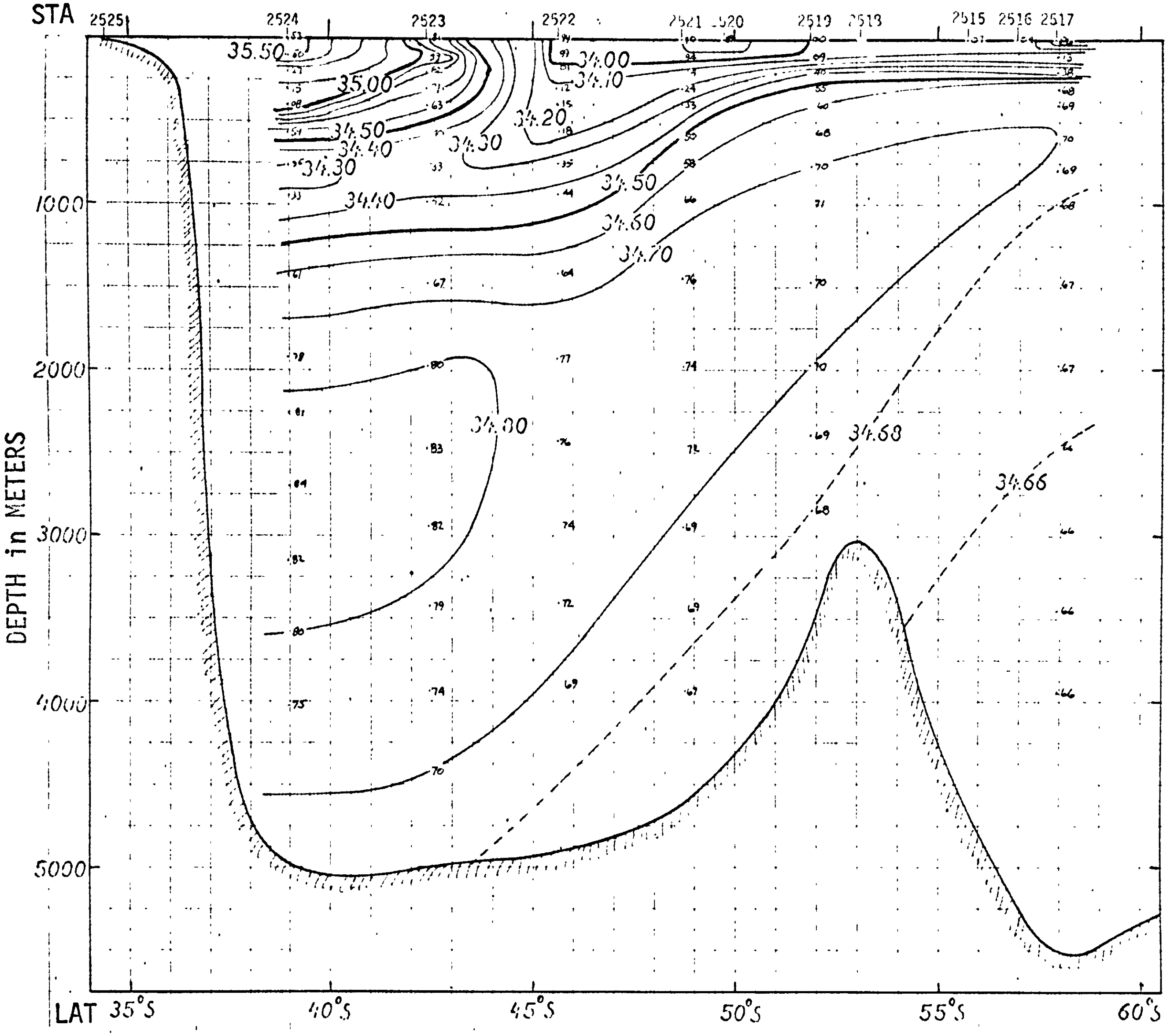

Figure 34. The distribution of salinity along section 12. A 20°E longitude section from 56°57'S to 34°29'S. 12 December to 18 December 1938.

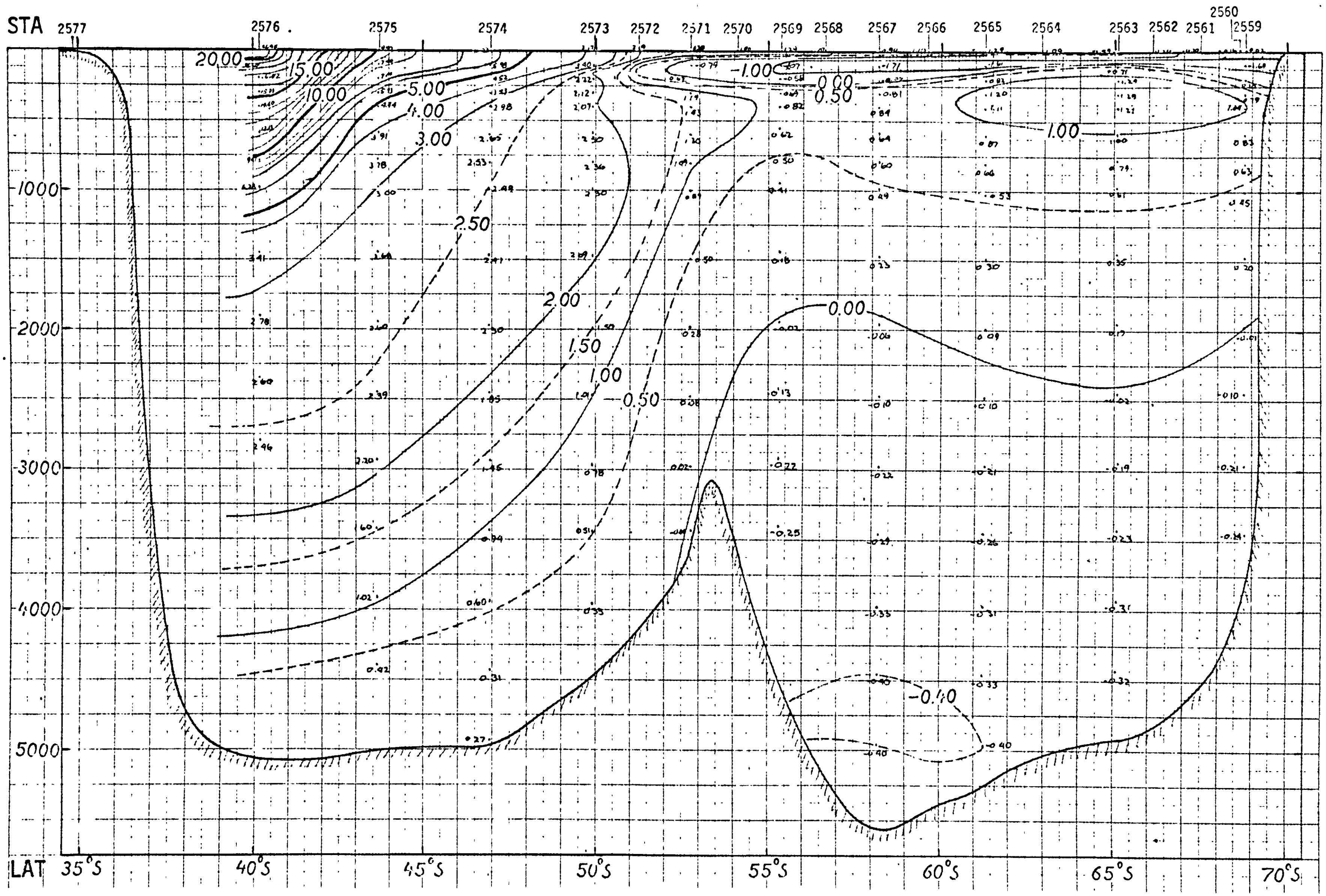

Figure 35. The distribution of temperature along section 14. A 20°E longitude section from 68°50'S to 40°12'S. 27 January to 5 February 1939.

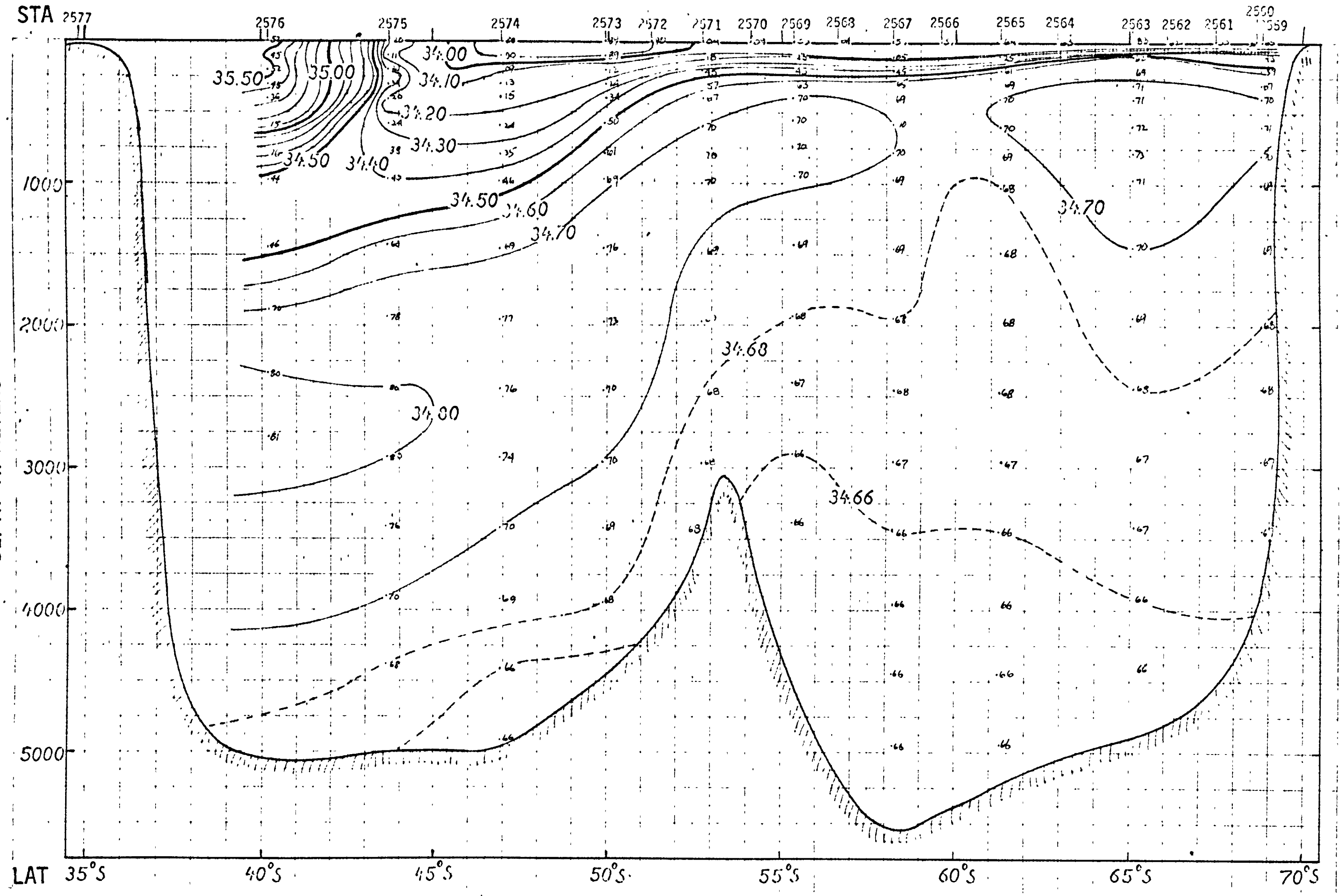

Figure 36. The distribution of salinity along section 14. A 20°E longitude section from 68°50'S to 40°12'S. 27 January to 5 February 1939.

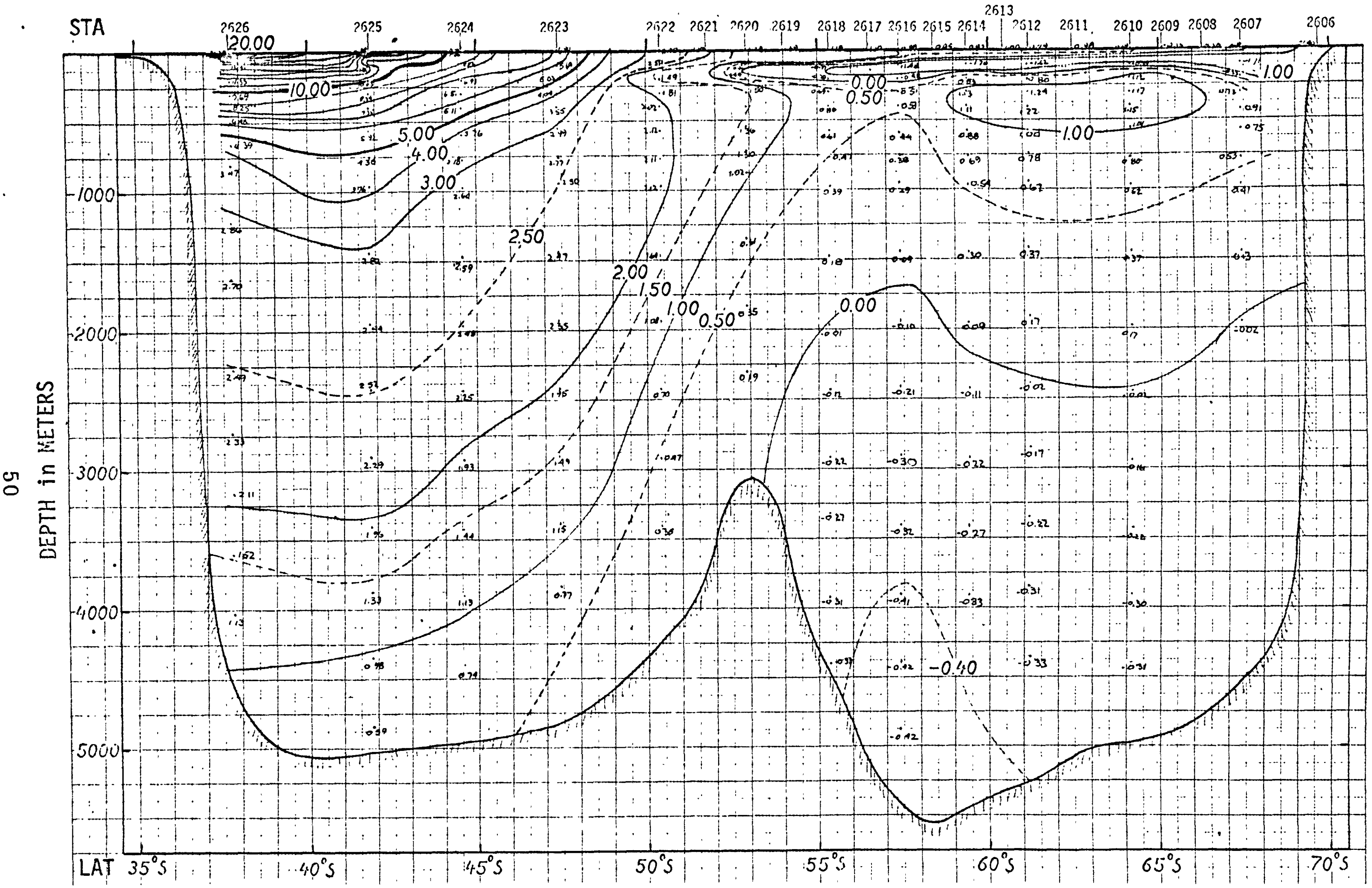

Figure 37. The distribution of temperature along section 16. A 20°E longitude section from 69°40'S to 37°47'S. 5 March to 18 March 1939.

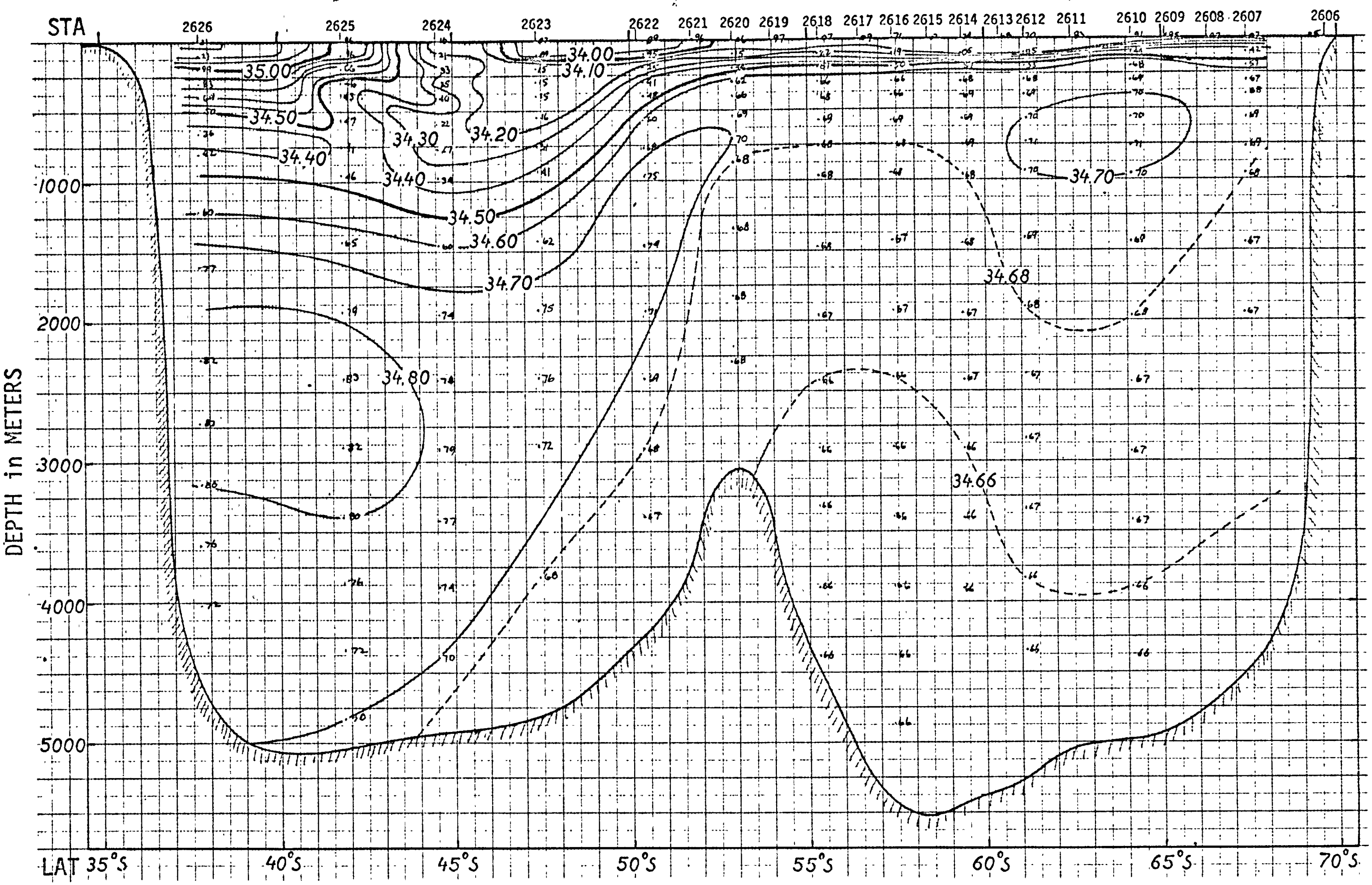

Figure 38. The distribution of salinity along section 16. A 20°E longitude section from 69°40' S to 37°47' S. 5 March to 18 March 1939.

SECTION	TOTAL VOLUME TRANSPORT (10^6 m^3/sec) wrt 4000 m	wrt 3000 m
2	239	175
4**	228	159
6**	225	160
8**	161	125
12**	220*	143
16	165	111
9**	-	117
13	213	142
15	195*	135

* 4000 m dynamic height interpolated.

** Winter section - does not extend across the current completely.

Table 2. Geostrophic volume transports across sections which have deep end stations.

REFERENCES

Deacon, G. E. R. (1937). "The Hydrology of the Southern Ocean," Discovery Reports, Vol. 15, pp. 1-124.

Defant, Albert (1961). Physical Oceanography, Pergamon Press, New York, Vol. 1, pp. 1-729.

Discovery Reports, Vol. 24, 1947, pp. 1-422.

Mackintosh, N. A. (1946). "The Antarctic Convergence and the Distribution of Surface Temperature in Antarctic Waters," Discovery Reports, Vol. 23, pp. 177-212.

Schott, G. (1942). "Grundlagen einer Weltkarte der Meeresstromungen" Ann. Hydr. Mar. Met., p. 247.